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Toil and Trade: 
Functional Bone Adaptation and 
Social Allocations of Labour in 
Urban Medieval Scotland

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Doctor of Philosophy in Archaeology 
University of Edinburgh 
2023
Abstract

Measures of functional bone adaptation have often been applied to archaeological populations to reconstruct behaviours from the past. Although there has been increasing interest in women’s history and feminist archaeology, work that centres functional adaptation in women is still uncommon. The three most frequently used methods, entheséal changes (EC), long bone cross-sectional geometry (CSG), and degenerative joint changes (DJC), have rarely been applied in conjunction. Skeletal collections from Scotland have not been studied as frequently as others in Britain and activity data are in short supply.

The primary aim of this thesis was to investigate patterns of skeletal changes compatible with social allocations of labour in urban medieval Scotland (c.800-1600 CE). The secondary aim was to determine the accuracy, value, and efficacy of using the three individual and concurrent methods. Sociohistorical, clinical, and palaeopathological data were synthesised to contextualise interpretations of functional adaptation. 204 individuals from medieval Edinburgh, Leith, St Andrews, Perth, and Dunbar were examined.

The effects of gender and social status on bone were found via all three methods. Females showed evidence of a wide variety of strenuous labour that was similar for both high and low status groups. Women’s work was bimanual, but asymmetrical, and often performed below shoulder level using the elbow and forearm such as sweeping with a broom or holding an object with one arm. Evidence of labour in males was asymmetrical and consistent with frequent work at or above shoulder level. Men’s tasks were more often unimanual, specialised, and had less variety like carrying heavy objects on one shoulder. High status males, however, displayed less wear at the shoulder and more use of the forearm. Affluent and educated men likely performed more detailed and specialised sedentary tasks like writing or fine metalworking.

This research confirms the value of clinical, anatomical, and kinesiological data to interpreting bone functional adaptation and highlights the effects of a highly gendered and stratified society on bone. This work adds to the growing field of feminist bioarchaeology and reveals the extraordinary contribution of women to the economy in urban medieval Scotland.
Lay Summary

Bioarchaeologists study the ways in which human bone adapts to activities of daily living and use those changes to reconstruct the behaviour of people in the past. Although more people are interested in women’s history and archaeologists have been applying a feminist perspective to archaeology, research that places the focus on the activities of women in the past is still uncommon. The three most frequently used methods of studying bony changes are muscle attachments, joint disease, and the cross-section of a long bone but they aren’t often used at the same time. Skeletal collections in Scotland haven’t been studied as often as others in Britain and research that incorporates bony changes is rare.

The primary aim of this thesis was to find patterns in bony changes that were caused by cultural differences in gender and social status in urban medieval Scotland (c.800-1600 CE). The secondary aim was to determine the value of using three different methods at the same time. Historical accounts, modern medical studies, and other evidence of diseases on bone were brought together to help provide context for the interpretation. 204 skeletons from medieval Edinburgh, Leith, St Andrews, Perth, and Dunbar were included in the study.

The effects of cultural differences in gender and social status were identified on bone by all three methods which offered unique yet compatible results. The bones of females showed a wide variety of strenuous labour that was similar across groups with higher and lower social status. Women’s work meant using both arms, but the work was different from left to right. Women most often worked with forearms and hands below shoulder level. The bones of males also showed evidence of manual labour, especially at the shoulders. Men’s work was more specialised and didn’t change as often. They used one arm more than the other and frequently worked at or above shoulder level. Higher status males, however, showed less wear at the shoulders and more use of the forearm. Affluent and educated men probably performed more detailed, specialised, and sedentary tasks.

This thesis confirms the value of using modern medical knowledge when interpreting any culture-induced bony changes in past populations and highlights the effects of a gendered and stratified society on human bone. This work adds to the growing field of feminist bioarchaeology and reveals the extraordinary contribution of women to the economy in urban medieval Scotland.
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<th>Description</th>
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<tbody>
<tr>
<td><strong>2D</strong></td>
<td>Two-dimensional</td>
</tr>
<tr>
<td><strong>3D</strong></td>
<td>Three-dimensional</td>
</tr>
<tr>
<td><strong>AC</strong></td>
<td>Acromioclavicular joint</td>
</tr>
<tr>
<td><strong>CA</strong></td>
<td>Cortical area</td>
</tr>
<tr>
<td><strong>CEO</strong></td>
<td>Common extensor origin, a.k.a. lateral epicondyle</td>
</tr>
<tr>
<td><strong>CFO</strong></td>
<td>Common flexor origin, a.k.a. medial epicondyle</td>
</tr>
<tr>
<td><strong>CPR</strong></td>
<td>Crude prevalence rate</td>
</tr>
<tr>
<td><strong>CSG</strong></td>
<td>Cross-sectional geometry</td>
</tr>
<tr>
<td><strong>CT</strong></td>
<td>Computed Tomography scan</td>
</tr>
<tr>
<td><strong>DJC</strong></td>
<td>Degenerative joint changes</td>
</tr>
<tr>
<td><strong>EC</strong></td>
<td>Enthesal changes</td>
</tr>
<tr>
<td><strong>F</strong></td>
<td>Female</td>
</tr>
<tr>
<td><strong>GH</strong></td>
<td>Glenohumeral joint</td>
</tr>
<tr>
<td><strong>I</strong></td>
<td>A measure of CSG that refers to an axis of a cross section (e.g., $I_{max}$, $I_{min}$, $I_x$, or $I_y$)</td>
</tr>
<tr>
<td><strong>I-ratio</strong></td>
<td>A ratio of two I-values given as a decimal (e.g., $I_x/I_y$)</td>
</tr>
<tr>
<td><strong>J</strong></td>
<td>A measure of CSG robusticity</td>
</tr>
<tr>
<td><strong>L</strong></td>
<td>Left or Lateral</td>
</tr>
<tr>
<td><strong>M</strong></td>
<td>Male or Medial</td>
</tr>
<tr>
<td><strong>MA</strong></td>
<td>Medullary area</td>
</tr>
<tr>
<td><strong>MRI</strong></td>
<td>Magnetic resonance imaging</td>
</tr>
<tr>
<td><strong>OA</strong></td>
<td>Osteoarthritis</td>
</tr>
<tr>
<td><strong>R</strong></td>
<td>Right</td>
</tr>
<tr>
<td><strong>SMA</strong></td>
<td>Second moments of area</td>
</tr>
<tr>
<td><strong>TA</strong></td>
<td>Total subperiosteal area, a measure of CSG robusticity</td>
</tr>
<tr>
<td><strong>TPR</strong></td>
<td>True prevalence rate</td>
</tr>
</tbody>
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This thesis is dedicated to the memory of my parents, Dottie and Jim, who instilled within me the value of education and a lifetime love of learning. I know they would have been proud.
Chapter 1 Introduction

Bioarchaeologists study the ways people in the past have adapted to their environments by examining evidence left behind on their skeletons. Bone is a living tissue that responds to the forces placed upon it by labour, sport, and activities of daily living (Hall 1999, Ruff 2007). These observable changes, or functional adaptations, in bone, have often been used to reconstruct behaviour and to infer social identities like gender or social status in archaeological populations (Jurmain 1999, Knüsel 2000, Ruff 2007, Jurmain et al. 2012, Larsen 2015a, 2015b).

In recent decades there has been increased interest in further exploring women’s history which, due to our own cultural biases, is often invisible (Ewan 2010, Higginbotham 2010, Kania and Abernethy 2015, Lansing 2017, Murray 2017). Feminist archaeology has seen a similar rise in popularity through the reinterpretation of established literature and a new focus on the bioarchaeology of women and gender (Foster et al. 2013, Agarwal and Wesp 2017, Macintosh et al. 2017, Henderson et al. 2018, Miller et al. 2018, Becker 2019a, Price et al. 2019, Bickle 2020). Yet research that centres the functional adaptation of bone in women within bioarchaeology is still lacking.

Skeletal collections in Scotland have not been as frequently studied as those in the rest of Britain leading to comparatively insufficient bioarchaeological knowledge of historical Scottish populations (Roberts and Cox 2003). Much of the work in Scotland has focused on palaeopathology so activity data are sparse.

1.1 Sex, Gender, and Urban Medieval Scotland

Historical records of medieval Scotland span various sources such as municipal court records, shipping manifests, and some religious art that survived the Protestant Reformation in the late 16th Century (Gibson and Smout 1994, Broun 2006). Historical scholars have portrayed a deeply religious, stratified, and highly gendered society (Lynch 1988a, Ewan 1990, Dennison 2006, Dennison and Simpson 2006, Foggie 2006). Literacy and education were often reserved for the clergy and elites, chiefly the men (Marshall 1983, Hall 2002, Broun 2006). Records of the Craft Guilds, which functioned somewhat as regulatory bodies, labour unions, and mutual aid societies, also provided members with social identities (Lynch
1981, Torrie 1988, Ewan 1990). Although there were occasional records of women being allowed access, the Craft Guilds were almost exclusive to men (Lynch 1981, Spence 2015).

Despite the evidence of this highly gendered society in medieval Scotland, modern scholars must not assume our 20th Century view of occupational gender roles of men as the breadwinner and woman as the homemaker extend back into history (Brotherstone 1999, Grauer and Buikstra 2019). There was no concept of a distinct separation of home and workplace, as work and home life were inextricably intertwined (Ewan 1999a, 2009). Young women learned the trade or craft of their fathers or husbands and contributed to the family business. Married women did have charge of the household and children, but also served as middle managers by supervising apprentices and running the day-to-day business. Many women also earned independent incomes through service, craft, food, or textile production (Ewan 1990, 2006, Neville 2008, Spence 2015).

Apart from the few surviving primary sources, much of the current body of knowledge about medieval Scotland has been pieced together by post-Reformation or early modern sources and extrapolated backwards into the past (Whyte 2006). In some remote areas, particularly the Scottish Isles, traditional folk crafts and subsistence activities continued nearly intact into the early 20th century (Gauldie 1995, Derevenski 2000, Berman 2007). Despite the work of historians, there is still much bioarchaeological knowledge to be gained about urbanisation, the specialisation of craft, and women’s work in medieval Scotland.

In studying sociocultural differences, especially that of gender, bioarchaeologists are seeking the effects of that social identity on bone and not genetics or the effects of post-pubertal sex hormones (Buikstra and Ubelaker 1994, Brickley and McKinley 2004, Sofaer 2006, Foster et al. 2013, Grauer and Buikstra 2019). It is important to note that estimated sex is not the same characteristic as gender, which is a socially constructed identity. We cannot automatically assume any social identity, such as gender, solely through estimating morphological sex (Sofaer 2006, Foster et al. 2013, Grauer and Buikstra 2019). We do, however, frequently use sex estimation as a proxy for gender because we are unable to observe the gender identity of any individual from the distant past. These associations are made cautiously and with the understanding that societies in the past did not conform or subscribe to our modern gender theories (Sofaer 2006, Foster et al. 2013, Grauer and Buikstra 2019). With these complex concepts in mind, when the terms sex, female, and male are used, this refers to the estimated sex of skeletal remains. When gender, women, and
men are used, this refers to living beings with sociohistorical identity. This research applies estimated sex as a proxy for gender while exploring the potential effects of social identity on skeletal remains.

1.2 Assessing Activity in Bioarchaeology

There are three common methods of reconstructing behaviour in the past: entheseal changes (EC), degenerative joint changes (DJC), and cross-sectional geometry (CSG) (Jurmain et al. 2012, Larsen 2015a, 2015b). Although EC/DJC and EC/CSG are not uncommon pairings, the three methods have rarely been used in conjunction with the same population (Foster et al. 2013, Henderson et al. 2013a, Kubicka and Myszka 2020, Laffranchi et al. 2020).

EC describe the ‘footprint’ left on dry bone by the attachment of muscle, tendon, or ligament (Benjamin et al. 2004a, Benjamin and McGonagle 2007a). The relationship between the enthesis and activity is complex. Recent studies on animal models have shown no clear relationship between the shape of muscles and the corresponding entheses. However, Turcotte and colleagues found evidence in animals of an adaptive response in enthesis architecture only in early development and activity (Williams-Hatala et al. 2015, 2016, Rabey et al. 2017, Turcotte et al. 2020).

Many EC studies on dry bone carefully infer broad activity categories such as heavy or light manual labour or right-to-left asymmetrical patterns, but note it is almost impossible to discern specific occupations or activities for any single individual (Alves Cardoso and Henderson 2013, Henderson and Alves Cardoso 2013, Perréard-Lopreno et al. 2013). Some newer EC research has instead focused on human movements. For example, Karakostis and colleagues (2021) explored gripping vs thumb opposition in occupation. Villotte and Knüsel (2014) use muscle contraction relationships (agonist/antagonist) to suggest that EC at the medial epicondyle (inner elbow) may be a sign of throwing in a prehistoric population.

The interpretation and study of EC, formerly known as ‘markers of occupational stress’, have also changed to reflect anatomical and medical data but continue to be plagued by a lack of standard methodologies. The new Coimbra Method, established but not yet widely used, reflects medical and anatomical knowledge without the assumption of an aetiological process. (Villotte and Knüsel 2013, Henderson et al. 2016b, 2016a, Villotte et al. 2016). The Method records detailed traits, such as bone growth, porosity, or texture at the
enthesis rather than relying on enthesis robusticity (size) like some methods in the past (Hawkey and Merbs 1995, Maggiano et al. 2008, Henderson et al. 2016b, 2016a). The new Coimbra Method had been applied primarily to modern identified skeletal collections with known occupation, sex, and age at death. The occupations listed for females in identified collections are often ambiguous, thus much of this work has excluded them and focused on the males (Niinimäki 2012, Alves Cardoso and Henderson 2013, Perréard-Lopreno et al. 2013, Milella et al. 2015, Alves Cardoso and Assis 2021). The new Coimbra Method has been less frequently applied to archaeological populations where age-at-death and sex are estimated and only material culture, such as grave goods, might be used to infer behaviour.

DJC describes the way in which the body compensates for joint distress by altering bone, cartilage, or other joint structures (Jurmain 1999, Waldron 2019). Formerly understood as primarily a ‘wear and tear’ condition, bioarchaeologists must now consider the phalanx of other genetic, biochemical, and physiological factors when discerning hints of biomechanical influence on bone (Jurmain 1999, Roberts and Manchester 2010a, Larsen 2015a, Waldron 2019).

DJC has been studied for decades and scoring/recording has changed little, but the interpretations of DJC have shifted drastically to reflect medical advances. DJC is no longer considered a reliable indicator for biomechanical activity (Jurmain 1999, Waldron 2009, 2019, Williams et al. 2018). The inclusion of DJC in this project allows for more comparison to literature and establishes a baseline with which the other two methods can be compared.

CSG employs measures of biomechanical force to a cross-section of the diaphysis (shaft) of a long bone which is obtained through direct sectioning, moulding, or imaging (Stock 2002, Ruff 2007). Engineering formulae applied to the cross-section can determine traits like rigidity and resistance to deformation from the forces of bending or torsion (Ruff 2007). CSG data has been used to study hominin evolution, migration and mobility, subsistence, or divisions of labour in past populations (Trinkaus et al. 1994, Sparacello and Marchi 2008, Ruff and Larsen 2014, Miller et al. 2018).

Previous destructive methods of collecting slices of bone for CSG studies were replaced with expensive computed tomography (CT) scans but access to medical imaging technologies often limited the work on archaeological remains (Ruff 2007, Weber 2015). Recent advances in 3D scanning and imaging have created a lower-cost option for archaeologists to obtain cross-sections.
1.3 Aims, Research Questions, and Objectives

The primary aim of this thesis was to investigate patterns of functional adaptation of bone compatible with social allocations of labour in urban medieval Scotland. The secondary aim was to determine the accuracy, value, and efficacy of using the three individual and concurrent methods of observing functional bone adaptation employed in bioarchaeology: enthesal changes (EC), degenerative joint changes (DJC), and cross-sectional geometry (CSG) (Jurmain et al. 2012, Larsen 2015a, 2015b).

The research questions explored in this thesis are:

1. Do medieval Scottish women (estimated females) show evidence of lighter and more varied manual labour when compared to medieval Scottish men (estimated males)?
2. Do individuals from lower status Burghs show more evidence of strenuous manual labour than those from higher status burghs?
3. Do individuals from Burghs with major shipping ports show more evidence of manual labour than those from inland burghs?
4. Does integration of palaeopathological data, historical contextualisation, and modern anatomical, kinesiological and medical literature into interpretations regarding functional adaptation of bone facilitate understanding of gendered activities in past populations?

The primary objectives of this research were to:

1. Investigate the efficacy of the new Coimbra Method in discovering the effects of gender and social status on bone
2. Discover any biomechanical effects of gender and social status on the development of degenerative joint changes
3. Apply measures of cross-sectional geometry (Solid I-ratio, Solid J, and Total Area) to describe evidence of gender and social status on the humeral diaphysis
4. Compare results from enthesal changes, degenerative joint changes, and cross-sectional geometry to determine potential common aetiological processes
5. Synthesise bioarchaeological and contextual data to identify connections between bone adaptation, historical documentation, and modern clinical studies.

The scope of this project includes 204 individuals from 11 skeletal collections representing five Scottish Burghs: Edinburgh, Leith, St Andrews, Perth, and Dunbar. All Burghs were identified as ‘urban’ to capture potential specialisation in task and labour that would not have been present in rural or agricultural populations. The collections represented cemeteries that were in use throughout the medieval period in Scotland (c.800-1600 CE) and included both females and males.

Chapter 2, Social and Historical Background, gives a rich context to urban medieval Scotland with an emphasis on Burgh (town) life, occupation, craft, and women’s work. Chapter 3, The Bioarchaeology of Activity, describes bone anatomy, kinesiology, the background of the three methods, and then discusses the concept of ‘occupation’ in bioarchaeology. Chapter 4, Materials and Methods, begins with the archaeology of the collections and then describes in detail the data collection, software, and statistical analyses. This chapter also covers some specific history for each Burgh represented by the skeletal collections. Chapter 5, Results, lists all study results in tabular and graphical formats. Chapter 6, Discussion, contextualises all results by gender (as proxied by estimated sex,) social status, and geography. The end of this chapter synthesises the previous sections within a clinical context and ends with a discussion of the limitations. Chapter 7, Conclusion, outlines key findings, summarises the impact and contribution of this work, then discusses future research directions.
Chapter 2 Social and Historical Background

Historical context is essential to any bioarchaeological interpretation. Knowledge of daily life, social structures, subsistence, gender roles, and occupation are key to the study of activity.

2.1 Medieval Scotland

The country known today as Scotland was not a single kingdom until the late 9th century but did not emerge as a complete cultural unit until sometime during the 11th century. The name ‘Scotland’ was not broadly used until the 13th (Barrell 2000, Broun 2006). The early medieval period in Scotland, 300-900 CE, saw the influx of Christianity from Ireland and the south. Newly freed via papal bull in 1299 CE from the rule of the archbishop of York in England, Scotland was organised into its own system of Catholic Church dioceses ruled by bishops, and smaller parishes run by priests (Foggie 2006).

This time saw the rise of monasteries such as Iona and Holyrood, and major religious centres at Glasgow, St Andrews and Aberdeen (Barrell 2000, Foggie 2006). Early monks, known as the Culdees, and devotees of St Columba were found throughout Scotland from Iona in the west to St Andrews in the east (Foggie 2006). With the support of Rome, Scotland was soon home to Cistercians, Franciscans, and Dominicans (Foggie 2006). With the friars came an emphasis on teaching, leading to the founding of the early Scottish Universities at St Andrews in 1413, Glasgow in 1451, and later, Aberdeen in 1495 (Foggie 2006).

By the late 13th and 14th centuries the Western Isles and the Highlands, the Gàidhealtachd (where Gaelic language is spoken), had already become distinct from the lowlands (McDonald 2006). Civil and dynastic conflicts known as the Wars of Independence were led by Robert the Bruce and William Wallace as Scotland worked hard for separation from England (McDonald 2006). Rising to power by his military success and through political opposition, King Robert Bruce died in 1329. He is known as one of Scotland’s greatest kings for achieving independence for Scotland and some semblance of peace, even if temporary, with the rulers of England (Watson 2006). His young son David II (and his regents) ruled for a time but soon Bruce’s grandson Robert II, born of his daughter Marjorie Bruce and Walter Stewart, established the Stewart monarchy when he was crowned in 1371 (Brown 2006). The Stewart monarchy lasted until the turbulent political upheavals in the 16th century, and this
stable period saw Scotland become recognised as an independent participant in the European political system (Brown 2006, Boardman 2014).

2.2 Rural and Town Life in Medieval Scotland

Much of what historians understand about Scotland’s early history comes from surviving written records and documents. Most of this history details the lives of the aristocracy, such as king lists, battles and conflicts, and early laws and religion (Broun 2006). Members of the clergy were the early record keepers; literacy was common among the wealthy, including women, but not for those of lower status (Marshall 1983, Hall 2002, Broun 2006). While historical sources and scholars reported the founding towns, known as ‘Burghs’ in Scotland, and religious centres like monasteries and nunneries, there is little discussion of early medieval rural life (McDonald 1999, Whyte 2006). What is known about rural life in early Scotland has been gleaned from Burgh records or projected backwards based upon the better documented 16th and 17th centuries (Whyte 2006). Archaeology can help to fill gaps in knowledge about how people actually lived (Ewan 1988, 2006, Spearman 1988, Hall 2002).

Rural medieval Scotland was largely an agrarian society, often supplemented by fishing, and not unlike small agricultural communities today. Historical information is scant, but can be gleaned from studies of communities from the Highlands and Islands that were relatively isolated even into the early 20th century (Gauldie 1995, Derevenski 2000, Whyte 2006, Berman 2007).

The focus of rural life was the home, but there is also evidence of frequent travel to towns for trade and legal purposes. Early records of trade and shipping establish Scotland as a major producer of wool in Europe, and archaeological evidence of trade and craft such as animal skins, wood, and wool in the Burghs show evidence that supplies came from distant locations and rural communities (Boonton 1988, Lynch 1988b, Spearman 1988, Stevenson 1988, Ewan 2006). Many Burgh residents would have had small allotments for growing plant foods or raising small animals like chickens or pigs, but large herd animals such as cattle or sheep were raised outside the walls (Spearman 1988, Ewan 1990, Gemmill and Mayhew 2006). Despite the walls that enveloped most medieval Burghs, the divide between rural and urban was not easily defined, and people of the past were constantly on the move driven by trade (Ewan 2006, Whyte 2006).
With a growing population and ongoing warfare in the early medieval period from the 10th through the 12th centuries, many people moved closer to larger towns and Burghs seeking work and protection (Barrow 2006, Broun 2006, Watson 2006, Whyte 2006). The same period also saw the shift to a money economy with the first coins minted by David I in 1136. The development of Burghs with large market centres gave opportunity for surplus agricultural produce and livestock to be sold (Ewan 1990, Whyte 2006). Arable lands surrounding towns grew during the 13th and 14th centuries. Agriculture on lands near monasteries located close to urban centres grew significantly more than arable lands in rural districts, providing evidence of the importance of urban market centres (Ewan 1990, Whyte 2006).

Monasteries and nunneries in Scotland were generally founded by wealthy, aristocratic, and even royal, donors (McDonald 1999, Thomas 1999, Foggie 2006). While broadly austere during the early medieval period, eventually the labour of the monks and nuns earned many such institutions a comfortable income (McDonald 1999, Foggie 2006). The religious orders worked the land, farmed sheep, and also acted as educational centres taking in young boys to train them in Latin, calligraphy, and theology (Marshall 1983, Ewan 1990, Foggie 2006). Many nunneries have been associated with the care of the elderly and the infirm, but this practice was not exclusive to the female religious establishments (McDonald 1999, Foggie 2006). Like smaller towns or Burghs of the time, settlements of lay people grew up around monastic communities and formed local economies (McDonald 1999, Foggie 2006, Whyte 2006).

The reign of David I brought other changes besides a money economy (Barrell 2000, Broun 2006, Ewan 2006). Edinburgh was officially founded as a Royal Burgh in 1130 CE (Collard et al. 2006). Life within a medieval Burgh was a distinct experience (Boonton 1988, Ewan 1988, 1990, 2006, Foggie 2006, McDonald 2006). Most medieval Burghs had walls and access for those who did not live within them was restricted (Ewan 1990, 2006, Gemmill and Mayhew 2006). One had to be a citizen of good standing with the Church, affluent enough to afford the fees and taxes associated with town life, and, of course, male, to become a burgess of the town (Ewan 1990, Hall 2002, Dennison 2006, Dennison and Simpson 2006). While there is some historical evidence of women achieving burgess status later in the medieval period, this would have initially been through their association with a father or a husband (Marshall 1983, Torrie 1988, Ewan 1990, Dennison 2006). Burgesses formed the
core of Scottish Burgh administration and government and were the town provost (mayor), council members, baillies, magistrates, aldermen, clergy, merchants, and master craftsmen (Ewan 1988, 1990, Torrie 1988, Dennison and Simpson 2006). Burgess status often carried the additional requirement of owning land. While it was easier to achieve through inheritance, it was not inaccessible to merchants or craftsmen who made enough money (Ewan 1990, Dennison and Simpson 2006). The residents of the Burgh, especially a large one like Edinburgh, were wealthier than residents of smaller Burghs in Scotland. The social structure of large Burghs was stratified with the very wealthy and the very poor represented (Lynch 1988b, Torrie 1988, Dennison 2006).

People of lower socioeconomic status also lived within the Burghs but were often relegated to poorer lodgings further away from the market square or administrative centre (Ewan 1990, 2006, Hall 2002). Anyone who was not an apprentice, journeyman, or a servant was considered a freeman, but not all freemen were burgesses (Lynch 1981). Many who lived in areas surrounding the Burgh were permitted to enter the city walls to buy or sell goods on market days or to engage in other trade, or for reasons relating to law or religion. This constant movement created an interdependence between the Burgh residents and those who lived directly outside the walls (Spearman 1988, Ewan 1990, Gemmill and Mayhew 2006).

It was not only the city walls and taxes that helped to form a sense of community within the Burgh, but also the Church. Residents of medieval cities in Scotland all worshipped together as one parish, a practice that continued until the Scottish Protestant Reformation in the 1560s (Lynch 1988b, Ewan 1990, Dennison 2006). Small, walkable city centres meant no one was ever very far from the sounds of church bells and the Church was inextricably linked with the socioeconomic and administrative life of the town. In Edinburgh, this church was the parish of St Giles (3.6.1.1). Outside the city walls of Edinburgh there was Holyrood Abbey and the community of Canongate (3.6.1.2) and to the south side of Edinburgh towards the later period was the Church of St Mary’s of the Field (3.6.1.3) and Blackfriars Monastery (3.6.1.4). Smaller Burghs worked in similar ways but on a smaller scale, with a lower population, and less economic disparity between the wealthiest and the poorest citizens. No matter the relative size, the Burgh community was close-knit, complex, and interrelated in many ways (Ewan 1988, 2006, Dennison 2006, Dennison and Simpson 2006).
2.3 Work and Occupation in the Scottish Medieval Town

The socio-political power of a medieval Scottish Burgh was distributed between the burgesses and magistrates of the town council, the Church and its representatives (e.g., the local bishop or priests), and the wealthy members of the various merchant and master craftsman organisations (Lynch 1981, 1988b, Ewan 1988, 1990, 2006, Hall 2002).

Church representatives would sit on the town council and every burgess had to be a respected man of God. In this way the Church was able to maintain high levels of control throughout the city (Ewan 1988, Dennison 2006). While religion was interwoven into daily life, it was the market that was the social and economic centre of town (Marshall 1983, Ewan 1988, 1990, 1999b, Dennison 2006). Merchants and sellers would barter and trade, craftsmen would find raw materials, servants could purchase textiles, food, or animals for supply or slaughter, and everyone would eat, drink, and gossip in the marketplace (Ewan 1988, 1990, 1999b, Spearman 1988).

The town council of burgesses controlled who could work and where, when the market days were held, the costs of goods, and even the number of employees a given business could have. They managed the inspection and quality of the market goods, especially staples such as bread and ale, by controlling the purchase price of raw materials so that most makers could access material even in lean economic times (Ewan 1990, 2006, Mayhew 1999, Gemmill and Mayhew 2006). According to court records, often this inspection included tasting or sampling the goods for sale. Sellers were fined for watering ale, charging too much, or for private sales that did not give equal access at market (Ewan 1999b, Mayhew 1999, Gemmill and Mayhew 2006). There was an appearance of an egalitarian marketplace, but there was still underground trading (Ewan 1990, 1999b, Gemmill and Mayhew 2006).

Much of the work for the men in the town was seasonal and dependent on agriculture, especially in the early medieval period. A labourer could work for a master craftsman or merchant in the town for part of the year and move outside to a rural area to work the land or the harvest for another (Spearman 1988, Ewan 1990, 1999b). As towns grew and populations increased, work became more specialised. Workers who performed similar tasks or who shared similar raw materials naturally began to come together and to organise into groups (Lynch 1981, 1988b, Torrie 1988, Ewan 1990, Dennison 2006). By the
late medieval period in Scotland, these groups were legally incorporated as Craft Guilds (Mackenzie 1949, Lynch 1988a, Torrie 1988).

Early guilds were fraternal organisations that functioned more like large family units with common interests (Torrie 1988). Agreements were made to obey the rules of the group in exchange for mutual aid, such as supporting a widow of a guild member or sharing resources in hard times (Torrie 1988, Ewan 1990). It was not all serious though; guilds were also known for communal merry-making, feasts, and festivals (Torrie 1988, Ewan 1990). Guilds also had a responsibility to the Church. Each guild was responsible for tithes and donations, and in exchange was granted designated altar space within the parish Church as well as the privilege of burial for guild members and their families near the guild’s altar (Lynch 1981, Ewan 1988, 2006, Torrie 1988). In addition to the guilds, many wealthy individuals also established altars within the Churches. St Giles’ in Edinburgh had over 40 such altars (Ewan 2006). This demonstrates the interrelationships of the craft guilds and the Church in a Scottish medieval town.

Growing urban populations and increasing specialisation led to increased hierarchy and a more formalised structure in the guilds. Formal incorporation occurred in the late 15th and early 16th centuries in Scotland. This granted official political power to the guilds, but undoubtedly the guilds wielded political influence long before being recognised (Lynch 1988b). The number and scope of guilds was dependent on a town’s size and relative prosperity. Broadly, bigger towns had a larger number of guild organisations (Mackenzie 1949, Lynch 1988a, Torrie 1988). When compared to English towns of similar size and population, the number of guild organisations upon incorporation was far lower in Scotland. Norwich, which was of roughly comparable size to Edinburgh, had by the early 16th century 79 different trade organisations. At that time Edinburgh had only 14, Perth and Dundee nine, Aberdeen and Stirling seven (Lynch 1988a). The amalgamated nature of Scottish Craft Guilds was quite unique to Scotland (Lynch 1981, 1988a, 1988b). The second guild to be incorporated in Edinburgh, and by 1550 also the largest, was the Hammermen. This guild is probably the best example of this combined structure as it represented metalworkers including blacksmiths but also those who worked with tin, copper, pewter, silver, and gold and other craftworkers such as saddlers and beltmakers (Lynch 1988a).

In an interesting and not at all paradoxical public display of both unity and hierarchy, ranking Church members and the various craft guilds would process through the Burgh and
around its borders on Corpus Christi Day reminding all who watched that they were a part of the community and that membership within the town was valuable. Inequality in status was an accepted part of medieval life and it did not preclude residents feeling a sense of inclusion in the Burgh community (Ewan 1990, 2006, Dennison 2006). The procession was a formal recognition of the status of the Church as the ultimate authority, but also displayed to all the relative rankings of the craft guilds (Ewan 1990, 2006, Dennison 2006). Those professions that dealt with animals, flesh, tallow, or lard were at the front of the parade as the lowest ranking guilds. The highest ranked, workers of stone and metal, were towards the back, close to the highest-ranking local representative of the Church. This translated excerpt from the National Records of Scotland tells us the relative value placed upon the various guilds in the Edinburgh Corpus Christi Day procession as written in a letter to a nearby town, Haddington:

“And all other general processions and gatherings that is to say that whole brothers of hammermen of all kind of sorts together with the masons wrights glazingwrights [glassmakers] and painters passes all together with their banners next the sacrament. And next there before, passes the baxsters [bakers]. The third craft before they is the wobstars [weavers] & walkars [fullers of cloth] together. The fourth is the tailors. The fifth place before the sacrament is the cordiners [shoemakers]. The sixth place is the skinners and furriers. The seventh place before the sacrament passes the barbers. The eighth place, which is the foremost place passing before the procession, is the fleshers [butchers] & candlemakers...” (Foular 1532).

Social hierarchy was a common theme within the internal craft and guild structure. Any business that produced a craft product had the business owner at the head, usually the master craftsman, but also employed a variety of skilled journeyman and apprentices (Mackenzie 1949, Lynch 1981). The journeymen and apprentices performed the labour, received wages and some amount of protection from the master craftsman, but had very little political power. Only the master craftsmen were permitted to be members of the craft guilds, and this led to a distinct craft aristocratic class of ruling business owners who controlled their employees. The mutual aid offered by the guilds as a benefit of membership was inaccessible to the labouring class of journeymen and apprentices (Lynch 1981, 1988a, Torrie 1988, Dennison 2006).
Early in the period, occupations were identified by simple terms like craftsman, merchant, knight, or priest (Lynch 1988a, Hall 2002). Yet with the more nuanced social hierarchy that permeated the Scottish Burghs, historical occupational terms had little to do with what a man did with his time and labour on a day-to-day basis. A common misconception was that a craftsman makes the goods, and the merchant sells them (Mackenzie 1949, Lynch 1981, 1988a). As discussed above, the master craftsman guild member was in fact among the wealthiest and most privileged members of the Burgh. The occupation of craftsman could refer to the young, newly apprenticed man, the journeyman who has laboured for decades, or the master, who quite likely did very little work aside from collecting profits (Lynch 1981, 1988a, Torrie 1988). The merchant occupation was also just as varied. The man who bought and sold at the market stall, or kept a shop, had a very different social standing and performed markedly different physical work than did the men who managed vast shipping networks for import or export (Lynch 1981, 1988a, Spearman 1988). The merchant guild in Edinburgh was founded in the 13th century, although not incorporated until 1518, but no doubt the members were the elite of the Burgh, much like the craft guild members (Lynch 1981, Torrie 1988).

Comparing one guild to another to understand work and labour is not an effective method for determining levels of physical activity in Scottish Burghs. Given the example above of the amalgamated Hammermen, the goldsmith or silversmith who made fine jewellery is not going to be of the same class or do the same labour as the blacksmith who works with iron. An apprentice or journeyman will be doing far more physical labour than the master craftsman despite all of them being members of the same trade and guild. If neither occupation title nor guild membership is helpful to understand who was doing the work, then perhaps better is the framework of social and economic hierarchy within the Scottish Burghs.

2.4 Medieval Scottish Women’s Work and History

No discussion of social and economic history of occupation and task can exclude the people who made up half the population, women. Female historian Elizabeth Ewan (1999b, pg. 26) stated “Because much recent work had been concerned with the basic task of finding historical women, questions of gender relations and the impact that gender can have on politics, society, etc. are only just beginning to be discussed.” The problem of ‘invisible’
women in history is complex and not always due to a lack of academic research; it is intimately linked to the importance placed on the topic within scholarly circles (Brotherstone 1999). It was not until the mid-19th century that historians began to value and explore women’s history by discussing noblewomen and queens, such as Mary Queen of Scots, Lady Sarah Bruce, and Flora MacDonald (Ewan 1999a, 2009).

Traditional views of Scottish history that glorify military prowess or highlight pride in labour lead to an emphasis on male strength and a skilled male workforce. This led to a stereotypical view of women as passive players in historical action as nurturers, supporters, or victims (Ewan 2009). As work in women’s history continued to progress, it has become clear that these stereotypes were barriers that needed to be overcome (Marshall 1983, Brotherstone 1999, Ewan 1999a, 2009). According to Ewan (Ewan 1999a: 27) who quotes Joy Hendry from Snug in the Asylum of Taciturnity: Women’s History in Scotland, “If you don’t expect women to do anything much, then you are likely to miss the impact of what they do accomplish.”

Much of women’s history during the medieval period has been pieced together through the eyes of the literary male gaze. By analysing how men of the period wrote about and viewed women, more accurate pictures can be formed (Ewan 1999a, 2009). Medieval women can be ‘found’ by reading court records, shipping manifests, and in religious documents. Most of what is known about women’s history comes from similar sources as there are precious few primary sources that centre women’s voices (Ewan 1999a, 2006, Mayhew 1999, McDonald 1999, Spence 2015). Interdisciplinary studies of literature, folklore, linguistics, song, and archaeology have also made significant contributions to the field of women’s history in Scotland (Ewan 1999a, 2006, 2009).

The outdated assumption that biology determines gender or social role is detrimental to interpretations of historical or archaeological populations. Neither can the modern perceptions of gender, role, or presentation as social constructs or identities be the sole lens through which social allocations of labour are interpreted because societies in the past did not share those ideals (Brotherstone 1999, Foster et al. 2013, Grauer and Buikstra 2019). It would also be a mistake to apply 20th century ideals of man as the breadwinner and woman as the homemaker, when this rarely applied to pre-industrial cultures (Ewan 1999b, 2009). The construct that imagines separate spheres of the private household (usually for women) and the public workplace (usually for men) are also industrial age ideas that have no bearing
on the most historical or archaeological populations or cultures (Ewan 1999a, 2009). In medieval Scotland, the home, workplace, market, and religious life were inseparably entwined (Lynch 1988b, Ewan 1990, 1999a, 2006).

2.4.1 Marriage and the Madonna: Women, Status, and the Church

Women were found in every medieval social stratum from royalty to peasants, from the wives of wealthy merchants to the sellers of ale and oatcakes in the marketplace, and in every role from nunneries to prostitution. A woman’s status in medieval Scotland was affected by complex and overlapping factors like birth status and social class, economic standing, and wealth, but none more than her relationships to her father, husband, to God, and to the Church (Marshall 1983, Ewan 1999a, 2009, Mayhew 1999, McDonald 1999, Spence 2015).

Women of high status, both royals and the aristocratic ruling class, were commonly seen as pawns in their fathers’ or husbands’ efforts to establish status, wealth, and power to secure land or allies, but there is also evidence that women, within these societal boundaries, were active players who were able to wield social and political power themselves (McDonald 1999, Barrell 2000, Ewan 2009, Spence 2015). Women of higher social status were more likely to be educated and literate, and while there is some scattered evidence of female literacy in the early medieval period, in the 14th and 15 centuries it was much more commonplace (Marshall 1983). Women who were married to wealthy, aristocratic, or royal men worked in middle-management roles running their households and checking accounts in their own hand (Thomas 1999). Arranged marriages would have been the norm, but for some women with political aspirations and skills this would have provided a rare opportunity for social standing and political influence, if not in her own right then certainly through her husband (Marshall 1983, Thomas 1999, Ewan 2009).

While there were fewer female religious establishments in early medieval Scotland when compared to England, possibly because of the already high financial drain of monasteries, most nuns were the daughters of wealthy parents (McDonald 1999, Foggie 2006). The nunneries were often established and maintained by wealthy noblewomen but although women were the driving force, monks would only record the names of their husbands, rendering women invisible to history (McDonald 1999, Foggie 2006).
Exerting influence through their husbands was not the only way women could gain social status or political power. In the later medieval period, some women achieved burgess status or associate guild membership in some of the larger Burghs. Often this status did come as a daughter of a burgess, which could then be handed to her husband upon marriage, or as the widow of a burgess or guild member (Ewan 1990, Spence 2015). Work was not seen as a way to social advancement, but marriage was (Marshall 1983). By the 16th century marriages between a non-burgess man and the daughter of a burgess were twice as common than earlier in the period (Dennison and Simpson 2006).

Widows were the women who had most agency in medieval Scotland as they retained the status conferred by marriage. When compared to England, Scottish women did retain some small signs of independence as most retained their family name upon marriage and were permitted by law to inherit property (Marshall 1983, Ewan 1990, 1999a, 2009, Fitch 1999, Mayhew 1999, Foggie 2006, Spence 2015).

The lives of single unmarried women were much more tightly controlled by society and by the Church. A young woman had very few life choices, these being most often decided upon by her father (Marshall 1983). Agency of unmarried women who were not widowed was virtually non-existent and expectations of behaviour were high, no matter the social standing. Broadly, while women of high status had to follow more strict social behaviours, women of all social classes were affected by the prevailing views of the Church (Marshall 1983, Fitch 1999, Thomas 1999). Most women, regardless of social class or wealth, walked a fine line between appearing pious and proper in public and still retaining and expressing whatever power and agency they could in private (Fitch 1999, Thomas 1999, Ewan 2009).

Religion and the Church are some of the oldest tools used to control women, sexuality, and reproduction (Marshall 1983, Fitch 1999, Standley 2016). Women, due to a combination of pregnancy, childbirth, and blame for Eve’s fall from grace in the Garden of Eden, were associated with the flesh, earthly life, and sexuality. In a culture that prioritised spiritual transcendence as a means to heaven and God’s favour, women and their earthly sinfulness and shame posed a unique problem to which suffering and saintly purity were the solutions (Fitch 1999). The Church offered many stories, imagery, poems, and plays featuring the virgin mother of Jesus and the virgin martyr saints as role models for how she was supposed to achieve this holiness. Sexual purity through virginity and chastity combined with
great sacrifice, commitment, and physical suffering brought women closer to salvation (Fitch 1999).

Little visual imagery survived the Scottish Reformation, but stories and legends of the virgin martyr saints were common throughout medieval Europe. Scotland did have a thriving virgin martyr tradition as evidenced by poems and literature (Fitch 1999). St Apolonia who was tortured by having her teeth pulled out before her death was pictured holding her teeth in her hands, St Katherine had her wheel of torment, and St Margaret, the clean, angelic virgin survived torture in a prison cell by the dark, filthy, and manly devil (Fitch 1999). In late medieval Scotland the concept of Jesus as a humanised brother, father, lover, or spouse was popular and this taught women that the next best thing to virginity and chastity was sexual purity within marriage. Women were given the option of being closer to God by being faithful to their husbands as a proxy for Jesus (Fitch 1999). Chaste widowhood was also an acceptable option for women, and many joined religious houses. Coupled with good works, a chaste widow could increase her status and earn her way to salvation (Fitch 1999, McDonald 1999).

This deeper understanding of the religious and societal expectations of women helps to explain why single women were controlled and protected by their fathers, and married women, while subservient to their husbands, were offered some amount of respect and agency. Although they are much more difficult to find in history, women who did not fit this image of the ‘good woman’ did exist. Deviant women deserted their husbands, committed verbal and physical assault, sought divorce, and served as concubines, lovers, mistresses, or prostitutes (Ewan 2009, 2010, Butler 2017, Lansing 2017). Historical evidence of lesbians has even been found by locating women for whom their primary relationships, emotional or sexual, were woman-identified (Murray 2017). Women could be either virginal, chaste, and proper, or they were called evil, sexual, temptress witches by the prevailing attitudes of the day (Marshall 1983, Fitch 1999, Ewan 2010, Murray 2017).

Despite the societal expectations and controls of religion, women at all rungs of the social ladder were far from passive participants in history. They had active social lives, families, political power, agency, and many also had their work, craft, businesses, and occupations (Marshall 1983, Torrie 1988, Ewan 1990, 1999b, 1999a, Mayhew 1999, Spence 2015).
2.4.2 Hearth and Handcraft: Evidence of Occupation

Much of the historical evidence of women’s work or occupation comes via municipal records, law books and court cases (Marshall 1983, Ewan 1999b, 1999a, Mayhew 1999, Spence 2015). Laws and rules established to exclude women from a profession or guild surely would not have been necessary unless some women were challenging the status quo and seeking both recognition for their work and the economic benefits of membership (Spence 2015). While royals’ and aristocrats’ concerns centred around politics, land, and wealth, for most other women it was business, family, and survival. Women of the middle and working classes performed an honest days’ labour, but not unlike today their contribution was either not as valued, or only valued when they worked in their ‘proper place’. Woman made goods, bought and sold, and contributed to the household income in a myriad of ways but their skills were seldom recognised by law (Marshall 1983, Lynch 1988a, Torrie 1988, Ewan 1999a, Mayhew 1999, Spence 2015).

As mentioned above, for women there was no clear boundary between the public and the private, and neither was there any clear division between the home and the workplace for any worker in a medieval Burgh (Ewan 1999a, Thomas 1999). There was, however, a moderately clear division of labour between the sexes that was based on rhythm and timing of work and the seasonality of agriculture (Spearman 1988, Ewan 1990, 1999a, 2006, Mayhew 1999, Gemmill and Mayhew 2006, Spence 2015). Men’s lifestyles, especially early in the period, revolved around agriculture, crops, and his trade. He might leave the city to help with planting or the harvest, then return to his regular trade during the winter months (Spearman 1988, Whyte 2006). Later in the medieval period many trades grew to be dependent on international shipping and this reinforced a seasonal rhythm (Lynch 1988a, Ewan 1999b, 2006, Mackenzie et al. 2018). Men’s labour worked on the scales of months to years while the women’s functioned on the scale of days to weeks.

Most brewsters were women as the rhythm of ale brewing took only 24-72 hours and it could be boiled at the hearth while managing other domestic or business duties. Men managed the malting, and later once hops were introduced, the beer making, as those relied more upon seasonal crops (Ewan 1999b, 2006). Similarly, it was the men who were the baxters (bakers of bread) a delicacy reserved for the upper classes, while the women were responsible for making cakes. In Scotland these were primarily oatcakes, that were the everyday fare of commoners. Men and women both worked in textile trades with the men as
wobsters (weavers), waulkers (fullers), and tailors, while the women did the carding, 
combing, and spinning, which could be put down while she attended to her other duties 
(Ewan 1990, 1999b, 2006). Work for all commoners, male or female, would have varied 
throughout a season or over a lifetime.

Daily life for Scottish medieval common women who were married would have 
centred around the home as they were responsible for the household, the business, and the 
market. Households in a medieval Burgh were both social and economic units (Ewan 1990, 
2006). A storefront would have faced the high street at ground level with a workshop in back. 
Private dwellings were often above the shop, and most had allotments, gardens, animals, and 
entrances for servants or apprentices at the back (Ewan 1990, 2006). Married women were 
the middle-managers of the medieval Burgh and were responsible for learning their 
husband’s craft, often working alongside him without recognition. Women might manage the 
shop, the business, and apprentices, along with any household servants. They also managed 
any children who were not without responsibilities to the family business (Ewan 1990, 2006, 

Medieval women were also ubiquitous in the marketplace. Early in the period this 
would have meant transporting their wares to market, setting up a stall, and bartering for 
goods and services. As market stalls became more permanent in Scotland, the Luckenbooth 
(a booth that locked) was established and women became the primary market sellers (Ewan 
1990). Any surplus of ale or cakes made at home would be sold at market and sometimes 
women were paid to provide food and drink for public building sites or the local port (Ewan 
1999b). Many common women were also responsible for clothing their families. Often the 
finer woven fabrics were reserved for the nobles or for export, only poorer quality wool was 
available for locals (Boonton 1988, Spearman 1988, Torrie 1988, Ewan 1990). Sales were 
made, households supported, and childcare managed through the social connections and 
networking of women in the marketplace (Ewan 1990, 1999b, 2006, Dennison and Simpson 
2006, Gemmill and Mayhew 2006).

Medical care was often administered at home and would have been the responsibility 
of the women of the household. Infirmaries at religious houses, both male and female 
establishments, catered to the poor or the sick and dying. It was not until the later medieval 
period that apothecaries and barber surgeons began to provide specialised medical care 
(Ewan 2006).
Burgh law reinforced divisions of labour. Often men were restricted to one occupation while most women’s work escaped legislation (Ewan 1999b). Many women might have appreciated this flexibility, but as guilds were incorporated and legally recognized, this also meant that women were excluded from economic success. No brewsters’ guild for women ever existed but once men took over the production of beer, they were relatively quick to form a brewsters’ guild to be recognised for their skills. The Edinburgh Society of Brewsters was incorporated in 1596 (Ewan 1999b, Mayhew 1999).

Ordinances restricting women from craft and specifically from guild membership were on the books in England from 1300-1700, which does show that some women were vying for more formal recognition (Spence 2015). Occasionally guild laws allowed for associate membership for women, but likely this was reserved for wives, daughters, or widows of guild members (Torrie 1988). It is also possible that the wife may have been a driving force behind a business but that her work rendered invisible to history when her husband’s name was the only one added to guild or burgess records (Ewan 1999b). There was informal recognition of women’s skills, but this can rarely be proven through laws and court records. In 1522 in Aberdeen, for instance, eight women were put in charge of determining the day’s price of malt and meal with local growers, which demonstrates business acumen and experience (Mayhew 1999).

In times of plenty or in areas of lower population women were more welcomed to participate in the marketplace but were quickly excluded during hard times. An ordinance in Aberdeen after a poor harvest in 1438 banned women from the victuals (food) market (Mayhew 1999). Unsurprisingly, laws made by male burgesses supported men and tended to exclude women from economic success (Ewan 1999b, Mayhew 1999).

If a woman in business should find herself widowed, there were legal avenues open to her. Often, she would choose to continue the business as she would have been familiar not only with the skilled craft but also the management and the administration (Ewan 1999b, Spence 2015). By the 15th century many town records show limitations on how long a widow could run a business by herself. Restrictions varied from three months to a full year, implying that before the law was enacted many widows were engaging in business on their own for longer periods of time (Spence 2015). In all cases, though, she was only permitted to continue until she was remarried (Spence 2015). Although she had little legal property while married, the business, household, and associated property would become hers on the death
of her husband. This relative wealth might make her an attractive wife for her next husband who would gain rights to her wealth upon marriage (Marshall 1983, Ewan 1990, 2006). Rather than marry a man and therefore be expected to learn a new trade, some widows chose to marry one of their husband’s apprentices to keep the business running and legal (Spence 2015). Wealthy or prosperous widows of merchants, especially international shipping, were sometimes permitted more leeway in conducting business on their own (Spence 2015).

Young men were generally apprenticed to a single craft and the number of apprentices any business could have was controlled by guild and Burghal law (Lynch 1981, Torrie 1988, Ewan 2006). Young women were occasionally apprenticed, but most often poorer women were trained in domestic service, or if being groomed for marriage, then household administration. They might learn about their father’s business but then upon marriage be required to learn their new husband’s craft, which shows how versatile many women had to be in the work they performed (Cowan 2008, Neville 2008, Spence 2015).

There is some evidence of young, unmarried women becoming indentured servants to pay a debt, either their own or their parents. Young women also learned a skills besides domestic service, namely lacework (Spence 2015). Records document female apprenticeships in London by the late 14th and early 15th centuries, and in Bristol, for example, two thirds of female apprentices were a combination of seamstress and domestic servant. No such records exist in Scotland, but it is possible that by later in the medieval period this did happen on a more informal basis (Spence 2015).

Unmarried women are rarely mentioned in historical sources unless they broke the law. Single women were considered suspicious and were often required to leave town (Ewan 1999b). Aside from those who were sworn to religious service or widowed, adult unmarried women might be seen working as prostitutes, wet nurses, in childcare, or in domestic service, such as sewing or washing (DesBrisay 1999, Spence 2015, Lansing 2017). Later in the period, some women were able to support themselves with textile work including combing, carding, and spinning, leading to the popular term for older, unmarried women of ‘spinster’. While offering some amount of economic independence for women, textile work restricted movement, networking, and social connection. Before the advent of the stationary spinning wheel, spinning was done with the highly mobile distaff, spindle, and whorl and was often a social activity. Although the wheel did not completely replace the spindle, as it became more
common in Scotland women were also forced to stay at home and out of public spheres (Berman 2007, Kania 2015, Kania and Abernethy 2015, Standley 2016).

2.5 Reformation and Enlightenment: The 16th Century

The medieval period in Scotland is often capped with the Scottish Reformation in the 1560s, and the 16th century brought change on many levels. 1513 saw the end of the Stewart Dynasty with the death of James IV at the Battle of Flodden and his son, James V, son of Mary Tudor, succeeded him at only 14 months old (Brown 2006). In 1538 James V married Mary of Guise who was well known for her political prowess and skill. She ruled as a powerful Queen Regent for their daughter, Mary Queen of Scots, for many years and encouraged contact between her native France, and the much smaller Scotland (Lynch 1981, Barrell 2000, Brown 2006). With these female rulers came slightly more opportunity for women (Spence 2015).

As populations in the Burghs continued to grow, governments were forced to introduce additional laws and to formalise governmental processes. Many of the powerful craft and merchant guilds were legally recognised and incorporated in Edinburgh between 1475 and 1536 giving greater administrative and political power to the guilds (Lynch 1988b, Torrie 1988). By 1580 in Edinburgh, craft guild members had seats on the town council (Lynch 1988b). The earliest surviving census in 1560 counted Edinburgh residents at 12,500 when many population estimates of earlier Burghs range between 1000 and 5000. This demonstrates the increasing importance of the capital city (Dennison and Simpson 2006). Tax musters during the 1560s document only c. 40% of male workers were taxpayers, as the poor were untaxed. Single women and widows made up approximately 22% of households but only formed 7-10% of tax payers (Lynch 1988a). Thirty percent of adult men were associated with the merchant or craft guilds and historians estimate approximately 50% of the population in the Burgh was engaged in manufacturing (Lynch 1988a).

Protestant reformers in Scotland brought literacy to the masses as they wanted every person to be able to read the Bible and to have their own relationship with God, not through an intercessor of priest or bishop (Lynch 1981). While the Reformation might have been swift, cultural change was slow and it took time for individuals to adjust. Some guild members maintained their Catholic faith and excluded from the religious life that they had
known before the Reformation, continued to meet in a ‘privy kirk’ (private church service) (Lynch 1981).

Post-Reformation Scottish Burghs established new charters and councils, Perth in 1556 and Edinburgh in 1583, which included the founding of the University of Edinburgh (Lynch 1981, 1988b). In 1565 a tax muster enabled the purchase by Edinburgh of the superiority of nearby Leith, which brought the port city under administrative control of the capital (Lynch 1981). Increasing entry fees and laws, which decreed that son, daughter, or apprentice “can be in no better estate nor their father or master was by their right” saw a shoring up of the wealth and privilege of the craft and merchant aristocracy in an increasingly stratified society (Lynch 1981: 54).

Continued and increasing contact and trade with European countries experiencing their own cultural renaissance on the continent influenced the culture of Scotland and set her on the path to the Scottish Enlightenment and the modern era.
Chapter 3 Bioarchaeology of Activity

3.1 Functional Anatomy of Bone and Soft Tissue

The skeleton, as the primary supportive system of the human body, has a variety of functions. As the anchor of the musculoskeletal system, bone serves as the attachment point for soft tissues such as tendon, ligament, and muscle (Lemos et al. 2005). When viewed as a part of the physiological whole, bone also assists in the production of red blood cells, storage of adipose tissue, and serves as a repository for minerals like calcium which are essential for the body’s physiological functions (Ortner 2003). As a living, dynamic tissue, bone allows for growth in the individual and is also responsive to the forces placed upon it throughout life (Ruff 2007, Ibáñez-Gimeno et al. 2013).

The primary component of bone is collagen, a large protein molecule that intertwines to form elastic, flexible fibres. The second component is an inorganic, mineralised hydroxyapatite (Bilezikian et al. 2002, Şenol and Özer 2020). Three types of cells make up bone. Osteoblasts deposit extracellular matrix and ossify it, while osteoclasts are active in the resorption of bone tissue (Ortner 2003, Bilgiç et al. 2020). This balance between synthesis and resorption is how bone is remodelled throughout the life cycle in response to environmental or mechanical stress, growth, and maintenance (Ruff 2007, Ibáñez-Gimeno et al. 2013). The third type of cells are osteocytes, which are formed from differentiated osteoblasts. Osteocytes are known to communicate with other cells via a cellular matrix and are responsive to hormones such as thyroid and parathyroid hormone, which regulate bone calcium and phosphorus (Ortner 2003, Bilgiç et al. 2020).

On a macroscopic level, bone can be divided into two major types, cortical or compact bone, which is found in the dense outer layer, and trabecular, or cancellous bone, which is the spongy inner layer of bone (Figure 1). Compact bone is nourished by Haversian systems, canals of blood vessels that permeate the dense layer, while spongy bone is fed by blood vessels in the surrounding marrow spaces (Enlow 1962, Pfeiffer et al. 2006, Bilgiç et al. 2020). During life, bone is covered by a thin, compact, and highly vascularised superficial layer called the periosteum.
Where bones connect to other bones an articulation, or joint, is formed. Joints occur in a variety of shapes, sizes, and degrees of movements classified as synarthrotic (immovable), amphiarthrotic (minimal movement), diarthrotic, for which mobility is the marked characteristic (Gray 1974). Synarthrotic, or fibrous, joints are divided up into sutures, such as the bones of the skull, gomphoses, joints formed by a tooth and the mandible or maxilla, and synchondroses, temporary cartilaginous joints at the epiphysis of juvenile bones that are eventually replaced with bone tissue (Gray 1974, Waldron 2009). Amphiarthrotic joints are classified into symphyses, such as the articulation between the vertebrae or the pubic symphysis, and syndesmoses, articulations featuring ligamentous attachment with minimal movement, such as the tibiofibular joint (Gray 1974, Waldron 2009).

The ends of the bone in diarthrotic (i.e., two bones), or synovial, joints are covered in a thin, smooth hyaline cartilage, and are connected by thicker cartilage and ligament tissue (Figure 2). A fibrous outer layer of ligament, the joint capsule, encloses the joint cavity which is filled with synovial fluid, a viscous joint cushion (Gray 1974, Stone and Stone 2000). The
varied morphology of the individual bones that form the joint allows classification of synovial joints into planar, saddle, ball and socket, or hinge; names that describe the basic movement of each joint (Gray 1974, White and Folkens 2005, Floyd 2012, Yakut and Tuncer 2020).

![Figure 2 Standard Synovial Joint](From Comparative Kinesiology of the Human Body, (Yakut and Tuncer 2020: fig. 4.7)).

While the bone provides the anchor and leverage for joint movement, the force originates from the attached muscle and tendon. The location of connection between tendon or muscle and bone is often known as the origin or insertion. The origin is traditionally the most proximal attachment and the insertion more distal (Stone and Stone 2000, Myers 2001, Milner 2008, Floyd 2012). The region on the bone where the muscle or tendon attaches is called the enthesis, which is comprised of up to four types of tissue, often termed the “enthesis organ” (Benjamin et al. 2004a, Benjamin and McGonagle 2007a). While bone proliferation or erosion can be stimulated by trauma, metabolic disease, or other conditions such as DISH (Diffuse Idiopathic Skeletal Hyperostosis), biomechanical force affects growth or remodelling as well (Brickley et al. 2005, Benjamin and McGonagle 2007a, Mays 2008). Bone functional adaptation refers to this ability of bone to adapt to its mechanical environment during life (Ruff 2007). If consistently high degrees of mechanical force are applied this can result in growth in the diameter of the diaphysis, with some diaphyses displaying an increase in cortical bone development. In the case of lack of movement or
paralysis it is not only the muscle that will atrophy, but the bone, which in the absence of mechanical force will also decrease in mass (Stock and Pfeiffer 2001, Ruff 2007, Novak et al. 2014, Smith-Guzman 2015, Tesorieri 2016).

Bony joints are surrounded, supported, and connected by four major types of soft tissue: ligament, fascia, tendon, and muscle. Ligament is a dense, fibrous connective tissue that connects bone to bone. Primarily made up of collagen, water, and amino acids, ligaments also contain mechanoreceptors, which transmit information to the nervous system, and elastin (Kaya 2020). Ligament tissue has a high tensile strength, allowing for some absorption and transfer of force, but very little movement when compared to tendon or muscle (Kaya 2020). Repeated mechanical loading can cause a pathological degenerative process leading to reduced mobility and increased stiffness of the tissue. Consistent elongation of a ligament during use can lead to increased laxity and further injury (Kaya 2020).

Fascia is a thin connective tissue that is found throughout the body. Superficial layers lie under the skin, subserous fascia encloses the visceral organs, and deep fascia surrounds all nerves, muscles, and blood vessels (Myers 2001, Milner 2008, Sayaca et al. 2020). Fascia supports and stabilises the structures of the body, lubricates, and transfers mechanical forces (Myers 2001, Sayaca et al. 2020). Fascia also provides a continuity between all other tissues of the body, while also providing proprioceptive and mechanical feedback. Dysfunctional fascia can be chronically inflamed causing pain and can affect posture or restrict range of motion through the continuous “trains” of tissue that run through the body (Myers 2001, Sayaca et al. 2020).

Tendons most often connect muscle to bone, but muscle can also connect to periosteum of the bone via a type of fascia known as epimysium. Trapezius, deltoid, and pectoralis major are examples of this type of attachment (Benjamin et al. 2004a, Kaya 2020, Gatt et al. 2023). This location is known as the ‘enthesis’ (Benjamin et al. 2004a). Tendons are composed of some cellular structures but are primarily extra-cellular matrix comprised of water, collagen, elastin, and a small amount of inorganic material. Tendons also exhibit tensile strength but are far more elastic than ligament (Kaya 2020). This tissue acts as a buffer by absorbing and transmitting forces generated by muscles to the bone. This transfer of force helps to prevent damage to the comparatively fragile muscle tissue but can lead to chronic tendinopathy or inflammation (e.g., tendonitis) (Benjamin et al. 2006, Kaya 2020).
The tissue location where the tendon becomes muscle tissue is known as the musculotendinous junction (MTJ) (Vila Pouca et al. 2021).

A bursa is a fluid filled sack that acts as a cushion between a muscle or tendon and an underlying bone. Some are anatomically constant, meaning everyone has them, while some are considered adventitial and develop in response to pressure (Akisue et al. 2003). The bursa can become inflamed, leading to localised pain, but the localised inflammation can affect the surrounding soft tissue contributing to changes in the muscle, tendon, and eventually the local bone (Benjamin and McGonagle 2001a, Benjamin et al. 2004b, Benjamin and McGonagle 2007b).

Human skeletal muscle is comprised of bundles of fascicles, which are in turn made up of muscle fibre cells (Figure 3). Each muscle fibre cell is a bundle of myofibrils. The contractile unit of the muscle cell is located within the sarcomere portion of the myofibril where thin (actin) and thick (myosin) filaments slide over each other and move closer together (Firat 2020).

![Figure 3 Muscle Fibre Cell](Adapted from Comparative Kinesiology of the Human Body, (Firat 2020: fig. 8.2)).

Muscle contraction begins in the human nervous system, the central nervous system (CNS,) and peripheral nervous system (PNS) (Ertan and Bayram 2020). Voluntary, autonomic, or reflexive action initiates the electrical signal that is communicated by the nerves to the muscle. The neuromuscular junction is the place where the nervous system sends and receives information to and from muscles and tendons. The electrical signal communicates
with mechanoreceptors in the muscle via muscle spindle cells, and the tendon via Golgi tendon organs (Ertan and Bayram 2020). Depending on many factors, including feedback from mechanoreceptors and proprioception (a sense of the body in space), the strength of this electrical action potential determines how many muscle spindle cells are recruited into action (Ertan and Bayram 2020).

3.1.1 Kinesiology

Kinesiology uses the principles of anatomy (structural and functional), physiology, and biomechanics to study human movement (Floyd 2012, Mansfield and Neumann 2019a). Knowledge of anatomical terms, directions, and muscle contractions is essential to understanding movement, and a deeper understanding of human movement is necessary when interpreting activity in bioarchaeology.

There are three types of muscle contractions. Isotonic is the most common and is broken down into concentric and eccentric contraction (Figure 4). An isotonic concentric contraction shortens the muscle length while under tension; an eccentric contraction is when the muscle is lengthening under tension. An isometric contraction means there is no change in the length of the muscle (Figure 4) (Milner 2008, Floyd 2012, Elvan and Ozyurek 2020).

![Figure 4 Types of muscle contraction](Comparative Kinesiology of the Human Body (Elvan and Ozyurek 2020: fig. 2.12).)

In the past, the portion of the muscle attachment that is more proximal was termed the origin, and more distal the insertion because the insertion most often moves closer to the origin. Modern terminology uses only the proximal and distal attachment acknowledging
the complexity of human movement (Mansfield and Neumann 2019b). The belly of the muscle is the portion with the most bulk that lies between the attachments (Myers 2001, Floyd 2012). Muscle actions and movement are described as occurring in the anatomical planes: sagittal (right/left), coronal or frontal (anterior/posterior), and transverse (superior/inferior) (Figure 5). An additional plane known as diagonal or oblique is also used when describing any movement that involves more than one plane of motion (Gray 1974, Abrahams et al. 1998, Floyd 2012, White et al. 2012).
Muscles fulfil various roles within contraction, action, and movement. The agonist muscle, also known as the prime mover, is any muscle that is contracting concentrically within a specific plane. A smaller muscle that acts as an accessory to the agonist movement by performing the same action is called an assistant muscle (Milner 2008, Floyd 2012). An antagonist muscle is one that is performing the opposite movement to the agonist by either...
relaxing or eccentrically contracting (lengthening) to allow the prime movement (Milner 2008, Floyd 2012). Stabilizer muscles will also contract to facilitate the prime movement by stabilising the surrounding joints (Milner 2008, Floyd 2012). Synergist muscles engage to either help another muscle move a joint or contract to prevent an undesired joint action, thereby allowing the prime movement. Neutralisers also perform a synergistic action by engaging to counteract or resist specific actions of other complex muscles to facilitate the desired action (Milner 2008, Floyd 2012). Some larger muscles with multiple fibre directions can often be antagonistic to each other or can work together to allow for rotation or stabilisation of a joint, also known as force coupling (Milner 2008, Floyd 2012). The basics of muscle contraction are essential when studying functional joint complexes, particularly agonist/antagonist relationships, in the bioarchaeology of activity.

When the nervous system must recruit a multiarticular muscle, there is a functional cost in the additional activation of synergists, stabilisers, or neutralisers required to perform the movement (Mansfield and Neumann 2019b). In the image below (Figure 6), the brachialis is the agonist or prime mover for flexion of the forearm at the elbow because it functions in both pronated and supinated positions (Placzek and Miskowski 2017). The triceps brachii is the antagonist working opposite to the flexion but would also be the prime mover/agonist for elbow extension. Biceps brachii in this example would have a smaller assistant role to the agonist (brachialis) as the forearm is supinated in this example. Recruitment of the biceps brachii would require additional activation of shoulder stabilisers to neutralise unwanted shoulder flexion (Mansfield and Neumann 2019b). Although not shown, other muscles of the rotator cuff and shoulder girdle would be stabilising the scapula and proximal humerus to allow for elbow flexion.
The three types of muscle contraction and the various actions and synergies of muscles actions show that human movement is quite complex. While isolated movements can be broken down into single planes or actions, most human activities combine several muscles all simultaneously performing multiple actions in complex and oblique planes. This balance of agonist, antagonist, synergist, and neutraliser occurs in any complex movement and during any type of muscle contraction. Understanding of how muscle contraction and movement affect soft tissue and bone can aid bioarchaeological researchers in interpretation of bony evidence in activity.

Human movement can be seen macroscopically as standing, walking, bending, kneeling, lifting, carrying, pushing, pulling, and fine manipulation of the hands and fingers. Each functional joint complex can be viewed in isolation, but each one synergistically contributes to movement, and stress, at adjacent functional complexes. A closer look at mechanisms for micro- and macroscopic tissue injury may help to dissect some of these complex biomechanical variables.
3.1.2 Mechanisms of Tissue Injury

The human functional musculoskeletal system (muscle, ligament, tendon) can be understood as a complex system that withstands multiple forces while balancing flexibility with durability (Porterfield and DeRosa 2003a). Human tissue adapts to forces of compression, tension, and shearing but will eventually reach a threshold of mechanical failure. The weakest place in a mechanical system is where two materials of differing properties meet such as the musculo-tendinous junction (MTJ) or the enthesis where the tendon attaches to the bone (Shaw and Benjamin 2007, Vila Pouca et al. 2021). Any structure can fail through a single maximum load that exceeds the tensile strength (i.e., traumatic injury) or through repetitive sub-maximum tension known as ‘material fatigue’ in engineering. This accumulation of microscopic damage over time is the mechanism of overuse or repetitive strain injuries (RSI) (Vila Pouca et al. 2021).

Healthy repetitive loading of the soft tissue must be of a particular frequency, range, and intensity. Any forces outside of this tolerance window will lead to microscopic changes in the intracellular matrices which then begin a cascade of degeneration and progression of disease. (Porterfield and DeRosa 2003a). Repetitive (or overuse) conditions of soft tissue are degenerative rather than inflammatory. Inflammation is a secondary change related to tissue repair and healing as the body attempts to compensate for the damage (Shaw and Benjamin 2007). Like a patch on the worn-out knees of a pair of jeans, the body attempts to compensate by creating new tissue matrices. Modified tissue is less responsive to tensile forces and the maximum tolerated tensile load is reduced, both of which make the tissue more vulnerable to injury (Porterfield and DeRosa 2003a). This disease process can happen at any age but is far more common with advanced age as older tissue is naturally more susceptible to microtrauma and injury (Porterfield and DeRosa 2003a, Shaw and Benjamin 2007, Vila Pouca et al. 2021). Confusingly, underuse injuries can also lead to an identical degradation process. In areas where the tissue is not conditioned for regular use, the maximum tensile load is also lower and therefore more susceptible to injury. An underuse injury may be seen in a weak, hypotonic muscle or be found at an enthesis site closest to the joint (Shaw and Benjamin 2007, Mansfield and Neumann 2019c, Yeşilyaprak 2020).

An injury to one tissue will often lead to destabilisation of adjacent and/or surrounding tissues, and one weak muscle can then upset the delicate balance between laxity and stability of any joint. The delicate balance of opposing forces such as internal vs
external rotation can lead to painful conditions such as rotator cuff injuries or tendinitis. Over time this joint instability may lead to bony changes that might be later diagnosed as joint disease or osteoarthritis (Laron et al. 2012, Mansfield and Neumann 2019d, Yeşilyaprak 2020).

The ability of a tissue to withstand mechanical failure is affected by both intrinsic and extrinsic factors. Direction, force, compression, shearing, load, or repetition are examples of extrinsic factors. Internal variables such as an individual’s physiology, anatomy, diet, past injuries, or age can all affect an individual’s ability to maintain the balance between laxity and stability (Porterfield and DeRosa 2003a, Shaw and Benjamin 2007, Laron et al. 2012). Biomechanical variables like structure, force, angles, velocity, torque, and pressure combined with anatomical, neurological, biochemical, and pathological differences form a complex and multifactorial picture of human movement (Uygur 2020). When investigating activities of past peoples such as tasks, weapon or tool use, or occupation, bioarchaeologists must consider all the potential variables while maintaining a holistic view of the human body as it was in life, not only in death.

3.2 Activity in Bioarchaeology

The study of activity in archaeology seeks to answer questions about how people in the past lived, worked, and died. Bioarchaeologists who study past peoples attempt to reconstruct behaviour by studying how the activity of those peoples affected their skeletons. As bone is a living tissue that remodels according to biomechanical force, bioarchaeologists may sometimes reconstruct broad patterns of activity such as repetitive daily use or heavy manual labour versus sedentary lifestyles (Hawkey and Merbs 1995, Hall 1999, Jurmain 1999, Molnar 2006, Ruff 2007). Often though, it is only possible to tell in the broadest sense that somebody was involved in strenuous physical activity, rather than identifying a specific activity (Perréard-Lopreno et al. 2013, Villotte and Knüsel 2013). An example of this is how regular heavy lifting can cause herniated lumbar discs, but lower back disc pathology can have many causes besides heavy lifting such as posture, trauma, anatomical variation, or infectious disease (Luqmani et al. 2013).

Skeletal markers of activity can take many forms, but three of the most common methods used in populational studies of activity are enthesal changes,
osteoarthritis/degenerative joint changes, and cross-sectional geometry. Enthesal changes (EC) (enthesopathies or musculoskeletal stress markers) have been used to cautiously infer information about occupation, task, manual labour, and sometimes specific activities (Hawkey and Merbs 1995, Cardoso and Henderson 2010, Villotte et al. 2010a, Molnar et al. 2011, Milella et al. 2015). Osteoarthritis and degenerative joint changes (OA/DJC) are the most frequently identified disease processes in archaeological skeletons. Associations with activity have been tenuous at best with other factors such as genetics, biochemistry, age, biomechanics, and trauma as competing aetiological factors (Waldron 1992, Molleson et al. 1994, Jurmain 1999, Roberts and Manchester 2010a, Palmer et al. 2014, Williams et al. 2018). Cross-sectional geometry (CSG) has promising applications in the study of activity in both archaeological and modern populations (Rhodes and Knüsel 2005, Fiorato et al. 2007, Ruff 2007, Shaw and Stock 2009, Ireland et al. 2013, Macintosh et al. 2017, Pomeroy et al. 2018). The radius or circumference, cortical thickness, asymmetry, and diaphyseal shape of a long bone can give us information on mechanical loading of the bone (Rhodes and Knüsel 2005, Ruff 2007, Maggiano et al. 2008, Miller et al. 2018, Sparacello et al. 2020).

3.2.1 Activity and Enthesal Changes

Muscle attachments, or entheses, have long been associated with the study of activity, the assumption being that increased and habitual use of muscles would lead to larger, more pronounced changes at the enthesis (Hawkey and Merbs 1995, Crubézy et al. 2002, Molnar 2010). It is now understood that the factors influencing EC are diverse and multifactorial, and no EC have been shown to be only activity related (Villotte et al. 2010a, Jurmain et al. 2012, Henderson 2013b). Well established research has shown that age, in particular, is positively correlated with the development of EC, and that EC are most notable after 50 years of age (Mariotti et al. 2007, Villotte et al. 2010a, Milella et al. 2012). Enthesal changes are, however, cautiously used to investigate broad concepts of activity such as heavy or light labour (Cardoso and Henderson 2010, Jurmain et al. 2012, Henderson and Alves Cardoso 2013, Perréard-Lopreno et al. 2013, Carballo-Pérez et al. 2021, Karakostis and Harvati 2021, Alves Cardoso and Assis 2021).

The anatomy of the enthesis is complex. In osteological studies, the enthesis is the “footprint” left on the bone, but anatomically the enthesis organ is comprised of up to four different associated soft tissues. The most common tissue attachment is the tendon, but
ligaments attach directly to the periosteum of the bone. Muscles will occasionally attach directly to another muscle (e.g., facial muscles) but often the attachment is through fibrous connective tissue (Gray 1974, Abrahams et al. 1998). Muscle attachment sites can be grossly divided into fibrous or fibrocartilaginous, although at the microscopic level most sites are to some degree both (Benjamin et al. 2002, 2006).

Fibrous entheses, often associated with the larger muscles of the appendicular skeleton, connect either directly to the bone or indirectly through an attachment to the periosteum (Figure 7). The site of the attachment is broad to disperse the contractile muscle force over a larger area, often the diaphysis of the long bones of the arms and legs (Benjamin et al. 2002, Henderson et al. 2013b). The origins of brachialis on the humerus and the quadriceps group on the femur are two examples of a broad, fibrous muscle attachment (Benjamin et al. 2002, Villotte and Knüsel 2013). According to recent work, the morphology of fibrous entheses seems to be slightly more affected by genetic factors over lifestyle or pathology when compared to fibrocartilaginous entheses (Villotte et al. 2010a).

Fibrocartilaginous entheses are small and compact, located close to a joint, and feature long tendons that permit increased movement. Rather than being dispersed over a large area, contractile force is distributed through four distinct types or areas of tissue: bone, calcified fibrocartilage, uncalcified fibrocartilage, and fibrous connective tissue with collagen fibres that maintain continuity through the types of tissue and give strength to the enthesis (Figure 8) (Benjamin et al. 2004a, 2006, Thomopoulos 2011). Even with this efficient system of mitigating contractile force, repetitive strain injuries such as tendonitis, soft tissue tears,
and avulsion fractures are known to be found at fibrocartilaginous entheses sites (Benjamin et al. 2002, 2006, Maganaris et al. 2004, Cardoso and Henderson 2010, Alves Cardoso and Henderson 2013).

Figure 8 Four Types of Tissue at Fibrocartilaginous Entheses
Dense fibrous connective tissue (CT), uncalcified fibrocartilage (UF), calcified fibrocartilage (CF) and bone (B). A tidemark (TM) separates calcified and uncalcified fibrocartilage and is continuous with the articular cartilage (AC) Adapted from Fibrocartilage in Tendons and Ligaments — an Adaptation to Compressive Load (Benjamin and Ralphs 1998: fig. 2(a)).

Even before the microscopic anatomy of entheses was known, enthesal changes were used to study activity in archaeology. Originally termed ‘musculoskeletal stress markers’, ‘markers of occupational stress’, or ‘enthesophytes’, the study of enthesal changes encompasses the variation in size and shape, as well as the proliferation or erosion of bone at the enthesis (Hawkey and Merbs 1995, Jurmain 1999, Crubézy et al. 2002, Molnar 2006, Jurmain et al. 2012, Henderson et al. 2013b, Villotte et al. 2016). Enthesal changes became the most accepted term because it does not assume a particular aetiology or pathological process like ‘enthesitis’ (-itis, inflammation), or ‘enthesopathy’ (-pathy, disease).

Work in the 1980’s on enthesal changes was carried out on a small, isolated population known as the Nunavut and Nunavik Inuit in the Hudson Bay region of Canada, and was foundational to the field of activity studies (Hawkey and Merbs 1995, Stern 2013). Within a small population with limited variation in activities, the authors were able to propose an association between specific patterns of musculoskeletal stress markers and
specific activities, including archery, harpooning, and kayaking. Most notable is the ‘kayaker’s clavicle’ with a distinct j-shaped lesion on the clavicle at the attachment of the costoclavicular ligament (Hawkey and Merbs 1995). A method of scoring the observed changes at the enthesis, originally developed as part of a master’s thesis, described the enthesis on a scale of robusticity and the presence of stress lesion (Hawkey 1988). The changes in stress markers were graded with 0 for absent, 1 for faint, 2 for moderate, and 3 for strong. The study did not differentiate between fibrous and fibrocartilaginous entheses, which are now known to react differently under the same biomechanical stress (Hawkey and Merbs 1995, Benjamin et al. 2002).

Hawkey and Merbs (1995) described their method as being applicable only within small, isolated populations that exist within a narrow span of time, in genetic and cultural isolation, and which performed a limited number of activities, such as the population of Inuit studied. Despite the limited applicability described in the original publication, the paper established that specific enthesial change patterns in archaeological populations could be associated with specific activities. While it is no longer practice to infer activity with such specificity, the widely applied standard influenced the assumptions of many researchers (Molnar 2006, 2010, Havelková and Villotte 2007, Milella et al. 2012, Alves Cardoso and Henderson 2013, Davis et al. 2013, Schrader 2015).

Another study that demonstrates how enthesial changes have been scored is a combined study on enthesal change and joint degeneration on two Neolithic populations from the Czech Republic and Slovakia (Crubézy et al. 2002). This method again scored enthesopathy, defined as the presence of enthesophytes at sites of tendon or ligament insertions, and osteoarthritis, indicated by the presence of geodes or osteophytes at joint epiphyses. The scores ranged from 0, with no indication of either osteophytosis or enthesophytosis, to 3, with the highest presence of the abnormality (Crubézy et al. 2002). Interestingly, while this study provided the criteria for the diagnosis of osteoarthritis in the samples, there was no information given to readers as to what, exactly, was considered an enthesopathy and what was determined to be a normal enthesis. In fact, the paper included an image of a thoracic vertebrae with an ossified ligamentum flavum, a not uncommon occurrence in mature skeletons, and refers to this ossification as an enthesopathy (Crubézy et al. 2002).

Bioarchaeologists who have studied activity and entheses who have combined fibrous
and fibrocartilaginous entheses, have found little correlation with activity (Hawkey and Merbs 1995, Molnar 2006, 2010, Henderson 2008, Cardoso and Henderson 2010, Henderson et al. 2013b). Similar results have been found when upper body entheses are combined with lower body entheses (Molnar 2006, 2010). Researchers who have chosen to focus on exclusively fibrocartilaginous entheses, the common sites of inflammation and repetitive strain injuries, have had much more success in correlating these with broad activity categories (Benjamin et al. 2002, Villotte et al. 2010a, Santos et al. 2011, Alves Cardoso and Henderson 2013, Henderson and Alves Cardoso 2013, Henderson et al. 2016a).

While acknowledging a multifactorial aetiology to enthesal changes, work on activity, tasks, and occupation using the enthesis continues. The Coimbra Research Group was formed after the Workshop in Musculoskeletal Stress Markers held at the University of Coimbra, in Portugal in 2009 to establish standards in scoring methods, categorization of occupation, and terminology. It was this research group that came up with the name ‘enthesal changes’ and developed the new Coimbra Method for scoring fibrocartilaginous enthesal changes (Jurmain and Villotte 2010, Alves Cardoso and Henderson 2013, Henderson and Alves Cardoso 2013, Henderson et al. 2016b, Villotte et al. 2016).

3.2.2 Osteoarthritis and Degenerative Joint Changes

Osteoarthritis (OA), formerly known as the ‘wear and tear’ type of joint disease, has long been used in bioarchaeology to infer activity in past populations (Bridges 1991, Jurmain and Kilgore 1995, Molnar et al. 2011, Palmer et al. 2014, Becker 2016a, Zhang et al. 2017). Many analyses of osteoarthritis were made with the tacit assumption that increased stress on a joint surface led to more severe disease and that the presence of joint wear on a skeleton meant that the individual must have used that joint excessively in life. Known as the ‘stress hypothesis’ this assumption and its resulting effect on the connection between osteoarthritis and activity in the archaeology record reflected the medical understanding of disease aetiology at the time (Jurmain 1999, Ortner 2003, Jurmain et al. 2012). There is also clear evidence of an association between advanced age and degree of arthritic changes on bone (Jurmain 1999, Larsen 2015a, Williams et al. 2018). With advancements in medical imaging and clinical studies that examined the biochemistry and anatomy of joint tissues, bioarchaeologists are better able to take the complex aetiology of osteoarthritis into account.

OA can be broadly broken down into a primary disease, which is often expressed throughout multiple joints and is thought to be genetic, and secondary, which is often the result of previous joint trauma and usually found in a single joint (Ortner 2003, Waldron 2019). Osteoarthritis is typically found in diarthrotic joints, in the axial and appendicular skeleton (Ortner 2003, Waldron 2009, Roberts and Manchester 2010a). Any evidence of a similar disease process found in the amphiarthrotic joints of the spine have a different aetiology as degeneration of the fibrous disc must be present first before any changes to the bony surfaces can be observed. Articular facet joints of the vertebrae can develop observable traits of OA, but the vertebral bodies are limited to osteophytic growth, often termed vertebral osteophytosis (VOP) (Jurmain 1999, Roberts and Manchester 2010a).

Clinicians agree that osteoarthritis is not a disease of bone at all, but rather of the synovium and articular cartilage (Ortner 2003, Felson and Neogi 2004, Benjamin and McGonagle 2007a, Waldron 2009, 2019). The proliferative bony changes are considered a functional adaptation as the body attempts to heal and correct. Despite the use of the term ‘degenerative’, this bony proliferation differentiates osteoarthritic changes from other rheumatic diseases of the joint that are erosive in nature (Ortner 2003, Waldron 2009, Roberts and Manchester 2010a, Waldron 2019). Complex factors of genetic predisposition, anatomy, biochemistry, physiology, age, trauma, and biomechanics can all affect the aetiology and development of disease (Jurmain 1999, Ortner 2003, Felson and Neogi 2004, Benjamin and McGonagle 2007a, Waldron 2009, Roberts and Manchester 2010a, Schrader 2012, Vaughn et al. 2019). There is growing evidence that moderate exercise as a modifiable contributing factor is preventative to the development of OA. However, there is equal evidence from extreme activities such as Olympic athletes and chronic repetitive heavy occupational movements contribute to higher rate of injury and OA (Johnson and Hunter 2014, Palazzo et al. 2016, Canetti et al. 2020, Cooper 2021).

Although invisible to clinicians, patients, and bioarchaeologists, the initial changes associated with degenerative joint disease and osteoarthritis begin in the articular cartilage (Ortner 2003, Felson and Neogi 2004, Waldron 2009, 2019). There may be a genetic predisposition based in ancestry or a particular phenotype expressed in metabolic or endocrine effects on cartilage (Waldron 2009). Differences in an individual’s physiology or
biochemistry can lead to a breakdown in the cartilaginous matrix (Felson and Neogi 2004, Waldron 2009). After this breakdown, a release of enzymes leads to further erosion of the cartilage, which can release fragments into the joint cavity (Waldron 2009). An inflammatory process in the synovial membrane follows with increased production of cytokines and further lytic enzymes. Eventually new blood vessels are formed as a part of the body’s attempt to regain homeostasis in the joint (Waldron 2009, 2019). This process continues with bony reactions including formation of new bone around the joint and joint surface that change the normal contour of the joint and pitting/porosity on the joint surface often leading to subchondral cysts (Ortner 2003, Waldron 2009, 2019). Lastly, we see eburnation, the hallmark of osteoarthritis in archaeological populations. This highly polished surface can sometimes be scored or grooved in the direction of the primary joint movement and occurs once the articular cartilage has been eroded and the joint is bone on bone (Jurmain and Kilgore 1995, Ortner 2003, Waldron 2009, Roberts and Manchester 2010a, Waldron 2019).

Increases in prevalence rates for osteoarthritis and degenerative joint changes by age are well established (Jurmain 1999, Ortner 2003, Waldron 2009, Roberts and Manchester 2010a, Williams et al. 2018, Waldron 2019). Rates can differ by sex, joint, population, and over time, with notable differences between archaeological and modern populations. OA of the upper body, especially the joints of the shoulder and elbow, are far more prevalent in Neolithic and medieval populations when compared to modern groups (Jurmain 1999, Crubézy et al. 2002, Ortner 2003, Roberts and Manchester 2010a, Waldron 2019). OA in the hand was more often unifocal in medieval populations but polyarticular in post-medieval groups, although this can be difficult to determine in archaeological populations due to missing bones of the hand (Waldron 1997, 2019, Crubézy et al. 2002). Overall rates for hip and knee arthritis are similar between archaeological and modern populations, but there tend to be slightly higher rates for hip arthritis in females, and there are noticeable differences in which joint surface of the knees was involved. Studies of OA in past and in modern populations observe females and males separately due to sex-specific differences in overall rates of development of OA and in the location of OA in the body. In some time periods males had significantly higher rates of OA, but in others the sexes developed OA equally suggesting that culture and gender roles are a contributing factor in OA (Williams et al. 2018). In the past, patellofemoral and lateral tibiofemoral were common, whereas medial tibiofemoral arthritis increases have only been seen in the past 200 years (Felson 1994,
Vertebral osteophytosis and degenerative changes in the spine remain more consistent over time and population, and are associated with age and biomechanical factors like compression and posture (Knüsel et al. 1997, Jurmain 1999, Ortner 2003, Waldron 2009, Roberts and Manchester 2010a, Waldron 2019). There is some evidence that cervical spine DJC have become more prominent in modern times when compared to medieval populations (Roberts and Manchester 2010a).

Despite the alluring prospect of associating degenerative joint changes with specific activities or occupations, there is no consistent evidence to support this relationship (Waldron 1994, 2019, Jurmain 1999). There is, however, some evidence that biomechanical loading and repetitive use may influence the development of degenerative joint disease in cases of prior traumatic injury or in those already predisposed to the disease (Waldron 1994, 2019, Jurmain 1999, Johnson and Hunter 2014, Palazzo et al. 2016). Arthritis of the knee has been associated with obesity in some populations but not arthritis of the hip (Waldron 1997, 2009, Jurmain 1999). Acute trauma has been positively correlated with later development of joint disease, but the effects of chronic overuse injuries are under debate (Jurmain 1999, Palazzo et al. 2016, Waldron 2019, Canetti et al. 2020, Cooper 2021). Some studies have shown that chronic overuse in elite athletes or certain manual occupations such as farming, may be one of many aetiological factors, especially in the case of prior injury (Felson 1994, Waldron 1997, Jurmain 1999, Palazzo et al. 2016, Cooper 2021). Others show no or little definitive association between manual labour or sport and osteoarthritis (Molleson et al. 1994, Jurmain 1999). During the osteological analysis of The Spitalfields Project in London, for example, a population known to have worked while standing in the silk weaving mills was studied. No correlation between OA of the hip or knee with occupation was found in this population (Molleson et al. 1994).

Osteoarthritis develops as a result of complex intrinsic factors, such as genetics, diet, or body mass, but also mechanical factors such as trauma or joint instability or misalignment (Johnson and Hunter 2014, Palazzo et al. 2016). The multifactorial aetiology of degenerative joint disease and osteoarthritis, of which biomechanical factors form only one small part, complicates the reconstruction of behaviour for bioarchaeologists (Jurmain 1999). Aside from a few cases of small, genetically similar populations with only a few known activities, analysis of degenerative joint changes and osteoarthritis offer no reliable answers in the bioarchaeological study of activity (Waldron 1994, 2019, Hawkey and Merbs 1995, Jurmain
DJD has been included in this study, despite its dubious direct value, to increase the comparability of this work to previous research.

3.2.3 Cross Sections in Bioarchaeology

In bioarchaeology and palaeoanthropology, the shape and size of the diaphysis (shaft) of long bones has frequently been used to garner data on past populations (Ruff et al. 1993, Trinkaus et al. 1994, Rhodes and Knüsel 2005, Ruff 2007, Stock and Shaw 2007, Pomeroy et al. 2018, Sparacello et al. 2020). The diaphyseal cross-section can be measured through multiple methods, some destructive, some not, and each with various benefits or drawbacks. Direct sectioning, which is the most accurate but also the most destructive, is rarely used in archaeological contexts. It has, however, been used on cadaver and animal bone to test the validity of other less destructive methods (Stock 2002, O’Neill and Ruff 2004).

One of the non-destructive methods often employed on hominin remains is that of biplanar radiography, where radiographs of the bone taken from both the medial/lateral and anterior/posterior direction are measured with digital callipers (Stock 2002, O’Neill and Ruff 2004, Ruff 2007). A mathematical elliptical model is then applied to model the cortex of the bone using periosteal and endosteal (medullary) measures to estimate internal bone contours (Ruff et al. 1993, Stock 2002, O’Neill and Ruff 2004, Stock and Shaw 2007).

In the absence of availability of radiographs, a latex (or now silicone) moulding method can be used to achieve an accurate outline of the periosteal surface (Ruff et al. 1993, Stock 2002, Ruff 2007, Stock and Shaw 2007). The mould is then marked to represent the standard anatomical position and placed on a flatbed scanner to achieve a digital image that can then be traced in Photoshop for analysis (Stock 2002, Stock and Shaw 2007, Pomeroy 2013). While this method lacks data from the endosteal contours, the casting method and other ‘solid’ measures have been shown to be accurate to within 5% of direct sectioning (Stock and Pfeiffer 2001, Stock 2002, O’Neill and Ruff 2004, Stock and Shaw 2007, Pomeroy 2013).

Computed tomography (CT) scans are frequently used to estimate measures of cross-sectional geometry (CSG). While ideal for studies of the living, the expensive technology is not often available for examining the dead (Ruff 2007). If CT is available to scan dry archaeological material, the long axis is placed flat on the table, parallel to the beam, and in a standard anterior facing position as estimated by the researcher (Rhodes and Knüsel 2005,
The accuracy of the periosteal contour in CT scans had been shown to be less accurate than other methods. The outer periosteal contour achieved by moulding is the most accurate next to direct sectioning (Ruff et al. 1993, Stock 2002, Ruff 2007).

Another technology that has great potential in the study of CSG in virtual (digital) anthropology is 3D scanning. While laser scanners were initially very expensive and only available to a few, lightweight and highly portable structured light scanners are now within reach for archaeologists (Weber 2015). Structured light scanners, provided there is a power source, can be taken to archaeological materials, rather than transporting fragile human remains to the 3D system (Weber 2015).


Biomechanical analysis of human (and non-human) long bone diaphyseal CSG has been performed with a model borrowed from mechanical and structural engineering known as the beam model (Trinkaus et al. 1994, Ruff 2007, Becker 2019b). While there is some evidence that human bone diaphyseal size has been used to determine strength since the European Renaissance, modern use of biomechanical principles in archaeology dates from the late 20th century (Ruff and Larsen 2014).

The beam model (Figure 9) envisions the long bone as a hollow I-beam subjected to external stress that will eventually fail (fracture) at a critical stress point (Ruff 2007). Strain at the central axis (mid-shaft) or centroid increases when the applied force moves further from this centre point (Ruff and Hayes 1983, Ruff 2007, Becker 2019b). When measured perpendicular to the long axis of the beam (the diaphysis,) the resulting bone changes can be calculated and measured.
Most frequently studied in archaeology are various measures of strength, the ability to resist breaking, and rigidity, the resistance of the structure to deformation from bending, compression, or torsion (Figure 10) (Rhodes and Knüsel 2005, Ruff 2007, Nikita et al. 2011, Pomeroy 2013, Miller et al. 2018).
Changes in cross-sectional bone shape from circular to oblique, or the thickness of cortical bone, also called periosteal expansion, can indicate response to external stress or tension (Ruff 2007, Becker 2019b). Unlike steel or other building materials, bone is rarely subjected to pure forces of tension or compression, so measures of second moments of area (SMA, aka ‘cross-sectional moments of inertia’) are used in archaeology to measure bending and torsional rigidity (Ruff 2007). SMAs are most often calculated through the centroid (middle) of a cross-section, using proportions such as medial/lateral to anterior/posterior (x/y-axes) or as the maximum/minimum (widest/narrowest) (Figure 11) (Ruff 2007).

The biomechanical measure of ‘I’ is the SMA, calculated through the centroid of the cross-section with $I_{\text{max}}$, $I_{\text{min}}$, $I_x$, or $I_y$ as the measure of bending rigidity (Figure 11) (Ruff 2007). The I-ratio of max/min or x/y can give the shape or direction of the cross-section in the medial/lateral to anterior/posterior (or max/min) planes (Ruff 2007, Stock and Shaw 2007, Pomeroy 2013). The shape may offer information on the anatomical direction of repetitive movement (Ruff and Larsen 2014).
The polar SMA known as ‘J’, which is the sum of two perpendicular SMA ($I_{\text{max}}+I_{\text{min}}$ or $I_x+I_y$), reflects a measure of torsional rigidity and twice average bending rigidity in two planes. This gives an overall indicator of periosteal expansion due to mechanical loading (Trinkaus et al. 1994, Ruff 2007, Stock and Shaw 2007, Pomeroy 2013). The total subperiosteal area (TA) of the cross section is highly correlated with J and is also a measure of bending and torsional rigidity (Ruff 2007, Stock and Shaw 2007, Pomeroy 2013). Cortical area (CA), and medullary area (MA) are two measures that can be used with CT scans that give internal bone data but cannot be used when only surface data is available (Rhodes and Knüsel 2005, Ruff 2007, Stock and Shaw 2007, Nikita et al. 2011, Pomeroy 2013). The measure of CA has also been associated with more errors in areas of higher cortical variability when predicting true measures of CSG from solid cross-sections (Macintosh et al. 2013).

Measures of CSG in anthropology and archaeology are most often used on the humerus and femur, but the tibia, fibula, radius, and ulna can also aid analysis and interpretation. In palaeoanthropology modern humans are compared to other hominins and primates for differences in evolutionary development such as robusticity or asymmetry (Ruff...

Measures of CSG have been widely used in the study of human migration, mobility, and subsistence patterns (Marchi et al. 2006, Maggiano et al. 2008, Nikita et al. 2011, Davies and Stock 2014, Ruff and Larsen 2014, Shaw et al. 2014, Ruff et al. 2015, Agarwal 2016, Sparacello et al. 2020). Division of labour, sex- or age-based differences, body size and robusticity have often been included in these studies (Mays 1999, Ruff 2000, Stock and Pfeiffer 2001, Marchi et al. 2006, Pearson et al. 2014, Ruff and Larsen 2014, Macintosh et al. 2017, Miller et al. 2018, Pomeroy et al. 2018, Carballo-Pérez et al. 2021). Age and sex changes in measures of CSG appear to be somewhat related as endosteal reabsorption, and hence a higher medullary area (MA), has been seen in both sexes, but females tended to have slightly higher reabsorption (Ruff and Hayes 1988). Periosteal expansion, however, occurs at far higher rates in males with increasing age than in females, resulting in females having a higher net loss of cortical bone with age compared to males (Ruff and Hayes 1988). Asymmetry has been of particular interest, especially when considering weapon or tool use (Trinkaus et al. 1994, Rhodes and Knüsel 2005, Knüsel 2007, Shaw et al. 2012, Macintosh et al. 2014, Maggiano et al. 2015, Sparacello et al. 2020). Some researchers have studied living populations, via medical imaging, to explore activity and CSG. Shaw and Stock (2009) looked at humeral robusticity and asymmetry in cricket players and swimmers to examine habitual throwing, Ireland and colleagues (2013) studied the muscle-bone relationship in modern elite tennis players, and recently Murray and Stock (2020) explored the relationship between muscles and robusticity in the bones of the leg in athletes and controls. Results from this work on living populations can help to interpret measures of CSG in skeletal collections.

There is some evidence to support the suggestion that males have a more efficient process of building bone strength. Studies of modern athletes and sedentary controls have shown that males have a more mechanically advantageous process of building bone in response to repeated stress (Macintosh et al. 2017). For example, among tennis players with known unilateral activities, males had a median asymmetry score of 74.56% for J, while cohort matched females achieved only 39.14% (Trinkaus et al. 1994, Sparacello and Marchi 2008). There are clear hormonal factors at play that advantage males and/or disadvantage females in building the same amount of bone in response to similar stressors.
Sex differences in age-related bone apposition may also complicate CSG interpretations. A cadaveric study showed that both women and men had endosteal reabsorption and medullary cavity expansion. Only men showed additional sub-periosteal cortical bone that maintained strength to counter the endosteal reabsorption in later life (Ruff and Hayes 1988). However, Ruff and Hayes (1988) also discuss a pre-industrial sample with high activity levels where both females and males displayed sub-periosteal bone expansion. This previous work, along with decades of medical data, do show that continued activity levels into old age can maintain bone strength (Ruff and Hayes 1988, Ireland et al. 2014, Biver et al. 2016). More recent studies have shown that, at least in the femur, there is increased periosteal bone apposition as cortical bone density decreases (Ruff and Hayes 1988, Feik et al. 2000, Laffranchi et al. 2020). This effect was most notable in post-menopausal women and may be a factor in periosteal bone contour and CSG measures. Both CSG measures of cortical area (CA) and medullary area (MA) are invisible on solid sections and hence cannot be included in the formal analysis of the Scottish population. Although not quantifiable in this study, senescence and menopause may have affected robusticity scores in females.

More relevant to this current study is potential hormone related differences present in childhood and adolescence which have a much greater effect on measures of CSG. Before puberty, both sexes have an equal ability to build bone in an adaptive response to loading, but with the onset of menarche, this changes. Oestradiol increases endosteal bone apposition in adolescents and young women leading to a narrowing of the medullary cavity and to smaller external diaphyseal dimensions (Petit et al. 2004, Laffranchi et al. 2020). Thus, a later age of menarche may give young women a longer period in which to build greater subperiosteal bone and therefore be more like their male peers.

Some measure of CSG can be interpreted differently depending on the location of the slice. A Solid I-ratio derived from $I_{\text{max}}/I_{\text{min}}$, which does not assume an anatomical direction, has limited value in interpreting movements (2.2.3). An I-ratio close to 1 indicates a more circular section and possibly a wide range of directional movements, however, in a slice that is congenitally more round an I-ratio close to 1 may also indicate lack of notable movements in any one plane. A higher ratio indicates a more ovoid or triangular shape which may indicate regular movement in a specific plane (Ruff and Larsen 2014). Shape and direction at the mid-distal location (35%) has been difficult to interpret for many researchers and some
have suggested that measures of robusticity (Solid J, TA) may be more meaningful at this location (Rhodes and Knüsel 2005, Sparacello and Marchi 2008, Ibáñez-Gimeno et al. 2013). According to Trinkaus et al. (1994), the immature humerus at midshaft (50%) is cylindrical and developmentally becomes more ovoid so the I-ratio is most valid at this location, whereas the roughly triangular shape at 35% makes shape via I-ratio more prone to errors of interpretation (Trinkaus et al. 1994). In a bone that is already triangular, a rounder shape may indicate more movements, but so too can a slice that is more triangular than is normal for the anatomy. It is this variation that confuses the picture for the mid-distal (35%) location.

3.2.4 Other Markers of Activity

Trauma and fractures can give us clues to activity as well. Weapon use, warfare, or interpersonal violence can be studied on the population level by looking at blunt or sharp force trauma, perimortem injuries, and healed fractures (Merbs 1989, Novak 2007, Redfern 2009, Roberts and Manchester 2010b, Fibiger et al. 2013). Skeletal evidence of scalping, decapitation, dismemberment, amputation, or trepanation can give clues about warfare and trophy taking, ritual behaviour, or medical technology (Christensen and Winter 1997, Anderson 2001, Andrushko et al. 2010, Roberts and Manchester 2010b, Selinsky 2015). Avulsion fractures, where the force of soft tissue injury breaks a small piece of bone away, are sometimes associated with trauma and activity. The medial epicondyle of the humerus is a common location for avulsion fractures and occurs before the epiphysis fuses by 18 years of age (Knüsel 2007, Schaefer et al. 2009). Previously called ‘little league elbow’, a fracture at this location can indicate injury or extreme repetitive activity during youth (Knüsel 2007).

Sometimes activity can result in specific areas of bone growth or reaction, such as in the case of external auditory exostosis. This condition features a small growth of bone around the external auditory meatus of the ear, and has been associated with swimming in cold water (Godde 2010). Activity markers can also consist of areas of worn or eroded bone or other hard tissues of the body. Squatting facets are small depressions on the distal anterior tibiae resulting from regular extreme ankle flexion and consistent pressure between the tibia and the talus of the foot (Brickley and McKinley 2004, Stodder and Palkovich 2012). Chronic and severe bursitis can eventually affect the underlying bone if left untreated. The sub-patellar bursa can change the appearance of the tibial tuberosity and has been associated with repetitive kneeling. Ischial osteitis describes the effect of inflammation of the
bursa located over the ischial tuberosity at the origin of the hamstring muscles on the pelvis, and is sometimes linked with sitting on hard surfaces (Iscan and Kennedy 1989, Capasso et al. 1998).

Asymmetry of long bones can be consistent with dominant-side handedness, although researchers have found that laterality is not sufficient for forensic identification purposes. Instead, we can have a general idea of handedness, but not absolute association (Steele and Mays 1995, Churchill and Formicola 1997, Ubelaker and Zarenko 2012, Ibáñez-Gimeno et al. 2013). Asymmetry can also be associated with atrophy and can occur secondary to a disease process such as neuromuscular conditions or infections such as poliomyelitis (Umbelino et al. 1996, Strong et al. 2017). Other indicators of disease or pathology can give clues to behaviour and activity. Tuberculosis is transmitted more frequently in close, cramped conditions such as factories or prisons, and Vitamin D deficiency can indicate a lack of exposure to sunlight (Roberts and Manchester 2010c, 2010d, Roberts 2011).

Dental indicators are often used to discern activity. Patterns in dental wear, decay, or disease between subsistence groups, such as hunter-gatherers and agriculturists, show striking differences. (Indriati and Buikstra 2001, Roberts and Manchester 2010e). Intentional scoring or grooving of the teeth may indicate social identity or ritual behaviour (Arcini 2005, Wasterlain et al. 2009, Roberts and Manchester 2010e). Fractured or broken teeth can give insight into warfare or combat (Lukacs 2007). Uneven wear or grooves may indicate that teeth were used as a ‘third hand’ while holding materials, such as vegetable fibres for basketry or threads for textile manufacture with the teeth for manipulation (Larsen 1985, Waters-Rist and Katzenberg 2009, Lorkiewicz 2011).

Spinal markers of activity can include posture, such as kyphosis or scoliosis, and Schmorl’s nodes, which have been associated with high stature, body mass, and vertebral morphology (Plomp et al. 2015, Trzcinski et al. 2017). Another spinal marker of activity is a bony defect in the pars interarticularis of the lumbar vertebrae known as spondylolysis. This stress fracture is thought to be caused by repetitive movements but it is also linked to hereditary factors (Merbs 1996, Fibiger and Knüsel 2005).

One special case from the Wars of the Roses was detailed in the book Blood Red Roses: The Archaeology of a Mass Grave from the Battle of Towton AD 1461 (Fiorato et al. 2007). Because of extensive historical documentation, it is known that the burials in Towton,
Yorkshire, were those of warriors and soldiers. Armed with this knowledge, researchers knew they were looking at evidence of combat and weapons training when interpreting the skeletons. Another rare example is that of the Mary Rose, the flagship of Henry the VIII, which provided a unique opportunity to study a population with a confirmed profession or skill. The Mary Rose was known to be carrying the king’s archers when it was sunk, and analysis showed a high incidence of os acromiale, an incomplete fusion of the acromion process of the scapula, among the population (Stirland 2005). The case of the Mary Rose is unusual as the researchers had additional contextual information that is not often available in the archaeological study of activity. Like most markers of activity, indicators can be seen as consistent with a particular activity, but absolute associations can seldom be made. Os acromiale may be more common among those who practice archery, but an isolated individual with the condition cannot be assumed to be an archer.

Mobility and migration can be studied in the lower body, but if specific evidence of activity is to be found, it will often be in the upper body as that is more reflective of differentiation of lifestyles (Jurmain 1999, Jurmain et al. 2012). The questions of whether or not activity is habitual and repetitive, such as sports or occupation, or exceptional, such as trauma or injury, and the many factors of duration, frequency, mechanical loading, intensity, or age of onset are still to be determined by future research (Jurmain 1999).

3.2.5 Task and Occupation in Bioarchaeology

The study of occupation has been inherently linked to that of activity for as long as osteologists have been attempting to reconstruct the behaviours of past peoples. Although it is commonly understood in the field that we cannot assume any specific skeletal marker is correlated with a specific occupation, the term continues to be used (Iscan and Kennedy 1989, Jurmain 1999, Knüsel 2000, Maggiano et al. 2008, Larsen 2015c, Karakostis et al. 2017). While they may have clinical origins, names for conditions associated with a specific occupation such as ‘weaver’s bottom’ (ischial osteitis), ‘housemaid’s knee’ (sub-patellar bursitis), ‘little league elbow’ (see above), or even the more modern ‘tennis or golfer’s elbow’ (common flexor or extensor tenosynovitis/epicondylitis), no doubt contribute to the false assumption of singular aetiology (Iscan and Kennedy 1989, Capasso et al. 1998). It is perhaps our modern Western and post-industrial bias to specialisation of occupation that does a
disseverce within archaeology, particularly with regards to pre-industrial or agricultural societies (Knüsel 2000).

Rather than attempting to discern a specific occupation from a skeleton, researchers have broadened the interpretation of this aspect of behavioural reconstruction to include concepts of task, manual labour, sedentary work, human movement, and motions. This focuses the research approach on habitual and repetitive activity and to some extent excludes the incidental, singular, or traumatic (Knüsel 2000, Shaw et al. 2012, Alves Cardoso and Henderson 2013, Karakostis et al. 2017, Macintosh et al. 2017). Occupation and task within archaeology and activity could be understood as the study of repetitive or habitual human movement. Even this work can be fraught with limitations due not only to multifactorial aetiologies but to occupational or economic mobility and to lifecycle variability (Jurmain 1999, Roberts and Manchester 2010a, Henderson et al. 2013a).

Despite the multiple limitations inherent in this work, many researchers have found ways to control for some of the variables. One way of examining occupation or task in archaeology is to focus the study on identified collections (Cunha and Umbelino 1995, Cardoso and Henderson 2010, Milella et al. 2012, Perréard-Lopreno et al. 2013). The individuals often have grave markers or nameplates that identify the occupation at the time of death or modern collections may have written data and identity associated with the individuals. Limitations to identified collections and the use of known occupation at death is the variability of occupation and the categorisation of occupations which itself can be a source of bias (Alves Cardoso and Henderson 2013, Perréard-Lopreno et al. 2013).

In identified collections, many of the females are listed as having ambiguous occupations such as ‘housewife,’ leading many researchers to limit investigations to only the male individuals (Niinimäki 2012, Alves Cardoso and Henderson 2013, Perréard-Lopreno et al. 2013, Milella et al. 2015, Alves Cardoso and Assis 2021). Some researchers did find ways to categorise occupation at death to include females by putting them in their own occupational category (Cunha and Umbelino 1995, Alves Cardoso et al. 2016). The results of categorising occupations were mixed, although efforts were made to address biomechanical force, skill, and socioeconomic status. Most differentiated between clerical work, such as civil servants, manual/heavy labour and load carrying, artisans or skilled workers like carpenters or shoemakers that may have repetitive upper limb movement, domestic work, farmers, and military with various levels of success (Alves Cardoso 2008, Cardoso and Henderson 2010,
Milella et al. 2012, Perréard-Lopreno et al. 2013). The variety of tasks performed within any one occupation as well as changes in occupation throughout life are often unknown factors in any identified collection that uses a death certificate or grave marker to determine an occupation (Henderson et al. 2013a).

Another way of studying occupation is to limit the investigations to small populations with known activities that control for geographic, temporal, or genetic variation. As referenced above in 1.2.1, Hawkey and Merbs (1995) did have some success with this limited approach. Many researchers have attempted this small data/small population approach to compare between populations, by sex, or by socioeconomic status (Lai and Lovell 1992, Sperduti 1997, Rhodes and Knüsel 2005, Maggiano et al. 2008, Molnar 2010, Palmer et al. 2014, Huelga-Suarez et al. 2016).

Case studies and osteobiographies are one way of taking this small population approach with known, limited activities method to the individual level. Circumstantial data may be available to provide context, such as other burials or historical knowledge of behaviour, e.g. localised fur trade or craft production (Lai and Lovell 1992, Becker 2016b). One example is an individual from Bronze Age Russia being buried in a seated position in a fully assembled wagon, known as the ‘wagon driver’ (Tucker et al. 2017). In another case, the presence of weapons, shields, and horses indicated a life of professional warrior, and this skeleton was presumed to be male based on the materials. Misidentified for decades, the skeleton was finally confirmed to be female after osteological and genomic examinations (Hedenstierna-Jonson et al. 2017). The authors quite rightly question assumptions of sex and gender as well as the conclusions that can be drawn from the presence of grave goods but support their conclusions with other contextual data such as nearby burials (Price et al. 2019). One must be cautious about drawing too many conclusions out of the desire to invent a story from incomplete skeletons and scant cultural history (Jurmain 1999, Jurmain and Roberts 2008, Oates et al. 2008).

Many modern researchers are employing various technologies to assist in the study of occupation. Radiography, CT, and MRI have been used to study living athletes, like tennis or hockey players and runners (Sci et al. 1997, Shaw and Stock 2009a, Ireland et al. 2013). Biomechanics and 3D motion capture technology has been used to study loads, movement, and in one specific case horticultural digging (Shippen 2013, Shippen et al. 2017). Electromyography, monitoring the electric signals of muscle contraction, helped researchers...
to understand movement and some ancient technologies such as quern stone grinding or spear thrusting (Ervilha et al. 2004, Shaw et al. 2012, Sládek et al. 2016).

### 3.3 3D Imaging in Bioarchaeology

Medical imaging and live volunteers are often unavailable to the archaeologist, but 3D scanning, modelling, and printing is far more accessible. Digital technologies are becoming increasingly popular within anthropology, archaeology, and osteology and have benefitted the field in several ways (Weber 2015). As discussed above, while 3D scans/models are surface only and cannot reveal internal structures like CT or MRI, 3D cameras and equipment are far more accessible to archaeologists (Ruff 2007, Weber 2015). Photogrammetry, of course, is another inexpensive method that uses a series of digital photographs taken from multiple angles to form a 3D image (Weber 2015, Profico et al. 2019).

Much like drawing and photography, 3D scanning technology is relatively portable and can be taken into the field or to museum basements to collect permanent digital records of artifacts or items in collections (Ruff 2007, Weber 2015). Accessibility to restricted materials can be expanded with digitised artifacts because a researcher no longer needs to travel in person and delicate artifacts are not handled as frequently and so are preserved in better condition. Although 3D models of human remains are not as detailed as other methods of replication and may not ever fully replace hands on study, 3D models of unique artifacts allow for infinite replication, data sharing, and international collaboration (Weber 2015, Weiss 2015, Profico et al. 2019). Models of artifacts or remains are often used in museum displays within cultural and heritage sectors (Profico et al. 2019).

With developments and increasing accessibility of 3D printers at universities, 3D printed models of bones can have many applications in the classroom. Sometimes osteology students can have their own set of bones with which to learn basic landmarks and models of other systems aid the teaching of gross human anatomy in anthropology and medical fields (Weber 2015, Kuzminsky et al. 2020, Ye et al. 2020). Although 3D printed human models will never fully replace cadaveric instruction, printed models do not carry the same ethical concerns as real remains. They can be handled more easily and less destructively, and can be reproduced inexpensively (Henson et al. 2019, Kuzminsky et al. 2020). Digital models have made online osteology and anatomy education far more accessible. However, debates and discussions around accessibility and ethics of 3D printed human bones continue.

3D technology has been used in various ways to study entheseal changes, activity, and occupation. Most of this research has focused on recording and quantifying the enthesis to determine the efficacy of the technology when compared to 2D methods and to determine morphologic characteristics such as body size, robusticity, sex and age (Noldner and Edgar 2013, Nolte and Wilczak 2013, Weiss 2015). Some interesting new work using morphometric patterns in 3D scans of hand entheses has led to some distinctions between gripping and opposition (1st to 5th ray) use of the hand muscles and some association to occupational activities (Karakostis and Lorenzo 2016, Karakostis et al. 2017, 2021, Karakostis and Harvati 2021). This chapter discussed the many ways to record or measure activity in the past, and a thorough discussion of the methods involved in data collection and analysis can be found in the next chapter.
Chapter 4 Materials and Methods

4.1 Archaeology of the Collections

Skeletal material for this study was selected based upon several criteria including accessibility and availability during the time allotted for data collection, the size of the collection, taphonomic condition and completeness of the remains, time period, and the social and economic status of the geographical area at the time of burial.

The broad medieval period (roughly the 9th through late 16th centuries CE in Scotland) was selected for two primary reasons. One was urbanisation and the development of specialised occupation and craft, and the other accessibility of material. Collections from town centres or Burghs were selected as this increased the chances that the individuals had more specialised activity that may have an osteological presentation (Ewan 1990, Hall 2002, Dennison and Simpson 2006). Activity in agrarian or rural communities would have been significantly more varied and hence made the osteological signs of activity much more difficult to discern (2.2).

At the time of data collection, skeletal material from Edinburgh, Leith, Dunbar, St Andrews, and Perth was available (Figure 12). The Edinburgh Museum granted access to six collections from medieval Edinburgh and Leith. The National Museums Scotland Collections Centre permitted access to the material from Dunbar. The Perth Museum and Gallery approved the study of two collections from Perth city centre. The University of Edinburgh School of History, Classics, and Archaeology maintains collections from Perth and St Andrews and research was completed on site in the University laboratories.
All the selected collections are roughly contemporaneous, though Dunbar dates to the early period of the 9th-12th centuries CE while two, Constitution St and St Andrews’ Library, extend into the early 17th century CE (Table 1).

<table>
<thead>
<tr>
<th>Collection</th>
<th>9th</th>
<th>10th</th>
<th>11th</th>
<th>12th</th>
<th>13th</th>
<th>14th</th>
<th>15th</th>
<th>16th</th>
<th>17th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constitution St</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Old College</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Blackfriars</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Holyrood</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>St Giles’/ Parliament</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>St Andrews</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>St John’s Kirk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whitefriars</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Horse Cross</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Captain’s Cabin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The number of individuals that met the requirement for inclusion in this study ranged from 6% to 36% of the total in each collection (Table 2). Individuals were excluded for four primary reasons: (i) incomplete fusion of long bones; (ii) taphonomic damage to the cortical surface; (iii) presence of disease, such as DISH (diffuse idiopathic skeletal hyperostosis) or seronegative arthropathies, which influence entheseal change development, and (iv) lack of minimum required elements (4.2).

Due to the damage found on the surfaces of bones from the natural processes of decay, burial, excavation, cleaning, and storage, it was often difficult to find intact entheses in satisfactory condition. The presence of the bones of the arms, the vertebrae, the os coxae, and the calcanei were desirable for inclusion in the study, in that order of preference. Therefore, no skeleton was included without at least one intact and scorable enthesis on a bone of the arm, but many skeletons were included that did not have complete os coxae, vertebrae, or calcanei.

The nature of medieval cemeteries with the common practice of overuse and cutting into previous graves to add additional burials means it can sometimes be difficult for excavating archaeologists or osteologists to determine discrete individuals (Bain et al. 1998, Franklin et al. 2019). The nature of excavations, quite often performed in tight spaces within Burgh or city limits, means that the excavating archaeologists are working in long narrow trenches. Often graves that may already be indistinct can be cut into or damaged by excavations that expose only a portion of a single grave or individuals extending beyond the predetermined limits of the excavation (Moloney et al. 2001, Franklin et al. 2019). This can result in truncated individuals sometimes consisting of only a pelvis and leg bones, or, as was common in the collection from Constitution Street, skulls only without any other elements (Bain et al. 1998, Moloney et al. 2001, Franklin et al. 2019).

<table>
<thead>
<tr>
<th>Collection</th>
<th>Status, Geography</th>
<th>Total in Collection</th>
<th>Females Included</th>
<th>Males Included</th>
<th>Total Included</th>
<th>% Total Included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constitution St</td>
<td>Lower status, port</td>
<td>308</td>
<td>33</td>
<td>13</td>
<td>46</td>
<td>15%</td>
</tr>
<tr>
<td>Old College</td>
<td>Lower status, inland</td>
<td>44</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>14%</td>
</tr>
<tr>
<td>Blackfriars</td>
<td>Lower status inland</td>
<td>95</td>
<td>7</td>
<td>19</td>
<td>26</td>
<td>27%</td>
</tr>
<tr>
<td>Holyrood</td>
<td>Lower status, inland</td>
<td>51</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>6%</td>
</tr>
<tr>
<td>St Giles’</td>
<td>Higher status, inland</td>
<td>110</td>
<td>15</td>
<td>17</td>
<td>32</td>
<td>29%</td>
</tr>
<tr>
<td>Parliament House</td>
<td>Higher status, inland</td>
<td>96</td>
<td>14</td>
<td>9</td>
<td>23</td>
<td>24%</td>
</tr>
<tr>
<td>St Andrews</td>
<td>Lower status, inland</td>
<td>58</td>
<td>10</td>
<td>11</td>
<td>21</td>
<td>36%</td>
</tr>
<tr>
<td>St John’s Kirk</td>
<td>Lower status, port</td>
<td>33</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>9%</td>
</tr>
</tbody>
</table>
4.1.1 Edinburgh and Leith

Edinburgh is in the eastern lowlands of Scotland and on the southern coast of the Firth of Forth (Figure 12). Easy access to the North Sea and continental Europe made Edinburgh and the nearby port city of Leith early centres of trade, shipping, and development of skilled craft (Foular 1532, Dingwall 1995, Franklin et al. 2019). The area had been a centre of human occupation for thousands of years, and was a thriving agricultural community before it was officially established a royal Burgh in 1130 CE (Collard et al. 2006). The town centre of Edinburgh (Figure 13) would have been represented the most affluent members of the clergy, the learned, and business when compared to surrounding towns and Burghs (Cowen and Easson 1976, Dingwall 1995, Spence 2015).

<table>
<thead>
<tr>
<th>Location</th>
<th>Status</th>
<th>Age</th>
<th>Sex</th>
<th>Sib.</th>
<th>Race</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whitefriars</td>
<td>Lower status, port</td>
<td>103</td>
<td>17</td>
<td>15</td>
<td>32</td>
</tr>
<tr>
<td>Horse Cross</td>
<td>Lower status, port</td>
<td>10</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Captain’s Cabin</td>
<td>Lower status, inland</td>
<td>69</td>
<td>8</td>
<td>6</td>
<td>14</td>
</tr>
</tbody>
</table>
Leith, which began as an early fishing village, was first mentioned in historical records in 1128 CE (Franklin et al. 2019). Although never officially awarded Burgh status, the town acted as the main harbour and port for Edinburgh, closely linking the two cities (Franklin et al. 2019). As the capital and largest Burgh (town) in Lothian, Edinburgh was served by surrounding port cities including Berwick, on the coast of the Firth of Forth, and Leith, which was much closer (Stevenson 1988). Berwick (not to be confused with modern North Berwick or Berwick-upon-Tweed), was ‘sacked’ after an English invasion in 1296 and subsequently lost much of its international trade allowing Leith to grow. By the 13th century Leith figured prominently in historical records (Stevenson 1988). While Edinburgh and Leith existed as two separate political entities, one would not have prospered as well without the other. Edinburgh as the capital and walled city had a great demand for resources for craft and industry, but few goods and supplies would have made it to the city without the port city of Leith (Spearman 1988, Stevenson 1988).

Figure 14 Six Collections from Edinburgh and Leith
(Source: https://www.google.co.uk/maps and author.)
Six collections from Edinburgh and Leith were studied in this project (Figure 14), five of them from Edinburgh City Centre (Figure 15).

![Map of Edinburgh with Canongate CE 1647](https://maps.nls.uk/view/74475427) Reproduced with the permission of the National Library of Scotland under a Creative Commons Licence 4.0 (Gordon 1647).

4.1.1.1 St Giles’ Cathedral and Parliament House (higher status, inland)

Medieval Scottish Burgh life was centred around the church and St Giles’ Cathedral, located on The Royal Mile in Old Town Edinburgh, would have been the centre of the medieval town both geographically and socially (Figure 16) (Ewan 1988). St Giles’ makes its first appearance in the historical records shortly after Edinburgh became a royal Burgh in 1130 (Collard et al. 2006). An early Romanesque church was built shortly after the founding of the royal Burgh of Edinburgh in the 12th century, although archaeologists have found no evidence of this structure (Cowen and Easson 1976, Collard et al. 2006). The core building dates from the mid-13th century and was followed by eight major additions and extensions dating from the late 13th century through the early 16th, which expanded the church into the current form (Cowen and Easson 1976, Collard et al. 2006). Burials around and within St Giles’ Cathedral began shortly after the founding of the original church and continued for approximately 450 years. In 1562, shortly after the Protestant Reformation came to Scotland, Queen Mary decreed the lands around Greyfriars Kirkyard as the central city cemetery, which
led to a slow decline of use through the early modern period of the early 17\textsuperscript{th} century (Collard et al. 2006). The parish cemeteries included both internal and external burials, with the outdoor cemetery eventually covering approximately 0.5 ha and extending down the hill nearly to the Grassmarket (Bain et al. 1998, Collard et al. 2006).

![Figure 16 Map of Edinburgh from CE 1582 Depicting Original Burgh Walls](https://maps.nls.uk/view/102190432). Reproduced with the permission of the National Library of Scotland under a Creative Commons Licence 4.0 (Braun and Hogenberg 1582).

Excavations from within the Cathedral are included as the ‘St Giles’ Collection,’ although some of those early burials would have originally been located outside the original structure and built over during subsequent construction expansions (Collard et al. 2006). Later excavations of some of the former outdoor burials are included below and are known as ‘Parliament House,’ (see next section). According to Collard et al. (Collard et al. 2006: 5), building works and renovations report from the 19\textsuperscript{th} century stated, “In the course of yesterday’s digging, a large quantity of human remains was turned up. Indeed, it was made
manifest that the whole area of the church is a charnel house crowded with the relics of humanity.” This history has led modern scholars to believe that extensive burials remain beneath the floor of the modern structures along the Royal Mile (Hay 1975, Collard et al. 2006).

Excavations in 1981 within St Giles’ Cathedral were performed in advance of a new staircase being installed near the southwest corner of the building and the sum total of the collection (113 in situ burials) were found in the South Choir Aisle (Figure 17) (Collard et al. 2006). Archaeologists were able to determine four broad periods of activity, with the first through the third dating to the pre-Reformation medieval period, and five phases of burials.
All burials in the collection date to the three medieval activity periods (Collard et al. 2006). Twenty-three burials date from the 12/13th century, 52 burials date to the 13th/14th century, 16 from the late 14th to mid-15th, and 19 from the mid-15th through mid-16th/Reformation. While this collection is likely only a fraction of the burials present within the Cathedral, it spans the medieval period in central Edinburgh (Collard et al. 2006).

The building known as Parliament House as it exists today, was built between 1632 and 1641 by Edinburgh’s Town Council (Figure 18). It was erected over what was the outdoor cemetery, known as a ‘kirkyard’ in Scotland, associated with St Giles’ Cathedral. Archaeologists estimate that hundreds more burials still remain under multiple other

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**Figure 18** Detail of St Giles’ Cathedral and Parliament House CE 1647

Detail from Figure 4. High resolution zoomable image available at [https://maps.nls.uk/view/74475427](https://maps.nls.uk/view/74475427). Reproduced with the permission of the National Library of Scotland under a Creative Commons Licence 4.0 (Gordon 1647).
neighbouring modern buildings along the Royal Mile (Toolis and Roy 2004). In advance of further development, trenches were opened in 2004 and 96 inhumations were discovered (Toolis and Roy 2004). Pottery excavated from these deposits was dated throughout the 12th to 15th centuries and late medieval pottery was recovered from grave soil (Toolis and Roy 2004). Inhumations were laid in east-west rows with heads to the west, which is consistent with Christian burials. Archaeologists concluded that these burials were part of a southward expansion of the burial ground associated with St Giles’ Church (Toolis and Roy 2004).

Broadly, interior burial would have been more representative of wealthier parishioners with outdoor burials more accessible for the poor (Collard et al. 2006). Early inhumations were made with shrouds or other fabric with coffins only becoming more popular towards the late period the 15th-16th centuries CE. There is some indication that coffin burials were more common among the affluent during this time (Collard et al. 2006).

Skeletal material from Edinburgh and Leith (Figure 13) was transported to the School of History, Classics, and Archaeology labs at the University of Edinburgh for analysis except for the St Giles’ Collection, which was analysed on site at one of the Edinburgh Museum’s storage and curatorial centres.

Of the 110 individuals from the St Giles’ Collection available at the time of access, 32 adults, 15 females and 17 males had the necessary elements for inclusion in this study. The remaining were excluded because of taphonomic damage or due to incomplete elements.

Of the 96 individuals from the Parliament House Collection, from the former outdoor cemetery associated with St Giles’ Cathedral, 23 adults, 14 females and nine males, had the necessary elements for inclusion in this study. Exclusion due to taphonomic damage of the cortical surface and the enthesis and missing elements remained a factor.

4.1.1.2 Holyrood Abbey (lower status, inland)

Holyrood Abbey and the Palace of Holyrood lie at the eastern end of The Royal Mile in Edinburgh, Scotland (Figure 15). Excavations funded by Historic Scotland, now Historic Environment Scotland, were performed in 1995 as part of a stairwell build at the Abbey and the area exposed was only 2m by 4.5m (Bain et al. 1998). Archaeologists propose that the human remains discovered at the Abbey were part of the parish cemetery of the Canongate labelled as ‘The Kirkyard’ in a map dating from 1647, rather than a cemetery associated with the Abbey (Figure 19) (Bain et al. 1998).
The town and parish of the Canongate, now well incorporated into Edinburgh’s Old Town, would have once been outside medieval Edinburgh’s city walls. Canongate eventually had its own churches, kirkyards (churchyard), government, and merkat (market) square, most of which still survive today. This skeletal collection from Holyrood Abbey is believed to represent members of the parish of Canongate, as a bias in age or sex, representative of higher social status, was not seen here (Figure 20). The individuals were likely labourers and craftsmen, artisans, merchants, and scribes which would have been typical of such a community (Bain et al. 1998).
Fifty-one individuals were identified during the 1995 excavations, but due to conditions common in medieval burials with overcrowding and undercutting, many were incomplete or truncated due to 17th century CE building works (Bain et al. 1998). Of all the skeletons observed only three, two females and one male, were included in the study. Most individuals were not complete and the required elements for this study were not present in sufficient quantity.

4.1.1.3 Old College Quadrangle/Collegiate Church of St Mary’s in the Field (lower status, inland)

The Collegiate Church of St Mary’s in the Field, a medieval church and hospital, was probably the first building on the site that is today the Old College Quadrangle of the University of Edinburgh (Figures 21 and 22) (Cameron et al. 2010). Little is known about the original site, but as it was located outside the medieval walled city of Edinburgh the church
patrons may have been those who were unable to afford to live within the city walls. It was, however, included inside the extended Flodden Wall built in the 16th century to defend the Burgh from English forces. The site was later occupied by Hamilton House, a residence of the Duke of Chatelherault in the 1500s but was later incorporated into the foundations for what became the original library of the University of Edinburgh established in 1583 CE (Cameron et al. 2010).

Forty-four individual burials were recovered and dated from the late medieval period associated with St Mary’s but at least another 15 were left in situ (Cameron et al. 2010). Only six individuals, three females and three males, from this assemblage met the required completeness and had the necessary elements for inclusion in the study.

4.1.1.4 Blackfriars/Old High School/Infirmary St (lower status, inland)

Edinburgh Blackfriars (Dominican) Monastery dates to about 1260 CE and based on historical records, it was burned by the English in the middle 16th century then completely demolished by Reformers in 1559 (Cowen and Easson 1976). A 16th century building was later
established on the site, known as the Royal High School, then a 19th century garden area occupied the site before the current structure currently known as the Old High School was built (Canmore 2014). This monastery would have been located outside the Edinburgh city walls for much of the medieval period but was later included. The dark line shown in the image (Figure 22) features the Flodden Wall completed in 1560, just before the Scottish Reformation (Brown 2006).

![Figure 22 Map of the ‘Priory of the Black Friars’](image)

**Figure 22 Map of the ‘Priory of the Black Friars’**
Extent of land associated with the University (Old College and St Mary’s Kirk’o’Fields) with ‘cemetery’ labelled (yellow) and extent of lands associated with the former ‘Priory of the Black Friars’ (blue). Cartographer unknown. Image courtesy of St Albert’s Catholic Chaplaincy and the Archdiocese of St Andrews and Edinburgh (St Albert’s 2021).

The site was excavated in 2012-2013 by Headland Archaeology after a previous desk-based assessment and commissioned by the University of Edinburgh (Canmore 2014). Remnants of several previous building phases were uncovered as well as 95 discrete individuals and one burial with an elaborately carved grave slab, all associated with the former Blackfriars Monastery (Canmore 2014). Based on the profiles and pathological conditions present within this collection, it is assumed that the monastery also served as a hospital.
Of the 95 individuals removed during the 2012-13 excavations at the Old High School, 26 adults, 7 females and 19 males, were complete enough to be included. Many were excluded due to lack of required elements and taphonomic damage. Aside from a few disarticulate and fragmentary remains, this collection is in remarkably good condition.

4.1.1.5 South Leith Parish Church/Constitution Street (lower status, port)

The earliest historical evidence for the site of South Leith Parish Church was the foundation of St Mary’s Church in 1483. The former St Mary’s Church can be seen on maps dated from the 16th century, but it is likely the site was used for worship long before that (Figures 23 and 24) (Franklin et al. 2019).

![Figure 23 Map of Leith CE 1777](https://maps.nls.uk/view/216390339) Reproduced with the permission of the National Library of Scotland under a Creative Commons Licence 4.0 (Wood 1777).

The original St Mary’s Church was considered a sizable structure for the time and would have been able to contain much of the population of contemporary Leith. Some of the original structure remains but was reworked in the 16th century into the modern structure known as South Leith Parish Church (formerly South Leith Parish Church of St Mary’s)
Excavation began in 2008 in advance of a planned extension of the Edinburgh city tram system originally meant to link Edinburgh Turnhouse Airport through the city centre and out to Leith and nearby Newhaven. The discovery of human remains was a surprise as archaeologists and planners believed that the extent of the cemetery associated with South Leith Parish Church did not extend past the current walls (Franklin et al. 2019). After the discovery, later research established that original borders of St Mary’s Church extended much further to the west and included the area excavated along modern Constitution Street (Franklin et al. 2019). Radiocarbon dating of 30 individuals returned a wider date range than expected, from the 14th through early post-Reformation 16th centuries (Franklin et al. 2019). Earlier burials predate the known establishment of St Mary’s Church as well as the nearby preceptory of St Anthony, an early 15th century hospital founded by Holyrood Abbey (Franklin et al. 2019).
et al. 2019). One individual’s radiocarbon result (c. 1275 CE) predates both known historical structures (Franklin et al. 2019). A total of 305 in situ inhumations were recovered with a further 73 discrete but disarticulated individuals, some identified by the skull only (Franklin et al. 2019). At the time of writing, further excavations at this site are beginning and are expected to yield around another 200 individuals.

Of the over 300 individuals observed, many were excluded for absence of the required elements and only a few for taphonomic damage of the cortical surface precluding a score for the enthesis. This excavation required particularly narrow trenches so many individuals were truncated and consisted of pelvis and leg bones only or skulls only (Franklin et al. 2019). A total of 46 individuals, 33 females and 13 males and 15% of the total collection, were included in the study. The second phase of excavations at this site, thought to yield an additional 200 individuals, were ongoing at the time of this writing and are not included.

4.1.2 Perth

Perth is a city located at the upper limit of navigation of the River Tay, north of the Kingdom of Fife and on the eastern side of Scotland (Figure 25). The name means ‘copse’ or ‘wood’ and it was an early focus of settlement due to the strategic location on the river important for transportation and shipping (Bowler 2004). At one time Perth was considered the fourth largest city in Scotland after Glasgow, Edinburgh, and Aberdeen, a status it would not have had without the waterway access (Boonton 1988, Bowler 2004).
Towards the later medieval period Dundee began to eclipse Perth as the major trade city along the River Tay (Stevenson 1988). The Burgh of Perth was first mentioned in the historical records during the reign of David I (1124-53) but there was likely an early Pictish settlement in the area before that time (Bowler 2004). Like Edinburgh, Perth was a walled city first enclosed early in the 14th century and was confined within the walls until the late 18th century (Bowler 2004).
Figure 26 Map of Perth CE 1823
St John’s Kirk (blue arrow), approximate location of Horse Cross (green arrow), and Whitefriars (black arrow). High resolution zoomable image available at https://maps.nls.uk/view/74400053. Reproduced with the permission of the National Library of Scotland under a Creative Commons Licence 4.0 (Wood 1823).

Two of the Perth collections, St John’s Kirk and Horse Cross, were analysed on site at the Perth Museum and Gallery (Figure 23). The third collection, Whitefriars, Perth, is curated by the University of Edinburgh and was analysed in the University Archaeology labs.
4.1.2.1 St John’s Kirk (lower status, port)

St John’s Kirk is the oldest building in Perth having been built on some of the highest ground in the area (Figure 27). Frequent and moderate flooding of the River Tay, estimated to have occurred every five to ten years, formed a small ‘island’ of safe land that included St John’s Kirk and much of the High Street (Bowler 2004). While the church was founded in the early 12th century, the oldest surviving portion of the church is a choir added in 1440 (Figure 15) (Bowler 2004). Until 1580 when the Reformation came to Perth, the area around St John’s served as the main Burgh cemetery with the wealthiest citizens being granted burial inside the church (Bowler 2004).

Figure 27 St John’s Kirk, Perth 1770
(Fyles et al. 2003: fig. 28)

Excavations in advance of improvements to surrounding road surfaces were undertaken in 2003 and a quantity of human bone was found (Figure 28). Previously, human remains were unearthed in the area in 1985, 1991, and in 2002, and it was established that
human remains lay close to the surface of the modern roadworks surrounding the Kirk (Fyles et al. 2003).

**Figure 28 Excavations at St John’s Kirk, Perth**  
(Fyles et al. 2003: fig. 3)

While a minimum number of 200 individuals were discovered during the 2003 excavations, only 33 were articulated, discrete individuals and fully excavated by archaeologists (Fyles et al. 2003). Many were left *in situ*. Of the 33 articulated skeletons observed for this study only three, two females and one male, contained the required minimum elements and were in adequate condition.
4.1.2.2 Horse Cross (lower status, port)

Located just inside the former medieval Burgh walls of Perth, the site known today as Horse Cross was most likely the former chapel of St Laurence that was contained within the original Perth Castle (Cox et al. 2007). Later, the area was known to be a centre of craft and industry within the lands of a Blackfriars (Dominican) Monastery (Cox et al. 2007). The burials formed no obvious pattern so it is unknown whether they were originally from inside the chapel boundaries or out (Cox et al. 2007). Radiocarbon dates from two individuals were calibrated to 1150-1290 CE at 95.4% probability (Cox et al. 2007).

Excavations in 2002 uncovered ten individuals, with nine of them thought to be associated with St Laurence Chapel (Figure 29). Five were discrete burials, one outlying burial (a possible murder victim) and disarticulated remains indicating a further four individuals round out this collection (Cox et al. 2007).

Of the ten discrete individuals observed for this study, three, two females and one male, were sufficiently intact and contained the necessary elements for the study. The
remaining individuals, including the aberrant burial of the assumed murder victim, were all aged to be too young at time of death to be included in this study.

4.1.2.3 Whitefriars, Perth (lower status, port)

Four religious orders established residences around the walled city of Perth, a Carthusian Priory, and the Carmelite, Dominican, and Franciscan Friaries (known as the White-, Black-, and Grey-friars, respectively) (Bowler 2004). The Carmelite Friary of Tullilum, possibly named for the Gaelic word *tulach* meaning ridge or hillock, likely dates from the middle 12th century (Hall 2014). The site was most likely an early chapel associated with a church in the shire of Perth before residence of the monks, but the buildings were later known to be a residence for the Bishop of Dunkeld with an associated convent (Hall 2014). The buildings were later deserted and demolished following the Scottish Reformation, as evidenced by distinct layers of collapsed stone roof slate (Hall 2014).

Figure 30 Excavations at Whitefriars Road, Perth 2008
Excavation area circled (blue arrow) (Hall 2014: fig. 1)
Excavations at the site in 1982 and 2008 yielded a large number of burials that date from the Friary period, the remodelled Bishop of Dunkeld period, and into later post-Reformation time frame, although the majority of the remains are associated with medieval/pre-Reformation stratigraphy (Figure 30) (Hall 2014). Further excavations at this site also yielded another 200+ individuals, but that collection, maintained by the University of Aberdeen, was not available to be included in this research (Hall 2014).

Of all collections examined, Whitefriars, Perth, had the poorest preservation. While many individuals were complete, most were exceptionally fragmented and broken. Of the total 103 individuals in the collection, the researcher was able to include 32 individuals, 17 females and 15 males, with the required elements. A second phase of excavations from this site is housed at the University of Aberdeen and was not available for this study.

4.1.3 Dunbar, Captain’s Cabin (lower status, inland)

Dunbar, meaning ‘summit fort,’ is a smaller Burgh located on the northeast point of the southern coast of the Firth of Forth and is part of what is known today as East Lothian, near Edinburgh, Scotland (Figure 31) (Perry 2000, Moloney et al. 2001). There is evidence of early human occupation in the area, including a number of standing stones, but it was first recorded in historical records in 680 CE (Perry 2000, Moloney et al. 2001).
Dunbar achieved royal Burgh status in the late 14th century but before that it was a thriving *toun* (town centre) thanks to the large amount of rich, arable land that surrounded the shipping port (Perry 2000). The residents of Dunbar probably experienced a diverse mixture of craft, shipping industry, and agriculture (Perry 2000).
Excavations on the site known to be the former location of Dunbar Castle were performed in 1993 and 1998 wherein evidence was discovered to support the continual occupation of the area from the Iron Age, through the medieval period, and into the modern era (Figure 32) (Perry 2000, Moloney et al. 2001). The assemblage of human remains known as Captain’s Cabin are all from the 1998 excavations although about 20 individuals (now reburied) were uncovered in 1993 and helped to round out the understanding of the medieval cemetery (Perry 2000, Moloney et al. 2001). The name Captain’s Cabin refers to a
modern gift shop associated with 19th century barracks that was located on the site (Moloney et al. 2001).

The 1998 excavations were performed in advance of a toilet block development associated with the gift shop, and while the area was small, it yielded some 74 individual human remains as well as some amount of disarticulated material (Figure 33)(Moloney et al. 2001). The cemetery was intensively used which made stratigraphic analysis difficult, but several skeletons were radiocarbon dated to the 9th-12th centuries CE (Moloney et al. 2001).
A combination of shroud and cist burials make this cemetery typical for the location and period, but the age of the remains (48% juvenile) make it unusual (Moloney et al. 2001). It is assumed that the excavated portion of the cemetery lay within an area set aside for the burial of children or perhaps for women and children (Perry 2000, Moloney et al. 2001).

The collection known as Captain’ Cabin was analysed on site at the National Museums Scotland Collections Centre in Granton, near Edinburgh. Of the 69 inhumations observed for this study, 14 were included, with at least 17 being excluded as juveniles, 28 for missing elements, and three for the suspected presence of early DISH (diffuse idiopathic skeletal hyperostosis). The collection is well preserved and curated and in expected taphonomic condition for the period.

4.1.4 St Andrews, St Andrews Library (lower status, inland)

St Andrews is a small Burgh located on the northern aspect of what was known as the Kingdom of Fife on the southern side of the Firth of Tay (Figure 34). The town is known for the oldest University in Scotland, the ruins of the once majestic cathedral, and one of the most famous golf courses in the world.

![Figure 34 Location of St Andrews Library/Holy Trinity Church](https://www.google.co.uk/maps) (Source: https://www.google.co.uk/maps and author.)
Although St Andrews is also on the eastern portion of Scotland, it didn’t grow as much as other eastern lowland cities because the shallow waters surrounding the city made it inaccessible to the largest ships (Stevenson 1988). During the medieval period, St Andrews and the Cathedral of St Andrews were a destination for travellers and pilgrims drawing people from the surrounding rural areas into the Burgh (Simpson 1981).

Figure 35 Map of St Andrews CE 1820
Trinity Church (blue arrow). High resolution zoomable image available at https://maps.nls.uk/view/74400057. Reproduced with the permission of the National Library of Scotland under a Creative Commons Licence 4.0 (Wood 1820).

According to historical records, the Parish Church of the Holy Trinity was granted to St Andrews priory in the middle 12th century but was probably established long before that (Figure 35)(Simpson 1981). The current church dates from 1412, but it has been almost entirely rebuilt (Cowen and Easson 1976). The burial ground served as the sole cemetery for both St Andrews and St Leonard’s parishes through the 17th century until a new burial ground at the east end of town was established (Rees et al. 2008). Like many medieval cemeteries, the land was overused, many graves were undercut, and there were few grave goods or
markers found (Rees et al. 2008). A portion of the cemetery remains undisturbed under a concrete walkway near the library (Figure 36).

The St Andrews Library collection is curated and stored at the University of Edinburgh and analysis was performed in the University Archaeology labs. Of the 58 individuals, 21 were included in this study, 10 females and 11 males. A large number were assigned an age at death as juvenile, were too affected by adverse soil conditions, or did not contain the necessary elements. This collection contains a large amount of disarticulated material. A second collection from this site known as Logie’s Lane, which was excavated earlier and is housed at the University of Aberdeen, was not available for this study.
4.2 Skeletal Analysis

4.2.1 General Inventory and Analysis

Skeletal analysis, which employed standard techniques for age and sex estimation, was performed on each skeleton in the study (Brothwell 1981, Buikstra and Ubelaker 1994, Buckberry and Chamberlain 2002, Brickley and McKinley 2004, White and Folkens 2005). The skeletal inventories were recorded in digital format and examples of these are included in the Appendix 1. All data were collected using Microsoft Excel 365 for Mac on a MacBook Pro 2016. Individuals were arranged in anatomical position and a digital photograph was taken of each full skeleton (Figure 37). All documentary images were taken using a Canon 60D DSLR camera and minimally processed using Adobe Photoshop, Lightroom, and Illustrator 2022. A selection of pathologies and traits were recorded in detail as relevant to the study of activity, but all pathological conditions visible were diagnosed and recorded (4.2.2). Humeral bone length measurements for cross-sectional analysis were taken with an osteometric board to ensure accuracy.

To maintain comparability with previous research on occupation as well as to break new ground, both males and females were included in this study. Sex estimation was performed using standard morphological methods (Phenice 1967, Buikstra and Ubelaker 1994, Rogers 2005, Walker 2005, 2008, White and Folkens 2005). Cranial and mandibular traits used included the orbital margin and ridge, the nuchal crest, the mastoid process, and the mental eminence and gonial angle on the mandible. Sex estimation of the pelvic bones
included morphological traits of the subpubic angle, preauricular sulcus, the subpubic concavity, the sciatic notch, and the ischiopubic ramus (Phenice 1967, Buikstra and Ubelaker 1994, Rogers 2005, Walker 2005, 2008, White and Folkens 2005). Based upon the presence or absence of some features, not all morphological traits were used for every skeleton. All skeletons examined were from previously analysed collections, but age and sex estimation were performed again for this study to ensure transparency and comparability across the study. Individuals for whom the estimated sex was probably female or probably male were included in the respective male or female categories.

Age at death estimation for each skeleton applied standard methodology (Buikstra and Ubelaker 1994, Buckberry and Chamberlain 2002). Among the primary methods used to age a skeleton, the auricular surface is often better preserved than the pubic symphysis, and this was the case with this study. The bone at the auricular surface is more dense and resistant to superficial taphonomic damage so this method is considered more reliable (Buckberry and Chamberlain 2002). The Buckberry-Chamberlain (2002) method for aging the auricular surface was selected because it was developed on British populations.

Age estimations from the auricular surface were prioritised and supported with secondary estimations from the pubic symphysis or dental attrition. Many skeletons were included in the study without the presence of an intact pubic symphysis or teeth. The practice of estimating age from dental attrition is questionable as it is highly dependent upon the population specifics such as genetics, diet, and the use of teeth as tools (Miles 1962, Brothwell 1981). When considering this, and the fact that the pubic symphysis is often damaged in archaeological populations, a decision was made to require at least one well-preserved auricular surface for detailed age assessment. Some individuals were excluded due to lack of an auricular surface. Brothwell’s (1981) method for estimating age based on dental attrition was selected as it was developed on British populations and was therefore the most appropriate in this case. Age estimation for the pubic symphysis used the Suchey-Brooks Method (Brooks and Suchey 1990b).

This study focused on adult skeletons as determined by skeletal development and excluded any juveniles in the collections. Osteological methods for determining what is considered an adult can be complex (Falys and Lewis 2011). Adult was defined for this study as a complete fusion of the long bones. For the proximal epiphysis of the humerus, which is the last portion of the bone to fuse, the age range for females is 16-21 and for males it is 14-

There were no upper age estimation limits placed on the basic inclusion for this study, but to control for age, individuals were divided into age groups. Biological changes throughout the lifecycle (e.g., menopause,) were balanced with sociocultural changes (e.g., marriage or heavy labour decreasing with age), and the decision was made to divide the sample into for decades of life (i.e., 20’s, 30’s, 40’s and 50’s) in an attempt to capture these lifecycle changes. EC also show a marked prevalence increase after 50 years of age which supports this decision (Mariotti et al. 2007, Villotte et al. 2010a, Milella et al. 2012). Four age groups were devised using the Buckberry-Chamberlain method for age estimation of the auricular surface. The median age for each Stage was substituted as a proxy for years of age at death (Buckberry and Chamberlain 2002). Young adults (20s, n = 42) were comprised of Stages I and II with median age range estimate of 17-27 years of age. Young middle adults (30s, n = 54) scored with Stage III had the median of 37 years of age. Older middle adults (40s, n = 40) scored with Stage IV had the median of 52 years of age. Older adults (50+, n = 68) included any individuals scored with Stage V, VI, or VII (Buckberry and Chamberlain 2002). To resolve any ambiguities if one individual fell near the borderline for a group, additional aging methods (see above) were employed to assign the individual to an age group. Images of data collection forms can be found in Appendix 1.1 and complete files in the accessory data.

4.2.2 Lifestyle Indicators

Each skeleton selected (based on age at death and estimated sex) was evaluated for other lifestyle indicators including pathological conditions and other non-EC related markers often associated with activity. Examples of recording spreadsheets are available in Appendix 1.1 and all data are included in accessory information. Degenerative joint changes and entheseseal changes were recorded in depth and are outlined below (4.2.3 and 4.2.4).

Fractures and other trauma were recorded because a previous injury may affect biomechanical functioning later in life. Signs of dental and metabolic diseases were recorded
as general indicators of stress. While some lesions have known aetiologies, many non-specific lesions can have various causes such as diet, disease, or vitamin deficiencies (Brickley and Ives 2008, Roberts and Manchester 2010d). Porotic hyperostosis and cribra orbitalia, often attributed to anaemia, scurvy (vitamin C deficiency), rickets (vitamin D deficiency), and dental enamel hypoplasia (evidence of childhood affliction), were also recorded collectively as metabolic disease (Ortner 2003, Brickley and Ives 2008, Mays 2008, Waldron 2009, Roberts and Manchester 2010d). Metabolic disease can often be an indicator of low social status which might lead to poorer access to food and medical resources (Brickley and Ives 2008, Roberts and Manchester 2010d).

Markers of non-specific infection such as periostitis and osteomyelitis were recorded as these conditions may also indicate poor access to medical care and lower socioeconomic status (Roberts and Manchester 2010c, Roberts 2019). Where possible a more specific diagnosis was made but was pooled into infectious disease. Leprosy (*Mycobacterium leprae*) was diagnosed in the presence of maxillofacial deformity (Ortner 2003, Roberts and Manchester 2010c, Roberts 2011, 2019). One advanced case of tertiary syphilis (*Treponema pallidum pallidum*) was diagnosed where multiple frontoparietal lytic lesions (caries sicca) were observed (Ortner 2003, Roberts and Manchester 2010c, Roberts 2019).

Evidence of any respiratory disease was recorded due to the association with occupation and industry in post-medieval and modern populations (Capasso et al. 1998, Roberts and Buikstra 2003). Rib lesions were the primary diagnostic indicator, but these were supported by other skeletal evidence such as spinal or appendicular joint lesions (Ortner 2003, Roberts and Buikstra 2003, Roberts and Manchester 2010c, Roberts 2011). Only external surfaces were observed so cases of sinusitis were not recorded. DNA analysis of the remains was unavailable for this study so no cases of tuberculosis (*Mycobacterium tuberculosis*) or additional cases of leprosy (*Mycobacterium leprae*) could be confirmed (Roberts and Manchester 2010c, Roberts 2019).

Other anomalous bone presentations were also recorded, many associated with activity, but with no assumptions made as to aetiology. Some examples include asymmetry in the manubrium and corpus secondary to a clavicular fracture, notched incisors, or unusual contact facets.

Due to low and occasionally singular case counts, testing for statistical significance was not performed and these data were excluded from further analysis. These data would be
better suited to case studies rather than population level investigation. Some conditions were pooled together (e.g., infectious disease), to offer some general information about the lifestyle and social status of individuals within this population. Cases were considered either present or absent and crude prevalence rates are displayed in the Results Chapter (5.1). Images of data collection forms can be found in Appendix 1.2 and complete files in the accessory data.

4.2.3 Entheseal Changes and the New Coimbra Method

Entheseal changes were recorded using the new Coimbra Method (Henderson et al. 2016a, 2016b). When considered in the context of the complex and multifactorial aetiology of EC and the unique physiology of the individual, discerning population patterns of any kind must be done with caution and with awareness of all variations and limitations. The new Coimbra Method, which divides the enthesis into two zones for scoring, builds on the awareness of the enthesis organ anatomy and fibre direction (Figure 8). This method also records many different traits at the enthesis which, in some cases, proves useful in understanding EC aetiology. For instance, bone formation is most associated with age, while porosity is more indicative of micro and/or macro trauma (Milella et al. 2012, Henderson et al. 2013b, Villotte and Knüsel 2013). Although the aetiology of EC is complex, a recording method that does not include the various EC traits is obscuring variability in analysis.

To meet minimum inclusion limits, the individuals must present with at least one scorable enthesis on a bone of the arm. Taphonomic damage can obscure changes to the bone and can sometimes be confused with enthesal change related porosity or other changes (Henderson et al. 2016a). Individuals with the presence or suspected presence of DISH (diffuse idiopathic skeletal hyperostosis) and seronegative spondyloarthropathies were excluded (Ortner 2003, McGonagle et al. 2007, Shaw and Benjamin 2007, Waldron 2009, Villotte et al. 2010a). The four tissue zones of fibrocartilaginous entheses are not present until late adolescence so all individuals included in this study were adults as determined by the complete fusion of the long bones (Benjamin and McGonagle 2001b, Villotte et al. 2010a).

Only fibrocartilaginous entheses were used in this study and selection balanced potential usefulness to the research questions with the ease of visually locating the bony landmark (Table 3). Each enthesis studied in bioarchaeology has a unique profile formed by the enthesis organ anatomy and the kinesiology of the associated muscle(s). The location of
the Zone 1 margin is different for each enthesis based on the direction of the attachment fibres. While this generally remains consistent for a single enthesis between individuals, there are some variations (Villotte 2013). The enthesis footprint, however, can be a factor in identifying and scoring as some are easier to locate than others.

**Table 3 List of Scored Entheses**

<table>
<thead>
<tr>
<th>Enthesis/Tendon/Muscle</th>
<th>Origin/ Insertion</th>
<th>Bony Landmark/Bone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subscapularis</td>
<td>Insertion</td>
<td>Lesser tubercle of the humerus</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>Insertion</td>
<td>Greater tubercle of the humerus</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>Insertion</td>
<td>Greater tubercle of the humerus</td>
</tr>
<tr>
<td>Common Flexor Group</td>
<td>Common Origin</td>
<td>Medial epicondyle of the humerus</td>
</tr>
<tr>
<td>Common Extensor Group</td>
<td>Common Origin</td>
<td>Lateral epicondyle of the humerus</td>
</tr>
<tr>
<td>Biceps Brachii</td>
<td>Insertion</td>
<td>Radial tuberosity of the radius</td>
</tr>
<tr>
<td>Brachialis</td>
<td>Insertion</td>
<td>Ulnar tuberosity of the ulna</td>
</tr>
<tr>
<td>Triceps Brachii</td>
<td>Insertion</td>
<td>Olecranon process of the ulna</td>
</tr>
<tr>
<td>Hamstring Group</td>
<td>Common Origin</td>
<td>Tuberosity on the ischium</td>
</tr>
<tr>
<td>Calcaneal Tendon</td>
<td>Common Insertion</td>
<td>Calcaneal tuber of the calcaneus</td>
</tr>
</tbody>
</table>

4.2.3.2 The Shoulder

The shoulder as a functional complex is made up of the acromioclavicular joint (AC) and glenohumeral (GH) joints between the clavicle, the scapula, and the humerus. While not a formal joint, the scapula also rests on the thorax and is subject to influences of other muscle attachments at the vertebrae, cranium, and ribs (Porterfield and DeRosa 2003b, Mansfield and Neumann 2019c, Yeşilyaprak 2020). Apart from the four rotator cuff muscles, the functional complex is influenced by many more structures (Figure 38). Trapezius, levator scapulae, and rhomboids, for example, are some of the proximal stabilisers (Porterfield and DeRosa 2003c, Yeşilyaprak 2020). Deltoid, biceps brachii, and pectoralis major are some of the distal mobilisers (Porterfield and DeRosa 2003c, Yeşilyaprak 2020). The shoulder joint is highly flexible and offers extensive range of motion (ROM) in multiple planes, but this variety comes at the expense of reduced stability (Porterfield and DeRosa 2003c, Mansfield and Neumann 2019c, Yeşilyaprak 2020). Shoulder stability rests primarily on the ligaments of the joint capsules of the AC and GH, and on the four muscles of the rotator cuff. This biomechanical trade-off between flexibility and stability means that the shoulder is a site of frequent dysfunction and both traumatic and chronic injury (Porterfield and DeRosa 2003c, Mansfield and Neumann 2019c, Greiner et al. 2019, Yeşilyaprak 2020). Compared to the GH,
the AC is far more stable as forces at the AC are transferred across the joint rather than in multiple planes like the GH (Mansfield and Neumann 2019c).

The largest of the four muscles of the rotator cuff, the subscapularis, is primarily an internal rotator and stabiliser that is responsible for 53% of rotator cuff strength (Figure 38, top) (Funk 2005, Mansfield and Neumann 2019c, Yeşilyaprak 2020). The superior fibres of the tendon interdigitate with the anterior fibres of the supraspinatus insertion (Di Giacomo et al. 2008).

The two entheses are easily discernible at the lesser tubercle (subscapularis) and greater tubercle (supraspinatus) of the humerus on dry bone. Zone 1 of the subscapularis enthesis is the lateral border (black line) and Zone 2 comprises the remaining area (white) (Figure 38, bottom) (Villotte 2013, Henderson et al. 2016a, 2016b).
Figure 38 Anterior Rotator Cuff and Zones 1 and 2 of the Subscapularis Insertion
Top: anterior rotator cuff (Source: author). Bottom: Zone 1 (black line) and Zone 2 (white area). Right proximal humerus, anterior view, proximal is up. Blackfriars 36. (Source: author.)
The insertions of the supraspinatus and infraspinatus (Figure 39, top) are also known to interdigitate (as are the infraspinatus and teres minor) (Di Giacomo et al. 2008). While they share the work of humeral stabilisation (as do all four rotator cuff muscles), their prime movements differ. Supraspinatus performs horizontal abduction of the arm (along with the deltoid) while most fibres of the infraspinatus perform external rotation of the humerus. All three must work to counter the force of the subscapularis to stabilise the shoulder joint (Mansfield and Neumann 2019c).

The enthesis areas on the greater tubercle are not always easily defined so some researchers score them as a single combined enthesis (Villotte et al. 2010a, Wilczak et al. 2017, Henderson et al. 2018). On many individuals, however, these two insertions are quite clearly defined and have often been scored individually for EC (Hawkey and Merbs 1995, Molnar 2006, Michopoulou et al. 2015, Santana-Cabrera et al. 2015). In this study the supraspinatus and infraspinatus were scored separately (Figure 39, bottom). In the rare case of no discernible division between the supra- and infraspinatus, then the anterior 50% of the enthesis was scored as the supraspinatus and the posterior 50% as the infraspinatus. Zone 1 is the lateral border of both entheses (black line), and Zone 2 comprises the remainder of the enthesis area (white) (Villotte 2013).
Figure 39 Posterior Rotator Cuff and Zones 1 and 2 of the Supraspinatus and Infraspinatus Insertions

Top: posterior rotator cuff (Source: author). Bottom: Zone 1 (black line) and Zone 2 (white area). Fine black line indicates the well-defined enthesis areas on this individual. Right proximal humerus, superior view, anterior is up. Blackfriars 36. (Source: author.)
4.2.3.3 The Elbow, Forearm, and Wrist

The functionality of elbow and forearm/wrist/hand as joint complexes is overlapping and synergistic. The elbow ‘hinge’ joint is made up of the distal humerus articulating with the olecranon fossa of the proximal ulna. The radial head facilitates rotation of the forearm via the radio-humeral joint and the proximal radioulnar joint (Placzek and Miskowski 2017, Mansfield and Neumann 2019b, Ayhan and Ayhan 2020b). All three joints are encased within the ligamentous capsule (Mansfield and Neumann 2019b, Ayhan and Ayhan 2020b).

Functions of the forearm, wrist and hand are facilitated by multiple structures such as the brachioradialis at the elbow, pronator teres, pronator quadratus, and supinator which facilitate rotation, and the multiple intrinsic muscles and ligaments of the hand and fingers (Mansfield and Neumann 2019b, 2019e, 2019f, Ayhan and Ayhan 2020a, 2020b). The elbow is the second most dislocated joint in adults after the shoulder, but the most common in juveniles, and is still prone to injuries both acute and repetitive (Mansfield and Neumann 2019b, Ayhan and Ayhan 2020b).

The forearm flexor group with the common origin on the medial epicondyle performs wrist, hand, and finger flexion and forearm pronation (Figure 40, top left). The flexor group is far stronger than the antagonistic extensors (Mansfield and Neumann 2019b, 2019e). The forearm extensor group with the common origin on the lateral epicondyle engages in wrist, hand, and finger extension, and supination of the forearm (Figure 40, top right). This group also stabilises the wrist and hand during flexion to maintain a neutral position (Mansfield and Neumann 2019e, 2019b).
Figure 40 Forearm Flexor and Extensor Groups and Zones 1 and 2 of the Common Flexor and Common Extensor Origins

Top left: forearm flexor group (Source: author). Top right: forearm extensor group (Source: author). Bottom: Zone 1 (black line) and Zone 2 (white area). Right distal humerus, anterior view, proximal is up, lateral is left, medial is right. Blackfriars 90. (Source: author.)
Both the common flexor (CFO) and common extensor (CEO) tendon origins are each scored as a single enthesis on the medial and lateral epicondyles, respectively (Figure 40, bottom). The medial epicondyle score (CFO) included any changes associated with the ulnar medial collateral ligament (MCL), although other researchers have chosen to separate the two for their scoring and interpretations (Varalli et al. 2020). Zone 1 is the inferior-medial aspect of the epicondyle (black line) and Zone 2 the remainder (white). The lateral epicondyle score (CEO) did not include the lateral epicondylar ridge or the origins of the anconeus or brachioradialis muscles. Zone 1 is the inferior-lateral aspect of the epicondyle (black line) and Zone 2 the remaining area (white) (Villotte 2013, Henderson et al. 2016b, 2016a).

The biceps brachii has two origins on the scapula with the tendons coming together to form the belly and distal insertion of the muscle on the radius (Figure 41, top). The fibre direction twists near the distal attachment with the medial fibres forming the most lateral portion of the insertion (Gray 1974, Abrahams et al. 1998, Floyd 2012). It performs flexion of the elbow (second to the brachialis), and the distal fibre twist facilitates the secondary movement of pronation of the forearm via the radius (Porterfield and DeRosa 2003d, Yeşilyaprak 2020). The proximal biceps brachii also assists in shoulder stabilisation (Mansfield and Neumann 2019c).

The biceps brachii was scored as a single enthesis on the radial tuberosity although it is technically a common insertion of fibres from two proximal muscle heads (Gray 1974, Abrahams et al. 1998, Floyd 2012). Zone 1 is the medial border of the enthesis, and Zone 2 comprises the remaining area (Figure 41, bottom left) (Villotte 2013, Henderson et al. 2016a, 2016b).
Figure 41 Biceps Brachii and Brachialis and Zones 1 and 2 of the Biceps Brachii and Brachialis Insertions
Top: biceps brachii and brachialis (Source: author). Bottom left: Zone 1 (black line) and Zone 2 (white area). Right proximal radius, anterior view, proximal is up. Constitution St 655. (Source: author.) Bottom right: Zone 1 (black line) and Zone 2 (white area). Left proximal ulna, anterior view, proximal is up. Blackfriars 75. (Source: author.)
The brachialis is a thin, flat muscle that lies under the biceps directly on the shaft of the humerus and attaches at the proximal ulna (Figure 41, top). Brachialis is the first to be recruited for isolated elbow flexion (Floyd 2012, Mansfield and Neumann 2019b, Ayhan and Ayhan 2020b). The biceps brachii and brachialis have a synergistic relationship to each other but an antagonistic one with the triceps brachii (Floyd 2012, Mansfield and Neumann 2019b, Ayhan and Ayhan 2020b).

The brachialis enthesis on the ulna is easy to discern (Figure 41, bottom right). The enthesis is quite variable and tends to develop frequent changes, but there is some lack of consensus over the specifics of Zone 1 due to the unusual anatomy consisting of comparatively thin uncalcified fibrocartilage (Benjamin et al. 1992, Villotte and Knüsel 2013). For this study, Zone 1 was the distal, but rounded aspect of the insertion and Zone 2 the remaining area.

The triceps brachii has three origins: the long head on the scapula, and both medial and lateral heads on the shaft of the humerus with a common insertion at the proximal ulna (Figure 42, left) (Gray 1974, Abrahams et al. 1998, Floyd 2012). The prime movement is elbow extension and it is antagonistic to the brachialis and biceps (Mansfield and Neumann 2019b, Ayhan and Ayhan 2020b). The common insertion of the triceps brachii was scored as a single enthesis on the olecranon of the ulna (Figure 42, right). For this study, Zone 1 was the most posterior aspect of the insertion and Zone 2 the remaining area.
4.2.3.4 The Lower Body

The hamstring group performs hip and leg extension and knee flexion (Figure 43, left). The short head of the biceps femoris (not shown) is located on the shaft of the posterior femur. The common origin of the hamstring group on the ischial tuberosity was scored as a single enthesis (Villotte 2013). Zone 1 is the proximal and superior portion of the enthesis and Zone 2 the remainder (Figure 43, right).
The muscles of the low leg that form the calcaneal (Achilles’) tendon, the gastrocnemius, soleus, and plantaris (not shown) perform knee flexion and ankle extension (a.k.a. plantar flexion) (Figure 44, left). The common insertion of the superficial low leg muscles on the calcaneus was scored as a single enthesis in this study (Figure 44, right).
**4.2.3.5 The New Coimbra Method**

As described by the method, the observer received training from one of the original developers of the new Coimbra Method, Charlotte Henderson, on 13 March, 2017 at the University of Edinburgh (Henderson et al. 2013b, 2016a, 2016b, Henderson 2017). Environment, lighting, and recording distance between the observer and the enthesis was observed in accordance with the method as far as possible depending on location of data collection (i.e., lab vs museum) (Henderson et al. 2013b, 2016a, 2016b). Six traits (bone formation, erosion, textural change, fine and macro porosity, and cavitation) were scored over two zones of activity on each enthesis leading to eight scores per enthesis (Figures 45-47) (Henderson et al. 2013b, 2016a, 2016b).
Figure 45 Enthesal Change Traits at Biceps Brachii Insertion
Bone formation in Zone 1 (white arrow), macro pore in Zone 2 (blue arrow), cavitation in Zone 2 (black arrow), fine porosity (green arrow). Right proximal radius, anterior view, proximal is up. Constitution St 655. (Source: author.)
Figure 46 Enthesal Change Traits at Supraspinatus/Infraspinatus Insertion
Fine porosity in Zone 2 (white arrow), macro pore in Zone 2 (black arrow). Left proximal humerus, superior view, anterior is up. Constitution St 648. (Source: author.)
If the enthesis was missing, damaged, or obscured by pathology it was scored with a 9. If it was present and unaffected, a 0. Entheses affected by changes were scored according to the method with 1 or 2 accordingly (Henderson et al. 2016a, 2016b). At least 50%, with both Zones 1 and 2 present, of the enthesis must be present to be considered scorable. Images of data collection forms can be found in Appendix 1.3 and complete files in the accessory data. A written description of the traits can be found in Appendix 2.

4.2.4 Degenerative Joint Changes and Osteoarthritis

Osteoarthritis, in clinical practice, is often diagnosed based on reported symptoms such as pain and stiffness, clinical signs such as swelling or inflammation in the affected joint, or radiologically in the case of narrowing of the joint space or the presence of osteophytes (Cooper et al. 1994, Waldron 2009). While osteoarthritis is one of the most common
pathological conditions found in skeletons, the diagnostic process in skeletal material is different. Terminology used in the diagnosis of osteoarthritis and degenerative changes to bone are varied and change based upon new research, but most agree that these conditions have a complex aetiology (Larsen 2015a). In this study, osteoarthritis (OA) was diagnosed based on the presence of eburnation on joint surfaces (Rogers et al. 1987, Waldron 2009). In the absence of eburnation, and in the presence of marginal osteophytosis, new bone on the joint surface, pitting or porosity on the joint surface, or alteration of the joint contour, a diagnosis of degenerative joint changes (DJC) was made. The term ‘degenerative joint changes’ was selected as it does not assume a specific disease process nor aetiology. Both osteoarthritis and degenerative joint changes are conditions of bone proliferation and erosion, however, both conditions are commonly termed ‘degenerative’ as there are changes from the natural and unaltered joint anatomy (Waldron 2009, Larsen 2015a).

4.2.4.1 Appendicular Skeleton

All instances of OA and DJC were recorded, but not all data collected was used in the analysis. Of special interest in this project was the upper body, specifically, the shoulder, elbow, and wrist. For the appendicular skeleton, each joint surface was recorded separately but later pooled. If any surface of the joint displayed eburnation (1), osteophytosis (2), new bone (3), pitting (4), joint contour change (5), or porosity (6), this was recorded with the assigned number. If the joint surface was present but did not display any changes, it was scored with 0. Any missing surfaces were scored with 9. For all individuals who displayed eburnation, a single cumulative score of ‘present’ (1) for OA was assigned. For individuals who displayed eburnation or at least two of the other traits of DJC, an overall score for DJC of present (1) was assigned. In every case of eburnation, the individual also displayed other signs that qualified as DJC and are therefore included in the overall DJC numbers. This method allows for greater comparability to various sources over time and with different recording methodologies (Waldron 1992, 2009, Brickley and Waldron 1998, Molnar et al. 2011, Schrader 2012, Becker 2019b).

To facilitate comparisons to EC and CSG, which were also pooled by functional complex, if DJC was present at any joint surface, then DJC at the functional complex was considered ‘present’ (1). All joint surfaces of the shoulder (scapula, clavicle, and proximal humerus) were combined into one shoulder score. The combined shoulder score was
assigned in the presence of DJC at either the AC or GH joints. For certain comparative analyses, DJC at the acromioclavicular (AC) joint and the glenohumeral (GH) joint were kept as distinct.

The pooled elbow included joint surfaces at the distal humerus and proximal ulna and radius. The pooled wrist was scored for DJC at the distal radius and ulna and the proximal surfaces of the scaphoid or lunate. DJC of the hip was recorded if surfaces of the acetabulum or femoral head showed changes, and the knee included all patellofemoral and tibiofemoral surfaces. Ankle DJC was recorded for the distal tibia and superior talus.

4.2.4.2 Axial Skeleton

DJC for the axial skeleton was recorded by vertebra, including the occipital condyles and the sacrum. Eburnation was scored as evidence of OA. The body of the vertebra was recorded separately from the facet surfaces. Changes to the vertebral body are technically termed degenerative disc disease (DDD) and are sometimes referred to as vertebral osteophytosis (VOP), while facet surfaces exhibit similar changes to appendicular joints so the term DJC was used (Jurmain 1999, Roberts and Manchester 2010a).

Scores for the axial skeleton were handled the same way as the appendicular skeleton with coded numbers (1-6) representing traits, 0 for present but no traits, and 9 if the element was absent. Due to frequently incomplete spines, evidence of changes on the vertebral body were pooled with those of vertebral facets, then data from individual vertebrae were pooled by segment. Any evidence in at least one cervical vertebra, including the occipital condyles, was considered present for the cervical segment. All thoracic vertebrae were pooled and any changes to the sacrum/sacral vertebrae were pooled into the lumbar segment.

4.3 Cross-sectional Geometrical Analysis

Data collection and analysis for CSG consisted of multiple parts. Appropriate individuals must be identified, and quality 3D scans must be obtained with accessible technology. All scans must then be processed and measured, then then sliced at the appropriate location. Those slices are then analysed by unique software for the selected measures of CSG.
4.3.1 Scan Collection

Scan collection began first with identifying and accessing the appropriate technology, then by identifying individuals with humeri suitable for scanning. The scanning process itself is dependent on several factors including light, stability, and accuracy.

4.3.1.1 EinScan Pro 3D System

3D scanning technology can be broken down into laser and structured light systems. Laser scanning, which uses a single pass over an object, can often be faster. Structured light scanners (also known as white light) take much longer as the camera takes multiple passes over the object from many different angles and requires those scans to be ‘meshed’ into one complete scan. Because of the multiple views, structured light scanners are often considered to be more accurate (Tong 2019). At the time of project development, both technologies were available but structured light was selected for its higher accuracy and availability. The EinScan Pro equipment could be easily transported to the securely stored human remains, avoiding logistical and ethical concerns (Figure 48).

The EinScan Pro system consists of a tripod mounted camera, a turntable with reflective markings, and proprietary software (Shining 3D 2021). Various PC computers were used for scan collection and were loaned to the researcher with the 3D scanner as higher end processors and graphics not common to personal computers were required.
4.3.1.2 Inclusion Criteria

Inclusion in this study required a complete humerus with little taphonomic damage and a near-intact cortical surface. The most proximal portion, the humeral head, and the most distal portion, the trochlea, had to be intact to allow for digital measurement, which is more precise than an osteometric board (4.2.1). Often a human long bone from an archaeological collection may be intact but broken at part of the shaft. Humeri were only included if the bone could be held together securely using a temporary solution such as low-stick masking tape and the break was not located distal to the 50% mark on the bone. As this technology provides a surface scan, any material on the surface of the bone could affect the eventual shape of the cross-sectional slice. The scans were performed making use of a rotating turntable, so any bone that was not complete and stable moved too much during the process to produce a sufficient scan.

4.3.1.3 Scan Collection

The EinScan Pro camera needed to be calibrated for existing lighting conditions before scanning. If fully indoors, once per day was often enough, but when natural light was present the camera needed to be recalibrated throughout the day. Most scans were taken in
controlled conditions in the labs at the School of History, Classics, and Archaeology at the University of Edinburgh but working onsite at museum storage facilities could be more challenging.

The camera can be handheld, but the turntable was used for better consistency between scans. The software offers two methods of locating the object. One uses the reflective points on the turntable, the other identifies features on the object. The software then uses these points to identify unique landmarks to synthesize (mesh) multiple successive scans into one file at the end of the collection process. The default option of eight stopping points, each at 45° of a circle, was selected. During the scan the turntable rotated automatically. The feature method was used, which required covering the turntable with non-reflective black fabric to reduce the amount of visual noise captured by the camera. Due to anatomical variations in the humerus, especially torsion, two small bean bags were used to stabilise the bone to prevent movement from the turntable between scans. The length of the humerus also extended past the limits of the turntable so a black, non-reflective piece of foam core board was used to stabilise the bone on a flat surface.

Features at the proximal and distal ends of the humerus were easily identified by the camera, but the diaphysis is comparatively featureless. To capture the smooth surface of the shaft, multiple rounds of eight scans were required. The long, narrow shape also required the scans to be repeated to capture the entire bone as often only one end of the humerus could be in view of the camera at a time. Some individuals of greater stature had much longer bones and were more challenging to capture. A simple scan may only take 15 to 20 minutes, but many took an hour or more. After each capture, the EinScan software meshed the multiple views of the bone and the compiled scan was exported with the *.stl file extension, a file common to 3D processing. Single scans were retained but can only be accessed or edited with the EinScan proprietary software. Single files and meshed *.stl files were saved on an external hard drive for later processing.

4.3.2 Scan Processing
4.3.2.1 Mesh Lab

Each *.stl file was imported into the open-source 3D digitization programme Mesh Lab v.1.3.3 and not the most updated version 2020.12 (Cignoni et al. 2008). The older version
had a specific tool, later removed by developers, that was essential to a quick process. The Mac version for v1.3.3 was located on a Source Forge archive site (Slashdot Media Inc 2021).

To maintain consistency, each scan first had to be oriented (Figure 49). The object (bone), the vertex (zero point of three converging axes (x, y, z)) and the origin (a zero-point located at the 50% mark) of a bounding box that is created by the software must all align before the slice location could be determined. First the principal z-axis (proximal/distal) of the object (bone), was aligned to the bounding box. Without this step, the bounding box is assigned automatically by using the longest measurement of the object (i.e., corner to corner) and not a direction that approximates the length of a long bone when placed on a flat surface. The vertex must then be aligned to the origin of the bounding box. This step assigns the z-axis to the principal axis of the object allowing the slice to be taken perpendicular to the principal axis (transverse plane). The assigned x- and y-axes then approximate anterior/posterior and medial/lateral respectively.

![Figure 49 Right humerus showing the bounding box with digital measurements. The x-axis (red), the y-axis (green), and the z-axis (blue) are centred on the origin (white arrow) of the object. The z-axis aligned to the principal axis of the object (proximal/distal). Blackfriars 09. (Source: MeshLab)](image)

The Compute Geometric Measures tool measured multiple dimensions of the scans including length, surface area, and volume. A location on the bone that corresponds with 35% of the length as measured from the distal end was selected as it is widely used in CSG studies of the humerus and offered the most comparability across all measures of CSG. This location also avoids the deltoid tuberosity as changes at the fibrous deltoid insertion may affect the shape of the cross-section and distort the calculation (Marchi et al. 2006, Ibáñez-Gimeno et al. 2013, Miller et al. 2018, Pomeroy et al. 2018).
Figure 50 Right humerus showing slice at 35% taken in Mesh Lab
Slice (white arrow) taken at 55.78 mm from the origin (red arrow). The bounding box length (green arrow) is measured in two directions from the origin (length = 159.34*2). The x-axis (red line), the y-axis (green line), and the z-axis (blue line) are centered on the origin of the object. Blackfriars 09, anterior view, medial is up. Scale is in mm. (Note: slice appears to not align with 55.78 (black arrow) because this view was selected for visual clarity and is shifted from neutral.) Blackfriars 09. (Source: MeshLab)

Manual calculation was required to determine the precise slice location on each object. Thirty-five percent of the total digital length (as measured by MeshLab via the Compute Geometric Measures tool) was then divided by 2 ((length * 0.35)/2) (Figure 50). This distance must be measured from the origin (0, red arrow) at mid-shaft because the bounding box labels the length as two halves (green arrow).

The Compute Planar Section tool was used to slice the bone perpendicular to the principal axis using the above calculation as the cross-plane offset measured from the origin. For each slice a polyline, an outline of the cross-section shape (*.dxf), was saved, as well as solid section surface (*.stl) (Figure 51). Geometric measures data was saved into a Word document and each scan was saved as a MeshLab Project (*.mlp) in the event further manipulation was needed. Detailed steps and specific MeshLab tools are outlined in Appendix 3.1.
4.3.2.2 File Conversion

Files saved from MeshLab still contain 3D data and are difficult to use in ImageJ, a free and open-source programme for manipulating scientific and medical 2D images (Schindelin et al. 2012). Files with the *.dxf extension were selected, and the polyline slice was used, as this file type could most simply be converted to a 2D image file. TIFF was chosen as recommended by ImageJ and MomentMacroJ, a free plug-in used to further process images (Figure 52) (Ruff 2019). Many free file conversion websites were tried but not all yielded the same quality results. Zamzar was chosen for highest image resolution and lowest cost for bulk conversions (Zamzar Ltd 2006).
The high resolution *.tif image took up to 25 minutes in processing time in ImageJ, but too low a resolution had gaps in the pixels and could not be recognised as an outline by the software. To reduce processing time to under one minute, the *.tif file size was reduced to 72 ppi, the quality used for most web images. Preview for Mac accomplished this easily, but many free versions of similar software are available. This quality was small enough to speed processing time while complete enough for MomentMacroJ to recognise the outline and calculate accurate results. Detailed steps are outlined in Appendix 3.2 and 3.3.

4.3.2.3 Image J and MomentMacroJ

ImageJ is a free and open-source 2D image processing software designed for medical images and research (Schindelin et al. 2012). MomentMacroJ is a plug-in, one of thousands available for ImageJ, offered for free by Dr Christopher Ruff of the Center for Functional Anatomy and Evolution at Johns Hopkins School of Medicine. The most up to date version, MomentMacroJ v.1.4B, and an instructional PDF, are available for download on the website (https://www.hopkinsmedicine.org/FAE/mmacro.html) (Ruff 2019).
MomentMacro must be installed before use and repeated each time ImageJ is opened. The converted polyline file (*.tif) was opened and converted to 8-bit greyscale as recommended by the instructions. The Wand tool was used to select the region of interest and the default scale of 1pixel/pixel was selected. The macro required just under one minute processing time per scan and when complete a log text file was produced. The text files were imported into Excel 365 and saved. See Appendix 3 for detailed step by step instructions. All files related to this process (*.mlp, *.stl, *.dxf, *.tif) plus the original EinScanPro files compromise 3.15 GB of data. They are stored by the author on an external hard drive for potential future use. Detailed steps are outlined in Appendix 3.4 and all original outputs and standardisation files can be found in the accessory data.

4.4 Statistical Analysis

True prevalence rates (TPR), the number of elements affected divided by the number of elements present in the sample, were calculated in Excel 365 for Mac (Waldron 1994). In most cases in this analysis, “prevalence” means TPR. Crude prevalence rate was only used when calculating the prevalence of lifestyle indicators and that has been clearly labelled (5.1.2). Statistical significance was determined at 5% (p < .05). Data prepared in Excel 365 for Mac was imported into RStudio Version 1.3.1093 using R Version 4.0.3 (R Core Team 2020, RStudio Team 2020). All statistical testing was performed in RStudio using standard packages except for percent agreement and Cohen’s Kappa, which required the irr package (Gamer et al. 2019, RStudio Team 2020). Histograms were used to determine variance and visualisations presented in the Results were created in Excel and Word 365 for Mac or in Adobe Illustrator CC on a MacBook Pro 2016. All Excel files can be found in the accessory data.

4.4.1 Preparing Enthesal Change Scores for Analysis

As discussed in Section 4.2.3, each scorable enthesis had eight individual characteristics that could be present. Single individuals could, based on completeness and preservation, have up to 10 entheses and two sides for a potential total of 160 data points. Due to the complexity of this data and the need to make comparisons to degenerative joint changes (DJC) and cross-sectional geometry (CSG) data, the decision was made to pool the eight traits of the entheseal change into a simplified binary (presence/absence) system.
the complete Coimbra scores were recorded, they could be analysed in more detail at some point in the future.

Any missing enthesis originally scored as a 9 was changed to NA (not applicable) as required by the R Studio software to recognise missing data. If an enthesis displayed any scorable trait out of eight at either a 1 or 2 it was marked as present with a 1, even if the other seven traits were also 0. Any present enthesis with only 0 scores across all eight traits was marked as absent with a 0. The present/absent data was then broken down into groups of females, males, rights, lefts, and age groups for further analysis.

As some analyses required enthesal change scores to be compared by functional complex, enthesis scores were pooled further for those cases (Table 4). If EC scores for the subscapularis, supraspinatus, or infraspinatus were present at any one enthesis, the shoulder EC was considered present and scored with 1.

<table>
<thead>
<tr>
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<th>Enthesis</th>
<th>Attachment</th>
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<th>Prime Movement</th>
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<td>humerus</td>
<td>internal rotation</td>
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<td>Supraspinatus</td>
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<td>extension</td>
</tr>
<tr>
<td>Ankle</td>
<td>Calcaneal tendon</td>
<td>distal</td>
<td>calcaneus</td>
<td>extension</td>
</tr>
</tbody>
</table>

Biceps brachii, brachialis, or triceps brachii were pooled to form the elbow complex. The common flexor and extensor muscle groups were pooled and termed the wrist. The origins of the biceps femoris, semimembranosus, and semitendinosus muscles of the hamstring group, located on the ischial tuberosity, were used to compare to DJC/OA of the hip. The insertion of the calcaneal tendon on the calcaneus (gastrocnemius, soleus, and plantaris tendons) was used to compare to DJC/OA of the ankle. These two pairings at the hip and ankle were made as those were the only available EC scores in the respective regions. This enthesis functional complex breakdown was used for all comparisons to other methods and for all location-based analyses.

Due to low case counts and small sample sizes, individuals of all ages were included in location-based analyses, and these were not controlled for age. Collections were distributed
into Burgh groups based on geography and socioeconomic factors (Table 5). The collections known as St Giles’ and Parliament House made up the Old Town Edinburgh group \((n = 55)\), both from within the original medieval Burgh walls (Collard et al. 2006). Old College Quad/Church of St Mary’s of the Field, Holyrood Abbey, and Blackfriars/Infirmary Street were considered City of Edinburgh \((n = 35)\) as each of these locations were outside the original Burgh walls (Ewan 1988, Bain et al. 1998, Cameron et al. 2010, Canmore 2014). Leith \((n = 43)\) was entirely comprised of the Constitution St collection. Perth \((n = 36)\) was made up of Whitefriars, Perth, St John’s Kirk, and Horsecross. Dunbar \((n = 14)\) included only Captain’s Cabin, and St Andrews \((n = 21)\) only St Andrews’ Library. These groups were later subdivided by sex for further analysis.

<table>
<thead>
<tr>
<th>Burgh Group</th>
<th>(n)</th>
<th>Collection(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Town Edinburgh</td>
<td>55</td>
<td>St Giles’</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Parliament House</td>
</tr>
<tr>
<td>City of Edinburgh</td>
<td>35</td>
<td>Old College</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Holyrood</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blackfriars</td>
</tr>
<tr>
<td>Leith</td>
<td>43</td>
<td>Constitution St</td>
</tr>
<tr>
<td>Perth</td>
<td>36</td>
<td>Whitefriars Perth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>St John’s Kirk</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Horse Cross</td>
</tr>
<tr>
<td>Dunbar</td>
<td>14</td>
<td>Captain’s Cabin</td>
</tr>
<tr>
<td>St Andrews</td>
<td>21</td>
<td>St Andrews’ Library</td>
</tr>
</tbody>
</table>

An analysis comparing the Old Town Edinburgh group to all other Burghs was performed to explore social status. Individuals buried at St Giles’ Cathedral, the St Giles’ and Parliament House collections, may have been among those with the highest socioeconomic status when compared to collections from outside the old medieval Burgh limits and other Burghs (4.1) (Collard et al. 2006).

Another analysis comparing Burghs with active shipping ports to those located further inland or without major ports was performed to explore lifestyle and subsistence (Table 6). Leith and Perth contained the busiest known shipping trade (Bowler 2004, Franklin et al. 2019). Old Town Edinburgh and City of Edinburgh were further inland while neither Dunbar nor St Andrews were known for the shipping trade (see section 2.6) (Stevenson 1988, Perry 2000).
Asymmetry of entheseal changes was recorded per individual (i.e., did the individual have evidence of either right or left side dominance) for the EC of the arms only. For the single enthesis analysis only individuals with at least one bilateral asymmetrical presence of an EC were included \((n = 89, 42 \text{ females}, 47 \text{ males})\). Pooled EC scores of presence/absence were used so differences between left and right were either 0, for present but unaffected, or 1 for present and affected by EC trait. For each enthesis pair either an R or L was assigned. Some individuals \((n = 60)\) showed only symmetrical presentation (either both 0 or both 1) and were not included. As some individuals had more than one pair of entheses present, case counts \((n = 139)\) per paired enthesis were used rather than prevalence rate. For overall entheseal change asymmetry, individuals were assigned either left, right, or mixed presentation \((n = 87, 40 \text{ females}, 47 \text{ males})\).

Agonist/antagonist muscle relationships for functional complexes of the arms were compared using EC prevalence. While there are complex synergistic relationships for muscle recruitment and actions, movements here were simplified (Table 7). Movement at the shoulder was simplified to internal rotation, represented by the subscapularis insertion, and external rotation, by either the supraspinatus or infraspinatus insertion. The elbow was divided into flexion, represented by the biceps brachii and/or brachialis insertions, and extension represented by the triceps brachii. The wrist was divided into internal rotation/flexion, the common origin of the flexors of the forearm, and external rotation/extension represented by the common origin of the extensors of the forearm.

<table>
<thead>
<tr>
<th>Table 6 Land vs Port Burgh Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group</strong></td>
</tr>
<tr>
<td>Port Burgh group</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Land Burgh group</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 7 Simplified/Combined Joint Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Joint</strong></td>
</tr>
<tr>
<td>Shoulder</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
For one analysis, the TPR of one oppositional pair was compared to the TPR of the other (e.g., internal vs external rotation). For a second analysis, individuals with a presence of one or the other oppositional pair, but not both, were compared by sex (i.e., for each oppositional pair, individuals were assigned to only one).

Ratios were calculated after Villotte and Knüsel (2014) as used for the lateral/medial epicondyle (L/M) of the humerus (CEO/CFO). The enthesis with the higher TPR of EC, is divided by the TPR of EC at the antagonist muscle (group). This formula was extrapolated for the shoulder (subscapularis/supra- or infraspinatus) and the elbow (biceps brachii or brachialis/triceps brachii). The ratio is given as a whole number to one decimal place.

4.4.2 Preparing Degenerative Joint Change and Osteoarthritis Data for Analysis

All location-based analyses for DJC used the same breakdowns outlined above for entheseal changes. Adult and older adult age groups were identical to those used above. DJC analysis by sex was controlled for age and included only the young, young middle, and older middle adults as did comparisons between DJC and EC. Due to exceptionally low case counts, and therefore sample sizes, all adults of all ages were included in geographic analysis. Six Burgh groups were compared for differences by joint, and Old Town Edinburgh was compared to all other Burghs (Table 5). Burghs with major shipping ports were compared to those without (Table 6). The same by joint pooling detailed above was used for comparison to EC scores and to CSG data and was controlled for age.

4.4.3 Test Statistics for Enthesal Changes and Degenerative Joint Changes

All tests on entheseal changes and degenerative joint changes had two nominal (categorical) non-ranked variables. The Chi-square Goodness-of-Fit test was selected for the statistical power of a parametric test. Cross-tabulation was computed for every test to confirm sample sizes in each category were higher than five. In the situation of five or fewer cases the non-parametric Fisher’s Exact Test of Independence was performed instead (McDonald 2014).
4.4.4 Preparing Cross-sectional Geometric Data for Analysis

MomentMacro computes several standard biomechanical measurements but only four were selected for this analysis. 3D cameras are capable only of surface scans as opposed to CT scans, which give data about the medullary cavity, endosteal surface, and total cortical area. Solid cross-sections have been shown to be strongly correlated with calculations achieved by other methods such as CT, moulding, direct sectioning, and radiography (O’Neill and Ruff 2004, Stock and Shaw 2007, Pomeroy 2013). Percent cortical area (%CA,) when calculated from solid sections, has been shown to be a source of errors in a study that compared solid (periosteal) to true (endosteal) sections, and not included in the analysis (Macintosh et al. 2013). To differentiate between solid (periosteal) and true (including the endosteal contour) in the final measurements, the prefix of solid will be added to J and I-ratio used in this study (Stock and Shaw 2007, Pomeroy 2013). Original outputs are available in supplemental data.

Total area (TA), $I_{max}$, $I_{min}$, and J were chosen for high comparability and applicability to the research questions. Even though I-ratio has proved difficult to interpret at this location, both J and TA are common and offered wide comparability (Trinkaus et al. 1994). TA and J were used as is, while $I_{max}$ and $I_{min}$ were used to calculate the I-ratio ($I_{max}/I_{min}$) (Ruff 2007). $I_{max}$ and $I_{min}$ were selected rather than $I_x$ and $I_y$ because the process used did not consistently align visual/morphological anatomical direction with the x/y-axes within MeshLab. Assigning anatomical direction to the cross-section can be arbitrary and unreliable as it depends on the observer (Stock and Shaw 2007). J can be calculated from either $I_{max}/I_{min}$ or $I_x/I_y$, so the result is identical even without confirmed anatomical direction or x/y-axes (O’Neill and Ruff 2004, Shaw and Stock 2009b, Pomeroy 2013).

Solid I-ratio is self-standardizing, but both TA and Solid J required standardization to eliminate differences in robusticity due to sexual dimorphism (Ruff 2007, Pomeroy 2013). The TA of the lower body is influenced by body mass, but as the humerus is non-weight bearing and measurements for calculation of body mass were not available for most individuals, only the cubed bone length was used (TA/bone length$^3$) (Ruff 2007). $J$, the second moment of area, is proportional to body mass multiplied by the square of the bone length, but again, as body mass data was not available a valid alternative method of dividing by the bone length raised to the power of 5.33 ($J$/bone length$^{5.33}$) was used (Marchi et al. 2006, Ruff...
Bone length was presented in centimetres to retain consistency with measurements taken by osteometric board, but digital MeshLab geometric measures rounded to two decimal places were used for all standardizations. Copies of the standardisation calculations are available in the supplemental data.

Some analyses were performed on all individuals represented by 3D scans by sex and by side. Sex comparison was performed using whichever side was present, but for individuals with bilateral humeral presence a mean of left and right sides was used (Pomeroy 2013). For side comparison all present lefts and all presents rights were used so some individuals were in both groups.

The same comparisons were made for only individuals with bilateral presence \(n = 23\), although further analysis was possible between sex and side for this group. Percent absolute bilateral asymmetry (AA) was calculated after Rhodes and Knüsel (2005) by subtracting the minimum from the maximum and then dividing by the minimum \((\text{max-min})/\text{min} \times 100\) and is presented as a single percentage score. This method obscures any side dominance and eliminates negative numbers from calculations. Percent directional asymmetry (DA) was calculated similarly by subtracting the left from the right and dividing by left \((\text{right-left})/\text{left} \times 100\). This gives a positive value for right bias and a negative for left bias (Marchi et al. 2006, Pomeroy and Zakrzewski 2009, Miller et al. 2018). This smaller bilateral group was also used to compare to presence of EC and DJC by joint.

4.4.5 Test Statistics for Cross-sectional Geometric Data

Tests for all cross-sectional geometrical (CSG) data consisted of numerical (quantitative) variables. When combined with EC and DJC data the variables were mixed numerical and nominal (McDonald 2014). The three CSG variables, Solid I-ratio, Solid J, Total Area (TA) were visualised in histograms to test for normal distribution. Visualisations were inconclusive with mixed results so the Shapiro-Wilk test for normality was performed as well. Half of the results passed the test of normality for Shapiro-Wilk \((p > .05)\) while the other half did not \((p < .05)\). Tests with small sample sizes are more likely to falsely pass tests of normality, so the decision was made to use the non-parametric Mann-Whitney/Wilcoxon test for all cases.

All box and whisker plots for CSG measures display the interquartile range (IQR) (middle 50% of scores) within the box and whiskers describe the minimum and maximum
values within the data set. The horizontal line within the box depicts the median and the ‘x’ shows the mean value. Outliers, shown by a dot outside the whisker, represent data that is outside 1.5 times the interquartile range above the upper quartile (Q3) or below the lower quartile (Q1) \((Q1 - 1.5 \times ICR \text{ or } Q3 - 1.5 \times IQR)\).

4.4.6 Test Statistics for Repeatability

Repeatability testing was performed only on binary (presence/absence) EC scores for each enthesis of the humerus, radius and ulna. Access to skeletal material and 3D equipment was severely restricted due to COVID-19 so no repeatability for CSG scan collection was performed and only 46 individuals could be scored for EC repeatability. Both intraobserver and interobserver scoring was performed as described in the new Coimbra Method by scoring both left and right entheses according to each of eight traits. However, since only the pooled binary EC scores were used for all the analysis in this project, the same scores were used to determine percent agreement and Cohen’s Kappa scores.

The data met the assumptions for use of the Cohen’s Kappa test statistic of two deliberately chosen raters and one trial per sample or one rater performing two trials (Glen 2020). The trials must also be independent. Since there is a biological relationship between the left and right for entheseal changes, only the scores for the left sides were compared for both interobserver and intraobserver testing (Wilczak et al. 2017). Kappa is subject to two major limitations, that of marginal distribution and prevalence bias (Wilczak et al. 2017). In the case of marginal distribution, if both raters are equally accurate there is a larger standard error than if one rater is highly accurate and one is inaccurate (Conger 2017). In this study, one rater is considered an expert as they were one of the developers of the method, and the author has moderate, not beginner, level skill. The differing levels of experience and scoring accuracy address this limitation. The second Kappa limitation, prevalence bias (when a large number of ratings fall into one category more than another), was addressed in this study by the use of a binary (presence/absence) scoring system (Wilczak et al. 2017). Results for all analyses and testing are reported in the next chapter.
Chapter 5 Results

5.1 Demographics and Lifestyle Indicators

5.1.1 Enthesal Changes and Degenerative Joint Changes

Case counts are reported but were not included in statistical analysis. A combination of geographical and socioeconomic factors was used to determine Burgh groups (4.4.1). All individuals \( n = 204 \), 113 females and 89 males) were subdivided into age groups for analysis. Age at death estimations pooled into decades of life (e.g., 18-29, 30-39, 40-49, 50+, <50, and >50 years) are used to simplify reporting. EC, OA, and pathology was recorded for all individuals (4.2).

The female to male ratio in Old Town Edinburgh, Dunbar, and St Andrews was close to 50%, the City of Edinburgh had more males and both Leith and Perth had more females (Table 8, Figure 53). The 50+ years age group was evenly distributed by sex, the 40-49 had more males, and both the 18-29 and 30-39 groups had notably higher numbers of females (Figure 54). St Andrews had the most unevenly distributed age groups with the highest number of 50+ with low numbers of young and middle adults (Figure 55). Old Town Edinburgh had many 50+ but also had many young (18-29 years) and young middle adults (30-39 years) like Leith.

<table>
<thead>
<tr>
<th>Burgh</th>
<th>18-29 Years</th>
<th>30-39 Years</th>
<th>40-49 Years</th>
<th>50+ Years</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Old Town Edinburgh</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>City of Edinburgh</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Leith</td>
<td>7</td>
<td>3</td>
<td>14</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Perth</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Dunbar</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>St Andrews</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Totals</td>
<td>42</td>
<td>54</td>
<td>40</td>
<td>68</td>
<td>204</td>
</tr>
</tbody>
</table>

Table 8 Number of Individuals by Burgh, Sex, and Age
Figure 53 Number of Individuals by Burgh and Sex

Figure 54 Number of Individuals by Sex and Age
Lifestyle indicators are reported to give a broad overview of socioeconomic conditions but were not included in the statistical analysis (Table 9). Linear enamel hypoplasia (LEH) was notably lower in Old Town Edinburgh (7%) and Leith (9%) when compared to the other populations (37%, 44%, 43%, 52%) (Figure 5.6). Dental caries, periodontal disease, and calculus were also frequently seen in all populations.

Fractures and other trauma varied across groups, with the highest prevalence in the City of Edinburgh (23%) and the lowest in Dunbar (0%) (Table 9, Figure 5.6). Aside from one individual with perimortem cranial trauma, all other evidence recorded was for healed callouses at various stages of repair. Healed fractures in this population were most often observed at the clavicles, ribs, and the distal radius.

Porotic hyperostosis, cribra orbitalia, and rickets (vitamin D deficiency) were all quite common in this population and were combined in the ‘metabolic disease’ category (Table 9, Figure 5.6). The highest rate of metabolic disease was found in Dunbar (14%) and the lowest in Perth (6%). Cases of periostitis and osteomyelitis were reported collectively in the category ‘infectious disease’ with the highest prevalence in the City of Edinburgh (26%) and the lowest
in Dunbar (0%) (Table 9, Figure 56). Respiratory disease did not appear to be especially common during the medieval period in Scotland as there were few signs of respiratory disease in any burgh group (Table 9). Old Town Edinburgh (4%), the City of Edinburgh (3%), and Perth (3%) were the only burghs with cases of respiratory disease (Table 9).

Neoplastic disease was identified in only one individual (Old Town Edinburgh), possibly an osteosarcoma due to the ‘sunburst’ appearance (Ortner 2003, Roberts and Manchester 2010f). An unknown neoplasm was suspected in a second individual from Blackfriars due to multiple lesions present on the pelvic bones. It is possible these lesions were secondary to organ or tissue cancer and formed due to metastases (Roberts and Manchester 2010f).

<table>
<thead>
<tr>
<th>Table 9 Lifestyle Indicator Crude Prevalence Rate by Burgh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel Hypoplasia</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Ct</td>
</tr>
<tr>
<td>Enamel Hypoplasia</td>
</tr>
<tr>
<td>Trauma</td>
</tr>
<tr>
<td>Metabolic</td>
</tr>
<tr>
<td>Infectious</td>
</tr>
<tr>
<td>Respiratory</td>
</tr>
<tr>
<td>Neoplastic</td>
</tr>
</tbody>
</table>

CPR: Crude Prevalence Rate, Ct: Case counts
5.1.3 Demographics of Cross-sectional Geometry Groups

All individuals with at least one humeral scan were analysed by three measures of Cross-sectional Geometry (CSG); Solid I-ratio, Solid J, and Total Area (TA). All scanned individuals \((n = 70)\) were compared by sex and side. A group with bilateral scans \((n = 23)\) were compared by sex and side. The Mann-Whitney/Wilcoxon test was used for all CSG data analysis.

5.1.3.1 Total Cross-sectional Geometry Sample

All individuals included in scans \((n = 70)\) are shown divided into Burgh groups (Table 10). In total 23 individuals had both humeri present and so are represented in both the right and left columns. With only single individuals in some groups, no statistical analysis based on Burgh group or location was performed due to small sample sizes. While not reflected in the pooled Burgh groups, the were no individuals from St John’s Kirk or Horsecross in Perth, no females in Old College, one female in Holyrood, no males in Holyrood, and only one male each from Old College, Parliament House, and Whitefriars Perth.
### Table 10 Total Cross-sectional Geometry Sample by Burgh Group

<table>
<thead>
<tr>
<th>Burgh Group</th>
<th>Female</th>
<th></th>
<th>Male</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
<td>Total</td>
<td>Right</td>
</tr>
<tr>
<td>Old Town Edinburgh</td>
<td>7</td>
<td>8</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>City of Edinburgh</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Leith</td>
<td>6</td>
<td>10</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>Perth</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Dunbar</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>St Andrews</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Totals</td>
<td>19</td>
<td>28</td>
<td>38</td>
<td>24</td>
</tr>
</tbody>
</table>

5.1.3.2 Bilateral Humeral Presence Group

Individuals with bilateral presence of the humerus (n = 23, 9 females, 14 males) were compared by sex and side. These CSG scores were then compared to upper body EC and DJC scores by sex and side. All individuals with bilateral scans are shown by Burgh group. As there were Burgh groups with no or a single individual, no further testing on Burgh groups was performed due to small sample sizes.

### Table 11 Number of Bilaterally Scanned individuals by Burgh Group

<table>
<thead>
<tr>
<th>Burgh Group</th>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Town Edinburgh</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>City of Edinburgh</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Leith</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Perth</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Dunbar</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>St Andrews</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Totals</td>
<td>9</td>
<td>14</td>
</tr>
</tbody>
</table>

5.2 Age

Degenerative joint changes (DJC) and osteoarthritis (OA) were recorded for all individuals. Some tests were controlled for advanced age, and these are clearly marked. TPR for pooled joints complexes were compared by age group. Three measures of cross-sectional geometry were evaluated by age group for all individuals scanned. For data on single entheseal changes and age see Appendix 4.

5.2.1 Age and Degenerative Joint Changes

All individuals (N = 204) were compared by four age groups for differences in DJC and OA prevalence (Table 12). Statistically significant differences between age groups were seen
for DJC (Fisher’s Exact, $p = .001$) and OA (Fisher’s Exact, $p = .002$) of all individuals when divided into four age groups (18-29, 30-39, 40-49, and 50+). Visualisation shows a clear relationship between increasing age and higher TPR for both OA and DJC (Figure 57).

**Table 12 Prevalence Rates for Degenerative Joint Changes and Osteoarthritis by Age Group**

<table>
<thead>
<tr>
<th>Age Group</th>
<th>18-29</th>
<th>30-39</th>
<th>40-49</th>
<th>50+</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 204</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18-29</td>
<td>42</td>
<td>54</td>
<td>40</td>
<td>68</td>
</tr>
<tr>
<td>30-39</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>40-49</td>
<td>6</td>
<td>16</td>
<td>23</td>
<td>48</td>
</tr>
<tr>
<td>50+</td>
<td>6</td>
<td>13</td>
<td>19</td>
<td>71</td>
</tr>
</tbody>
</table>

| $p$ value | .002***† | <.001***† |

*$p < .05$, **$p < .01$, ***$p < .001$, † Fisher’s Exact, Ct- Case Count

**Figure 57 Prevalence Rates for Degenerative Joint Change and Osteoarthritis by Age Group**

*$p < .05$

### 5.2.2 Age and Cross-sectional Geometry

All individuals assessed for all three measures of CSG ($n = 70$) are shown by age group and sex (Table 13). No statistical analysis was performed because CSG was not correlated with advanced age in these populations (i.e., advanced age does not positively correlate with
larger or more robust CSG scores) like EC and DJC (where higher EC/DJC prevalence is positively correlated with higher scores and more frequent prevalence). Those with bilateral presence were represented by mean right/left score.

Table 13 Number of Individuals per Age Group

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-29</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>30-39</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>40-49</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>50+</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>38</td>
<td>32</td>
</tr>
</tbody>
</table>

Female Solid I-ratios appeared to stay relatively constant across age groups (Figure 58). Male Solid I-ratios appeared to increase in greater age groups and then dropped in the over 50 years of age group. Summary statistics for the three CSG measures and age groups are presented below (Table 14).

Table 14 CSG and Age Summary Statistics

<table>
<thead>
<tr>
<th></th>
<th>Females</th>
<th></th>
<th>Males</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I-ratio</td>
<td>Solid J</td>
<td>Total Area</td>
<td>I-ratio</td>
</tr>
<tr>
<td>18-29</td>
<td>Mean</td>
<td>1.24</td>
<td>10172.69</td>
<td>81.23</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>1.08</td>
<td>7967.71</td>
<td>70.75</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>1.51</td>
<td>11936.33</td>
<td>89.52</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.16</td>
<td>1646.00</td>
<td>7.60</td>
</tr>
<tr>
<td>30-39</td>
<td>Mean</td>
<td>1.34</td>
<td>7475.22</td>
<td>68.26</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>1.09</td>
<td>4786.45</td>
<td>53.76</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>1.64</td>
<td>9327.72</td>
<td>77.26</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.18</td>
<td>1542.21</td>
<td>7.91</td>
</tr>
<tr>
<td>40-49</td>
<td>Mean</td>
<td>1.30</td>
<td>7119.24</td>
<td>66.22</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>1.19</td>
<td>4796.45</td>
<td>53.30</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>1.48</td>
<td>9301.65</td>
<td>77.55</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.14</td>
<td>2025.15</td>
<td>10.85</td>
</tr>
<tr>
<td>50+</td>
<td>Mean</td>
<td>1.35</td>
<td>8061.43</td>
<td>70.87</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>1.04</td>
<td>3315.11</td>
<td>43.54</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>1.66</td>
<td>12058.58</td>
<td>90.83</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.19</td>
<td>2582.60</td>
<td>13.48</td>
</tr>
</tbody>
</table>
Females showed the highest Solid J values in the young adult (18-29) age group, then a drop in the young middle (30-39) adults but stay relatively stable with older age groups (Figure 59). The range was widest in the 50+ years of age group (3315.11 - 12058.58). Males were much lower than females in the young adult (18-39) group (with lower means overall) and had the widest range in the young middle (30-39) adult group (3051.54 – 11561.36). Male scores then decreased in the older middle adults (40-49) group which was similar in the older adults (50+) group.
Both female and male scores for total area (TA) follow a similar pattern as those of Solid J (Figure 60). Females were high in the young adult (18-29) group then scores drop in the younger middle (30-39) group. The widest range (43.54 – 90.83) was in the older adult (50+) group. Males have a consistently lower score than females with an increase in the younger middle adult (30-39) group (as well as the widest range (41.14 – 86.97)), which then drops in the older middle adults (40-49) and stays consistent into the older adult (50+) group (Figure 60).
Figure 60 Total Area by Sex and Age Group

5.3 Sex

All individuals under 50 (n = 136), were studied for degenerative joint changes (DJC) and osteoarthritis (OA) and compared by sex. Three measures of cross-sectional geometry were evaluated by sex for all scanned individuals (n = 70), and the bilateral humeral presence group (n = 23) was evaluated by sex and by side (right/left). For data on single entheseal changes and sex see Appendix 4.

5.3.1 Sex and Degenerative Joint Changes

To control for advanced age, DJC TPR for all individuals under 50 (n = 136, 79 females, 57 males) were compared by joint, side, and sex (Table 23). No statistically significant differences were shown (Table 15).

For the shoulder, males had higher rates of DJC on both sides with the right side being more common (37%). Females showed more cases at the right elbow (6%) and wrist (4%) (Figures 61 and 62). The right hip had the same prevalence for females and males (14%) but for the left males (20%) had higher rates than females (15%). There were very few cases present at the elbows, wrists, knees, or ankles making it difficult to discern any patterns. Males had higher prevalence rates for all the segments of the spine (cervical, thoracic, and lumbar) and more overall DJC presence (Figure 63).
Table 15 Prevalence for Degenerative Joint Changes by Joint and Sex

<table>
<thead>
<tr>
<th>Joint- Adults (&lt;50)</th>
<th>$N$</th>
<th>Female</th>
<th></th>
<th></th>
<th>Male</th>
<th></th>
<th></th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>$Ct$</td>
<td>$TPR$</td>
<td>$n$</td>
<td>$Ct$</td>
<td>$TPR$</td>
<td></td>
</tr>
<tr>
<td>R Shoulder</td>
<td>109</td>
<td>66</td>
<td>13</td>
<td>20%</td>
<td>43</td>
<td>16</td>
<td>37%</td>
<td>0.072</td>
</tr>
<tr>
<td>R Acromioclavicular</td>
<td>73</td>
<td>38</td>
<td>7</td>
<td>18%</td>
<td>35</td>
<td>14</td>
<td>40%</td>
<td>0.076</td>
</tr>
<tr>
<td>R Glenohumeral</td>
<td>111</td>
<td>66</td>
<td>8</td>
<td>12%</td>
<td>45</td>
<td>10</td>
<td>22%</td>
<td>0.248</td>
</tr>
<tr>
<td>R Elbow</td>
<td>111</td>
<td>62</td>
<td>4</td>
<td>6%</td>
<td>49</td>
<td>1</td>
<td>2%</td>
<td>0.381†</td>
</tr>
<tr>
<td>R Wrist</td>
<td>102</td>
<td>56</td>
<td>2</td>
<td>4%</td>
<td>46</td>
<td>1</td>
<td>2%</td>
<td>1†</td>
</tr>
<tr>
<td>R Hip</td>
<td>118</td>
<td>69</td>
<td>10</td>
<td>14%</td>
<td>49</td>
<td>7</td>
<td>14%</td>
<td>1†</td>
</tr>
<tr>
<td>R Knee</td>
<td>107</td>
<td>63</td>
<td>1</td>
<td>2%</td>
<td>44</td>
<td>1</td>
<td>2%</td>
<td>1†</td>
</tr>
<tr>
<td>R Ankle</td>
<td>75</td>
<td>44</td>
<td>0</td>
<td>2%</td>
<td>30</td>
<td>0</td>
<td>0%</td>
<td>1†</td>
</tr>
<tr>
<td>L Shoulder</td>
<td>102</td>
<td>61</td>
<td>7</td>
<td>11%</td>
<td>41</td>
<td>7</td>
<td>17%</td>
<td>0.608</td>
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<tr>
<td>L Acromioclavicular</td>
<td>65</td>
<td>37</td>
<td>5</td>
<td>14%</td>
<td>28</td>
<td>7</td>
<td>25%</td>
<td>0.390</td>
</tr>
<tr>
<td>L Glenohumeral</td>
<td>99</td>
<td>59</td>
<td>3</td>
<td>5%</td>
<td>40</td>
<td>3</td>
<td>8%</td>
<td>0.683†</td>
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<tr>
<td>L Elbow</td>
<td>115</td>
<td>63</td>
<td>1</td>
<td>3%</td>
<td>51</td>
<td>2</td>
<td>4%</td>
<td>1†</td>
</tr>
<tr>
<td>L Wrist</td>
<td>104</td>
<td>57</td>
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<td>0%</td>
<td>47</td>
<td>0</td>
<td>0%</td>
<td>0.326†</td>
</tr>
<tr>
<td>L Hip</td>
<td>126</td>
<td>71</td>
<td>11</td>
<td>15%</td>
<td>55</td>
<td>11</td>
<td>20%</td>
<td>0.78†</td>
</tr>
<tr>
<td>L Knee</td>
<td>107</td>
<td>60</td>
<td>2</td>
<td>3%</td>
<td>47</td>
<td>0</td>
<td>0%</td>
<td>0.503†</td>
</tr>
<tr>
<td>L Ankle</td>
<td>74</td>
<td>43</td>
<td>0</td>
<td>2%</td>
<td>30</td>
<td>0</td>
<td>0%</td>
<td>1†</td>
</tr>
<tr>
<td>Cervical Spine</td>
<td>116</td>
<td>69</td>
<td>9</td>
<td>13%</td>
<td>47</td>
<td>9</td>
<td>19%</td>
<td>0.511</td>
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<tr>
<td>Thoracic Spine</td>
<td>126</td>
<td>77</td>
<td>11</td>
<td>14%</td>
<td>49</td>
<td>17</td>
<td>35%</td>
<td>1</td>
</tr>
<tr>
<td>Lumbar Spine</td>
<td>131</td>
<td>76</td>
<td>15</td>
<td>20%</td>
<td>55</td>
<td>13</td>
<td>24%</td>
<td>0.154</td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>136</td>
<td>79</td>
<td>4</td>
<td>5%</td>
<td>57</td>
<td>3</td>
<td>5%</td>
<td>0.452</td>
</tr>
<tr>
<td>Degenerative Joint Changes</td>
<td>136</td>
<td>79</td>
<td>21</td>
<td>27%</td>
<td>57</td>
<td>24</td>
<td>42%</td>
<td>0.544</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001, † Fisher’s Exact, Ct- Case counts
Figure 61 Right Appendicular Prevalence for Degenerative Joint Changes by Joint and Sex for those <50 years of age
*p < .05

Figure 62 Left Appendicular Prevalence for Degenerative Joint Changes by Joint and Sex for those <50 years of age
*p < .05
Figure 63 Spinal Prevalence for Degenerative Joint Changes by Joint and Sex for those <50 years of age

* $p < .05$

5.3.2 Sex and Cross-sectional Geometry

Three CSG measures were compared for all scanned individuals ($n = 70$) and for the group with bilateral humeral presence ($n = 23$), then compared by sex and side (Table 16).

5.3.2.1 Total Cross-sectional Geometry Sample by Sex and Side

All females ($n = 38$) and all males ($n = 32$) with scans of either side were compared by sex. All individuals with right-side (R) scans ($n = 43$, 19 females, 24 males) and left-side scans (L) ($n = 50$, 28 females, 22 males) were also compared by sex (Table 16).

Statistically significant differences between females and males were found for both Solid J and TA measurements for all three groups: all individuals (Solid J $p = <.001$, TA $p = <.001$), all right-side comparisons (Solid J $p = .004$, TA $p = .003$), and all left side comparisons (Solid J $p = .001$, TA $p = .001$) (Figures 65 and 66). There was no significant difference between the sexes for any of the Solid I-ratio tests (Figure 64). Visualisation for Solid I-ratio values show little difference between females and males, but for Solid J and TA clear differences between females and males can be seen. Aside from one or two male outliers
(which did not affect significance when excluded), female Solid J and TA scores have a broader range (Solid J 3315.11 – 12058.58, TA 43.54 – 90.83) of values when compared to males (Solid J 3051.54 – 11561.36, TA 41.13 – 86.97). This pattern is consistent for combined sides as well as both right and left when compared separately.

Table 16 Measures of Cross-Sectional Geometry by Sex and Side

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Female</th>
<th>Male</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>n</td>
<td>n</td>
</tr>
<tr>
<td>All F to M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid I-ratio</td>
<td>70</td>
<td>38 1.32</td>
<td>32 1.34</td>
</tr>
<tr>
<td>Solid J</td>
<td>70</td>
<td>38 8024.08</td>
<td>32 5756.15</td>
</tr>
<tr>
<td>Total Area</td>
<td>70</td>
<td>38 70.78</td>
<td>32 58.37</td>
</tr>
<tr>
<td>Rights F to M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid I-ratio</td>
<td>43</td>
<td>19 1.24</td>
<td>24 1.33</td>
</tr>
<tr>
<td>Solid J</td>
<td>43</td>
<td>19 8339.84</td>
<td>24 5582</td>
</tr>
<tr>
<td>Total Area</td>
<td>43</td>
<td>19 72.06</td>
<td>24 57.52</td>
</tr>
<tr>
<td>Lefts F to M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid I-ratio</td>
<td>50</td>
<td>28 1.37</td>
<td>22 1.35</td>
</tr>
<tr>
<td>Solid J</td>
<td>50</td>
<td>28 8097.31</td>
<td>22 5997.71</td>
</tr>
<tr>
<td>Total Area</td>
<td>50</td>
<td>28 71.23</td>
<td>22 59.83</td>
</tr>
</tbody>
</table>

F- female, M- male
*p < .05, **p < .01, ***p < .001, Mann-Whitney-U test

Figure 64 Solid I-ratio by Sex and Side
*p < .05
Figure 65 Solid J by Sex and Side
*p < .05

Figure 66 Total Area by Sex and Side
*p < .05
5.3.2.2 Bilateral Humeral Presence by Sex and Side

Individuals with bilateral scans were compared for three measurements of CSG by sex, within each side by sex, and within sex by side (Table 17). Like that seen for the total CSG sample (Table 16) when compared by sex, statistical significance was seen in the bilateral group for both Solid J ($p < .001$) and TA ($p < .001$), but not for Solid I-ratio (Figures 67-69). When all rights (Solid J $p = .003$, TA $p = .003$) and all lefts (Solid J $p = .001$, TA $p = .003$) were compared by sex, statistically significant differences between sexes were also seen for both the Solid J and Total Areas measurements, but not for Solid I-ratio (Figures 70-72). When females and males were compared by side, no statistically significant differences were seen for any CSG measurement.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Female</th>
<th>Male</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$N$</td>
<td>$n$</td>
<td>Mean</td>
</tr>
<tr>
<td><strong>All F to M</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid I-ratio</td>
<td>23</td>
<td>9</td>
<td>1.27</td>
</tr>
<tr>
<td>Solid J</td>
<td>23</td>
<td>9</td>
<td>8925.04</td>
</tr>
<tr>
<td>Total Area</td>
<td>23</td>
<td>9</td>
<td>74.89</td>
</tr>
<tr>
<td><strong>Rights F to M</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Solid I-ratio</td>
<td>23</td>
<td>9</td>
<td>1.25</td>
</tr>
<tr>
<td>Solid J</td>
<td>23</td>
<td>9</td>
<td>8814.61</td>
</tr>
<tr>
<td>Total Area</td>
<td>23</td>
<td>9</td>
<td>74.29</td>
</tr>
<tr>
<td><strong>Lefts F to M</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid I-ratio</td>
<td>23</td>
<td>9</td>
<td>1.29</td>
</tr>
<tr>
<td>Solid J</td>
<td>23</td>
<td>9</td>
<td>9035.47</td>
</tr>
<tr>
<td>Total Area</td>
<td>23</td>
<td>9</td>
<td>75.49</td>
</tr>
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<td><strong>Females R to L</strong></td>
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<td></td>
</tr>
<tr>
<td>Solid I-ratio</td>
<td>9</td>
<td>9</td>
<td>1.25</td>
</tr>
<tr>
<td>Solid J</td>
<td>9</td>
<td>9</td>
<td>8814.61</td>
</tr>
<tr>
<td>Total Area</td>
<td>9</td>
<td>9</td>
<td>74.29</td>
</tr>
<tr>
<td><strong>Males R to L</strong></td>
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<td></td>
</tr>
<tr>
<td>Solid I-ratio</td>
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<td>14</td>
<td>1.31</td>
</tr>
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<td>Solid J</td>
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</tr>
<tr>
<td>Total Area</td>
<td>14</td>
<td>14</td>
<td>58.05</td>
</tr>
</tbody>
</table>


* $p < .05$, ** $p < .01$, *** $p < .001$, Mann-Whitney-U test
Figure 67 Bilateral Solid I-ratio by Sex and Side
*p < .05

Figure 68 Bilateral Solid J by Sex and Side
*p < .05
Figure 69 Bilateral Total Area by Sex and Side
*p < .05

Figure 70 Bilateral Solid l-ratio by Side
*p < .05
Figure 71 Bilateral Solid J by Side
\*p < .05

Figure 72 Bilateral Total Area by Side
\*p < .05
5.3 Geographic Location

For all individuals, entheses pooled by joint complex were compared by six different Burgh location groups which were determined by socioeconomic and geographic characteristics. All females, then all males were compared the same way. Lower body data were not included due low case counts and because they are not generally associated with differentiated occupational activity (Jurmain 1999). Degenerative joint change data were compared the same way.

5.3.1 Entheseal Changes and Geographic Location

EC scores were pooled by shoulder joint (subscapularis, supraspinatus, and infraspinatus), elbow (triceps brachii, brachialis, and biceps brachii), and wrist (common extensor and flexor). Location-based analyses were not controlled for age to increase sample sizes which were exceedingly small once broken down by six Burgh groups (4.4.1 and 4.4.2). TPR for all individuals (N = 204) of all ages were compared for differences between Burgh group (Table 18). Statistically significant differences were seen between the Burgh groups at the right wrist (Fisher’s Exact, p = .016) and the left shoulder (Fisher’s Exact, p = .009) and wrist (Fisher’s Exact, p = .001). Aside from the very low TPR in Perth and Dunbar at the bilateral wrist, in Dunbar at the left shoulder, and in Leith at the left wrist, there is little consistent difference between Burgh groups (Figure 73).

Table 18 Prevalence of Entheseal Changes by Burgh

<table>
<thead>
<tr>
<th>Joint</th>
<th>Old Town Edinburgh</th>
<th>City of Edinburgh</th>
<th>Leith</th>
<th>Perth</th>
<th>Dunbar</th>
<th>St Andrews</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>a</td>
<td>Ct</td>
<td>TPR</td>
<td>a</td>
<td>Ct</td>
<td>TPR</td>
<td>a</td>
</tr>
<tr>
<td>R Shoulder</td>
<td>93</td>
<td>27</td>
<td>52%</td>
<td>18</td>
<td>9</td>
<td>50%</td>
<td>21</td>
</tr>
<tr>
<td>R Elbow</td>
<td>166</td>
<td>46</td>
<td>74%</td>
<td>26</td>
<td>20</td>
<td>77%</td>
<td>38</td>
</tr>
<tr>
<td>R Wrist</td>
<td>139</td>
<td>39</td>
<td>38%</td>
<td>27</td>
<td>11</td>
<td>41%</td>
<td>26</td>
</tr>
<tr>
<td>R Shoulder</td>
<td>92</td>
<td>26</td>
<td>54%</td>
<td>19</td>
<td>11</td>
<td>58%</td>
<td>19</td>
</tr>
<tr>
<td>R Elbow</td>
<td>171</td>
<td>50</td>
<td>72%</td>
<td>26</td>
<td>16</td>
<td>62%</td>
<td>34</td>
</tr>
<tr>
<td>R Wrist</td>
<td>140</td>
<td>38</td>
<td>29%</td>
<td>27</td>
<td>8</td>
<td>30%</td>
<td>26</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001, † Fisher’s Exact, Ct- Case counts
Prevalence of Entheseal Changes by Burgh

EC presence pooled by joint for all females (n = 113) were compared by Burgh group and statistical significance between the six burgh groups was seen at both left (Fisher’s Exact, \( p < .001 \)) and right (Fisher’s Exact, \( p = .011 \)) wrists (Table 19). Visualisation reveals very little difference between Burgh groups except for the Perth and Dunbar where there are no cases present in either population group for both wrists and one shoulder (Figure 74). Females are similar to the combined sex group with Perth with lower TPR at the bilateral wrist (0%), Dunbar low at the right wrist (0%) and left shoulder (0%), and Leith low at the left wrist (14%) (Table 19). In the combined sex group, the left shoulder showed significant differences between the six burgh groups that were not found in the female left shoulder. There is an absence of significance difference between the six burgh groups at the left shoulder in females that was present in the combined sex group. Females showed a left-side bias at the shoulder in City of Edinburgh and Leith, while the other Burgh groups showed a right bias.

Table 19 Female Prevalence of Entheseal Changes by Burgh

<table>
<thead>
<tr>
<th>Burgh</th>
<th>R Shoulder</th>
<th>L Shoulder</th>
<th>R Elbow</th>
<th>L Elbow</th>
<th>R Wrist</th>
<th>L Wrist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Town Edinburgh</td>
<td>52</td>
<td>15</td>
<td>7</td>
<td>47%</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>City of Edinburgh</td>
<td>90</td>
<td>24</td>
<td>17</td>
<td>71%</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Leith</td>
<td>80</td>
<td>23</td>
<td>11</td>
<td>48%</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Perth</td>
<td>80</td>
<td>23</td>
<td>11</td>
<td>48%</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Dunbar</td>
<td>72</td>
<td>15</td>
<td>7</td>
<td>47%</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>St Andrews</td>
<td>72</td>
<td>15</td>
<td>7</td>
<td>47%</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

*Denotes statistical significance: 0.05 < \( p \) < 0.1, \( \cdot \) Denotes statistical significance: \( p \) < 0.05, \( \cdot \cdot \) Denotes statistical significance: \( p \) < 0.01
EC TPR for all males (n = 91) of all ages were compared by burgh group with no significant results (Table 20). The lack of cases in Leith and Dunbar can be seen upon visualisation, which was like the combined sex group (Table 18) and females (Table 19), but otherwise there are few notable differences between the groups (Figure 75). The male bilateral wrists in Dunbar, Perth, and Leith showed the lowest TPR like females in Dunbar and Perth, however Leith was different with female TPR 40% at the right wrist and 14% at the left. In males, Dunbar was also noted for the lack of cases at the left shoulder and 100% TPR at the right, but this was like females who showed 0% on the left and 75% on the right. Interestingly, Perth males were reversed at the shoulder with 100% on the left and only 33% on the right. Old Town Edinburgh and City of Edinburgh both had a left bias at the shoulder like Perth, but Leith and Dunbar had a right-side bias. Females were showed a right bias at
the shoulder in Old Town Edinburgh, Perth, Dunbar, and St Andrews and a left at City of Edinburgh and Leith.

Table 20 Male Prevalence of Enthesal Changes by Burgh

<table>
<thead>
<tr>
<th>Enthesis</th>
<th>Old Town Edinburgh</th>
<th>City of Edinburgh</th>
<th>Leith</th>
<th>Perth</th>
<th>Dunbar</th>
<th>St Andrews</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>n Ct TPR</td>
<td>n Ct TPR</td>
<td>n Ct TPR</td>
<td>n Ct TPR</td>
<td>n Ct TPR</td>
<td></td>
</tr>
<tr>
<td>R Shoulder</td>
<td>41</td>
<td>12 7 58%</td>
<td>12 7 58%</td>
<td>3 1 33%</td>
<td>4 4 100%</td>
<td>4 3 75%</td>
<td>.477†</td>
</tr>
<tr>
<td>R Elbow</td>
<td>76</td>
<td>22 17 77%</td>
<td>16 15 94%</td>
<td>10 7 70%</td>
<td>6 5 83%</td>
<td>7 7 100%</td>
<td>.409†</td>
</tr>
<tr>
<td>R Wrist</td>
<td>59</td>
<td>16 4 25%</td>
<td>16 6 38%</td>
<td>6 0 0%</td>
<td>9 2 22%</td>
<td>5 0 0%</td>
<td>.477†</td>
</tr>
<tr>
<td>R Shoulder</td>
<td>40</td>
<td>11 8 73%</td>
<td>15 9 60%</td>
<td>4 3 75%</td>
<td>11 1 100%</td>
<td>5 0 0%</td>
<td>4 3 75%</td>
</tr>
<tr>
<td>R Elbow</td>
<td>80</td>
<td>23 16 70%</td>
<td>19 13 68%</td>
<td>8 6 75%</td>
<td>15 10 67%</td>
<td>6 5 83%</td>
<td>9 9 100%</td>
</tr>
<tr>
<td>R Wrist</td>
<td>62</td>
<td>15 5 33%</td>
<td>18 4 22%</td>
<td>4 0 0%</td>
<td>12 1 8%</td>
<td>5 0 0%</td>
<td>8 4 50%</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001, † Fisher’s Exact, Ct- Case counts

Figure 75 Male Prevalence of Enthesal Changes by Burgh

*p < .05

5.3.2 Degenerative Joint Changes and Geographic Location

DJC TPR for all individuals of all ages (N = 204) were compared by six Burgh groups (Table 21). Statistically significant differences were seen between burgh groups on the right side at the shoulder (Fisher’s Exact, p = .023), acromioclavicular joint (Fisher’s Exact, p = .001), knee (Fisher’s Exact, p = .012), cervical (Fisher’s Exact, p = .007), thoracic (Fisher’s Exact, p = .009), and lumbar spine (Fisher’s Exact, p = <.001), and for overall osteoarthritis
(Fisher’s Exact, \( p = .001 \)) (Figures 76 and 77). There were very low case counts for all Burghs at the wrists, knees and ankles which made noting any trends difficult. TPR for right and left sides was similar with the right side often higher but not remarkably so. For all three spinal segments, Perth was notably low (C-15%, T- 8%, L- 9%) with St Andrews notably higher (C-50%, T- 47%, L- 52%). While there was a lot of variation, Old Town Edinburgh displayed consistently low TPR across all joints (Figure 78).

### Table 21: Prevalence of Degenerative Joint Changes by Burgh

<table>
<thead>
<tr>
<th>Joint</th>
<th>Old Town Edinburgh</th>
<th>City of Edinburgh</th>
<th>Leith</th>
<th>Perth</th>
<th>Dunbar</th>
<th>St Andrews</th>
<th>( p ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>n</td>
<td>TPR</td>
<td>N</td>
<td>n</td>
<td>TPR</td>
<td>N</td>
</tr>
<tr>
<td>R Shoulder</td>
<td>167</td>
<td>41</td>
<td>9%</td>
<td>27</td>
<td>14</td>
<td>52%</td>
<td>35</td>
</tr>
<tr>
<td>R AC Joint</td>
<td>107</td>
<td>24</td>
<td>5%</td>
<td>20</td>
<td>11</td>
<td>55%</td>
<td>27</td>
</tr>
<tr>
<td>R GH Joint</td>
<td>165</td>
<td>40</td>
<td>6%</td>
<td>28</td>
<td>9</td>
<td>32%</td>
<td>35</td>
</tr>
<tr>
<td>R Elbow</td>
<td>165</td>
<td>46</td>
<td>7%</td>
<td>31</td>
<td>5</td>
<td>16%</td>
<td>36</td>
</tr>
<tr>
<td>R Wrist</td>
<td>155</td>
<td>38</td>
<td>4%</td>
<td>30</td>
<td>4</td>
<td>13%</td>
<td>26</td>
</tr>
<tr>
<td>R Hip</td>
<td>183</td>
<td>43</td>
<td>4%</td>
<td>35</td>
<td>10</td>
<td>29%</td>
<td>21</td>
</tr>
<tr>
<td>R Knee</td>
<td>160</td>
<td>44</td>
<td>1%</td>
<td>27</td>
<td>0</td>
<td>0%</td>
<td>32</td>
</tr>
<tr>
<td>R Ankle</td>
<td>118</td>
<td>36</td>
<td>2%</td>
<td>15</td>
<td>0</td>
<td>0%</td>
<td>26</td>
</tr>
<tr>
<td>L Shoulder</td>
<td>161</td>
<td>43</td>
<td>5%</td>
<td>15</td>
<td>9</td>
<td>35%</td>
<td>21</td>
</tr>
<tr>
<td>L AC Joint</td>
<td>97</td>
<td>23</td>
<td>3%</td>
<td>26</td>
<td>8</td>
<td>50%</td>
<td>32</td>
</tr>
<tr>
<td>L GH Joint</td>
<td>155</td>
<td>42</td>
<td>3%</td>
<td>16</td>
<td>4</td>
<td>16%</td>
<td>23</td>
</tr>
<tr>
<td>L Elbow</td>
<td>176</td>
<td>49</td>
<td>5%</td>
<td>29</td>
<td>1</td>
<td>3%</td>
<td>29</td>
</tr>
<tr>
<td>L Wrist</td>
<td>158</td>
<td>42</td>
<td>2%</td>
<td>30</td>
<td>1</td>
<td>3%</td>
<td>37</td>
</tr>
<tr>
<td>L Hip</td>
<td>183</td>
<td>42</td>
<td>7%</td>
<td>35</td>
<td>10</td>
<td>29%</td>
<td>35</td>
</tr>
<tr>
<td>L Knee</td>
<td>159</td>
<td>43</td>
<td>1%</td>
<td>26</td>
<td>0</td>
<td>0%</td>
<td>35</td>
</tr>
<tr>
<td>L Ankle</td>
<td>114</td>
<td>35</td>
<td>2%</td>
<td>15</td>
<td>0</td>
<td>0%</td>
<td>26</td>
</tr>
<tr>
<td>Cervical Spine</td>
<td>176</td>
<td>46</td>
<td>6%</td>
<td>23</td>
<td>10</td>
<td>43%</td>
<td>43</td>
</tr>
<tr>
<td>Thoracic Spine</td>
<td>190</td>
<td>49</td>
<td>17%</td>
<td>30</td>
<td>9</td>
<td>30%</td>
<td>43</td>
</tr>
<tr>
<td>Lumbar Spine</td>
<td>197</td>
<td>52</td>
<td>13%</td>
<td>34</td>
<td>10</td>
<td>29%</td>
<td>43</td>
</tr>
<tr>
<td>Schmor's Nodes</td>
<td>197</td>
<td>52</td>
<td>12%</td>
<td>32</td>
<td>8</td>
<td>25%</td>
<td>43</td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>204</td>
<td>55</td>
<td>2%</td>
<td>35</td>
<td>5</td>
<td>14%</td>
<td>43</td>
</tr>
<tr>
<td>Degenerative</td>
<td>204</td>
<td>55</td>
<td>2%</td>
<td>35</td>
<td>16</td>
<td>46%</td>
<td>43</td>
</tr>
</tbody>
</table>

*\( p < .05 \), **\( p < .01 \), ***\( p < .001 \), † Fisher’s Exact, Ct- Case counts*
Figure 76 Right Appendicular Prevalence of Degenerative Joint Changes by Burgh
*\( p < .05 \)

Figure 77 Left Appendicular Prevalence of Degenerative Joint Changes by Burgh
*\( p < .05 \)
Figure 78 Spinal Prevalence of Degenerative Joint Changes by Burgh
\( *p < .05 \)

DJC TPR for females \((n = 113)\) were compared by six Burgh groups (Table 22). Lower body joints were not included due to low sample sizes and because differentiation of occupational activity is rarely seen in the lower body. Statistical significance between the six burgh groups was found at the right acromioclavicular joint (Fisher’s Exact, \( p = .022 \)), the left glenohumeral joint (Fisher’s Exact, \( p = .028 \)), for all three segments of the spine (cervical, Fisher’s Exact, \( p = .001 \), thoracic, Fishers Exact, \( p = <.001 \), lumbar, Fisher’s Exact, \( p = <.001 \), and for overall osteoarthritis (Fisher’s Exact, \( p = .035 \)). Right and left sides were consistently similar in prevalence but with the right side often slightly higher (Figures 79-81).

Scores for Perth were notably low across all appendicular and spinal joints and St Andrews was notably high across all joints. Female TPR differed from the combined sex group (Table 21) in significance between the six burghs of the left glenohumeral joint, and lack of significance between the six burghs at the right knee.

Table 22 Female Prevalence of Degenerative Joint Changes by Burgh

<table>
<thead>
<tr>
<th>Joint</th>
<th>Old Town Edinburgh</th>
<th>City of Edinburgh</th>
<th>Leith</th>
<th>Perth</th>
<th>Dunbar</th>
<th>St Andrews</th>
<th>( \rho ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>n</td>
<td>( \text{CT} )</td>
<td>TPR</td>
<td>n</td>
<td>( \text{CT} )</td>
<td>TPR</td>
<td>n</td>
</tr>
<tr>
<td>R Shoulder</td>
<td>97</td>
<td>23</td>
<td>5 22%</td>
<td>10</td>
<td>4 40%</td>
<td>27</td>
<td>7 26</td>
</tr>
<tr>
<td>Site</td>
<td>Case counts</td>
<td>0%</td>
<td>20%</td>
<td>40%</td>
<td>60%</td>
<td>80%</td>
<td>100%</td>
</tr>
<tr>
<td>------------</td>
<td>-------------</td>
<td>----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>------</td>
</tr>
<tr>
<td>R AC Joint</td>
<td>56</td>
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<td>3</td>
<td>25%</td>
<td>6</td>
<td>3</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19</td>
<td>6</td>
<td>32%</td>
<td>8</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>3</td>
<td>75%</td>
<td>7</td>
<td>5</td>
<td>71%</td>
</tr>
<tr>
<td>R GH Joint</td>
<td>94</td>
<td>23</td>
<td>3</td>
<td>13%</td>
<td>10</td>
<td>2</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27</td>
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<td>11%</td>
<td>19</td>
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<tr>
<td></td>
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<td>14%</td>
<td>8</td>
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<td>25%</td>
</tr>
<tr>
<td>R Elbow</td>
<td>93</td>
<td>24</td>
<td>3</td>
<td>13%</td>
<td>12</td>
<td>2</td>
<td>17%</td>
</tr>
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<td>17%</td>
<td>9</td>
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<td>22%</td>
</tr>
<tr>
<td>R Wrist</td>
<td>83</td>
<td>19</td>
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<td>11</td>
<td>2</td>
<td>17%</td>
</tr>
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<td>12</td>
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</tr>
<tr>
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<td>12%</td>
<td>8</td>
<td>2</td>
<td>25%</td>
</tr>
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<td></td>
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<td>3</td>
<td>33%</td>
</tr>
<tr>
<td>L AC Joint</td>
<td>55</td>
<td>13</td>
<td>2</td>
<td>15%</td>
<td>6</td>
<td>2</td>
<td>33%</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>5</td>
<td>2</td>
<td>40%</td>
<td>4</td>
<td>2</td>
<td>50%</td>
</tr>
<tr>
<td>L GH Joint</td>
<td>88</td>
<td>25</td>
<td>2</td>
<td>8%</td>
<td>8</td>
<td>1</td>
<td>13%</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>2</td>
<td>33%</td>
<td>9</td>
<td>3</td>
<td>33%</td>
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<tr>
<td>L Elbow</td>
<td>94</td>
<td>26</td>
<td>2</td>
<td>8%</td>
<td>9</td>
<td>0</td>
<td>0%</td>
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<tr>
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<td></td>
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<td>25%</td>
</tr>
<tr>
<td>L Wrist</td>
<td>84</td>
<td>22</td>
<td>2</td>
<td>9%</td>
<td>8</td>
<td>0</td>
<td>0%</td>
</tr>
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<td></td>
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<td>7</td>
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</tr>
<tr>
<td>Cervical Spine</td>
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<td>2</td>
<td>8%</td>
<td>8</td>
<td>4</td>
<td>50%</td>
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<td>9</td>
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</tr>
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<td></td>
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<td>2</td>
<td>29%</td>
<td>10</td>
<td>5</td>
<td>50%</td>
</tr>
<tr>
<td>Thoracic Spine</td>
<td>111</td>
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<td>8</td>
<td>29%</td>
<td>11</td>
<td>2</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>11</td>
<td>33%</td>
<td>21</td>
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<td>0%</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>4</td>
<td>50%</td>
<td>10</td>
<td>5</td>
<td>50%</td>
</tr>
<tr>
<td>Lumbar Spine</td>
<td>110</td>
<td>28</td>
<td>7</td>
<td>25%</td>
<td>12</td>
<td>2</td>
<td>17%</td>
</tr>
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<td>33</td>
<td>18</td>
<td>55%</td>
<td>20</td>
<td>1</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>3</td>
<td>43%</td>
<td>10</td>
<td>5</td>
<td>50%</td>
</tr>
<tr>
<td>Schmor's Nodes</td>
<td>111</td>
<td>28</td>
<td>7</td>
<td>25%</td>
<td>12</td>
<td>3</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>33</td>
<td>11</td>
<td>39%</td>
<td>20</td>
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<td>15%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>3</td>
<td>38%</td>
<td>10</td>
<td>1</td>
<td>10%</td>
</tr>
<tr>
<td>Osteoarthrits</td>
<td>113</td>
<td>29</td>
<td>2</td>
<td>7%</td>
<td>12</td>
<td>1</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>33</td>
<td>3</td>
<td>9%</td>
<td>21</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>1</td>
<td>13%</td>
<td>10</td>
<td>4</td>
<td>40%</td>
</tr>
<tr>
<td>Degenerative Joint Changes</td>
<td>113</td>
<td>29</td>
<td>3</td>
<td>11%</td>
<td>12</td>
<td>5</td>
<td>42%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>33</td>
<td>12</td>
<td>36%</td>
<td>21</td>
<td>5</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>4</td>
<td>50%</td>
<td>10</td>
<td>8</td>
<td>80%</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001, † Fisher’s Exact, Ct.- Case counts

Figure 79 Female Right Arm Prevalence of Degenerative Joint Changes by Burgh

*p < .05
Figure 80 Female Left Arm Prevalence of Degenerative Joint Changes by Burgh
*p < .05

Figure 81 Female Spinal Prevalence of Degenerative Joint Changes by Burgh
*p < .05
DJC TPR for all males (n = 91) of all ages were compared by joint and six burgh groups and statistical significance between the six burghs was seen only for overall osteoarthritis (Fisher’s Exact, p = .025) (Table 23). Prevalence rates of ECs for Old Town Edinburgh were consistently low and consistently high for St Andrews across most or all appendicular joints (Table 23, Figures 82-84). Prevalence rates for DJC in St Andrews were consistently high across all three spinal segments for most appendicular joints and had the highest TPR for overall DJC. Male TPR differed from the combined sex group (Table 21) with a lack of significance between the burgh groups except for overall presence of OA. For the right acromioclavicular, left glenohumeral, and all three spinal segments, males (Table 23) showed a lack of significance between the six burghs, but females (Table 22) were significantly different between the six burgh groups.

Table 23 Male Prevalence of Degenerative Joint Changes by Burgh

<table>
<thead>
<tr>
<th>Joint</th>
<th>DJC</th>
<th>Old Town Edinburgh</th>
<th>City of Edinburgh</th>
<th>Leith</th>
<th>Perth</th>
<th>Dunbar</th>
<th>St Andrews</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>n</td>
<td>Ct</td>
<td>TPR</td>
<td>n</td>
<td>Ct</td>
<td>TPR</td>
</tr>
<tr>
<td>R Shoulder</td>
<td>70</td>
<td>18</td>
<td>4</td>
<td>22%</td>
<td>17</td>
<td>10</td>
<td>59%</td>
</tr>
<tr>
<td>R AC Joint</td>
<td>51</td>
<td>12</td>
<td>2</td>
<td>17%</td>
<td>14</td>
<td>8</td>
<td>57%</td>
</tr>
<tr>
<td>R GH Joint</td>
<td>71</td>
<td>17</td>
<td>3</td>
<td>18%</td>
<td>18</td>
<td>7</td>
<td>39%</td>
</tr>
<tr>
<td>R Elbow</td>
<td>76</td>
<td>22</td>
<td>4</td>
<td>18%</td>
<td>19</td>
<td>3</td>
<td>16%</td>
</tr>
<tr>
<td>R Wrist</td>
<td>72</td>
<td>19</td>
<td>3</td>
<td>16%</td>
<td>19</td>
<td>2</td>
<td>11%</td>
</tr>
<tr>
<td>L Shoulder</td>
<td>70</td>
<td>18</td>
<td>2</td>
<td>11%</td>
<td>18</td>
<td>7</td>
<td>39%</td>
</tr>
<tr>
<td>L AC Joint</td>
<td>42</td>
<td>10</td>
<td>1</td>
<td>10%</td>
<td>10</td>
<td>6</td>
<td>60%</td>
</tr>
<tr>
<td>L GH Joint</td>
<td>67</td>
<td>17</td>
<td>1</td>
<td>6%</td>
<td>17</td>
<td>3</td>
<td>18%</td>
</tr>
<tr>
<td>L Elbow</td>
<td>82</td>
<td>23</td>
<td>3</td>
<td>13%</td>
<td>20</td>
<td>1</td>
<td>5%</td>
</tr>
<tr>
<td>L Wrist</td>
<td>74</td>
<td>20</td>
<td>0</td>
<td>0%</td>
<td>22</td>
<td>1</td>
<td>5%</td>
</tr>
<tr>
<td>Cervical Spine</td>
<td>74</td>
<td>21</td>
<td>4</td>
<td>19%</td>
<td>15</td>
<td>6</td>
<td>40%</td>
</tr>
<tr>
<td>Thoracic Spine</td>
<td>79</td>
<td>21</td>
<td>9</td>
<td>43%</td>
<td>19</td>
<td>7</td>
<td>37%</td>
</tr>
<tr>
<td>Lumbar Spine</td>
<td>87</td>
<td>24</td>
<td>6</td>
<td>25%</td>
<td>22</td>
<td>8</td>
<td>36%</td>
</tr>
<tr>
<td>Schmorl’s Nodes</td>
<td>86</td>
<td>24</td>
<td>5</td>
<td>21%</td>
<td>20</td>
<td>5</td>
<td>25%</td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>91</td>
<td>26</td>
<td>0</td>
<td>0%</td>
<td>23</td>
<td>4</td>
<td>17%</td>
</tr>
<tr>
<td>Degenerative Joint Changes</td>
<td>91</td>
<td>26</td>
<td>12</td>
<td>46%</td>
<td>23</td>
<td>11</td>
<td>48%</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001, † Fisher’s Exact, Ct. - Case counts
Figure 82 Male Right Arm Prevalence of Degenerative Joint Changes by Burgh

\*p < .05

Figure 83 Male Left Arm Prevalence of Degenerative Joint Changes by Burgh

\*p < .05
5.4 Social Status

Social status for both entheseal changes and degenerative joint changes were evaluated by comparing the Old Town Edinburgh group, the most affluent, with all other groups.

5.4.1 Entheseal Changes and Social Status

All individuals (N = 204) of all ages from the Old Town Edinburgh group (n = 55) were compared with all other burghs (n = 149). There were no statistically significant differences in prevalence of ECs aligned to social status (Table 24). Old Town Edinburgh had slightly higher TPR at both wrists (R - 38%, L - 39%) and the left shoulder (54%) while the right shoulder (61%) and both elbows (R - 81%, L - 76%) were higher for the Other Burgh group (Figure 85).

Table 24 Combined Sex Prevalence of Entheseal Changes for Old Town Edinburgh vs All Other Burghs

<table>
<thead>
<tr>
<th>Enthesis</th>
<th>Old Town Edinburgh</th>
<th>All Other Burghs</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>n</td>
<td>Ct</td>
</tr>
<tr>
<td>Right Shoulder</td>
<td>93</td>
<td>27</td>
<td>14</td>
</tr>
<tr>
<td>Elbow</td>
<td>166</td>
<td>46</td>
<td>34</td>
</tr>
</tbody>
</table>
EC TPR pooled by joint for all females ($n = 113$) of all ages was compared for the Old Town Edinburgh group ($n = 29$) to all other burghs ($n = 84$) and no significance between the two groups was observed (Table 25). Visualisation confirms little difference between the groups (Figure 86). Females were similar to the combined sex group (Table 24), with Old Town Edinburgh having higher rates at the wrist and all other Burghs higher at the shoulder and elbow. Females differed from the combined sex group only at the left shoulder. In the combined sex group, Old Town Edinburgh was higher, whereas females were higher at the left shoulder in all other Burghs group.

EC TPR for all males ($n = 91$) of all ages were compared between Old Town Edinburgh ($n = 25$) and all other burghs ($n = 66$) with no statistically significant differences (Table 25).
Visualisation shows higher rates in Old Town Edinburgh at the left shoulder and both wrists but higher for the other Burghs at the right shoulder and both elbows (Figure 87). Females (Figure 86) differ from the combined sex group (Figure 85) at the left shoulder (the other Burghs group is higher). Males (Figure 87) are similar to the combined sex group with Old Town Edinburgh having higher rates at the left shoulder and both wrists.

Table 25 Prevalence of Enthesal Changes for Old Town Edinburgh vs All Other Burghs by Sex

<table>
<thead>
<tr>
<th>Enthesis</th>
<th>Female</th>
<th></th>
<th></th>
<th>Male</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Old Town Edinburgh</td>
<td>All Other Burghs</td>
<td>p value</td>
<td>Old Town Edinburgh</td>
<td>All Other Burghs</td>
<td>p value</td>
</tr>
<tr>
<td>Right Shoulder</td>
<td>N 52 n 15 Ct 7 TPR 47%</td>
<td>N 37 n 20 Ct 54%</td>
<td>0.86</td>
<td>N 41 n 12 Ct 7 TPR 58%</td>
<td>N 29 n 20 Ct TPR 69%</td>
<td>.719†</td>
</tr>
<tr>
<td>Elbow</td>
<td>N 90 n 24 Ct 17 TPR 71%</td>
<td>N 66 n 52 Ct 79%</td>
<td>0.612</td>
<td>N 76 n 22 Ct 17 TPR 77%</td>
<td>N 54 n 45 Ct 83%</td>
<td>.531†</td>
</tr>
<tr>
<td>Wrist</td>
<td>N 80 n 23 Ct 11 TPR 48%</td>
<td>N 57 n 17 Ct 30%</td>
<td>0.0205</td>
<td>N 59 n 16 Ct 4 TPR 25%</td>
<td>N 43 n 10 Ct TPR 23%</td>
<td>1†</td>
</tr>
<tr>
<td>Left Shoulder</td>
<td>N 52 n 15 Ct 6 TPR 40%</td>
<td>N 37 n 16 Ct 43%</td>
<td>1</td>
<td>N 40 n 11 Ct 8 TPR 73%</td>
<td>N 29 n 16 Ct TPR 55%</td>
<td>.473†</td>
</tr>
<tr>
<td>Elbow</td>
<td>N 91 n 27 Ct 20 TPR 74%</td>
<td>N 64 n 49 Ct 77%</td>
<td>1</td>
<td>N 80 n 22 Ct 15 TPR 68%</td>
<td>N 58 n 44 Ct 76%</td>
<td>.795</td>
</tr>
<tr>
<td>Wrist</td>
<td>N 78 n 23 Ct 10 TPR 43%</td>
<td>N 55 n 13 Ct 24%</td>
<td>0.139</td>
<td>N 62 n 15 Ct 5 TPR 33%</td>
<td>N 47 n 9 Ct TPR 19%</td>
<td>.296†</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001, † Fisher’s Exact, Ct.- Case counts

Figure 86 Female Prevalence of Enthesal Changes for Old Town Edinburgh vs All Other Burghs

*p < .05
5.4.2 Degenerative Joint Changes and Social Status

DJC TPR for all individuals (N = 204) of all ages were compared between Old Town Edinburgh (n = 55) and all other Burghs (n = 149) (Table 26). Statistically significant differences were seen at the right acromioclavicular joint ($X^2$, $p = .04$), left shoulder (Fisher’s Exact, $p = .036$) and acromioclavicular joint (Fisher’s Exact, $p = .039$) and at the cervical spine ($X^2$, $p = .023$).

For all joints with statistically significant differences, Old Town Edinburgh had a lower TPR than the other Burghs (Figure 88). Old Town Edinburgh had lower rates at the shoulders for all joints (RSh- 22%, RAC- 21%, RGH- 15%, LSh- 12%, LAC- 13%, LGH- 7%), but higher rates at the elbows (R- 15%, L- 10%) and wrists (R- 11%, L- 5%). Old Town Edinburgh had a lower rate within the cervical (13%) and lumbar (25%) spine but a higher rate within the thoracic region (35%). The prevalence rate of OA and DJC was lower in the Old Town Edinburgh population (Table 26).
## Table 26 Combined Sex Prevalence of Degenerative Joint Changes for Old Town Edinburgh vs All Other Burghs

<table>
<thead>
<tr>
<th>Joint</th>
<th>N</th>
<th>Old Town Edinburgh</th>
<th>All Other Burghs</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Ct.</td>
<td>TPR</td>
<td>n</td>
</tr>
<tr>
<td>R Shoulder</td>
<td>167</td>
<td>41</td>
<td>9</td>
<td>22%</td>
</tr>
<tr>
<td>R Acromioclavicular</td>
<td>107</td>
<td>24</td>
<td>5</td>
<td>21%</td>
</tr>
<tr>
<td>R Glenohumeral</td>
<td>165</td>
<td>40</td>
<td>6</td>
<td>15%</td>
</tr>
<tr>
<td>R Elbow</td>
<td>169</td>
<td>46</td>
<td>7</td>
<td>15%</td>
</tr>
<tr>
<td>R Wrist</td>
<td>155</td>
<td>38</td>
<td>4</td>
<td>11%</td>
</tr>
<tr>
<td>L Shoulder</td>
<td>161</td>
<td>43</td>
<td>5</td>
<td>12%</td>
</tr>
<tr>
<td>L Acromioclavicular</td>
<td>97</td>
<td>23</td>
<td>3</td>
<td>13%</td>
</tr>
<tr>
<td>L Glenohumeral</td>
<td>155</td>
<td>42</td>
<td>3</td>
<td>7%</td>
</tr>
<tr>
<td>L Elbow</td>
<td>176</td>
<td>49</td>
<td>5</td>
<td>10%</td>
</tr>
<tr>
<td>L Wrist</td>
<td>158</td>
<td>42</td>
<td>2</td>
<td>5%</td>
</tr>
<tr>
<td>Cervical Spine</td>
<td>176</td>
<td>46</td>
<td>6</td>
<td>13%</td>
</tr>
<tr>
<td>Thoracic Spine</td>
<td>190</td>
<td>49</td>
<td>17</td>
<td>35%</td>
</tr>
<tr>
<td>Lumbar Spine</td>
<td>197</td>
<td>52</td>
<td>13</td>
<td>25%</td>
</tr>
<tr>
<td>Schmorl’s Nodes</td>
<td>197</td>
<td>52</td>
<td>12</td>
<td>23%</td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>204</td>
<td>55</td>
<td>2</td>
<td>4%</td>
</tr>
<tr>
<td>Degenerative Joint Changes</td>
<td>204</td>
<td>55</td>
<td>21</td>
<td>38%</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001, † Fisher’s Exact, Ct.-Case counts
DJC TPR for all females ($n = 113$) of all ages were compared between Old Town Edinburgh ($n = 55$) and all other burghs ($n = 84$). There was no significance in prevalence rates between the two groups at any joint (Table 27). For most joint complexes all other Burghs had higher rates except for the bilateral elbow, left wrist, and the thoracic spine where Old Town Edinburgh had higher rates (Figure 89). Again, the left and right sides were similar with the right having slightly higher case counts except for the wrist. While statistically significant differences in DJC TPR between the two groups were seen for the combined sex group for the right acromioclavicular, the left combined shoulder, and left acromioclavicular joints, and the cervical spine no significant differences between the two groups were seen in female TPR for any joints.

DJC TPR for all males ($n = 91$) of all ages in Old Town Edinburgh ($n = 26$) were compared to those in all other burgh groups ($n = 65$) (Table 29). Statistical significance of four joints between the two groups with higher TPR for the other Burgh groups than Old Town Edinburgh. This difference was observed for the (combined) right (54%, Fisher’s exact, $p = .028$) and left (38%, Fisher’s Exact, $p = .04$) shoulders, and for the right (56%, Fishers Exact, $p$
and left (53%, Fisher’s Exact, \( p = .026 \)) acromioclavicular joints (Table 27).

Visualisation shows Old Town Edinburgh males with higher prevalence rates at both elbows (R-18%, L- 13%) and the right wrist (16%), but not the left wrist (0%) (Figure 90). All other Burghs had high rates for the cervical (40%) and lumbar spine (38%), and overall OA (14%) and DJC (60%), with the notable exception of the thoracic segment (43%) where Old Town Edinburgh was higher. Patterning in male DJC TPR differed from that seen in the combined sex group with statistically significant differences between the groups at the right combined shoulder and no statistically significant differences between the two groups at the cervical spine. Patterns in TPR of DJC differed in males from that of females, with statistically significant differences between the two groups seen at both combined shoulders and bilateral acromioclavicular joints.

Table 27 Prevalence of Degenerative Joint Changes for Old Town Edinburgh vs All Other Burghs by Sex

<table>
<thead>
<tr>
<th>Enthesis</th>
<th>Female Old Town Edinburgh</th>
<th>Female All Other Burghs</th>
<th>( p ) value</th>
<th>Male Old Town Edinburgh</th>
<th>Male All Other Burghs</th>
<th>( p ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>n</td>
<td>Ct</td>
<td>TPR</td>
<td>n</td>
<td>Ct</td>
<td>TPR</td>
</tr>
<tr>
<td>R Shoulder</td>
<td>97</td>
<td>23</td>
<td>5</td>
<td>22%</td>
<td>74</td>
<td>22</td>
</tr>
<tr>
<td>R Acromioclavicular</td>
<td>56</td>
<td>12</td>
<td>3</td>
<td>25%</td>
<td>48</td>
<td>17</td>
</tr>
<tr>
<td>R Glenohumeral</td>
<td>94</td>
<td>23</td>
<td>3</td>
<td>13%</td>
<td>71</td>
<td>10</td>
</tr>
<tr>
<td>R Elbow</td>
<td>93</td>
<td>24</td>
<td>3</td>
<td>13%</td>
<td>69</td>
<td>7</td>
</tr>
<tr>
<td>R Wrist</td>
<td>83</td>
<td>19</td>
<td>1</td>
<td>5%</td>
<td>64</td>
<td>4</td>
</tr>
<tr>
<td>L Shoulder</td>
<td>91</td>
<td>25</td>
<td>3</td>
<td>12%</td>
<td>66</td>
<td>13</td>
</tr>
<tr>
<td>L Acromioclavicular</td>
<td>55</td>
<td>13</td>
<td>2</td>
<td>15%</td>
<td>42</td>
<td>11</td>
</tr>
<tr>
<td>L Glenohumeral</td>
<td>88</td>
<td>25</td>
<td>2</td>
<td>8%</td>
<td>63</td>
<td>7</td>
</tr>
<tr>
<td>L Elbow</td>
<td>94</td>
<td>26</td>
<td>2</td>
<td>8%</td>
<td>68</td>
<td>5</td>
</tr>
<tr>
<td>L Wrist</td>
<td>84</td>
<td>22</td>
<td>2</td>
<td>9%</td>
<td>62</td>
<td>1</td>
</tr>
<tr>
<td>Cervical Spine</td>
<td>102</td>
<td>25</td>
<td>2</td>
<td>8%</td>
<td>77</td>
<td>20</td>
</tr>
<tr>
<td>Thoracic Spine</td>
<td>111</td>
<td>28</td>
<td>8</td>
<td>29%</td>
<td>83</td>
<td>22</td>
</tr>
<tr>
<td>Lumbar Spine</td>
<td>110</td>
<td>28</td>
<td>7</td>
<td>25%</td>
<td>82</td>
<td>29</td>
</tr>
<tr>
<td>Schmorl’s Nodes</td>
<td>111</td>
<td>28</td>
<td>7</td>
<td>25%</td>
<td>83</td>
<td>23</td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>113</td>
<td>29</td>
<td>2</td>
<td>7%</td>
<td>84</td>
<td>9</td>
</tr>
<tr>
<td>Degenerative Joint Changes</td>
<td>113</td>
<td>29</td>
<td>9</td>
<td>31%</td>
<td>84</td>
<td>34</td>
</tr>
</tbody>
</table>

*\( p < .05 \), **\( p < .01 \), ***\( p < .001 \), † Fisher’s Exact, Ct.- Case counts
Figure 89 Female Prevalence of Degenerative Joint Changes for Old Town Edinburgh vs All Other Burghs
*p < .05

Figure 90 Male Prevalence of Degenerative Joint Changes for Old Town Edinburgh vs All Other Burghs
*p < .05
5.5 Lifestyle/Subsistence

Port Burghs and Land Burghs were compared as a proxy for lifestyle and subsistence. All individuals were compared with the sexes combined, and then female and male data were explored for both enthesal changes and degenerative joint changes.

5.5.1 Enthesal Changes and Lifestyle/Subsistence

All individuals (N = 204) of all ages from Burghs (Leith and Perth) with active shipping ports (n = 79) were compared to Burghs that were either based further inland (n = 125) or were not major shipping ports (Table 28). The left wrist showed a statistically significant difference ($X^2$, $p = <.001$) with land Burghs having higher rates. Visualisation shows unremarkable differences between the groups except at the left shoulder where rates are higher in port Burghs (56%)(Figure 91).

<table>
<thead>
<tr>
<th>Enthesis</th>
<th>Port Burgh</th>
<th>Land Burgh</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>n</td>
<td>Ct</td>
</tr>
<tr>
<td>Right</td>
<td>Shoulder</td>
<td>93</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Elbow</td>
<td>166</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Wrist</td>
<td>139</td>
<td>46</td>
</tr>
<tr>
<td>Left</td>
<td>Shoulder</td>
<td>92</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Elbow</td>
<td>171</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>Wrist</td>
<td>140</td>
<td>49</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001, (n), † Fisher’s Exact, Ct. - Case counts
Figure 91 Combined Sex Prevalence of Enthesial Changes for Port vs Land Burghs

EC TPR pooled by joint for all females (n = 113) of all ages was compared for Burghs with major shipping ports (n = 54) and Burghs further inland or without major ports (n = 59). Statistical significance between the two groups was found at only the left wrist ($X^2$, $p = .001$) (Table 29). Visualisation shows that port Burghs had higher rates at the shoulder (R- 55%, L- 50%) and elbow (R- 82%, L- 80%) while land Burghs had higher rates at the wrist (R- 41%, L- 44%) (Figure 92) which was the same as the combined sex group (Table 28).

EC TPR for all males (n = 91) of all ages were compared for port Burghs (n = 25) and Burghs located inland or without major shipping ports (n = 66) and no significance between the two groups was found at any joint complex (Table 29). Visualisation reveals that for both shoulders rates are slightly higher for port Burghs (R- 67%, L- 80%) while rates for both elbows (R- 86%, L- 75%) and wrists (R- 27%, L- 28%) are higher for inland Burghs (Figure 93). Males differ from the combined sex group (Table 28) with notably higher rates at the left shoulder (80%) for port Burghs and higher rates at the elbows (R- 86%, L-75%) for inland Burghs. Males differ from females again with only the shoulders with higher rates of ECs (R- 67%, L- 80%) in the port Burghs and both elbows (R- 86%, L- 75%) and wrists (R- 27%, L- 28%)
higher in inland Burghs. Whereas females only had higher rates of ECs in inland Burghs at the wrists (R- 41%, L- 44%).

Table 29 Prevalence of Enthesal Changes for Port vs Land Burghs by Sex

<table>
<thead>
<tr>
<th>Enthesis</th>
<th>Female</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Male</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Port Burgh</td>
<td>Land Burgh</td>
<td>p value</td>
<td>Port Burgh</td>
<td>Land Burgh</td>
<td>p value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N  n  Ct  TPR</td>
<td>n  Ct  TPR</td>
<td></td>
<td>N  n  Ct  TPR</td>
<td>n  Ct  TPR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td>52 20 11 55%</td>
<td>32 16 50%</td>
<td>.948</td>
<td>41 9 6 67%</td>
<td>32 21 66%</td>
<td>1†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow</td>
<td>90 44 36 82%</td>
<td>46 33 72%</td>
<td>.378</td>
<td>76 25 18 72%</td>
<td>51 44 86%</td>
<td>.206†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wrist</td>
<td>80 31 8 26%</td>
<td>49 20 41%</td>
<td>.258</td>
<td>59 15 2 13%</td>
<td>44 12 27%</td>
<td>.483</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td>52 22 11 50%</td>
<td>30 11 37%</td>
<td>.498</td>
<td>40 5 4 80%</td>
<td>35 20 57%</td>
<td>.631†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow</td>
<td>91 44 35 80%</td>
<td>47 34 72%</td>
<td>.577</td>
<td>80 23 16 70%</td>
<td>57 43 75%</td>
<td>.795</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wrist</td>
<td>78 33 3 9%</td>
<td>45 20 44%</td>
<td>.001**</td>
<td>62 16 1 6%</td>
<td>46 13 28%</td>
<td>.09</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p < .05, ** p < .01, *** p < .001, (n), † Fisher’s Exact, Ct. - Case counts

Figure 92 Female Prevalence of Enthesal Changes for Port vs Land Burghs

*p < .05
5.5.2 Degenerative Joint Changes and Lifestyle/Subsistence

DJC TPR for all individuals \((N = 204)\) of all ages were compared between Burghs with major shipping ports \((n = 79)\) and for those without \((n = 125)\) (Table 30). Statistical significance between the two groups was seen only at the right elbow (Fisher’s Exact, \(p = .027\)). Visualisation shows higher rates of DJC for Burghs with major shipping ports only in the lumbar region of the spine (34%) and in all other cases Burghs without ports had higher rates (Figure 94).

Table 30 Combined Sex Prevalence of Degenerative Joint Changes for Port vs Land Burghs

<table>
<thead>
<tr>
<th>Joint</th>
<th>Port Burgh</th>
<th></th>
<th>Land Burgh</th>
<th></th>
<th>(p) value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(N)</td>
<td>(n)</td>
<td>Ct</td>
<td>TPR</td>
<td>(n)</td>
</tr>
<tr>
<td>R Shoulder</td>
<td>167</td>
<td>67</td>
<td>19</td>
<td>28%</td>
<td>100</td>
</tr>
<tr>
<td>R Acromioclavicular</td>
<td>107</td>
<td>42</td>
<td>12</td>
<td>29%</td>
<td>65</td>
</tr>
<tr>
<td>R Glenohumeral</td>
<td>165</td>
<td>67</td>
<td>13</td>
<td>19%</td>
<td>98</td>
</tr>
<tr>
<td>R Elbow</td>
<td>169</td>
<td>64</td>
<td>3</td>
<td>5%</td>
<td>105</td>
</tr>
<tr>
<td>R Wrist</td>
<td>155</td>
<td>60</td>
<td>2</td>
<td>3%</td>
<td>95</td>
</tr>
<tr>
<td>L Shoulder</td>
<td>161</td>
<td>61</td>
<td>13</td>
<td>21%</td>
<td>100</td>
</tr>
<tr>
<td>L Acromioclavicular</td>
<td>97</td>
<td>38</td>
<td>10</td>
<td>26%</td>
<td>59</td>
</tr>
<tr>
<td>L Glenohumeral</td>
<td>155</td>
<td>57</td>
<td>7</td>
<td>12%</td>
<td>98</td>
</tr>
</tbody>
</table>
DJC TPR for all females ($n = 113$) of all ages were compared between burghs with major shipping ports ($n = 54$) and those without ($n = 59$) (Table 31). Statistical significance between the two groups was seen only at the left glenohumeral joint (Fisher’s Exact, $p = .036$) with land Burghs being higher (17%). Land Burghs had higher rates of DJC in almost every case except for the lumbar spine (36%) (Figure 95). Prevalence rates of DJC for left and right sides of all appendicular joints were again similar but with the right side slightly higher. Female TPR differed from the combined sex group (Table 30) with significance between the
two groups at the left glenohumeral joint, whereas the combined sex group was significantly different between the two groups only at the right elbow.

DJC TPR for all males \( (n = 91) \) of all ages were compared between Burghs with major shipping ports \( (n = 25) \) and those without \( (n = 66) \) (Table 31). No joints showed any significant differences in prevalence rates of DJC.

Visualisation reveals variable patterns in DJC prevalence (Figures 95 and 96). For the male shoulders, Burghs with major shipping ports had higher rates with the exception of the right acromioclavicular joint where land Burghs had a higher rate of DJC (50%). The male TPR of DJC in the elbow and wrist joints of both sides were all higher in land Burghs. Port Burghs had higher TPR of cervical DJC (38%) while the land Burghs had higher rates of DJC for the thoracic (41%) and lumbar (37%) region of the spine. Overall OA was more common for land Burghs and overall DJC more common in port Burghs (Table 31). The tendency for higher TPR of DJC in the right-side joints compared to the left was reversed with more cases on the left than right only for port Burghs at the acromioclavicular joint and the elbows. Males differed from the combined sex group (Table 30) with a lack of significance between the two groups at the right elbow and the right acromioclavicular. Patterns in DJC prevalence in males differed from that of females showing no significant difference between the two groups at the glenohumeral joint whereas females were significantly different.

### Table 31 Prevalence of Degenerative Joint Changes for Port vs Land Burghs by Sex

<table>
<thead>
<tr>
<th>Enthesis</th>
<th>Female</th>
<th></th>
<th></th>
<th>Male</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Port Burgh</td>
<td>Land Burgh</td>
<td>Port Burgh</td>
<td>Land Burgh</td>
<td>p value</td>
<td>Port Burgh</td>
</tr>
<tr>
<td>R Shoulder</td>
<td>97</td>
<td>46</td>
<td>9</td>
<td>20%</td>
<td>51</td>
<td>18</td>
</tr>
<tr>
<td>R Acromioclavicular</td>
<td>56</td>
<td>27</td>
<td>6</td>
<td>22%</td>
<td>29</td>
<td>14</td>
</tr>
<tr>
<td>R Glenohumeral</td>
<td>94</td>
<td>46</td>
<td>5</td>
<td>11%</td>
<td>48</td>
<td>8</td>
</tr>
<tr>
<td>R Elbow</td>
<td>93</td>
<td>42</td>
<td>2</td>
<td>5%</td>
<td>51</td>
<td>8</td>
</tr>
<tr>
<td>R Wrist</td>
<td>83</td>
<td>37</td>
<td>2</td>
<td>5%</td>
<td>46</td>
<td>3</td>
</tr>
<tr>
<td>L Shoulder</td>
<td>91</td>
<td>42</td>
<td>6</td>
<td>14%</td>
<td>49</td>
<td>10</td>
</tr>
<tr>
<td>L Acromioclavicular</td>
<td>55</td>
<td>27</td>
<td>5</td>
<td>19%</td>
<td>28</td>
<td>8</td>
</tr>
<tr>
<td>L Glenohumeral</td>
<td>88</td>
<td>40</td>
<td>1</td>
<td>3%</td>
<td>48</td>
<td>8</td>
</tr>
<tr>
<td>L Elbow</td>
<td>94</td>
<td>45</td>
<td>2</td>
<td>4%</td>
<td>49</td>
<td>5</td>
</tr>
<tr>
<td>L Wrist</td>
<td>84</td>
<td>40</td>
<td>1</td>
<td>3%</td>
<td>44</td>
<td>2</td>
</tr>
<tr>
<td>Cervical Spine</td>
<td>102</td>
<td>52</td>
<td>9</td>
<td>17%</td>
<td>50</td>
<td>13</td>
</tr>
<tr>
<td>Thoracic Spine</td>
<td>111</td>
<td>54</td>
<td>11</td>
<td>20%</td>
<td>57</td>
<td>19</td>
</tr>
<tr>
<td>Lumbar Spine</td>
<td>110</td>
<td>53</td>
<td>19</td>
<td>36%</td>
<td>57</td>
<td>17</td>
</tr>
<tr>
<td>Schmor's Nodes</td>
<td>111</td>
<td>53</td>
<td>16</td>
<td>30%</td>
<td>58</td>
<td>14</td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>113</td>
<td>54</td>
<td>3</td>
<td>6%</td>
<td>59</td>
<td>8</td>
</tr>
<tr>
<td>Degenerative Joint Changes</td>
<td>113</td>
<td>54</td>
<td>17</td>
<td>31%</td>
<td>59</td>
<td>26</td>
</tr>
</tbody>
</table>

\*p < .05, \**p < .01, \***p < .001, \( (n) \), † Fisher's Exact, Ct, - Case counts

171
Figure 95 Female Prevalence of Degenerative Joint Changes for Port vs Land Burghs
*p < .05

Figure 96 Male Prevalence of Degenerative Joint Changes for Port vs Land Burghs
*p < .05
5.6 Asymmetry, Dimorphism, and Agonist/Antagonist Muscle Relationships

Within individual asymmetry was explored for entheseal changes (paired entheses) and cross-sectional geometry (in the bilateral humeral presence group). Cross-sectional geometry was also employed to determine sexual dimorphism, and entheseal changes were used to explore against/antagonist muscle relationships.

5.6.1 Asymmetry and Entheseal Changes

EC asymmetry was compared for each enthesis of the arm for individuals of any age group \( (n = 89, 42\) females, 47 males) with an asymmetrical bilateral presence of at least one enthesis pair (Table 32). Case counts \( (n = 139) \) are presented here as several individuals had more than one enthesis present that showed asymmetry. Individuals with a bilateral EC presence that had no EC asymmetry or no EC at all were not included in this analysis. As binary presence/absence scoring was used throughout the entire EC analysis, asymmetry here represents one side with any EC trait or score and the opposing side with a normal enthesis (4.4.1).

When females and males were compared by single enthesis only the triceps brachii (Fisher’s Exact, \( p = .033 \)) showed a statistically significant difference (Table 32). Females had significantly more frequent right-side bias while males were equal. Females had more frequent asymmetry in EC formation than males at the right infraspinatus and the right common flexor but in both cases, this is the difference of one individual. Males had higher or equal presence of asymmetry for all other entheses and sides. Graphs show a sex comparison for all those with right bias and then with left bias asymmetry (Figures 97 and 98).

<table>
<thead>
<tr>
<th>Enthesis</th>
<th>Females</th>
<th>Males</th>
<th>p value</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( N )</td>
<td>( \text{Right Ct} )</td>
<td>( \text{Left Ct} )</td>
<td>( \text{Right Ct} )</td>
</tr>
<tr>
<td>Subscapularis</td>
<td>22</td>
<td>8</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Infra spinatus</td>
<td>6</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Triceps Brachii</td>
<td>20</td>
<td>10</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Brachialis</td>
<td>31</td>
<td>8</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Biceps Brachii</td>
<td>30</td>
<td>11</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Common Flexor</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Common Extensor</td>
<td>17</td>
<td>5</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

\( ^{*} p < .05 \), \( ^{**} p < .01 \), \( ^{***} p < .001 \), \( ^{+} \) Fisher’s Exact, \( \text{Ct.} \) - Case counts
Figure 97 Asymmetry by Single Enthesis and Sex for Individuals with Higher Scores on the Right Side
*p < .05

Figure 98 Asymmetry by Single Enthesis and Sex for Individuals with Higher Scores on the Left Side
*p < .05
Individuals of all ages with bilateral and asymmetrical presence of at least one enthesis \((n = 87, 40 \text{ females}, 47 \text{ males})\) were assigned either right, left, or mixed asymmetry and compared by sex (Table 33). There was a statistically significant difference between females and males (Fisher’s Exact, \(p = .04\)). Right side bias was nearly equal while females had more frequent mixed asymmetry and males had more left side bias asymmetry (Figure 99).

<table>
<thead>
<tr>
<th>(N)</th>
<th>Asymmetry Side</th>
<th>Females</th>
<th>Males</th>
<th>(p) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>87</td>
<td>Right side</td>
<td>26</td>
<td>25</td>
<td>.04*†</td>
</tr>
<tr>
<td></td>
<td>Left side</td>
<td>4</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mixed</td>
<td>10</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>40</td>
<td>47</td>
<td></td>
</tr>
</tbody>
</table>

*\(p < .05\), **\(p < .01\), ***\(p < .001\), † Fisher’s Exact

![Diagram showing number of cases per side by sex](image)

**Figure 99 Enthesal Change Asymmetry by Sex**

*\(p < .05\)

### 5.6.2 Asymmetry and Cross-sectional Geometry

Absolute (AA) and directional (DA) percent bilateral asymmetry was calculated for three measures of CSG for females and males (4.4.4). Negative percentages indicate a left-side bias. In all cases of AA, males were more asymmetrical than females (Table 34). All DA percentages indicated a left side bias. Females had a greater left side bias than males for Solid I-Ratio, but for Solid J and TA, males were more left side biased than females.
Table 34 Percent Bilateral Asymmetry

<table>
<thead>
<tr>
<th></th>
<th>Solid I-ratio</th>
<th>Solid J</th>
<th>TA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%AA</td>
<td>%DA</td>
<td>%AA</td>
</tr>
<tr>
<td>Female Mean</td>
<td>9</td>
<td>4.64</td>
<td>-3.18</td>
</tr>
<tr>
<td>Male Mean</td>
<td>14</td>
<td>9.05</td>
<td>-0.99</td>
</tr>
</tbody>
</table>

AA – absolute asymmetry, DA -directional asymmetry. Negative percentages indicate left bias.

5.6.3 Sexual Dimorphism and Cross-sectional Geometry

Percent sexual dimorphism was calculated for humeral length and for all three CSG measures for the population with bilateral scores (4.4.4). Solid I-ratio showed low sexual dimorphism with males having the higher score (Table 35). For Solid J and TA, females had higher scores with the right-side Solid J the most dimorphic.

Table 35 Percent Sexual Dimorphism for Females and Males in Bilateral Group

<table>
<thead>
<tr>
<th>CSG Measure</th>
<th>n</th>
<th>Female Mean</th>
<th>n</th>
<th>Male Mean</th>
<th>% Dimorphism</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Right</td>
<td>Left</td>
<td></td>
<td>Right</td>
</tr>
<tr>
<td>Humerus Length (cm)</td>
<td>9</td>
<td>29.41</td>
<td>29</td>
<td>14</td>
<td>31.84</td>
</tr>
<tr>
<td>Solid I-ratio</td>
<td></td>
<td>1.25</td>
<td>3.88</td>
<td></td>
<td>1.31</td>
</tr>
<tr>
<td>Solid J</td>
<td></td>
<td>8814.61</td>
<td>9035.47</td>
<td></td>
<td>5635.6</td>
</tr>
<tr>
<td>Total Area</td>
<td></td>
<td>74.29</td>
<td>75.49</td>
<td></td>
<td>58.05</td>
</tr>
</tbody>
</table>

Bold indicates larger/higher scores in females

5.6.4 Enthesal Changes and Agonist/Antagonist Muscle Relationships

For all individuals (n = 204) of all ages, EC presence was pooled by (simplified) agonist/antagonist oppositional movement (4.4.1). Statistically significant differences were found at the right shoulder (Fisher’s Exact, p = .001), right elbow (X^2, p = .028), and both wrists (Fisher’s Exact, right p = <.001, left Fisher’s Exact, p = .004) (Table 36). The left side shows a similar trend, but this was not statistically significant. In all cases the shoulder and the elbow had higher rates of ECs associated with internal rotation/flexion, while at the wrist it was opposite with higher rates of ECs associated with external rotation/supination (Figure 100).

Table 36 Arm Joint Enthesal Change Prevalence by Side for Agonist/Antagonist Relationships

<table>
<thead>
<tr>
<th>Side</th>
<th>Joint</th>
<th>Movement</th>
<th>n</th>
<th>Ct</th>
<th>TPR</th>
<th>Movement</th>
<th>n</th>
<th>Ct</th>
<th>TPR</th>
<th>Ratio</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>Shoulder</td>
<td>Internal Rotation</td>
<td>79</td>
<td>50</td>
<td>63.3%</td>
<td>External Rotation</td>
<td>88</td>
<td>19</td>
<td>21.6%</td>
<td>2.9</td>
<td>.001***</td>
</tr>
<tr>
<td></td>
<td>Elbow</td>
<td>Flexion</td>
<td>175</td>
<td>130</td>
<td>74.1%</td>
<td>Extension</td>
<td>132</td>
<td>56</td>
<td>42.4%</td>
<td>1.8</td>
<td>.028*</td>
</tr>
</tbody>
</table>
Individuals of all ages (n = 204) with EC scores at one enthesis of an oppositional pair, but not both, were compared by sex (Table 37). No statistically significant differences were seen between the sexes (Figures 101 and 102).
Figure 101 Female Arm Joint Entheseal Changes for Agonist/Antagonist Movement
*p < .05

Figure 102 Male Arm Joint Entheseal Changes for Agonist/Antagonist Movement
*p < .05
5.7 Method Comparisons

5.7.1 Entheseal Changes to Degenerative Joint Changes

Rates of EC and DJC, both pooled by joint, were compared for all individuals, for all females, and for all males. These tests were controlled for age and limited to individuals under 50.

For all adults under 50 ($n = 136$) the prevalence rates of EC were compared to DJC (Table 38). Statistically significant differences were found at the right shoulder ($X^2, p = .014$) and the right glenohumeral joint (Fisher’s Exact, $p = .014$). For arm joints, prevalence rates for the right side compared to the left side follow similar patterns to other analyses with the right side demonstrating slightly higher TPR of ECs and DJC (Figure 103). The lower body joints of the hip and ankle did not follow this pattern and were more variable. There were several statistical tests that could not be completed due to sample sizes being too small, or no data existing for comparison.

<table>
<thead>
<tr>
<th>DIC Joint</th>
<th>n</th>
<th>Ct</th>
<th>TPR</th>
<th>EC Joint</th>
<th>n</th>
<th>Ct</th>
<th>TPR</th>
<th>$p$ values</th>
</tr>
</thead>
<tbody>
<tr>
<td>R Shoulder</td>
<td>109</td>
<td>29</td>
<td>27%</td>
<td>R Shoulder</td>
<td>66</td>
<td>36</td>
<td>55%</td>
<td>.014*</td>
</tr>
<tr>
<td>R Acromioclavicular</td>
<td>73</td>
<td>21</td>
<td>29%</td>
<td>R Shoulder</td>
<td>66</td>
<td>36</td>
<td>55%</td>
<td>.065</td>
</tr>
<tr>
<td>R Glenohumeral</td>
<td>111</td>
<td>18</td>
<td>16%</td>
<td>R Shoulder</td>
<td>66</td>
<td>36</td>
<td>55%</td>
<td>.014**†</td>
</tr>
<tr>
<td>R Elbow</td>
<td>111</td>
<td>5</td>
<td>5%</td>
<td>R Elbow</td>
<td>111</td>
<td>82</td>
<td>74%</td>
<td>.32†</td>
</tr>
<tr>
<td>R Wrist</td>
<td>102</td>
<td>4</td>
<td>3%</td>
<td>R Wrist</td>
<td>90</td>
<td>21</td>
<td>23%</td>
<td>1†</td>
</tr>
<tr>
<td>R Hip</td>
<td>118</td>
<td>3</td>
<td>14%</td>
<td>R Hamstring</td>
<td>65</td>
<td>12</td>
<td>18%</td>
<td>.607</td>
</tr>
<tr>
<td>R Ankle</td>
<td>75</td>
<td>1</td>
<td>1%</td>
<td>R Calcaneal Tendon</td>
<td>45</td>
<td>26</td>
<td>56%</td>
<td>NA†</td>
</tr>
<tr>
<td>L Shoulder</td>
<td>102</td>
<td>14</td>
<td>14%</td>
<td>L Shoulder</td>
<td>61</td>
<td>28</td>
<td>46%</td>
<td>.195</td>
</tr>
<tr>
<td>L Acromioclavicular</td>
<td>65</td>
<td>12</td>
<td>18%</td>
<td>L Shoulder</td>
<td>61</td>
<td>28</td>
<td>46%</td>
<td>.144</td>
</tr>
<tr>
<td>L Glenohumeral</td>
<td>99</td>
<td>6</td>
<td>6%</td>
<td>L Shoulder</td>
<td>61</td>
<td>28</td>
<td>46%</td>
<td>1†</td>
</tr>
<tr>
<td>L Elbow</td>
<td>115</td>
<td>4</td>
<td>3%</td>
<td>L Elbow</td>
<td>114</td>
<td>79</td>
<td>69%</td>
<td>.306†</td>
</tr>
<tr>
<td>L Wrist</td>
<td>104</td>
<td>3</td>
<td>0%</td>
<td>L Wrist</td>
<td>87</td>
<td>14</td>
<td>16%</td>
<td>NA†</td>
</tr>
<tr>
<td>L Hip</td>
<td>126</td>
<td>0</td>
<td>17%</td>
<td>L Hamstring</td>
<td>50</td>
<td>7</td>
<td>14%</td>
<td>.564†</td>
</tr>
<tr>
<td>L Ankle</td>
<td>74</td>
<td>1</td>
<td>1%</td>
<td>L Calcaneal Tendon</td>
<td>44</td>
<td>26</td>
<td>59%</td>
<td>NA†</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001, (n), † Fisher’s Exact, Ct, - Case counts
For all females under 50 (n = 79) the prevalence rates of EC were compared to DJC (Table 39). No statistically significant difference was found at any joint. As with the combined sex group, EC rates were higher than DJC rates apart from those seen for both hip joints (Figure 104). For upper body EC, the pattern of right-side prevalence rates being slightly higher than the left side was maintained. For upper body DJC, this was similar with the notable exception of the left acromioclavicular joint which had a higher TPR on the left side compared to the right. This pattern was not maintained for either EC or DJC of the lower body just like the combined sex group.

For all males under 50 (n = 57) the prevalence rates of EC were compared to DJC (Table 39). Statistically significant differences between EC and DJC were found at the (combined) right shoulder ($X^2$, $p = .001$), right acromioclavicular joint (Fisher’s exact, $p = .019$), and the right glenohumeral joint (Fisher’s Exact, $p = .004$). The left side shoulder joints followed a similar pattern as the right but the differences were not statistically significant (Figure 105). Acromioclavicular DJC was far more common than glenohumeral joint DJC for both right and left sides. For the upper body, the patterning of the right-side EC and DJC
having higher TPR was consistent for EC and for most DJC, with the exception of the left elbow which had a slightly higher TPR than the right. As with the combined sex group and the female group, the lower body of males had variability in the patterning between right and left for both EC and DJC (Table 38). Males were notably different from the combined sex group and females with significant differences between EC and DJC at the right combined shoulder and both acromioclavicular and glenohumeral joints. There were several statistical tests that could not be completed due to sample sizes being too small, or no data existing for comparison.

Table 39 Prevalence of Entheséal Changes Compared to Degenerative Joint Changes by Sex

<table>
<thead>
<tr>
<th>DJC Joint</th>
<th>Female</th>
<th>Male</th>
<th>Female</th>
<th>Male</th>
<th>Female</th>
<th>Male</th>
<th>p values</th>
<th>p values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Ct</td>
<td>TPR</td>
<td>n</td>
<td>Ct</td>
<td>TPR</td>
<td>n</td>
<td>TPR</td>
</tr>
<tr>
<td>R Shoulder</td>
<td>66</td>
<td>13</td>
<td>20%</td>
<td>43</td>
<td>16</td>
<td>37%</td>
<td>52</td>
<td>17</td>
</tr>
<tr>
<td>R Acromioclavicular</td>
<td>38</td>
<td>7</td>
<td>18%</td>
<td>35</td>
<td>14</td>
<td>40%</td>
<td>52</td>
<td>17</td>
</tr>
<tr>
<td>R Glenohumeral</td>
<td>66</td>
<td>8</td>
<td>12%</td>
<td>45</td>
<td>10</td>
<td>22%</td>
<td>52</td>
<td>17</td>
</tr>
<tr>
<td>R Elbow</td>
<td>62</td>
<td>4</td>
<td>6%</td>
<td>49</td>
<td>1</td>
<td>2%</td>
<td>90</td>
<td>46</td>
</tr>
<tr>
<td>R Wrist</td>
<td>56</td>
<td>2</td>
<td>4%</td>
<td>46</td>
<td>1</td>
<td>2%</td>
<td>80</td>
<td>13</td>
</tr>
<tr>
<td>R Hip</td>
<td>69</td>
<td>10</td>
<td>14%</td>
<td>49</td>
<td>7</td>
<td>14%</td>
<td>57</td>
<td>6</td>
</tr>
<tr>
<td>R Ankle</td>
<td>44</td>
<td>1</td>
<td>2%</td>
<td>30</td>
<td>0</td>
<td>0%</td>
<td>34</td>
<td>11</td>
</tr>
<tr>
<td>L Shoulder</td>
<td>61</td>
<td>7</td>
<td>11%</td>
<td>41</td>
<td>7</td>
<td>17%</td>
<td>52</td>
<td>13</td>
</tr>
<tr>
<td>L Acromioclavicular</td>
<td>37</td>
<td>5</td>
<td>14%</td>
<td>28</td>
<td>7</td>
<td>25%</td>
<td>52</td>
<td>13</td>
</tr>
<tr>
<td>L Glenohumeral</td>
<td>59</td>
<td>3</td>
<td>5%</td>
<td>40</td>
<td>3</td>
<td>8%</td>
<td>52</td>
<td>13</td>
</tr>
<tr>
<td>L Elbow</td>
<td>63</td>
<td>2</td>
<td>3%</td>
<td>51</td>
<td>2</td>
<td>4%</td>
<td>91</td>
<td>46</td>
</tr>
<tr>
<td>L Wrist</td>
<td>57</td>
<td>0</td>
<td>0%</td>
<td>47</td>
<td>0</td>
<td>0%</td>
<td>78</td>
<td>18</td>
</tr>
<tr>
<td>L Hip</td>
<td>71</td>
<td>11</td>
<td>15%</td>
<td>55</td>
<td>11</td>
<td>20%</td>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>L Ankle</td>
<td>43</td>
<td>1</td>
<td>2%</td>
<td>30</td>
<td>0</td>
<td>0%</td>
<td>29</td>
<td>11</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001, (n), † Fisher’s Exact, Ct.- Case counts
Figure 104 Female Prevalence of Enthesal Changes Compared to Degenerative Joint Changes
*p < .05

Figure 105 Male Prevalence of Enthesal Changes Compared to Degenerative Joint Changes
*p < .05
5.7.2 Enthesal Changes to Cross Sectional Geometry

In individuals with bilateral humeral scans (n = 23, 9 females, 14 males) three measures of CSG were compared to frequency of EC presence at the shoulder, elbow, and wrist (Table 40). Statistical significance between CSG and EC was seen for Solid J (Right $p = .032$, Left $p = .032$) and TA (Right $p = .032$, Left $p = .032$) in females at both elbows (Table 45, Figures 72-74). For males, statistical significance between CSG and EC was found for Solid I-ratio only at the left shoulder ($p = .029$) (Figures 106-108). Box plots show the CSG scores for individuals with EC presence.

Table 40 Bilateral Measures of Cross-Sectional Geometry Compared to Enthesal Changes

<table>
<thead>
<tr>
<th>Joint</th>
<th>Females</th>
<th></th>
<th></th>
<th>Males</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Ctg</td>
<td>p value</td>
<td></td>
<td>Ctg</td>
<td>p value</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Solid I-ratio</td>
<td>Solid J</td>
<td>Total Area</td>
<td></td>
</tr>
<tr>
<td>Elbow</td>
<td>9</td>
<td>9</td>
<td>4</td>
<td>.191</td>
<td>.032*</td>
<td>.032*</td>
</tr>
<tr>
<td>Wrist</td>
<td>9</td>
<td>9</td>
<td>4</td>
<td>.191</td>
<td>.286</td>
<td>.286</td>
</tr>
<tr>
<td>Left Shoulder</td>
<td>9</td>
<td>9</td>
<td>4</td>
<td>.905</td>
<td>.556</td>
<td>.556</td>
</tr>
<tr>
<td>Elbow</td>
<td>9</td>
<td>9</td>
<td>4</td>
<td>.413</td>
<td>.032*</td>
<td>.032*</td>
</tr>
<tr>
<td>Wrist</td>
<td>9</td>
<td>9</td>
<td>2</td>
<td>.643</td>
<td>.429</td>
<td>.429</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001, Mann-Whitney-U test
Figure 106 Solid I-ratio to Enthoseal Changes
*p < .05

Figure 107 Solid J to Enthoseal Changes
*p < .05
5.7.3 Cross Sectional Geometry to Degenerative Joint Changes

Three CSG measurements for individuals with bilateral humeral scans (n = 23, 9 females, 14 males) were compared to DJC scores at the shoulder and elbow (Table 41). The wrist was excluded due to so few cases of DJC. No significant statistical difference was seen for any measurement at either joint for either females or males (Figures 109-111). There were several statistical tests that could not be completed due to sample sizes being too small, or no data existing for comparison. Box plots show the CSG scores for individuals with DJC presence.

Table 41 Bilateral Measures of Cross-Sectional Geometry Compared to Degenerative Joint Changes

<table>
<thead>
<tr>
<th>Joint</th>
<th>Female</th>
<th>Male</th>
<th>p value</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CSG</td>
<td>Djc</td>
<td>Solid I-ratio</td>
<td>Solid J</td>
</tr>
<tr>
<td>Elbow</td>
<td>9 9 1</td>
<td>.667</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Left Shoulder</td>
<td>9 9 2</td>
<td>.5</td>
<td>.889</td>
<td>.889</td>
</tr>
<tr>
<td>Elbow</td>
<td>9 9 1</td>
<td>.889</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001, Mann-Whitney-U test
Figure 109 Solid I-ratio to Degenerative Joint Changes
*p < .05

Figure 110 Solid J to Degenerative Joint Changes
*p < .05
5.8 Repeatability

Interobserver reliability \((n = 46)\) was calculated for the new Coimbra Method for scoring entheseal changes for all left-sided entheseal change scores of the humerus, radius, and ulna by enthesis for pooled presence/absence (Table 42). Cohen’s Kappa scores show substantial agreement \((.61-.80)\) except at the infraspinatus and the common extensor where agreement is moderate \((.41-.60)\). There was near perfect agreement \((.81-.99)\) for the supraspinatus. When comparing percent agreement, most results are considered strong \((64-81\%)\), except for the supraspinatus and brachialis which could be considered almost perfect \((82-100\%)\) (McHugh 2012, Glen 2020).

<table>
<thead>
<tr>
<th>Enthesis</th>
<th>Percent Agreement</th>
<th>Kappa Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subscapularis</td>
<td>78.3%</td>
<td>.646</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>91.3%</td>
<td>.85</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>73.9%</td>
<td>.593</td>
</tr>
<tr>
<td>Common Flexor</td>
<td>87%</td>
<td>.773</td>
</tr>
<tr>
<td>Common Extensor</td>
<td>67.4%</td>
<td>.511</td>
</tr>
<tr>
<td>Triceps Brachii</td>
<td>69.6%</td>
<td>.556</td>
</tr>
<tr>
<td>Brachialis</td>
<td>84.8%</td>
<td>.714</td>
</tr>
<tr>
<td>Biceps Brachii</td>
<td>78.3%</td>
<td>.658</td>
</tr>
<tr>
<td>Average</td>
<td>78.83%</td>
<td></td>
</tr>
</tbody>
</table>
Intraobserver reliability \((n = 46)\) was calculated for the new Coimbra Method for scoring entheseal changes for all left-sided entheseal change scores of the humerus, radius, and ulna by enthesis for pooled presence/absence (Table 43). Cohen’s Kappa scores were higher when compared to those for interobserver error. Most reach substantial agreement \((.61-.80)\) but two, supraspinatus and infraspinatus, reach near perfect agreement \((.81-.99)\). For percent agreement, common extensor, triceps brachii, and biceps brachii are in strong agreement \((64-81\%)\). All others reach almost perfect agreement \((82-100\%)\) (McHugh 2012, McDonald 2014).

<table>
<thead>
<tr>
<th>Enthesis</th>
<th>Percent Agreement</th>
<th>Kappa Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subscapularis</td>
<td>84.8%</td>
<td>.752</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>91.3%</td>
<td>.85</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>91.3%</td>
<td>.852</td>
</tr>
<tr>
<td>Common Flexor</td>
<td>82.6%</td>
<td>.711</td>
</tr>
<tr>
<td>Common Extensor</td>
<td>80.4%</td>
<td>.702</td>
</tr>
<tr>
<td>Triceps Brachii</td>
<td>80.4%</td>
<td>.703</td>
</tr>
<tr>
<td>Brachialis</td>
<td>76.1%</td>
<td>.618</td>
</tr>
<tr>
<td>Biceps Brachii</td>
<td>80.4%</td>
<td>.703</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>83.41%</strong></td>
<td></td>
</tr>
</tbody>
</table>
Chapter 6 Discussion

6.1 Lifestyle, Age, and Sex

6.1.1 Lifestyle Indicators

This thesis focused on functional bone adaptations and the interpretations for activity in past populations, but basic attributes such as age, sex and the presence of pathology or other observable conditions are essential to providing context to those inferences of past human behaviour.

The Old Town Edinburgh group is evenly distributed between females and males (Figure 53). There were notably fewer deaths in those aged 40-49 years when compared to those aged 20-29 years or 30-39 years, but many more in the 50+ years age category. The City of Edinburgh had a higher number of males than females (Table 8). As this group is in large part composed of skeletons from Blackfriars monastery, male members of the order may account for this discrepancy. Both Leith and Perth had higher numbers of females and higher numbers of deaths in those aged 30-39 years (Table 8). Both Burghs were major shipping ports, but it is unknown why there were more deaths in females in the 30-39 years group versus the 20-29 years group, when both would be considered ‘childbearing’ ages. Dunbar and St Andrews had an even distribution of males and females, but both had higher numbers of individuals aged over 50 years, St Andrews markedly so.

The overall sample displays higher rates of female deaths in the 20-29 and 30-39 years of age groups, higher rates for males in the 40-49 years age group, and a near equal sex distribution for those aged over 50 years (Figure 54). The higher female death rates in the younger adults can most likely be attributed to higher rates of complications and death due to pregnancy and childbirth (Jackes 2011, Shapland et al. 2015). One osteological project that examined medieval females in England determined that young women often had high rates of tuberculosis and sexually transmitted treponemal disease, syphilis, with more frequent cases in urban over rural areas (Shapland et al. 2015). These various diseases may also be part of the reason for high numbers of female deaths in the younger adult groups.

Linear enamel hypoplasia (LEH), used as a nonspecific indicator of chronic childhood stress, infection, and disease, is notably lower in Old Town Edinburgh and Leith when compared to other Burgh groups which may indicate a population with fewer childhood stressors in both Burgh groups (Cucina 2002, Reitsema and Mcllvaine 2014, Kinaston et al.
Fractures are more prevalent in the City of Edinburgh and Perth, with both Burgh groups comprised of the Blackfriars and Whitefriars collections respectively (Figure 56). There is some evidence of caring for the sick and injured at Blackfriars which may account for the higher rates, although Whitefriars is largely considered to be representative of the parish community and not a monastery hospital (Cowen and Easson 1976, Canmore 2014, Hall 2014).

Metabolic disease, most commonly vitamin D deficiency (rickets) was evenly distributed across all Burgh groups which might indicate similar nutritional deficiencies across all populations. Infectious disease was far more prevalent in the City of Edinburgh and St Andrews groups. Hospital-related activities at Blackfriars could account for this in Edinburgh. St Andrews' status as a major religious centre drawing travellers and pilgrims, many of them potentially infirm and seeking healing, could account for higher rates of infectious disease there (Simpson 1981, Foggie 2006, Willows 2016). Most recorded cases of non-specific infectious disease were diagnosed via osteomyelitis or periostitis, however, there were three cases of suspected leprosy (*Mycobacterium leprae*), and three suspected cases of treponemal disease (*Treponema pallidum*). People with outwardly observable diseases like leprosy were often social outcasts and very few were expected to be present in a general urban population such as these Burghs. Treponemal diseases are considered tropical and would not be common at higher latitudes in Scotland, however one sexually transmitted condition, syphilis, was far more widespread. Leith and Perth represented major shipping ports and St Andrews, a centre of religious pilgrimage, both situations where travellers might spread disease. The collection from Blackfriars Monastery showed evidence of religious care for the sick so a few cases of syphilis might be expected. In fact, one case of suspected tertiary syphilis in a male with pervasive cranial lesions and erosion of the outer table of the frontal and parietal bones was from this collection.

Respiratory disease had very low prevalence rates across all Burgh groups when compared to similar studies of medieval England (Mays et al. 2001, Lewis 2016). These rates include any osteological evidence of respiratory disease, but Tuberculosis (*Mycobacterium tuberculosis*) especially has been of great interest to bioarchaeologists. Transmitted via droplets, TB is associated with increasing population and crowded conditions. It has been seen in high rates during the Industrial Revolution, although many scholars believe rates were increasing from late in the medieval period (Mays et al. 2001, Roberts and Buikstra
2003, Roberts 2011, 2019, Lewis 2016). Only 5-7% of TB cases show bony changes, although milder cases can be diagnosed via polymerase chain reaction (PCR) aimed at detecting trace DNA from *M. tuberculosis* (Mays et al. 2001, 2002, Roberts and Buikstra 2003). As DNA evidence was not considered in this study, it is possible that cases of TB-related respiratory disease were not discovered. The researcher has not observed many cases of TB in osteological collections so some cases may have been missed. Aside from these limitations, low prevalence rates of respiratory disease in Scotland may be due to lower population density or to the fact that more activities occurred outdoors or with adequate ventilation when compared to England. Urbanisation and crowded working conditions that developed with specialisation of occupation occurred later in Scotland when compared to England, so it is possible the rise in TB in Scotland was slower than in England (Lynch 1988a, Spence 2015).

Taken together, the lifestyle indicators support an overall picture of better health, diet, and access to medical care in the higher status group of Old Town Edinburgh. The lower rates of LEH, indicative of fewer childhood stressors, supports this conclusion. However, rates of LEH are also low in Leith. This might reflect the geographical proximity of Edinburgh and Leith (4.1.1) and the consistent interaction of the two populations over time. Higher rates of infectious disease and fractures in the City of Edinburgh group (Blackfriars) and St Andrews show evidence of the religious orders caring for the sick and injured. This may also indicate a lower socioeconomic status in the City of Edinburgh when compared to Old Town Edinburgh, which is consistent with a highly stratified society in the capital city.

6.1.2 Age and Sex

6.1.2.1 Enthesal Changes

Initial tests to establish a relationship between increased frequency of EC and age supported previous well-established research showing a marked increase in EC after 50 years of age (Mariotti et al. 2007, Villotte et al. 2010a, Milella et al. 2012, Henderson et al. 2013b, Godde et al. 2018). Statistically significant differences between adults under 50 years and over 50 years were seen across all entheses at the elbow and wrist, but not at the shoulders (Appendix 4, Table 48, Figures 125 and 126). This may point to a tendency for shoulder EC to develop at a younger age or that young and middle adults in the populations examined engaged in more activities involving the shoulder than those that involved the elbow and
wrist. EC of the lower body, which are less indicative of specialised or gendered activity than the upper body, were also higher for those over 50 years of age.

Studies have shown that the prevalence of EC increases significantly after 50 years of age and that EC are more reliable indicators of activity before the age of 50 years (Villotte et al. 2010a, Milella et al. 2012, Villotte and Knüsel 2013, Perez-Arzak et al. 2022). There were some notable differences between females and males. For instance, males had a higher frequency for the subscapularis while this was reversed in females (Appendix 4, Figures 127 and 128). Most studies with comparable recording methods have been performed on males of identified collections so comparative female data are limited (Villotte 2013, Henderson et al. 2016a, 2016b). According to Palmer et. al. (2019) which compared the Mariotti Method and the new Coimbra Method through averaging scores for each limb, significant differences were found between males and females with the Mariotti Method but not with the new Coimbra Method. The Mariotti Method, which incorporates a robusticity score as one measure, showed significant differences between the sexes, but when upper and lower body were analysed separately the difference was seen only for the lower limbs (Milella et al. 2012, Santana-Cabrera et al. 2015). The new Coimbra Method, which does not use a robusticity score, appears to more accurately reflect activity that differs by sex.

TPR rates of all EC broadly increased with age (Appendix ?, Figures 10 and 11). While some variety exists in the literature, these results support previous research (Villotte et al. 2010a, Milella et al. 2012). When EC data for females and males within each age group are compared, a few patterns emerge (Appendix 4, Figures 129-130). The 20-29 years of age group appeared quite similar between the sexes with a few exceptions (Appendix 4, Figure 135). Males had higher rates at the shoulder, but there was a lot of variability at the elbow which does not show notable differences between the sexes. The 30-39 years of age group begins to diverge into clear sex/gender-based differences (Appendix 4, Figure 136). In the 40-49 years of age group there is even more inconsistency and variation with sex differences at nearly every enthesis (Appendix 4, Figure 135). Males have higher TPR on the right for all entheses while females are quite mixed.

The clear positive association of higher prevalence of EC with advancing age in the combined sexes is more variable when the sexes are divided. In both sexes some entheses followed this pattern of positive association between higher TPR and age and other did not.
Milella et al. (2012) found significant differences by sex for the lower body entheses and in the upper body for erosions at the costoclavicular ligament and the pectoralis major, both fibrous entheses. It has since been established that fibrous entheses are more affected by genetic and physiological factors while fibrocartilaginous entheses may be more associated with biomechanical activity (Benjamin et al. 2002, Jurmain and Roberts 2008, Villotte et al. 2010a, Jurmain et al. 2012, Villotte 2013). Other studies that have found correlations with EC and sex have associated this with overall robusticity of the individual (i.e., males have higher robusticity scores for EC) or with body mass, which is unlikely to be true for fibrocartilaginous entheses (Molnar 2006, Villotte et al. 2010a, Santana-Cabrera et al. 2015).

Interpretations must also be made cautiously due to the small sample sizes from dividing by sex and then again into three age groups. It is also important to note that this is not a longitudinal study looking at the same individuals throughout the lifecycle, however, a few broad conclusions might still be drawn from directly comparing the sexes. While there is a clear correlation between EC and age, there is enough variability between individual entheses, sex, and age group to state that age is not the only factor in their development.

It may be that the young adults in the 20-29 years of age group will not have developed different patterns based on gendered allocations of labour. As EC are so strongly correlated with advanced age, and with the aetiology of EC inherently linked to tissue degeneration, the young adults in this group may have yet to display the effects of their labour on the entheses. In the young middle adult group (30-39 years) there appears to be the clearest pattern of difference between the sexes. This group may be old enough to show some wear and degeneration associated with their labours but will not yet have experienced the full range of lifecycle changes as the older age groups. This suggests that this age group may more reliably demonstrate activity related EC than younger or older individuals. The older middle adults (40-49 years) show far higher variability between the sexes, and for females between the right and left sides. There are many changes that occur throughout the lifecycle such as type of work, hormonal changes in females, or a decrease in heavy manual labour with advancing age or expertise. The older middle adults show evidence of increased age-related tissue degeneration through higher TPR rates, but also variability across the lifecycle.
6.1.2.1.1 Enthesesal Change Asymmetry

Most EC TPR follow the pattern of the right side having a higher frequency than the left, which is supported in the literature no matter the scoring method used (Hawkey and Merbs 1995, Molnar 2006, Villotte et al. 2010a, Milella et al. 2012, Henderson et al. 2013b, Santana-Cabrera et al. 2015). This pattern has been attributed to right side dominance, although researchers understand that unilateral and bilateral activities, as well as left-side dominance, are the likely cause of any variations to this pattern (Molnar 2006, Ruff 2007, Villotte and Knüsel 2014, Santana-Cabrera et al. 2015).

Most studies of EC asymmetry were based on raw populational based frequency scores and not within individual asymmetry scores (Molnar 2006, Villotte et al. 2010a, Milella et al. 2012, Henderson et al. 2013b, Santana-Cabrera et al. 2015). Within individual asymmetry may be a better measure of sex, gender, or other social divisions of labour and reduce the effect of age on EC scores (Henderson 2013a, Henderson et al. 2018). A previous study found statistically significant differences only between those with bilaterally equal scores and those with asymmetry, which suggests that aging is unlikely to be a factor in forming within individual EC asymmetries (Henderson et al. 2018). In this study all ages were represented to increase sample sizes, but only those with asymmetrical presentation were included (5.6.1). There were no noteworthy nor statistically significant differences between females and males except at one, the triceps brachii (Table 32). This pattern is reversed to that found in Portugal. The triceps brachii had a greater range of features (bone formation, porosity, and erosions) in females, and where asymmetries were present higher scores were found on the left (Henderson et al. 2018).

Results here are consistent with the overall right sided preference seen in means-based populational studies on EC asymmetry, but there were some interesting exceptions to this ‘normal’ pattern. In every case, females had more right over left bias, and for males, half of the entheses followed this pattern. Both the single enthesis and side preference results of this study support the previously established ‘normal’ pattern of right-side dominance but inconsistencies in this pattern hint at some differences between females and males, suggesting more unilateral use patterns for females and a more bilateral use for males. It could be, however, that combining scores for shoulder, elbow, and forearm/wrist into a single within individual score (right, left, or mixed) to simplify scoring is obscuring a more detailed picture of sex-based differences (Table 33).
Some means-based EC asymmetry studies have found more frequent reversal of the ‘normal’ trend in males (i.e., more left bias) and less frequent ‘normal’ trend reversal (i.e., more right bias) in females, which suggests that differences may be biomechanical and not solely from biology or age (Henderson et al. 2018). The within individual asymmetry pattern in this Scottish study shows a similar result to the means-based asymmetry studies.

This study’s results are opposite for asymmetry per individual data from the modern (20th Century) Coimbra identified collection (Henderson et al. 2018). Males in the modern identified collection had more frequent right bias and females more frequent left bias (Henderson et al. 2018). The reversed pattern between the two single individual groups may be related to temporal, subsistence, or genetic factors rather than being a clear indicator of sex or biomechanical influence associated with activity, however, biomechanics do appear to play a role.

With so many individuals with only one paired set of EC, these results may not be representative of the entire sample and one paired enthesis may not be indicative of the use pattern for that individual. Those with ‘mixed’ asymmetry may have clouded the results on the single enthesis tests. Incomplete skeletons with missing entheses surely affected the entire analysis and larger sample sizes may have allowed for more noteworthy results. With so few cases a couple of left-handed males may have skewed the data.

6.1.2.1.2 Entheosel Change Agonist/Antagonist Relationships

Agonist/antagonist relationships demonstrated by simplified muscle movements (4.4.1) showed a bilateral pattern of increased internal rotation/flexion at the shoulder and external rotation at the elbow (Table 36). The pattern shown for the combined sexes establishes an average, or ‘normal’ pattern for this population and is, in most cases, supported by multiple other studies of EC frequency. Data on the shoulder and wrist in medieval Portuguese females matches this pattern, but not the elbow, which had higher rates for the triceps over the biceps (Henderson et al. 2018). Data for all three arm joints from an identified collection in Greece collected using the Villotte Method (which is comparable to the new Coimbra Method), matches this study (Villotte 2013, Michopoulou et al. 2015). Data on biceps brachii vs triceps brachii from an archaeological collection in Belgium using the new Coimbra Method also matches this study’s ‘normal’ pattern (Palmer et al. 2019). Data from a modern (18-20th century CE) London (Spitalfields), and medieval
England (11th-12th century CE) from the medial and lateral epicondyle (wrist) also matches the overall ‘normal’ pattern (Villotte and Knüsel 2014).

The ratio employed here was established by Villotte and Knüsel (2014) for the common extensor origin (CEO) and common flexor origin (CFO) (The L/M ratio, i.e., lateral/medial epicondyle), and was applied to the shoulder (subscapularis/supra- and/or infraspinatus) and the elbow (biceps brachii and/or brachialis/triceps brachii). This ratio is easily comparable to other literature as it is calculated at the population level from the TPR for each EC and shows that the Scottish population in this study is similar to other groups (Table 44, Figure 112). Only data from studies using the new Coimbra Method or the Villotte Method are shown below (Villotte 2013, Henderson et al. 2016b, 2016a).

<table>
<thead>
<tr>
<th>Location</th>
<th>Right Shoulder</th>
<th>Left Shoulder</th>
<th>Right Elbow</th>
<th>Left Elbow</th>
<th>Right Wrist</th>
<th>Left Wrist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scotland</td>
<td>2.9</td>
<td>2</td>
<td>1.8</td>
<td>1.6</td>
<td>2.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Portugal* (medieval)*</td>
<td>1.6</td>
<td>2.7</td>
<td>0.7</td>
<td>0.9</td>
<td>2.8</td>
<td>3.3</td>
</tr>
<tr>
<td>Greece* (modern)</td>
<td>2.6</td>
<td>2.6</td>
<td>1.4</td>
<td>1.7</td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>Londonc (modern)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.9</td>
<td>2.6</td>
</tr>
<tr>
<td>Londond (medieval)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.8</td>
<td>2.1</td>
</tr>
<tr>
<td>Belgium* (post-medieval)</td>
<td>0</td>
<td>0</td>
<td>1.1</td>
<td>1.1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*Data from Portugal is for females only. Ratios extrapolated from published EC frequencies, not raw data, and except for Villotte and Knüsel authors did not employ ratios in analysis. * (Henderson et al. 2018), b (Michopoulou et al. 2015), c d (Villotte and Knüsel 2014), e (Palmer et al. 2019).
When these patterns in the Scottish collection were directly compared by sex there was no significant difference between females and males, however, there was some noteworthy variation at the shoulders and wrists (Table 37, Figures 101 and 102). The right shoulder ratio for males was higher (4.1) than for females (2.2). This high ratio in males indicates more frequent internal rotation and flexion (subscapularis) at the shoulder over external rotation or extension (supraspinatus or infraspinatus) and therefore an uneven balance between directions of movement. For males the left shoulder was lower (2.9) but still higher than females (1.3). For both females and males, internal rotation and flexion (subscapularis) were the most common movements and for both sexes the right shoulder was used more often than the left. Together this hints at higher levels of specialization for males and more variety in activities for females for whom shoulder movements were more balanced in all directions. The elbows (flexion/extension) were near equal bilaterally. At the wrists (common extensor/flexor) the males were again higher than females at the right (3.4/2.2) and left (5.1/3.0). Again, males had more unbalanced direction of movements than...
females which also indicates more specialization in males and more variety and balanced movements in females.

While this ratio method has been rarely used, Villotte and Knüsel (2014) do offer some context as to the meaning of the ratio from medical and occupational reports on lateral and medial epicondylosis (Table 45). High ratios indicate frequent lateral epicondylosis (CEO), low ratios (>1) indicate some mixture of both medial and lateral epicondylosis with lateral still more prevalent. Rates below 1 indicate a higher prevalence of medial epicondylosis and a reversal of the ‘normal’ pattern. According to Villotte and Knüsel (2014), a reversal of the standard pattern may be indicative of activity in past populations.

<table>
<thead>
<tr>
<th>Table 45 Example Population Ratios by Activity or Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
</tr>
<tr>
<td>Cases of work-related peri-articular injuries</td>
</tr>
<tr>
<td>General Practice</td>
</tr>
<tr>
<td>Workers Exposed to Repetitive Movements</td>
</tr>
<tr>
<td>Workers Not Exposed to Repetitive Movements</td>
</tr>
<tr>
<td>General Population (men)</td>
</tr>
<tr>
<td>Workers in Repetitive Constrained Jobs (women)</td>
</tr>
<tr>
<td>Automobile Manufacturing Workers</td>
</tr>
<tr>
<td>General Population (women)</td>
</tr>
<tr>
<td>Assembly Line Packers (women)</td>
</tr>
<tr>
<td>Workers in Repetitive Constrained Jobs (men)</td>
</tr>
</tbody>
</table>

Bold indicates a reversal of the ‘normal’ pattern. All data reported in Villotte and Knüsel (2014).

The data from Villotte and Knüsel (2014) shows a wide range of activities and ratios. A general practice population (assumedly of mixed sex) was high at 6.0, but in another general population study men were at 2.2 and women at 1.0. Repetitive movements seem to show higher ratios (3.1) versus the same population of workers not exposed to repetitive movements (2.3). Both women (assembly line packers) and men (workers in repetitive constrained jobs) show a reversal (<1) of the ‘normal’ pattern. This implies it is possible that the potential for a pattern reversal is equal for both sexes, and to follow, that it is not exclusively sex-linked and may indeed be associated with activity.

As this is a new method without much comparative literature or testing it is unknown what ratios might be considered average for what activity, nor what the implications of variation may be for interpreting activity. All that can be said of the Scottish population is that there is some difference based in sex that may imply some allocation of labour. This
pattern is the same at the shoulder and elbow in Scotland, but there is no direct comparative data in bioarchaeology.

It is worth noting that agonist/antagonist pairs have been explored in one study using scores per individual (requiring the presence of the enthesis pair) which has the potential of larger sample sizes because it can include individuals of advanced age (Henderson et al. 2018). This study used a subtraction method (higher score – lower score) and analysed all Coimbra Method traits (i.e., bone formation, erosion, etc.), not only a binary presence/absence score. A similar subtraction method (but not single individual scoring) was used in a meta-analysis that attempted to discern diachronic/subsistence patterns in agonist/antagonist pairs (Henderson 2015). The multiple EC recording methods, inclusion of fibrous enthesis, and variations in reporting methodologies (TPR, individual mean, population mean, etc) made it a challenge to discern any patterns and highlights the need for standardised recording and reporting protocols (Henderson 2015).

6.1.2.2 Degenerative Joint Changes

It is widely accepted that osteoarthritis and joint degeneration in bioarchaeology are correlated with age and the result of this study confirms this association (Jurmain 1999, Ortner 2003, Waldron 2009, 2019, Roberts and Manchester 2010a). Osteoarthritis (OA) was less frequently seen than degenerative joint changes (DJC,) but in both cases there was a clear positive correlation between prevalence and increased age (Figure 57).

In the upper body, prevalence rates were higher for the right side over the left which does indicate some laterality. Although DJC is not a reliable indicator of activity, this evidence supports the idea that biomechanical stress is one contributing factor to the aetiology of DJC (Jurmain 1999). Caution should be taken, however, in equating increased right-side prevalence of DJC with increased right-sided use as the picture is far more complex. DJC in a single joint (secondary disease) can develop secondary to repetitive use, by intermittent high levels of joint force, or by an isolated accident or trauma, such as a fall, and does not necessarily indicate systemic (primary) joint disease (Ortner 2003). None of these biomechanical stress-only scenarios consider the complex aetiology of unique physiology, genetic traits, the effect of hormones, or anatomy (Ortner 2003, Felson and Neogi 2004, Roberts and Manchester 2010a, Waldron 2019).
Differences between females and males were most notable at the shoulder (Figures 61 and 62). Considering the above limitations, a cautious conclusion may be drawn that males used the shoulder more frequently than females, or that males had more injuries to the shoulder than females. It may also be the case that males in this population were more susceptible to developing OA/DJC at the shoulder than females. If only biomechanical factors were considered, males may have performed more shoulder-related activities such as lifting and carrying heavy loads or working with the arms above the head, while females may have been more inclined to carry smaller loads close to the body or to perform small, detailed tasks. However, there are far too many aetiological factors for OA/DJC for these conclusions to be valuable without additional and more detailed contextual evidence.

The Global History of Health Project (GHHP) analysis of OA found similar results between females and males in upper body OA/DJC prevalence for the Early, High, and Late Medieval time periods (Williams et al. 2018). Males had consistently higher rates than females, especially at the shoulder, throughout the three medieval time periods. The only exception was at the elbow, where female prevalence increased during the High Medieval period and surpassed male prevalence (Williams et al. 2018).

Females and males were near equal in prevalence rate for hip DJC which has been more associated with age or genetic predisposition than other joints, and less with any activity or occupation (Molleson et al. 1994, Waldron 1997, Jurmain 1999, Felson and Neogi 2004, Roberts and Manchester 2010a). Among non-genetic factors, there is some evidence that hip DJC may be associated with a heavy workload (Waldron 1997). In that case, females and males in this population may have been close to equal in workload.

OA and DJC in this study were pooled, as were any changes on the facets versus the body of the vertebrae. This is a limitation as it reduces comparability to other studies which recorded more detailed scores. Also, aetiologies may be different for facet changes and vertebral osteophytosis, which is secondary to degenerative disc disease (Knüsel et al. 1997, Derevenski 2000, Waldron 2019).

In this current study, DJC of the spine was more prevalent in males in all three spinal segments with thoracic being the most common. Among females the lumbar spine was most prevalent (Figure 63). Degenerative joint disease in the spine has remained consistent over time and has been more associated with age and individual biomechanics (i.e., posture, gait).

The GHHP results for the three spinal segments were not dissimilar from the study in Scotland with males having higher prevalence for thoracic and lumbar, but cervical prevalence showed temporal variance. In the Early and Late Medieval groups males had higher prevalence but for the High Medieval group female cervical OA/DJC prevalence surpassed that of males (Williams et al. 2018). Without the temporal groupings, the GHHP results for the overall medieval sample would appear quite like those of urban medieval Scotland placing Scotland within similar ranges to other medieval European populations.

A study on medieval males from the cemetery of St Andrew, Fishergate, York showed that changes on the vertebral body were most severe at C 5-7 followed by T 8-10. Changes at the facet (apophyseal) joints were more mixed with highest scores in the cervical spine at C 2-5, C 7/ T 1, and in the lumbar region L 4-5 (Knüsel et al. 1997). While in this study facet and vertebral body scores were pooled and it is therefore not as detailed as the Fishergate study, thoracic changes in males appear to be more prevalent in Scotland when compared to the Fishergate population.

An older study looked at a site from the Isle of Ensay, Outer Hebrides, Scotland with burials from the late 16th to 19th centuries, and the medieval agricultural site at Wharram Percy, Yorkshire on individuals carbon dated to between the 10th and 16th centuries CE (Derevenski 2000). Historical evidence described Ensay to have a strict sex/gender division of labour with limited variety of activities, while medieval Wharram Percy was known to have less stringent sex/gender roles and more variety of agricultural activities (Derevenski 2000). The Ensay sample showed higher levels of stress via more frequent and severe OA/DJC of the spine but with marked differences between females and males. Skeletons from Wharram Percy showed less stress than Ensay, and fewer differences between females and males (Derevenski 2000). Ensay females had highest prevalence in the upper thoracic, while males had higher prevalence in lower thoracic and lumbar. Both thoracic and lumbar prevalence were higher than cervical for both sexes (Derevenski 2000). Prevalence rates for Wharram Percy females and males were very similar with upper and lower thoracic most common, followed by lumbar, and then cervical (Derevenski 2000). These results from Ensay and Wharram Percy support a suggested conclusion of sex/gender-based allocation of labour in urban medieval Scotland.
6.1.2.3 Cross-sectional Geometry

6.1.2.3.1 I-Ratio

Age comparisons for Solid I-ratio scores showed that the shape of the female humerus stayed relatively consistent across age groups which points to more consistent tasks across age groups (Table 14, Figure 58). The shape of the males’ humeri appeared to increase and then drop with advanced age. The variation in male scores may show that throughout the working years (20-50 years of age) males performed more tasks that caused a more ovoid shape to develop, but then after 50 years of age those tasks may have declined.

For the large group of all individuals scanned and the smaller group with bilateral humeral presence, Solid I-ratio was not significantly different between females and males (Tables 16 and 17, Figures 64 and 67). This measure shows that female and male behaviours/activities were not significantly different enough to affect the shape of the mid-distal (35%) humerus. There was within-sex variation in shape of the cross-sections consistent with performing a wide variety of activities, but no indication of noteworthy sex/gender difference.

6.1.2.3.2 Solid J

Females had the highest Solid J values in the young adult (20-29 years) group (Table 14, Figure 59) which may indicate higher levels of strenuous manual labour than older age groups. The Solid J mean in males appeared to be constant across the age groups may be consistent with regular manual labour throughout life. The range in the younger middle (30-39 years) adults was the broadest which points to a wide variety of level of manual labour.

Measures of strength and rigidity yielded clear differences between the sexes for both the larger group and the smaller bilateral presence group (Tables 16 and 17, Figures 65 and 68). For the Solid J measure, females had higher scores than males in both the large group and the small bilateral group. Visualisation of Solid J from the large group illustrates the much greater range of female Solid J measures compared to male (Figure 65).

A 2018 study from Columbia found similar high J scores for females over males, with the male mean reaching 60% of the female (Miller et al. 2018). Two groups of Indigenous Americans, the Pottery Mound culture and the Arikara both showed higher J scores for
females than males (Wescott and Cunningham 2006, Ogilvie and Hilton 2011). However, the diachronic study of Early and Late Classic Maya period populations found the opposite with male scores of diaphyseal rigidity at the mid-distal humerus higher than female (Maggiano et al. 2008). The other diachronic study from Neolithic and Medieval Italy also showed mean scores for diaphyseal rigidity (J) to be higher in males than females for both time periods (Sparacello and Marchi 2008).

6.1.2.3.3 Total Area

The age comparison for TA looked similar to that of Solid J, but as the area of the slice influences other measures of robusticity this was not surprising (Figure 60)(Ruff 2007, Larsen 2015b). The differences between females and males in both Solid J and TA indicate some variation between the sexes, however, there were so few individuals within each age group (Table 13) one or two individuals may have skewed the results. Age groups were also not evenly represented, so more information might be gleaned from a larger data set. This is not a longitudinal study, however, and any conclusions are made cautiously.

The sex-based significant differences in TA are also much like those of Solid J (Tables 16 and 17, Figures 66 and 69). Millet and colleagues (2018) found higher mean TA scores in females over males, but the difference was not as wide as for J scores in that population. Farmers from Pottery Mound and the Arikara, both from North America, also show higher TA scores for females (Wescott and Cunningham 2006, Ogilvie and Hilton 2011). As with J, scores for TA in many other populations show consistently higher scores for males (Trinkaus et al. 1994, Marchi et al. 2006, Maggiano et al. 2008, Sparacello and Marchi 2008, Sparacello et al. 2017, 2020).

The greater range of robusticity scores (Solid J and TA) evident for females in the Scottish population may mean that females also had a wider variety of activities than males. A lower range of robusticity scores in males is consistent with more restricted activities. For a more complete picture of the sex/gender differences in this Scottish population, it is necessary to explore both bilateral asymmetry and sexual dimorphism.
6.1.2.3.4 Bilateral Asymmetry

The mean bilateral absolute asymmetry scores for female I-ratio were small at 5% but ranged from 0-13%, while the male mean was slightly higher at 9% but had a slightly greater range from 0-25% (Tables 34 and 46). While the difference is small, it is consistent with males having slightly more asymmetrical unimanual patterns than females. All comparable populations show similar ranges for diaphyseal shape (Table 46). Again, Solid I-ratio at this 35% slice location is difficult to interpret but measures of robusticity (J and TA) are widely analysed at this location.

Males in the Scottish population display a higher level of asymmetry for both measures of robusticity (J and TA), which is consistent with more frequent unimanual activities (Tables 34 and 46). Lower levels of asymmetry for females generally indicates bimanual activities (Wescott and Cunningham 2006, Maggiano et al. 2008, Sparacello and Marchi 2008, Ogilvie and Hilton 2011, Nikita et al. 2011, Miller et al. 2018). The comparative populations show this is a common pattern when considering allocations of labour by sex/gender and the Scottish population is no different.

<table>
<thead>
<tr>
<th>Table 46 Comparison of Mean Percent Bilateral Asymmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Scotland</td>
</tr>
<tr>
<td>Columbia&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>American/Pottery Mound&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>American/Arikara&lt;sup&gt;c&lt;/sup&gt; (EC period)</td>
</tr>
<tr>
<td>Sahara/Garamantes&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mayan&lt;sup&gt;e&lt;/sup&gt; (Early Classic)</td>
</tr>
<tr>
<td>Mayan&lt;sup&gt;e&lt;/sup&gt; (Late Classic)</td>
</tr>
<tr>
<td>Italy&lt;sup&gt;f&lt;/sup&gt; (medieval)</td>
</tr>
</tbody>
</table>

*Population median, **I_x/I_y
<sup>a</sup> (Miller et al. 2018), <sup>b</sup> (Ogilvie and Hilton 2011), <sup>c</sup> (Wescott and Cunningham 2006), <sup>d</sup> (Nikita et al. 2011), <sup>e</sup> (Maggiano et al. 2008), <sup>f</sup> (Sparacello and Marchi 2008).

Many comparative studies explore inter-populational subsistence patterns and temporal changes, and both are impossible in this small Scottish intra-population study. Yet some comparisons can be made. While there is some variety, in prehistoric populations females tend to have low asymmetry while males exhibit quite high levels of asymmetry,
usually focused on the right (dominant) side. *H. neanderthalensis* asymmetry ranges from 24-57%, while prehistoric *H. sapiens* tend to reach up to 30% (Trinkaus et al. 1994, Shaw and Stock 2009b, Sparacello et al. 2017). This has often been associated with certain hunting techniques such as spear throwing, atlatl use, or unilateral activities such as grinding, scraping, or tool manufacture (e.g., flint knapping) (Trinkaus et al. 1994, Marchi et al. 2006, Sparacello and Marchi 2008, Shaw and Stock 2009b, Shaw et al. 2012, Macintosh et al. 2017, Sparacello et al. 2017, 2020). In most cases low asymmetry, especially in females, has been broadly associated with agriculture, but also other bilateral activities such as cereal grinding with quern stones, childcare, use of digging sticks, or lighter but still bilateral work such as textile manufacture (Marchi et al. 2006, Wescott and Cunningham 2006, Maggiano et al. 2008, Ogilvie and Hilton 2011, Nikita et al. 2011, Sparacello et al. 2017, Miller et al. 2018),

Foragers and hunter/gathering populations tend to follow this pattern, but transitions to agriculture or intensifications in horticulture tend to show a decreased asymmetry in males (but still higher than females) with little corresponding change for females (Bridges et al. 2000, Ruff 2007, Maggiano et al. 2008, Sparacello and Marchi 2008, Ogilvie and Hilton 2011, Ruff and Larsen 2014, Miller et al. 2018). Agricultural populations’ mean asymmetry tends to be low at around 10%, and similar to modern sedentary controls (Trinkaus et al. 1994, Shaw and Stock 2009b, Ogilvie and Hilton 2011, Sparacello et al. 2011, 2017, Sládek et al. 2016). When medieval populations are compared to prehistoric ones, asymmetry is also lower with little difference based on sex, although males retain slightly higher asymmetry than females (Sparacello and Marchi 2008). Medieval asymmetry scores are similar to those of modern populations except in cases of elite athletes with strong unilateral activities such as tennis players (Trinkaus et al. 1994, Sparacello and Marchi 2008). Modern population averages range from 4-14% while modern elite athletes like cricket, squash, or tennis players can range from 26-46% (Shaw and Stock 2009b). Medieval populations of males known to have engaged in warfare with sword or longbow have slightly higher humeral asymmetry (12-17%) when compared to sedentary controls (Rhodes and Knüsel 2005, Knüsel 2007). However, these rates still fall well below those of modern tennis players (Trinkaus et al. 1994, Rhodes and Knüsel 2005, Sparacello and Marchi 2008).

Associations between asymmetry and unilateral vs bilateral activity are far from clear. In many cases, if the dominant side performed more work, it would therefore be larger, longer, and more robust. Yet some studies have proved this assumption to be oversimplified.
For example, a study using electromyography compared spear thrusting to scraping using modern volunteers (Shaw et al. 2012). In spear thrusting the non-dominant side is used to stabilize or support, often taking on more biomechanical load, while the dominant side may direct the movement. While spear throwing in prehistoric populations has been associated with unilateral movements, spear thrusting would not cause the same distinct levels of asymmetry (Shaw et al. 2012).

This complex picture of asymmetry was also explored in a landmark study on medieval male British soldiers from Towton and compared to blade injured and non-blade injured controls from Fishergate in York (Rhodes and Knüsel 2005). Differences in asymmetry between slice locations (35% and 50%) on the humerus and higher robusticity scores on the nondominant side (left) were consistent with bilateral weapon training such as the long bow. Asymmetry with higher robusticity scores on the dominant side (right) were associated with unilateral weapons use such as a sword. A population that had high asymmetry on the dominant side, similar to the unilateral sword users, but lower robusticity scores overall served as a control to demonstrate non-weapon users (Rhodes and Knüsel 2005). These examples illustrate the value of caution in interpretations of humeral asymmetry.

Side dominance is one more aspect that must be considered in any discussion on asymmetry in archaeological interpretations. It is well understood that humans have a right-sided dominance that is approximately 9:1 and that this side preference has persisted through time (Stirland 1993, Trinkaus et al. 1994, Steele and Mays 1995, Steele 2000, Shaw and Stock 2009b, Sparacello et al. 2017). When looking more closely at laterality of CSG robusticity in this population, only two (22%) females had larger right sides for Solid J (Tables 11 and 34) while six males (43%) had a larger right side. The number of females with robust left humeri (67-78%) is reflected in the low asymmetry scores and the number of males with robust left sides (57%) can also be seen in the higher asymmetry when compared to females.

One comparable study explored directional asymmetry and the intensification of metallurgy in Central European populations dating from the middle Neolithic through the Bronze and Iron Ages (Macintosh et al. 2014). The authors concluded that low absolute asymmetry in females when compared to males, coupled with a right-side bias (i.e., higher robusticity on the right), could indicate more unilateral loading and would therefore be consistent with a mixture of uni- and bi-manual activities. This change was seen in the Bronze and Iron Age populations when compared to the Neolithic populations and may indicate an
increase in specialisation of labour in females, but this effect was not seen in males (Macintosh et al. 2014).

Left-side bias is common in Neolithic populations and has been associated with bimanual activities such as grinding grain, the use of a digging stick, or spear thrusting. Some of these activities would have differentially loaded the non-dominant limb (Shaw et al. 2012, Macintosh et al. 2014). Modern right-handed coalmen and millers for example, who carried heavy loads on their left sides, had far stronger left sides (Steele 2000).

Considering all the complexities in interpretation, the percent bilateral asymmetry rates of this Scottish population situate this group into an average ‘non-specialised’ range when compared to other medieval and modern industrialised populations. As this is a mixed population with unknown specialisation, these results were expected. Broadly, males were more often engaged in unilateral activities that rarely reached the levels associated with specialisation such as throwing or weapons. Females, much like their peers across geography and time, were more frequently engaged in bilateral activities. The left bias in directional asymmetry of robusticity in Scotland, higher in females but also seen in males, is consistent with few unimanual tasks overall. If unimanual tasks were performed, it was the males doing them. However, the left-side bias may also indicate some more specialised tasks that may have preferentially loaded the non-dominant limb.

Interpretations of asymmetry benefit from a more complete picture consisting of multiple data points. For example, low asymmetry and low robusticity can indicate overall gracility, but the same symmetry combined with high robusticity is an indication of bilateral upper limb use (Rhodes and Knüsel 2005, Nikita et al. 2011). Interpreting bilateral asymmetry of CSG properties is incomplete without also discussing sexual dimorphism, body size, and robusticity.

6.1.2.3.5 Sexual Dimorphism

Humeral length in centimetres showed an 8.26% difference between the sexes on the right and 8.21% on the left (Table 35). A previous study using humeral length from Anglo-Saxon (450-600 CE) England was calculated from published data to be 11% on the right and 8.74% on the left (Pomeroy and Zakrzewski 2009). Another dimorphism study of the Indigenous American Great Plains tribe, the Arikara, had a similar dimorphism score (also calculated from published data) of 8.36% (Wescott and Cunningham 2006). These two
studies place medieval Scotland into context with average scores for dimorphism when using the humeral length.

The Solid I-ratio was unremarkable at 4.8% on the right and 3.88% on the left (Table 35). Miller and colleagues’ (2018) Columbian study which had similar results, found 5.3% for the right and 4.4% for the left, however, other studies had more variability in I-ratio scores. The Scottish population appeared near equal left to right, but some other groups had higher scores on one side or the other (Table 47). Lower scores in this case indicate a more circular diaphysis while higher scores indicate a less circular/more triangular/more ovoid cross-sectional shape. It is interesting to note that for this small comparison of previous work, where the I-ratio is more similar between right and left sides (even though this does not reach statistical significance in any group) the robusticity scores in females are higher. In the context of laterality, having similar I-ratio scores may indicate more bimanual activities.

As mentioned above for this study of medieval Scotland, female Solid J and TA scores were significantly higher than male scores, which is unusual, and this was reflected in the percent dimorphism (Table 47). Percent sexual dimorphism, as calculated from published data, from several populations is shown in Table 3. To account for sexual dimorphism, all CSG values have been standardized to remove the effect of taller stature and larger body size in males (4.4.4). This process equalizes the sexes so differences in labour can be more clearly observed.

<table>
<thead>
<tr>
<th>Population</th>
<th>Dates</th>
<th>I-ratio</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Scotland</td>
<td>900-1600 CE</td>
<td>4.8</td>
<td>3.88</td>
</tr>
<tr>
<td>Columbia*</td>
<td>1000-1400 CE</td>
<td>5.3</td>
<td>4.4</td>
</tr>
<tr>
<td>American/Pottery Mound*</td>
<td>1300-1540 CE</td>
<td>17.44*</td>
<td></td>
</tr>
<tr>
<td>American/Arikara* (EC period)</td>
<td>1500-1650 CE</td>
<td>7.69</td>
<td>0***</td>
</tr>
<tr>
<td>Sahara/Garamantes*</td>
<td>900 BCE-500 CE</td>
<td>6.1</td>
<td>2.8</td>
</tr>
<tr>
<td>Mayan* (Early Classic)</td>
<td>250-550 CE</td>
<td>.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Mayan* (Late Classic)</td>
<td>550-700 CE</td>
<td>3.6</td>
<td>6.7</td>
</tr>
<tr>
<td>Italy* (medieval)</td>
<td>10th-15th Century CE</td>
<td>4.8**</td>
<td>2.34**</td>
</tr>
</tbody>
</table>

Bold is females with higher scores, *side specific values not given, **Iₓ/Iᵧ, ***Female and male scores equal.

a (Miller et al. 2018), b (Ogilvie and Hilton 2011), c (Wescott and Cunningham 2006), d (Nikita et al. 2011), e (Maggiano et al. 2008), f (Sparacello and Marchi 2008).
Percent dimorphism scores for measures of robusticity in the humerus are highly variable and are often associated with changes or differences in subsistence activities, socioeconomic status, or environmental stress (Trinkaus et al. 1994, Marchi et al. 2006, Wescott and Cunningham 2006, Maggiano et al. 2008, Sparacello and Marchi 2008, Nikita et al. 2011, Miller et al. 2018).

Except for the few named studies, results from the Scottish population are contrary to the widely accepted view that males were engaging in more strenuous physical labour than their female peers. While most of these studies included prehistoric populations, this association was often reinforced when studying medieval and modern populations as well (Trinkaus et al. 1994, Stock and Pfeiffer 2001, 2004, Marchi et al. 2006, Maggiano et al. 2008, Sparacello and Marchi 2008, Sparacello et al. 2017). Despite this paradigm, it is not as simple a story as male sex equals higher robusticity equals heavier manual labour as there are multiple confounding factors.

Genetics are unlikely to be a factor in this single Scottish population, but many social and environmental factors might be at play. This study has shown consistent presence of vitamin D deficiency and frequent non-specific markers of childhood stress to be pervasive across medieval urban Scotland (6.1). High developmental stress in the form of poor diet or high rates of disease, unequal access to resources (often present in a stratified society), or intense physical activity can all affect the overall health of a population.

The age of onset of adult activities in youth is also thought to be a major variable in inter-population studies but is unlikely to have notable influence on this population. Historical records in Scotland show all children were expected to contribute to the household as soon as they were able (2.2-2.4). Young men may have been formally apprenticed to a trade, but young women also worked at home, in domestic service, or as apprentices themselves. There did not appear to be a notable sex or age difference in societal expectation of child or adolescent labour, only in the type of work.

This study of medieval Scotland adds to the other emerging evidence that for certain populations, CSG robusticity could be culturally mediated and not exclusively determined by biology (Wescott and Cunningham 2006, Ogilvie and Hilton 2011, Miller et al. 2018). The extent to which various factors directly affect humeral robusticity has yet to be determined and future research is needed.
6.1.2.3.6 Summary

The positive correlation between high CSG robusticity scores and comparatively higher levels of physically demanding labour has long been accepted (Trinkaus et al. 1994, Stock and Pfeiffer 2001, 2004, Rhodes and Knüsel 2005, Ruff 2007, Maggiano et al. 2008, Sparacello and Marchi 2008, Shaw and Stock 2009b, Nikita et al. 2011, Pomeroy 2013, Ruff and Larsen 2014, Macintosh et al. 2017, Miller et al. 2018). High percent sexual dimorphism in CSG robusticity has been associated with more physically demanding labour (Sparacello and Marchi 2008). High dimorphism in robusticity scores is often associated with marked sex/gender-based allocations of labour (Sparacello et al. 2011). Lower CSG robusticity scores have been associated with improved living standards, decreased workload, and low environmental stress (Wescott and Cunningham 2006, Maggiano et al. 2008). There is also the widely accepted inverse relationship between high physical workload and high social status (Maggiano et al. 2008).

Lower asymmetry in females over time has led some researchers to conclude that females are more insulated from socioeconomic changes while males may more acutely experience both the benefits and the drawbacks of changes in status, subsistence, or stress. (Maggiano et al. 2008, Sparacello et al. 2011, Macintosh et al. 2017, Miller et al. 2018).

When considering all these factors together, some distinct conclusions can be drawn about females in this population from medieval Scotland using CSG robusticity scores, asymmetry, and dimorphism. It should be noted that while much of the discussion of asymmetry and dimorphism naturally focused on the small bilateral population, females also had significantly higher robusticity scores across the larger group \(n = 71\) as well.

First, stature-based sexual dimorphism (as proxied by the humeral bone length) was within average ranges, which indicates females were predictably smaller in size. Females, due to hormonal factors, have less ability to build bone in response to biomechanical forces than males. With their high CSG robusticity scores (and high percent dimorphism), females had significantly greater amounts of bone remodelling when compared to their male peers. Although higher robusticity scores in females could be influenced by factors such as environmental stress and disease, the most significant factor in higher robusticity scores is increased bone loading indicating greater strength and to follow, increased manual labour. Females in medieval Scotland appeared stronger than their male peers and may have
performed more manual labour than males despite their shorter stature and smaller physical size (Figure 113).

Second, while low female asymmetry when compared to males usually indicates more frequent bimanual activities, the high left side bias may be consistent with more mixed tasks including those that may have preferentially loaded the non-dominant arm while requiring the dominant arm for precision or specialisation. An easy example of this would be childcare, where a toddler is held on the left hip while tasks are performed with the right hand. Males were more likely to use their right and therefore dominant arm for unimanual tasks than females.
Third, it is entirely plausible that females in medieval Scotland also experienced lower social status, less affluence, and greater environmental stress when compared to their male peers, but this does not fully account for the degree of difference seen here. It does, however, support the conclusion that women may have experienced broadly lower social status and lack of access to resources compared to men. Males with social status surely benefitted, perhaps in performing lighter or less physically demanding tasks, but many males of lower status did not.

Lower scores in males do not indicate that they were not engaged in demanding physical activities, only that the female activities may have been more mechanically strenuous. Evidence shows that women in medieval Scotland worked much harder than their male peers and made remarkable contributions to society and to the economy of urban medieval Scotland. These results taken together indicate clear differences in sex/gender-based allocations of labour in the medieval Scottish Burgh.

6.2 Social Status and Geography

The complex, multifactorial aetiology of both EC and DJC might best be addressed through a well-contextualised interpretation (Henderson et al. 2013a, Becker 2019c). Analysing EC and DJC data through Burgh location groups was an effort to add more context and nuance to the discussion. Interpretation is challenging, however, due to the small sample sizes and low case counts (some with zero prevalence) once broken down by joint. To address this the location-based analysis was not controlled for age to bolster sample sizes. Because all CSG-related analysis was performed at a later time, and due to the even smaller sample sizes, CSG was not included in the statistical analysis on geography or social status but is addressed in each section and the summary (6.2.4).

6.2.1 Social Status

6.2.1.1 Enthesal Changes and Old Town Edinburgh vs Other Burghs

Although there were no significant differences between Old Town Edinburgh and Other Burghs, prevalence rates for EC of the combined sex were higher in Old Town Edinburgh (Table 24) which may indicate more labour and lower social status in the Other Burghs group. Females in Old Town Edinburgh were higher only at the wrist bilaterally.
(Figure 114, A and C) and males also had higher prevalence at the wrist bilaterally and left shoulder (Figure 114, B and D).

EC at the wrists seen bilaterally (CEO/CFO) may be more consistent with smaller movements of forearm rotation, hand flexion/extension and some fine digital movements but have also been associated with larger ‘throwing’ motions if only the CFO, and not CEO, is affected (Villotte et al. 2010b, Villotte and Knüsel 2014, Varalli et al. 2020). EC at the shoulder and elbow may be more consistent with larger movements of the shoulder, such as heavy lifting and carrying, and with flexion extension of the arm and lifting or carrying lighter loads. While not significant, the EC trends here may indicate that the more affluent Old Town Edinburgh residents were performing small, more detailed tasks involving the forearm while individuals in All Other Burghs were performing larger movements using the shoulders and elbows. The difference is slight but the higher rate for males at the left shoulder in Old Town Edinburgh does indicate some use of the shoulder and upper arm and suggests some small difference between females and males.
6.2.1.2 Degenerative Joint Changes and Old Town Edinburgh vs Other Burgh

Comparing the most affluent group, Old Town Edinburgh, to all the other groups did show some interesting patterns (Table 26). While keeping in mind all the limitations to
associating DJC with activity and the slight differences at many joints, a few associations can be suggested.

All Other Burghs had higher rates at the bilateral AC joint, the left shoulder, and the cervical and lumbar spine. These results may indicate that individuals in All Other Burghs were performing more heavy manual labour and potentially lifting heavy loads (Figure 114, C/D vs A/B). DJC of the shoulder has been associated with rotator cuff disease and one aetiology of lumbar DJC, among many, is heavy lifting.

Old Town Edinburgh had higher rates for the elbows and wrists bilaterally, but the differences were very slight and case counts were low. Residents in Old Town Edinburgh may have been performing smaller movements of the elbow and wrists such as lifting and carrying smaller loads or activities requiring manual dexterity of the hands and fingers (Figure 114, A/B vs C/D). These sorts of activities often require close visual observation which may have led to poor posture and therefore a higher prevalence of thoracic DJC (Figure 114, B).

Males better reflected the differences in status than females. Comparatively high affluence and less frequent manual labour of males in Old Town Edinburgh suggests that men benefitted from their improved social status. In contrast, females displayed little difference between the two groups suggesting that female labour was less dependent on socioeconomic standing, and women may not have benefitted equally from improved status or affluence.

DJC, especially appendicular presentations, has been more often attributed to individual genetics and physiology (Ortner 2003, Waldron 2009, 2019). Ancestry and genetic differences between Edinburgh society and other Burghs may have affected the results. Those of higher socioeconomic status in Scotland had better living conditions and diet, lower rates of infectious and metabolic disease, and improved access to health care (Willows 2016). It is also plausible that some hormonal effect in females equalised the development of DJC across populations making it less dependent on other factors and therefore less reflective of social status.

6.2.1.3 Cross-sectional Geometry and Old Town Edinburgh vs Other Burghs

Although CSG data were not included in the statistical analysis (6.5) some conclusions can be drawn from visualizing the Solid J values (Figure 115). There appears to be some association between status and robusticity of the humerus for both females and males.
mean values for high status females may indicate more consistent diet health care, or activity and well as potentially more strenuous labour for those of high status. Lower status females show a greater range which suggests more variety in sustained manual labour. Males of higher status also appear to have experienced more strenuous manual labour than males of lower status although the difference is not as great. In most populations there tends to be a negative relationship between workload and social status, but in this case that appears to be reversed (Maggiano et al. 2008, Sparacello et al. 2011).

![Figure 115 Female and Male Solid J Values for Social Status](image)

6.2.2.1 Entheseal Changes and Port vs Land Burghs

When EC prevalence rates in Port and Land Burghs were explored, females had high prevalence for the shoulders and elbows bilaterally in the Port Burghs and wrists bilaterally in the Land Burghs (Figure 116, A vs C). Males had higher prevalence only at the shoulder bilaterally in the Port Burgh with both elbows and wrists bilaterally higher in the Land Burgh (Figure 116, D vs B).

Differences are slight so any interpretation must be made with caution. It appears that forearm rotation, hand and elbow flexion, and fine motor movements of the hand may have been more common in both sexes in Land Burghs (Figure 116, A and B). Larger upper
body movements of the shoulder (in males) and shoulder and elbow (in females) such as lifting, carrying, or thrusting were more common in Port Burghs (Figure 116, C and D). There is some difference in the sexes that is indicative of gendered allocation of labour, this pattern hints at a slightly higher level of skilled craft or activity in land locked burghs and more manual labouring near ports.
Figure 116 Entheseal and Degenerative Joint Change Prevalence Rates for Land and Port Burghs
For precise prevalence rates, see data on females from Table 13, males from Table 16 in Chapter 5 Results.

6.2.2.2 Degenerative Joint Changes and Port vs Land Burghs

Although differences were slight, Land Burghs had higher prevalence in all joints except for the lumbar segment (which was near equal) (Table 30). Females in the Land Burghs group had higher rates across all joints except for the lumbar segment. As discussed earlier,
the high number of young and middle adult females in Leith may account for this result. Males did not show any significant differences, but five of the joints had higher rates in the Land Burgh and nine were higher in the Port Burgh.

The trends here demonstrate some small differences in prevalence rates of DJC that may or may not become clearer with larger sample sizes. They also hint at a slight difference in DJC by sex and gender. A cautious interpretation might be that females were slightly more different (Figure 116, A vs C) and males more similar between the Port and Land Burghs (Figure 116, B vs D).

Populations in the Burghs with major shipping ports would have been genetically more variable with the possibility of higher numbers of immigrants or transient populations when compared to inland Burghs. While this may account for some differences, St Andrews' would have had high variation as well as it attracted the religious on pilgrimage. Old Town Edinburgh and City of Edinburgh groups were considered Land Burghs for this analysis, but Edinburgh was geographically and economically close enough to Leith that the differences may not have been unique enough to be discerned in this study.

6.2.2.3 Cross-sectional Geometry and Port vs Land Burghs

Visualization of Solid J values for Port vs Land Burghs show the characteristic high female values, but there does not appear to be much difference between Port and Land Burghs for either females or males (Figure 117).
6.2.3 Geographic Location

6.2.3.1 Enthesal Changes and Six Burgh Locations

There is little overall difference between the Burgh groups, a lot of variability, and no discernible patterns (Figure 73). Dividing the sexes did not make any patterns clearer (Figures 74 and 75). There has been positive correlation between EC and age in many studies (6.1.2.1) but associations here are not clearly defined. Burghs with the highest number of those over 50 years of age and/or lower rates of young adults, did not have higher prevalence rates of EC.

The six-burgh division doesn’t appear to yield much due to small sample sizes, but it may also be that geographical variation at this scale is not an important factor in interpreting ECs or that the populations are too alike to reveal anything noteworthy. Pooling EC by joint may obscure patterns in individual entheses and firm associations between joint movement and specific entheses are far from clear. Human movement is complex and synergistic so any categorisation of entheses by joints will always come with limitations and cautious interpretations. Including all over 50s to boost sample sizes may also have obscured results as these individuals may have EC due to ageing. It is likely that this is simply not an effective method of comparison for EC, or that different statistical tests may be more effective at elucidating a pattern.

6.2.3.2 Degenerative Joint Changes and Six Burgh Locations

With the positive correlation between DJC and increasing age (5.2.1) it appears that the groups with higher numbers of older individuals and/or lower numbers of younger individuals had some of the highest prevalence of DJC (Tables 8 and 21). These results show that advanced age is the most noteworthy factor when comparing Burgh groups for DJC, but not the only one. Old Town Edinburgh had the most consistently low prevalence despite a high number of those over 50 years of age (Table 21). Perth and Leith both showed lower prevalence rates for some joints than Old Town Edinburgh. Old Town Edinburgh would have been the most affluent Burgh group, followed by the two large shipping ports of Leith and Perth (Cowen and Easson 1976, Dingwall 1995, Spence 2015, Franklin et al. 2019). Social stratification existed in every Burgh, and these are broad generalisations, but these results do
suggest some relationship between less affluent populations and higher prevalence of DJC. (Lynch 1981).

If this is the case, it could be that individuals in less affluent Burghs had other differences that would affect development of DJC. Poor diets, higher rates of disease, or genetic differences could be factors in addition to higher rates of manual labour or injury associated with work and activity. The Dunbar group dates to before Dunbar became a Royal Burgh in the late 14th century and this population may have been engaged in more agricultural labour when compared to the groups from larger Burghs (Perry 2000). St Andrews is well known as a centre for pilgrimage and may have attracted those with advanced age or severe illness in search of religious healing (Simpson 1981). The City of Edinburgh group is made up of individuals from the Blackfriars Monastery but also Holyrood Abbey and St Mary’s Kirk of the Fields. Religious orders often operated hospitals to care for the elderly and infirm, although only St Mary’s is known to have done this (Cameron et al. 2010). These social factors may have affected the rates of DJC for the three high prevalence Burgh groups. Differences are slight, however, and any conclusions are made with caution.

High rates of lumbar DJC in females in Leith, comparable to St Andrews, City of Edinburgh, and Dunbar, may point to one other non-age-related factor; that of activity-related lumbar DJC in young people. The Leith Burgh group not only has high numbers of individuals in the 30s age group (Figure 55), but there are also a high number of females in Leith (Figure 53). While the high numbers of younger females inflated the result in this case, it does suggest that age is not the only factor to development of lumbar DJC in females in Leith.

DJC of the appendicular skeleton is not clearly associated with activity but spinal DJC and disc disease have been linked with posture (3.2.2) which can, in some cases, be an indicator for activity. The small sample sizes here make any association tenuous, but the significant differences in females for all three spinal segments demonstrate variation in females across Burgh groups.

This variation in females, while males stay more consistent across locations, suggests some sex/gender differences. While there may, of course, be hormonal factors at play, this seems to suggest that males had more consistent activities or standard of living. Females appeared more variable by activity and socioeconomic status between Burgh groups. The difference is slight, however, and considering the multiple factors at play any associations
with activity or social status are made with caution. This is also counter to CSG robusticity measures where females had a wider range. CSG is more strongly correlated to activity than DJC, so it is doubtful that biomechanical factors explain the DJC variation in females seen here.

6.2.3.3 Cross-sectional Geometry and Six Burgh Locations

Visualization of Solid J values comparing Six Burgh locations for both females (Figure 118) and males (Figure 119) do not show much discernible difference based in geography. As in Section 6.2.1.3, the mean score for females in Old Town Edinburgh is higher than the other Burgh locations with Leith and the City of Edinburgh groups the lowest. If starting with the assumption that higher status in this population meant more strenuous manual labour (6.2.1.3) then it could be that collectively the Burgh groups in and around Edinburgh (Old Town Edinburgh, City of Edinburgh, and Leith), were more socially stratified than the smaller individual Burghs of Perth, Dunbar, and St Andrews.

Solid J values for males across the Six Burgh groups (Figure 119) were similar in distribution to the female scores (Figure 118) with Old Town Edinburgh being slightly higher than the City of Edinburgh and Leith, which supports the assertion of a more highly stratified society. Dunbar is similar to the Edinburgh surrounds, but Perth (n = 1) and St Andrews (n = 1) in this case are unhelpful for any notable interpretations.
Figure 118 Female Solid J Values from Six Burgh Locations

Figure 119 Male Solid J Values from Six Burgh Locations
6.2.4 Summary

The three location analyses illustrate sex differences in the development of DJC/OA which may be indicative of gendered and/or socioeconomic allocations of labour. Age was a clear factor in the development of DJC in all cases, but it is not the only determinant. There are a few significant results and more trends that point to activity, manual labour, and socioeconomic status that can be considered as small but relevant facets of the analysis. It must be noted, however, that the three groups with the highest prevalence, St Andrews, City of Edinburgh, and Dunbar were included in All Other Burghs and Land Burgh groups, both of which showed high prevalence rates when compared to Old Town Edinburgh and Port Burghs, respectively, so age could not be eliminated as a factor at any point.

DJC and EC have different and complex aetiologies and except for males at the right shoulder, there were no notable associations between them by functional complexes (6.4.1). However, the location-based analyses in this study may imply some similar, if imprecise, patterns. Both EC and DJC location analysis points to finer, more dextrous use of the hands and forearms to be more common in Land Burghs (Figure 116, A and B) and those of higher socioeconomic status like Old Town Edinburgh (Figure 114, A and B). Larger movements of the shoulders and elbows are more common in Port Burghs (Figure 116, C and D) and All Other Burghs (Figure 116, C and D) with lower socioeconomic status.

There are a few conclusions from CSG that buttress those of EC and DJC. Like DJC in this study, low female CSG asymmetry in Scotland and in many other populations (6.1.2.3.4) illustrates that female labour is less affected by changes in socioeconomic circumstance while males better reflect changes in status. High humeral robusticity scores (J and TA) in females indicating more manual labour also points to females having lower status when compared to males. Although within the group of females, those of higher social status appear to have performed more strenuous manual labour indicating that females were, in fact, slightly more affected by social status than males. With the Six Burgh groups taken together, it appears that Edinburgh and the surrounding areas were potentially more socially stratified than the small Burghs of Perth, Dunbar, and St Andrews. Each method taken alone, especially when considering the small sample sizes, may not have much interpretive value. When similar inferences can be drawn from each one independently, however, one lends support to the other.
Bioarchaeologists understand the challenges of interpreting the intricacies of past behaviour with any level of specificity, especially without extensive contextual information (Jurmain 1999, Henderson et al. 2013a, Larsen 2015a, Becker 2019b). Specific diagnoses of musculoskeletal conditions in palaeopathology are also quite challenging due to the multifactorial aetiology of tissue degeneration and the differences between clinical and palaeopathological clinical criteria (Ortner 2003, Roberts et al. 2007, Buikstra and DeWitte 2019, Rothschild 2019). In an effort to address these complexities, many bioarchaeologists have advocated for exploring human movement through functional joint complexes and kinesiology (Knüsel 2000, Milella et al. 2012, Schrader 2012, Foster et al. 2013). A clearer picture of the multiple methodologies and discussion points can be developed by incorporating clinical and historical data and by framing the results by the shoulder (6.3.1), elbow, forearm, and wrist (6.3.2), and the spine and lower body (6.3.3).

### 6.3.1 The Shoulder

EC at the shoulder were not positively correlated with advanced age (over 50 years) while every other enthesis was (6.1.2.1). This suggests that shoulder related EC are more common in younger groups or potentially less influenced by age than other upper body EC. It follows that shoulder EC may be slightly more indicative of activity than other upper body EC and that shoulder dysfunction was present earlier in life.

Degenerative joint changes at the shoulder for both the AC and GH were higher in males (6.1.2.2) and the EC/DJC comparison was statistically significant for males at the right shoulder (6.4.1). Taken together this suggests some aetiological relationship between EC and DJC for males at the right shoulder which may indicate activity, injury, or degenerative process. As roughly 90% of humans are right-side dominant, a right bias usually indicates increased biomechanical use.

While sex differences in EC asymmetry at the shoulder were not significant, males had more frequent bilateral EC at the subscapularis and right infraspinatus while females had a higher prevalence at the left infraspinatus (Table 32). Supraspinatus was near equal. Single individual EC asymmetry was nearly equal between the sexes for right-bias, but males had more frequent left-bias (Table 33). This makes females slightly more asymmetrical. It is likely
that within individual asymmetry with all upper body joints pooled is obscuring functional patterns because in this population female within individual asymmetry was most influenced by elbow and forearm EC prevalence, not shoulder.

Both males and females in this population had low CSG asymmetry indicative of non-specialised and/or sedentary work, but males were slightly more asymmetrical than females with a right bias which indicates slightly more frequent unimanual use with the dominant side (6.1.2.3.4). When only the shoulder functional complex is considered, both EC and CSG asymmetry indicate slightly more unimanual and right bias activity for males.

Agonist/antagonist patterns for females had right and left ratios of 2.2 and 1.3 respectively, while males had 4.1 at the right and 2.9 at the left (Table 37 and Appendix 4, Figure 138). This shows a higher rate of subscapularis EC for males at the right side and indicates a gendered allocation of labour. This also supports the asymmetry results of EC and CSG at the shoulder pointing to more unimanual activities in males. In a study of male professional painters, Loew and colleagues (2019) found that 63.3% of work was at shoulder level or above and that 82% of them presented with symptoms, 27% at the dominant side and 48% bilaterally. In males on the right side, EC, DJC, and CSG data all support the conclusion of more unimanual manual labour in males at the shoulder which probably consisted of overhead or shoulder-level use.

The relationship between EC and DJC in males on the right (6.4.1) and the higher rate of subscapularis EC in males on the right both indicate that the most likely cause is rotator cuff disease (RCD). Females, however, still had a notable right-bias in shoulder EC (Table 32) and displayed some shoulder related degenerative change.

A common clinical diagnosis, RCD is most often associated with sub-acromial impingement and GH instability (Porterfield and DeRosa 2003a, Roberts et al. 2007, Greiner et al. 2019, Loew et al. 2019). However, this condition encompasses several pathologies including multiple tendinopathies, bursitis, labral tears, and impingement syndromes all of which may eventually lead to arthrosis (Roberts et al. 2007, Laron et al. 2012, Neidich 2014, Mansfield and Neumann 2019c). Tendinopathy at one of the four rotator cuff tendons, the fibres of which interdigitate (4.2.3.2), may easily affect the adjacent tendon causing weakness and dysfunction (3.1.2). RCD is also highly correlated to biceps tendinopathy, usually the long head, which has a role in stabilising the humeral head in the glenoid fossa to prevent reduced sub-acromial space (Mansfield and Neumann 2019c, Yeşilyaprap 2020).
In clinical literature and practice, supraspinatus tendinopathy is the most common rotator cuff pathological finding and patient complaint (Walker-Bone et al. 2004, Roberts et al. 2007, Greiner et al. 2019, Loew et al. 2019). Although sub-clinical tendinopathy can be found via medical imaging even when there is no pain, and patient reports of pain do not always correlate with objective disease process (Jurmain 1999, Loew et al. 2019). RCD has been discussed in palaeopathological literature as the main aetiological factor in developing GH and AC DJC. EC at the rotator cuff insertions (pitting and bone formation) have also been considered diagnostic in palaeopathology for RCD (Waldron 2009, 2019). AC DJC is far more common in palaeopathology than GH DJC and this is true in these Scottish populations (Roberts et al. 2007, Williams et al. 2018). EC at the subscapularis is far more common than EC of the supra/infraspinatus (Appendix 4, Table 49), despite clinical presentation of RCD.

This phenomenon was explained by Roberts and colleagues (2007) who found correlations between GH DJC, bicipital groove degeneration, and EC at the subscapularis then proposed these traits as a potential disease progression for RCD. Roberts et al. also found no suggestion that AC DJC was directly involved in RCD progression, despite the high prevalence in palaeopathology, and suggested that it may be more related to age and degeneration than RCD. Biomechanical forces in the AC joint are transferred across the joint rather than in multiple directions like the GH so the findings of Roberts et.al. are consistent with kinesiological understanding of the shoulder joint (4.2.3.2). Taken together, these findings suggest that subscapularis is more frequently involved in RCD than previously understood (Roberts et al. 2007).

This research supports the results obtained by Roberts and colleagues (2007) that suggests subscapularis may be more frequently involved in RCD progression than supra/infraspinatus. If this is true, then subscapularis EC may be an indicator of early RCD that might be identified in young and middle adults which may then indicate activity.

6.3.2 The Elbow, Forearm, and Wrist

EC at the elbow and wrist, performing both flexion/extension and pronation/supination were all positively correlated with advanced age which suggests they may be slightly more associated with degenerative processes than those of the shoulder and possibly less indicative of activity (Appendix 4, Table 50). Flexion/extension related EC were more common in younger age groups reflecting use earlier in life, however both CEO and
CFO were uncommon in younger groups and increased in the 40-49 and over 50 years of age groups suggesting a more degenerative development process at those EC.

Females had higher rates of DJC at the right elbow and right wrist but with so few cases not even cautious conclusions can be drawn. There was also no association between EC and DJC around the elbow, so it is unlikely there is any shared aetiological process other than age related degeneration.

Females had higher rates bilaterally for all elbow EC except the biceps brachii and left CEO which may indicate some gendered difference in activity (Appendix 4, Table 51). It is possible that the higher shoulder use in males, and the potential involvement of the proximal biceps brachii tendon in RCD, could be seen in development of EC at the distal biceps brachii insertion in males. Overhead movements in males may also be related to lifting loads above shoulder level which does require elbow flexion using the biceps brachii. Before an object can be lifted above the head it must be lifted using flexion of the elbow (Mansfield and Neumann 2019b). Complex aetiological factors such as hormones aside, and if only considering biomechanical forces, females appear to have been using the smaller elbow and wrist functional complexes more frequently than males.

Females had the only significant EC asymmetry for any elbow or wrist EC at the triceps brachii. Overall females were more asymmetrical around the elbow which indicates more unimanual activity in females than males. Females had higher right-bias single individual asymmetry which was influenced primarily by EC at elbow. This contrasts with CSG asymmetry where males were slightly more asymmetrical. Taken together this suggests that females performed more bimanual but asymmetrical activities at the elbow and wrist. Male activities are not quite as clear as they were slightly more asymmetrical for robusticity but more symmetrical for EC. CSG robusticity is more reflective of use earlier in life while EC are more reflective of cumulative, repetitive, and degenerative use throughout the lifecycle (3.2). This may mean that females’ labour was more bimanual at younger ages and grew more unimanual or specialised with time. Males were opposite with more unimanual use in youth and young adulthood but then grew more bimanual with age. CSG and EC asymmetry give different but equally valuable glimpses of past activity and gendered divisions of labour.

Measures of CSG robusticity (J and TA) were non-random for females at the bilateral elbow (flexion/extension) when compared to EC. There was no significance for the wrist (CEO/CFO) when compared to CSG measures (6.4.2). This suggests that flexion/extension at
the elbow for females in this population may affect robusticity at the mid-distal slice location. The highest prevalence in female elbow EC was at the triceps brachii which suggests that extension had the most influence in this case. It is an oversimplification, however, to exclude the complexities of movement at the elbow/wrist joint complexes. There may also be some unrelated reason, such as genetics or hormones, that females developed high prevalence of EC at the triceps brachii. While not within the scope of this study, it is not outside the realm of possibility to suggest that elbow and forearm movement may have more effect on distal CSG robusticity and large overhead movements at the shoulder may have more influence on proximal CSG robusticity.

Agonist/antagonist patterns at the elbow (flexion/extension) were nearly equal between females and males. For the elbow, female ratios were 1.6 and 1.5 on the right and left respectively while males were 1.5 on the right and 1.5 on the left. The three entheses of the elbow may be of limited use in determining activity due to variations in anatomy at the enthesis (4.2.3.3) which could be one reason why this measure does not support previous conclusions of gendered allocations of labour.

Tendon rupture is the most reported clinical injury involving the distal biceps brachii but is considered quite rare (Robinson 2017). Acute rupture tends to be reported in middle aged men after an unexpected and forceful elbow extension which causes an eccentric contraction (while lengthening) of the biceps brachii such as catching a heavy fallen object. (Robinson 2017, Ayhan and Ayhan 2020b). Chronic overuse of the biceps brachii may also predispose an individual to rupture (Ayhan and Ayhan 2020b). It is doubtful that EC at the elbow will be helpfully associated with any specific clinical condition. Chronic overuse injuries of the biceps brachii are most commonly found at the proximal (long head) tendon and appear to be more related to RCD and shoulder instability (Porterfield and DeRosa 2003a, Mansfield and Neumann 2019c)

Agonist/antagonist ratios for the CEO/CFO show similar patterns to the shoulder in that males have higher ratios than females, but both had higher rates on the left which is opposite from the shoulder ratios. Females had 2.2 on the right and 3.0 on the left and the male ratio was 3.4 on the right and 5.1 on the left.

This ratio of CEO/CFO is the only one that has been studied within bioarchaeological literature as a population ratio and not within individual scores, although even that research is limited (Henderson 2015, Henderson et al. 2018). Villotte and Knüsel (2014) found a
reversed ratio pattern of less than 1 (.6) in males on the right side in a prehistoric population and associated this with unilateral ‘throwing’ movements. This effect was most notable when medial epicondylitis (CFO) was present but absent from the lateral epicondyle (CEO) as the presence of both did not indicate throwing movements (Villotte and Knüsel 2014).

The most frequent complaints in clinical literature related to these entheses is medial and lateral epicondylitis, with lateral being more common (Greiner et al. 2019). Current consensus is that tissue degeneration due to repetitive microtrauma, decreased vascularisation, and impaired healing is the primary mechanism, and not inflammation (Robinson 2017, Mansfield and Neumann 2019b, Ayhan and Ayhan 2020b). Some scholars have begun to use epicondylalgia, which refers to pain at the epicondyle, instead (Mansfield and Neumann 2019b).

Medial epicondylitis and an injury or rupture to the medial collateral ligament (MCL) of the elbow are two distinct but frequently co-occurring conditions (Robinson 2017, Ayhan and Ayhan 2020b). Both are associated with repetitive use in throwing athletes such as baseball pitchers, from repeated activation of the wrist flexors and gripping, such as rock climbers. (Robinson 2017, Mansfield and Neumann 2019b, 2019e, Polet et al. 2019, Ayhan and Ayhan 2020b). The MCL can be damaged in acute injury such as attempting to catch oneself during a fall (Mansfield and Neumann 2019b). Both conditions can predispose an individual to developing lateral epicondylitis (Ayhan and Ayhan 2020b).

Common causes of lateral epicondylitis are from repetitive use such as rotation of the forearm and from grasping objects with the hand (Mansfield and Neumann 2019e, Ayhan and Ayhan 2020b). The extensor digitorum communis and extensor digiti minimi muscles, which are part of the CEO, extend across the dorsal hand and fingers and perform finger and hand extension (4.2.3.3)(Mansfield and Neumann 2019f). A main function of the extensor group, apart from extension, is to stabilise the wrist for activities involving the fingers. The flexors of the forearm and hand are stronger so the extensors, as a group, contract every time to maintain the wrist in a neutral position and to prevent extreme flexion (Mansfield and Neumann 2019e). If the wrist is flexed the grip strength is weaker than in a neutral position (Figure 120).
The muscles of the CFO and CEO also perform radial and ulnar deviation which, along with flexion and extension allow movement of the hand and wrist in all planes of movement (Mansfield and Neumann 2019f). The activity of hammering, for instance, requires the radial deviators (flexor carpi radialis and extensor carpi radialis longus/brevis) to engage when lifting the hammer up (Figure 121, A). The ulnar deviators (flexor carpi ulnaris and extensor carpi ulnaris) activate when the hammer comes down onto a nail (Figure 121, B) (Mansfield and Neumann 2019e).
Fine motor movements of the forearm and hand, especially grasping, hammering, and use of the fingers are associated with lateral epicondylitis. Both females and males in this study were performing this sort of activity but males slightly more than females. The left bias for both sexes points to an asymmetrical activity such as grasping and holding an object with the left hand while manipulating it with the right hand.

This supports the CSG results in that both sexes had a left side bias in measures of robusticity which is consistent with bimanual but asymmetrical activities that use the non-dominant hand to provide the power and the dominant arm to direct and refine that power (6.1.2.3). Female CSG robusticity measures were more symmetrical (with a higher left bias) than males indicating more bimanual but asymmetrical activities. Female ratios indicate some amount of grasping and holding with the left hand and manipulating with the right, but both hands were used near equally. Male CSG robusticity measures were less symmetrical indicating more unimanual activities. Male ratios also indicate more asymmetrical activities and much of this was grasping and holding with the left hand while manipulating with the right.

6.3.3 The Spine and Lower Body

EC related to the spine are not typically used in the study of activity and none were recorded in this study. DJC of the spinal segments were not significantly different between
females and males although males did have higher rates especially in the thoracic segment (6.1.2.2). It is interesting to note that RCD and imbalance can predispose an individual to poor posture via weakened external rotators (infraspinatus) leading to further instability and injury (Mansfield and Neumann 2019c). The opposite is also true in that poor posture leads to contracted anterior rotator cuff (subscapularis) and weak posterior rotator cuff (infraspinatus and teres minor) (Mansfield and Neumann 2019c). More detail might be gleaned from this data comparing posture to spinal DJC and shoulder EC, but that was outside the scope of this project.

Worth noting is the high rate of lumber DJC in females in Leith which may be explained by the fishing trade in the port Burghs (6.2.2.2). Historical accounts of ‘fishwives’ come mostly from the early modern post-industrial period, but traditional fishing villages maintained their unique culture and practices well into the 20th century (Gauldie 1995, Derevenski 2000, Probyn 2020). The Scottish fishwives were some of the hardest working women of the time and were responsible for gutting fish, hauling nets, and reportedly carrying their husbands out to sea to save the men the discomfort (and real danger) of being wet and cold on a fishing boat (Probyn 2020). In earlier times, their work would also have included carrying the fish from the coasts to the inland markets. The fishwives used large characteristic double baskets with straps that went around the shoulders or around the forehead (Figure 122).
In Derevenski’s (2000) work on DJC from the Isle of Ensay, Scotland (discussed at length in section 6.1.2.2), women used a similar basket, called a *creel*, to haul peat. The study from Ensay found higher rates of lumbar osteophytosis and thoracic facet DJC in females than males. The author attributed this pattern in the spines of Ensay females to use of the *creel*. It is entirely possible that women in the Leith Burgh group developed lumbar DJC from hauling fish to market or from carrying their husbands out to sea.

EC of the lower body were also not helpful in inferring activity (Appendix 4, Table 49). Neither the hamstring group origin on the ischial tuberosity or the insertion of the calcaneal tendon on the calcaneus were correlated with DJC (6.4.1). Cases of DJC at the hip were unremarkable with females and males displaying equal prevalence on the right side and
males slightly more on the left (Table 15). Cases at the knee and ankle were so infrequent no conclusions could be drawn.

6.3.4 Summary

Males showed more use of hand and forearm in inland and high-status Burgh groups which points to more specialised activities and higher social status (Figure 123, A). The males were also lifting and carrying heavier loads and working at or above shoulder level but doing so in Burghs with ports and outside of high-status Old Town Edinburgh (Figure 123, B). Males were performing more asymmetrical and unimanual movements, grasping and holding objects with the left hand while performing fine manipulations with the right, which is also consistent with specialisation (Figure 123, C and D).

![Figure 123 Possible Male Activities](image)

A) Sedentary unimanual activity of a cleric, scholar, or magistrate. B) Unimanual heavy labour above the level of the shoulders with most of the load on the non-dominant side. This would also have involved lifting and throwing movements. C) and D) Unimanual use of the dominant arm above shoulder level while grasping objects with the hands. (Source: author.)

All Scottish Burghs had a wide range of roles, occupations, and social status and no definitive lines can be drawn but men in inland Burghs, especially that of higher status Old Town Edinburgh, were more likely to be apprentices, craftsmen, merchants, clergy, or government professionals. There would have been more access to education and training in the larger, more affluent Burghs which would have meant lower levels of manual labour and more specialised occupations or crafts. Outside of Old Town Edinburgh and in Burghs with large shipping ports, the rest of the men probably made their living through heavy manual
labour by lifting, carrying, pushing, pulling, and grasping. Even with performing more manual labour, these men were still more specialised and unimanual in their work than the women.

Females in Scotland performed overall more bimanual, but asymmetrical, activities that focused on the elbow and forearm. These activities placed more load on the non-dominant arm, leaving the dominant arm and hand free for other tasks (Figure 124, B and C) or to direct the movement with more precision (Figure 124, D). This was evident across Burgh groups, including those of higher status. This suggests women’s activities were more consistent and less affected by social status or by inland/port economies than males. At the same time, females had a wider variety of activities and were less specialised than males. Females worked at least as hard as males, but with their smaller frames showed more evidence of manual labour. They were also lifting, pushing, pulling, and grasping, but this rarely went above shoulder height (Figure 124, A).

**Figure 124 Possible Female Activities**
A) Bimanual labour below shoulder level which would stress the elbows more than the shoulders and grasping objects with the hands. B) and C) Bimanual activity with most of the load on the non-dominant side leaving the dominant side free for other tasks. D) Bimanual but asymmetrical activity with most of the loading on the non-dominant arm while the dominant arm directs the movement. (Source: author.)

History shows that women were responsible for their families and household. They brewed ale, cared for children, and went to market but they also contributed to their husband’s business or craft (2.4). Women functioned as middle managers, shopkeepers, and developed expertise in craft and business. Women were also more likely to drastically change their professional roles throughout the life cycle. They would be taught domestic duties and their father’s business, then upon marriage they would be responsible for learning their new husband’s work. Many carried on a husband’s business upon his death, but then would have
to retrain upon a second marriage. While some higher status women had access to
education, it was uncommon among women leading them to earn with their labour more
often than men.

This research supports the historical records of hardworking people in medieval
Scottish Burghs with notable gendered allocations of labour. Men had more specialised work,
craft, and business and some enjoyed the benefits of higher social status. Women’s work was
broad and varied but consistent, suggesting that they did not enjoy the same social status
benefits as men. By shining a light on women’s labour and economic contribution, this thesis
adds to the growing body of feminist history and archaeology that shifts the perception of
women in the past from invisible, passive players to one of agency and value.

6.4 Method Comparison and Repeatability

6.4.1 Enthesear Changes and Degenerative Joint Changes

EC and DJC are both frequently used to infer activity within archaeological
populations despite the many limitations and recommended cautions (Crubézy et al. 2002,
2014, Becker 2016a, Alves Cardoso and Assis 2021). As both EC and DJC are positively
correlated with age, this analysis was limited to only individuals under 50 years of age.
However, DJC prevalence in this population was positively correlated with increasing age
even in the younger and middle adults (6.1.2.2).

Females showed no significant association at any joint, while males did for the
combined shoulder, the GH, and the AC on the right side (Tables 38 and 39). These results
indicate that for males at the right shoulder only, EC and DJC are not independent. This
suggests a relationship between these two markers of activity for males at the right shoulder,
but otherwise there does not appear to be any correlation between the two markers. It is
likely that comparisons between EC and DJC were hampered by small DJC sample sizes when
subdivided by joint and sex. The prevalence rates for shoulder DJC ranged from 12-20% in
females and 22-37% in males.

EC were in every case more frequently observed than DJC for all joints, but the
patterns were different between them. This is consistent with there being different causative
factors between EC and DJC such as type of force or variations in individual physiology or
genetics. Similar results were seen in one comparable study from 19th century England exploring occupational mobility in females, skilled workers, and farmers (Henderson et al. 2013a). This is the only study which used a comparable EC scoring method because only fibrocartilaginous enthesis were included (Villotte 2013, Henderson et al. 2016a, 2016b). This study suggested that due to variations in patterns of EC and DJC between occupation group, sex, and side, that each has differing causative factors (Henderson et al. 2013a).

Other studies have found some correlation between EC and DJC, but many used non-comparable EC scoring methods. Molnar (2011) found a positive relationship between EC and DJC but suggested that there was no direct link. This study measured MSM via mean robusticity score and made no distinction between fibrous and fibrocartilaginous entheses (Hawkey and Merbs 1995, Molnar et al. 2011). According to Schrader (2012), males had higher rates of both EC and DJC than females, but there was no single individual correlation between the two methods. A study from the Netherlands found only a weak correlation between OA and EC and suggested that they may be markers of different types of activity with differing aetiologies (Palmer et al. 2014). One recent study by Alves-Cardoso and Assis (2021) also failed to find patterns of EC or OA within occupation groups in an identified collection. The authors suggested that continuous and repetitive forces may be more likely to induce EC rather than DJC which is more linked to individual genetics and physiology. The results of that study supports the idea that EC and DJC have different causative factors (Alves Cardoso and Assis 2021).

The relationship between EC and DJC for males at the right shoulder in this study may be explained by rotator cuff disease (RCD) (6.3.1). In bioarchaeology, DJC at the shoulder joint, both GH and AC, has been considered bony evidence of advanced rotator cuff disease (Waldron 2009, 2019). With high asymmetry of EC and DJC in males, and with a marked right-side bias, this lends evidence to support the presence of RCD in males in this population. Similar disease processes occur at other joints, however, and more detailed information is needed to draw other conclusions.

6.4.2 Enthesal Changes and Cross-sectional Geometry

EC have often been used alongside measures of CSG to infer activity in past populations (Weiss 2003, Niinimäki 2012, Ibáñez-Gimeno et al. 2013, Nikita et al. 2019, Sparacello et al. 2020, Varalli et al. 2020, Kubicka and Myszka 2020, Laffranchi et al. 2020). In
the Scottish population, there was evidence of a non-random relationship for diaphyseal shape (I-ratio) at the left shoulder in males but not the right (Table 40). While statistically significant, the small sample sizes make this a weak correlation at best. This result suggests that muscular movements of the shoulder might have some effect on the diaphyseal shape at the mid-distal location. Interpretations of shape often consider movement within a plane (e.g., anterior/posterior, multidirectional). As all soft tissue of the shoulder is required to stabilise and move the arm in various directions, a relationship between them and shape seems a logical conclusion. It is surprising, however, that there is no relationship between these in males on the right side. With the left-bias asymmetry in males for both EC and CSG in this population, it could be that use of the non-dominant arm, either through stabilisation or imprecise forceful movement, is affecting the diaphyseal shape. Due to the difficulty in interpreting I-ratio at the mid-distal location, few comparative studies are available. Many researchers only study robusticity at 35% and reserve I-ratio to the mid-shaft, use only the mid-shaft, or use only robusticity (Trinkaus et al. 1994, Niinimäki 2012, Macintosh et al. 2014, 2017, Sparacello et al. 2017, 2020, Nikita et al. 2019, Varalli et al. 2020, Laffranchi et al. 2020).

Kubicka and Myszka (2020) found that I-ratios at 35% of the humerus (I_{max}/I_{min} and I_x/I_y) were not significant predictors for EC. They used the Mariotti and colleagues’ (2007) method to score EC, and then combined EC scores from the shoulder and elbow into a mean robusticity score (MRS) and a mean variables score (MVS) which included robusticity, proliferative, and osteolytic changes at the enthesis. The difference in EC scoring and pooling of both shoulder and elbow EC in Kubicka and Myszka (2020) does not make it directly comparable.

Michopoulou and colleagues (2015) compared three methods of scoring EC to CSG measures in males and did find a relationship between I_x/I_y (but not I_{max}/I_{min}) only with the teres minor. The two methods used are based in enthesis robusticity also not directly comparable (Hawkey and Merbs 1995, Mariotti et al. 2007). Michopoulou and colleagues (2015) do not state if the I-ratios were taken at 35%, but a follow-up study by the same authors states that slices were taken at 35%, so this was the assumption (Michopoulou et al. 2016). That subsequent study on males by Michopoulou and colleagues (2016) compared the individual traits of the new Coimbra Method only to subscapularis and biceps brachii. The authors found a correlation again for I_x/I_y (but not I_{max}/I_{min}) for cavitation at the left
subscapularis and fine porosity at the right subscapularis. There was also correlation between $l_x/l_y$ and fine porosity for the left biceps brachii and $l_{\text{max}}/l_{\text{min}}$ and cavitation on the right biceps brachii (Michopoulou et al. 2016).

As raw data were not available for the comparable studies, there is no way to know if the I-ratios that correlated to EC indicated a more circular or more ovoid/triangular shape. This information may help to draw more precise conclusions as to the movements and muscles that may affect the diaphyseal shape. At this point it can only be said that there may be a relationship between certain EC and diaphyseal shape. It may also be true that the diaphyseal shape at 35% is simply a poor predictor for any EC trait or location.

In the Scottish female population, there was a correlation between measures of robusticity ($J$ and $TA$) and EC at the elbow bilaterally (Table 40). These results suggest a potential shared aetiology for elbow EC and diaphyseal robusticity at the mid-distal humerus. As there were no correlations between CSG robusticity and EC for males, and no correlations between EC and I-ratio in females, this may be further evidence of a gendered division of labour. It is also possible that other sex differences such as hormonal development or age affected the results which may be uncovered with future research.

Most studies that employ both EC and CSG focus on measures of robusticity so there are more comparable studies. However, variation in EC scoring methods and in CSG robusticity measures posed a challenge to finding good comparative data. There are no studies available that compared the mid-distal cross section (35%) to elbow EC, but some compared the CEO and/or CFO and used a comparable EC scoring method (Villotte 2013). Varalli and colleagues (2020) found that individuals with higher EC scores were not consistently more robust, but that CSG asymmetry corresponded with EC asymmetry. This led the authors to suggest that although they failed to find a consistent association, there appears to be a general correspondence between the two markers of activity (Varalli et al. 2020). In a similar study, Sparacello and colleagues (2020) found no correspondence on an individual level, but also suggests that investigating bilateral asymmetry with both EC and CSG may be a way forward. The authors found that EC indicated unimanual activity but that CSG were more indicative of bimanual activity (Sparacello et al. 2020).

Nikita and colleagues (2019) came to the opposite conclusion when examining the microarchitecture of entheses at the shoulder compared to five slice locations on the humerus. Very few correlations were found between EC traits of roughness and reabsorption
and total area (TA). The authors expected more right-side correlations but found more left-side and suggested that EC were not an effective measure of activity. The authors do suggest, however, that there may be differing forces or aetiologies at play (Nikita et al. 2019).

One study found some correlation between EC of the shoulder with CSG properties and the mid-proximal (75%) humerus. Ibáñez-Gimeno and colleagues (2013) used a graded EC scoring method similar to Hawkey and Merbs, and found significant correlations for teres major, pectoralis major, deltoid, triceps brachii, and biceps brachii with cortical area (CA). This study also found that humeri with greater robusticity had more developed EC which is counter to the more recent studies. This is most likely because of the EC scoring method, however, as enthesis robusticity scores often correlate to greater body size and often with being male (Weiss 2003, Molnar 2006, Villotte et al. 2010a, Santana-Cabrera et al. 2015). The inclusion of pectoralis major and deltoid as fibrous enthesis may also have clouded the results and makes this less comparable to the Scottish study (Molnar 2006, Henderson 2008, Cardoso and Henderson 2010, Villotte et al. 2010a).

The study by Kubicka and Myszka (2020) used robusticity-based EC measures and proposed that EC scores should be standardised to body size similar to CSG. This problem could be solved by using an EC scoring method that does not include overall robusticity or by simplifying to a binary (present/absent) system (Villotte et al. 2010a, Villotte 2013, Henderson et al. 2016b, 2016a).

One concept agreed upon by most researchers who have compared CSG to EC is that both have different patterns and complex multifactorial aetiologies. CSG robusticity measures are affected by ontogenetic variables in adolescence whereas EC are far more strongly correlated with increasing age (Rhodes and Knüsel 2005, Shaw and Stock 2009a, Villotte et al. 2010a, Milella et al. 2012, Henderson et al. 2013a, Miller et al. 2018, Sparacello et al. 2020, Varalli et al. 2020). Age, sex, hormones, body size, and genetics are all confounding factors for both EC and CSG. Kubicka and Myszka (2020) suggested differing levels of mechanical stimuli and Michopoulou and colleagues (2016) suggested a high peak strain vs routine mechanical loading to account for differences between EC and CSG. Degree, repetition, and direction of mechanical loading are all variables in both EC and CSG development and largely unknown in archaeological populations (Niinimäki 2012, Ibáñez-Gimeno et al. 2013, Kubicka and Myszka 2020, Laffranchi et al. 2020).
The correlation for females in the Scottish population between EC and CSG at both elbows suggests that muscles at the elbow that perform flexion and extension may have some effect on robusticity at the mid-distal (35%) location. The different patterns between EC and CSG robusticity measures in this study support the recent evidence that the two methods capture different patterns of activity and have differing aetiologies, and more research is needed in the future. A detailed individual assessment employing as many methods as possible may provide some clarity.

6.4.3 Cross-sectional Geometry and Degenerative Joint Changes

Measures of CSG and DJC are not typically used together to study activity in bioarchaeology and there are no directly comparable studies. Because of the low number of cases of DJC in the small CSG bilateral group, the analysis was restricted to only the shoulder and elbow (Table 41). Small sample sizes meant that this could not be fully tested, but where this was possible there were no significant correlations at either the shoulder or elbow between DJC and any CSG measure. There appears to be no corresponding relationship between the two methods and there is little value in comparing them directly, especially with this small sample of 23 individuals. It may be possible that a large sample may eventually show some correlation, but that is doubtful. As DJC is rarely used to study activity today and CSG is considered far more valuable, there is little benefit to directly comparing DJC and CSG in studies of activity.

6.4.4 Enthesal Change Repeatability

Interobserver scores were on average lower than intraobserver, and as expected percent agreement was higher than Kappa scores (Tables 42 and 43). Cohen’s Kappa score evaluates the probability for random chance in agreement and functions as a more robust measure than simple percent agreement (Sim and Wright 2005, McHugh 2012, Glen 2020). Kappa scores ranged from ‘moderate,’ ‘substantial,’ and ‘near perfect’ agreement for interobserver and intraobserver scores were primarily ‘substantial’ with two reaching ‘near perfect’ agreement (Sim and Wright 2005, Glen 2020).

These scores fall well within similar ranges for other comparable studies although varying methodologies make direct comparison difficult. Henderson and colleagues’ (2013b)
interobserver error for the common extensor had a percent agreement of 75.4%, while this study was 67.4%. The biceps brachii was 72.9% compared to 78.3% in this study. Wilczak and colleagues (2017) scored all traits over both zones but had comparable ranges. Pooled trait interobserver percent agreements ranged from 68.6% to 80.0% while the intra observer agreement was 79.3%. In this study, interobserver ranged from 67.4% (common extensor) to 91.3% (supraspinatus) and intraobserver from 76.1% (brachialis) to 91.3% (supra- and infraspinatus).

6.5 Limitations

Data collection was primarily performed in relative comfort in lab space at the School of History, Classics, and Archaeology at the University of Edinburgh, but data was also collected at three different museums. On site data collection environments were variable with small tables or poor lighting which may have had a small effect on the quality of observation. Efforts were made to supplement with portable lighting where possible. All materials and supplies for data collection had to be carried on foot and public transport. Similarly, 3D equipment (camera, turntable, power cords, and large laptop) needed to be transported across the University campus for work in the Archaeology labs or carried to a research site. Despite these imitations, repeatability was high (6.4.4).

With an average inclusion rate of 22% per collection (Table 2) the sampled material may not be wholly representative of the entire skeletal collection. In many cases only a portion of a cemetery is fully excavated and made available for further study. For example, the Constitution St collection was excavated in two phases and only phase one is included in this study (4.1.1.5). Whitefriars Perth (4.1.2.3) and St Andrews (4.1.4) collections were also excavated in phases and parts of the population are now stored at the University of Aberdeen and were unavailable at the time of study. A single collection may not be a true representation of the cemetery, however, that is a common issue in bioarchaeology, and ultimately, researchers have to work with what is available (Pinhasi and Bourbou 2007). Lastly, one cemetery is not always an accurate representation of a living population either geographically or throughout the span of time a cemetery was in use (Pinhasi and Bourbou 2007, Jackes 2011). Migration, change in religious or social status, war, plague, or famine, are
only a few examples of changes that can occur that may affect where a body is buried (Jackes 2011).

All palaeoepidemiological research is subject to the factors of frailty and selective mortality, and the variation of these two factors within a given population are virtually unknown in bioarchaeology (Wood et al. 1992, DeWitte and Stojanowski 2015, Buikstra and DeWitte 2019). Certain individuals may succumb to death at a faster rate than those with more robust health and it is those that are most frail that are more likely to become part of a skeletal collection and hence be studied by bioarchaeologists (Wood et al. 1992, Buikstra and DeWitte 2019). The absence of disease or pathology does not always indicate a healthy population, and severe disease may indicate a healthier person who lived longer with a condition before death (Wood et al. 1992). This concept is known as the ‘osteological paradox’ in bioarchaeology (Wood et al. 1992, DeWitte and Stojanowski 2015). This paradox must be considered in any interpretation, even that of activity and functional adaptation. Healthier individuals may be capable of working harder and thus show more evidence of adaptation, but for a frail individual, even light labour may be strenuous and effect similar bony changes.

The sample size for CSG analysis of 3D scans was further narrowed due to the requirement of an intact humerus. Some collections are not represented in the CSG analysis at all, and some only by a single individual. All these factors are common in bioarchaeology and are accepted limitations within the field, the effects of which continue to be debated. Nonetheless, these limitations need to be mentioned and discussed.

While there are some limitations on sex estimation, it is age estimation that remains more variable and the various causative factors not well understood (Buckberry and Chamberlain 2002, Pinhasi and Bourbou 2007, Falys and Lewis 2011, Milella et al. 2020). Limitations posed by this were addressed by applying one age estimation method across all samples which was applied by a single consistent observer (Buckberry and Chamberlain 2002). The methods used here to pool individuals into age group categories are also a variable which may limit comparability to other studies that select different age categories or use other methods of estimation.

One notable limitation to this study is the statistical analyses applied here. The complexity and intricate detail involved when incorporating multiple methodologies could only be addressed by pooling much of the data and potentially obscuring valuable attributes.
within smaller data sets. This study was plagued by small sample sizes from the average of 20% inclusion in the study (Table 2), to the multiple individual entheses and joints, to the division of the data into age, sex, and Burgh groups. Time constraints and lack availability of resources during the COVID-19 pandemic meant that other statistical analyses such as cluster or principal component analysis or ANOVA could not be performed which may have limited the results and interpretations. The small sample sizes and non-normal distribution frequently limited the analyses to non-parametric tests, thereby reducing the statistical power of the analysis. These limitations could be addressed with future research on this data set.

When EC are utilised in the study of activity, age-related degeneration is a key limitation that must be addressed. Restricting much of the EC analysis to individuals aged at under 50 years partially addresses this issue but has the effect of limiting the data set to smaller sample sizes. The use of age categories, and within-individual analyses like asymmetry and agonist/antagonist ratios which do not need to be controlled for age also address this limitation. Tissue degeneration and inflammation associated with aging is an ongoing process and is highly variable between individuals. Genetics, health history, trauma, and diet are only some of the variables that can affect aging and are often unknown factors in bioarchaeology.

Fibrocartilaginous entheses commonly used in studies of EC vary in the enthesis organ anatomy at the histological level which is one factor in the rate and degree of development of EC and adaptations to force (Shaw and Benjamin 2007, Alves Cardoso and Assis 2021). All associated muscles used in EC studies are not equally used in movement and muscle recruitment, with some representing prime movers and others acting as synergists, stabilisers, and force couplers. In a healthy person the nervous system selects the precise number of muscle spindle cells which produce the force needed for a particular movement. In the case of neurological diseases, changes in proprioception, injuries, or tissue degeneration this muscle recruitment process is affected leading to even more variation which is impossible to discern on dry bone. Recording EC at a common attachment site (common flexors/extensors) may obscure the understanding of the full movement of the associated muscles. All these kinesiological variables are obscured when only using the single enthesis and must be considered in analysis and interpretation. This complexity was partially addressed in this thesis using functional complexes in parts of the analysis.
EC at the brachialis, biceps brachii, and triceps brachii may be of limited use in determining activity due to the individual anatomy of the entheses. The biceps brachii insertion contains a bursa and is split into superficial and deep region. The anatomy varies and can containing between one and nine tendonous bands of fibre (Benjamin et al. 1992, Nolte and Wilczak 2013, Villotte and Knüsel 2013). It is unknown to what degree bursitis or muscle use affect development of EC (Villotte and Knüsel 2013, Sparacello et al. 2020). EC at the biceps brachii insertion on the radius also appear to be more randomly distributed in archaeological populations when compared to those of the humerus which are more reliable indicators of activity (Villotte 2019). The brachialis may be an unreliable indicator possibly due to the relatively thin uncalcified fibrocartilage layer and the lack of clarity around determining the new Coimbra Method’s Zone 1 and Zone 2 at this location (Benjamin et al. 1992, Villotte 2013, Villotte and Knüsel 2013). Some researchers are no longer including the brachialis in their studies of EC (Perez-Arzak et al. 2022). There is also some debate as to the Zone locations at the triceps brachii and, while frequently scored by researchers it is not often discussed in the various methods (Villotte 2013, Henderson et al. 2016b, 2016a).

Osteologists are inherently limited to those entheses which leave a discernible bony landmark, so many soft tissue sites on bone that might be especially helpful in discerning behaviour cannot be observed nor utilised in any sizable population study. While some methods of using technology such as 3D scanning are being developed for some less discernible entheses, such as those of the intrinsic muscles of the hand on the carpals and metacarpals, access to this technology is limited (Karakostis and Lorenzo 2016, Karakostis and Harvati 2021). Low-tech morphological methods will always be more accessible to many researchers, especially students.

The new Coimbra Method has known limitations such as differences in observational conditions and in interpretations of the written descriptions (Henderson et al. 2016a). Individual anatomical variation can lead to errors in determining the extent and delineation of the two zones (Henderson et al. 2016a, 2016b). Some studies have shown little difference between the new Coimbra Method and simple robusticity scores when attempting to link EC to activity (Michopoulou et al. 2016, Palmer et al. 2019). However, as the research into the aetiology of EC continues, a method that records all the enthesis traits may prove to be the better choice.
The visual and morphological new Coimbra Method remains the most detailed and accessible method available, and the recording process is limited only by the access to proper training and the experience of the osteologist (Henderson et al. 2016a, 2016b). Many EC studies consider limitations of EC aetiology, pathology, and more recently knowledge of enthesis histological anatomy, but some approach without detailed knowledge of the soft tissue functional anatomy. With the knowledge of histology and kinesiology, the osteologist will be capable of a more thorough analysis and interpretation of EC and activity.

Repeatability studies were limited due to COVID-19 access restrictions at the University building and on travel. Both Intra- and Interobserver scoring could only be performed on whatever skeletal remains were on site at the University before restrictions began. Part of Blackfriars, which were on loan, and St Andrew’s Library and Whitefriars, both of which are curated by the University, were available. A total of 46 individuals were attainable on all three access days for repeatability scoring. Because time was extremely limited, the decision was made to only score the upper body entheses as these were most crucial to this project.

While every effort was made to conform to the details of the new Coimbra Method, it is highly likely that both sets of scores were affected by time constraints and observer fatigue. According to the method, the observer should take frequent breaks to prevent fatigue (Henderson et al. 2016b, 2016a). Intraobserver scores were completed in two visits of three hours each while interobserver scores (which required train travel) were collected in one day over five hours and without any significant breaks. One of the observers wears glasses and was struggling to keep them from fogging up while wearing a facemask which caused additional frustration. Although repeatability was high, it is entirely possible that without the limitations posed by COVID-19, both the Inter- and Intraobserver scoring may have been more accurate, leading to higher percent agreement and Cohen’s Kappa scores.

Initial lockdowns due to COVID-19 in 2020 caused delays to the processing and analysis of all 3D scans and data. University support staff with expertise in 3D technology were unavailable to students and the resources were entirely devoted to 3D printing protective gear for NHS providers and staff. Processing of all 3D scans and CSG data analysis were not performed until approximately 6 months after all other analyses had been completed. CSG data are therefore not directly included in the analyses on location, Burgh
group, and social status, but every effort has been made to include the CSG results in the larger discussion.

Osteological methods which are based in morphological observation are subject to similar limitations and depend on the experience of the observer in using the method as well as basic osteological experience to understand what traits fall within normal variation (Brooks and Suchey 1990a, Buckberry and Chamberlain 2002, Mulhern and Jones 2005, Cheverko and Hubbe 2017). When viewed in context with other repeatability studies on entheseal changes and when compared to average agreements for other morphological methods, both the percent agreement and Cohen’s Kappa scores in this study indicate a reliable EC data set.

Limitations around the use of DJC and OA are numerous and have been well considered by previous researchers (Jurmain 1999, Roberts and Manchester 2010a, Larsen 2015a, Waldron 2019). Variation in recording protocols such as a binary presence/absence or scores of severity limit comparability. Pooling a simple binary score into functional complexes can obscure details of joint surfaces which may give a more detailed analysis such as DJC of the AC and GH joints, for example. With the incorporation of clinical research into the aetiology of OA, the ways in which palaeopathologists make use of DJC and OA is changing. It is now well understood in the field that DJC and OA are not reliable methods for determining biomechanical activity, however, it was included in this study to increase comparability to previous research and to EC and CSG.

Aside from the limitations to 3D surface scanning in relation to CT scans discussed previously (4.3), some additional differences may have affected comparability to previous CSG studies. All measurements used for calculations and standardisations in this analysis were obtained digitally from MeshLab and are far more precise when compared to standard methods such as osteometric boards or callipers. This may very slightly affect comparability with other similar studies that employed these standard analogue measurement techniques (O’Neill and Ruff 2004, Stock and Shaw 2007, Pomeroy 2013). 3D obtained measures are still relatively rare but as these technologies and metrics become more popular, using digital measurements may become more comparable into the future.

The slice location at 35% was selected for highest comparability to established literature, but multiple slices would have surely increased the data and may have yielded a more complete picture. Some research utilising the cortical area (CA) obtained via CT scan has indicated that the 35% location may be indicative of elbow use in the anterior-posterior
plane (Niinimäki et al. 2013). Another study which compared other measures of CSG (J, TA, and I-ratio), confirms that bone adaptation at 35% is associated with flexion and extension of the elbow (Rhodes and Knüsel 2005). Slices at 50-80% of the diaphysis may yield more information about shoulder movements.

There is a small limitation to this research which uses the I-ratio of \( \frac{I_{\text{max}}}{I_{\text{min}}} \) when comparing to studies which used \( \frac{I_x}{I_y} \) in that there is less data about the anatomical direction of asymmetrical presentation. Knowledge of the direction of bone modification could aid interpretation of limb use in activity analysis, however, relationships between the direction of bony modification and the association with specific movements or muscle use is not well understood. Some correlation has been found for measures of \( \frac{I_x}{I_y} \) of the femur and patterns of terrestrial mobility, with higher ratios (greater asymmetry in cross-section,) associated with movement in one plane and lower ratios (rounder shafts) with more varied movement (Shaw and Stock 2009a, Ruff and Larsen 2014). Higher \( \frac{I_x}{I_y} \) ratios of the humerus have been interpreted by some researchers to be evidence of anterior to posterior loading of the bone (Stock and Pfeiffer 2001, 2004, Ruff 2007, Ruff and Larsen 2014). Similar results, however, have also been found when using \( \frac{I_{\text{max}}}{I_{\text{min}}} \) measure which is less sensitive to anatomical orientation errors (Stock and Pfeiffer 2001). It is therefore debateable precisely how inaccurate the use of \( \frac{I_{\text{max}}}{I_{\text{min}}} \) over \( \frac{I_x}{I_y} \) is in analysis and the margin is likely to be small.

When CSG data have been collected using radiographs, latex/silicone moulding, or CT scans, the anatomical orientation has been assigned by the researcher (Stock 2002, Stock and Shaw 2007, Pomeroy 2013). Both radiographs and CT scans require the bone to be placed on a flat surface with anatomical direction determined by the radiographer, although the CT scanning process allows for more precise orientation when compared to radiographs (Ruff 2000, Rhodes and Knüsel 2005, Pomeroy 2013). In the casting method the cast is marked on the anterior side and the cut away from the bone on the medial side to ensure correct orientation (Stock and Pfeiffer 2001, Stock 2002, Stock and Shaw 2007). Some researchers have taken great care to orient a slice in reference to the distal axis of the humerus, but when a humerus with torsion is laid flat, orientation is less accurate (Ruff 2000, Rhodes and Knüsel 2005, Pomeroy 2013). Variations in methodologies are a potential limitation to comparability.

Standardisation formulae used in CSG studies in bioarchaeology are widely accepted but may pose some limitations when applied to populations with varying degrees of sexual
dimorphism. It may be that in groups with low dimorphism or other variables which affect size and stature such as poor diet and frequent disease, such as medieval Scotland, scores for females may be artificially inflated and scores for males decreased.

Human variation by way of genetics, hormones, disease, diet, or age of onset of menarche are all variable that can limit comparisons and results of CSG analysis. One way to control for some of these variables is by intra-populational analysis which is what was done in this case (Wescott and Cunningham 2006). As CSG measures are most affected by activity in youth and adolescence, one further unknown in archaeological populations is the age of onset of work or intense labour. History describes children and adolescents having work responsibilities and helping to support the household and young men and women were often apprenticed in the early ‘teenage’ years (2.3). Levels of manual labour frequently change throughout the lifecycle. An apprentice or craftsperson may perform more of the heavier labour in youth, but by advancing to ‘master craftsperson’ one’s work may be limited to supervisory or light roles, much like today.

An effort has been made here to address the complexities of kinesiology via muscle contraction, recruitment, and functional anatomy but a more detailed analysis was outside the scope of this project. Biomechanical variables such as velocity, intensity, frequency, repetition, and loading all affect tissue degeneration and bone adaptation and are limitations to any study on functional bone adaptation. To understand human activity and movement in the past a greater understanding of kinetics, kinematics, and kinesiology is essential. In the absence of this, interdisciplinary projects that include kinesiologists, physiotherapists, or physicians would be the best way to incorporate this perspective.
7. Conclusion

This thesis set out to discover evidence of functional adaptations in bone that were influenced by gender and social status in urban medieval Scotland (c. 800-1600 CE). It asked if Scottish women performed more varied but less strenuous manual labour than men, if those of lower social status performed more manual labour, and if people living in Burghs with major shipping ports displayed evidence of higher levels of manual labour. The study utilised three methods (entheseal changes (EC), degenerative joint disease (DJC), and cross-sectional geometry (CSG)), compared those methods for potential common aetiological processes, and then interpreted the results within their appropriate palaeopathological, sociohistorical, and clinical contexts. The analysis uncovered osteological evidence of a highly gendered society with variation in socioeconomic status through all five Burghs included in the study.

This work focused on the theme of social allocations of labour, particularly that of gender (as proxied by estimated sex). Work, craft, task, and occupation in urban medieval Scotland were discussed within the themes of light vs. heavy manual labour, specialisation vs general, and unimanual vs bimanual tasks. This conclusion highlights the key findings and offers suggestions for potential future research directions.

7.1 Do medieval Scottish women (estimated females) show evidence of lighter manual labour when compared to medieval Scottish men (estimated males)?

- Females had notably high robusticity measures for both Solid J and TA
- Males had high rates of DJC at the right shoulder
- Females had higher rates of DJC at the elbow and wrist
- Males had higher rates of spinal related DJC at all three segments

Measures of CSG robusticity (J and TA) in females were higher compared to males, which shows clear gendered differences. Significantly higher female mean humeral Solid J and TA is indicative of substantially more strenuous manual labour. This is clear evidence of much higher mechanical loading on the humerus than what was experienced by males. Using size-standardized measures of CSG robusticity, it can be definitively said that females in medieval Scotland undertook substantially more rigorous manual labour compared to males.
DJC scores consistent with gendered labour are clearest at the right shoulder with high TPR in males is indicative of more large or overhead movements of the shoulder. Females had higher TPR than males for DJC of the elbow and wrist, but with so few cases of either there can only be the very cautious conclusion that females may have undertaken activities requiring movement of the elbow, wrist, and hand more than males. DJC of the spinal segments also showed some gendered differences, with males having higher TPR at every segment potentially indicative of greater loading on the vertebral column (3.2.2).

7.2 Do medieval Scottish women (estimated females) show evidence of more varied manual labour when compared to medieval Scottish men (estimated males)?

- EC for both sexes had an overall right-bias, but females were more frequently right-biased.
- Agonist/antagonist ratios showed gendered differences with males having higher ratios at all joint complexes
- Females had a wider range of robusticity scores (Solid J and TA)
- Robusticity measures in males were more frequently asymmetrical
- Robusticity scores in females were more frequently symmetrical
- Both sexes had a left bias in robusticity scores (females more frequent), indicating that bimanual tasks may have often been asymmetrical.

Females had more frequent right side-bias for EC asymmetry scores and may have been performing more unimanual tasks with the dominant arm. Agonist/antagonist muscle relationship ratios also support gendered labour as the males had higher ratios at five out of six joint complexes. This indicates unbalanced muscular use in one direction consistent with more specialized tasks. Females also displayed a wider range of CSG scores indicating they potentially undertook a greater variety of activities. The male range was narrower indicating lower variety of behaviours and potentially more specialised tasks.

Low overall CSG asymmetry scores place this population into non-specialised sedentary ranges. Males showed higher asymmetry indicating more specialised tasks than females who were far more symmetrical. Men performed more unimanual tasks, such as hammering or lifting and carrying on one shoulder, and women more bimanual tasks. The left-bias, which was more common in females, indicates these tasks were bimanual but
asymmetrical employing the non-dominant side for stabilisation and power while the dominant side directed the complex movements.

7.3 Is there evidence for differing levels of manual labour between Burghs of differing status, or between shipping vs inland Burghs?

- There was little difference seen in prevalence rates for DJC between females of differing social status.
- High and low status females both displayed wide variety, but no marked difference, in EC prevalence between groups.
- Males of higher social status had low rates of shoulder DJC while males of lower status had higher rates at the shoulder.
- High status males had more EC at the elbow and wrist than low status males who had more at the shoulder.
- EC prevalence at the shoulder was higher for both sexes in the Burghs associated with shipping ports but higher at the wrists in inland Burghs.

Females of high and low social status showed little difference in EC and DJC prevalence suggesting that women’s tasks might be similar despite status, or that women were less affected by socioeconomic changes. High status males had higher EC at the smaller joints of the elbow and wrist possibly indicating more detailed or specialised tasks, while males of lower status had more frequent EC at the shoulders which may indicate heavier manual labour. Males of higher status had notably low rates of DJC at the shoulder which may indicate lighter or more sedentary tasks. Lower status males had higher rates at the shoulder indicating more lifting of heavy loads, carrying, throwing, and heavy manual labour. For both sexes, there may have been heavier manual labour at the shipping ports, but lighter or more specialised or sedentary tasks in the inland Burghs.

7.4 Does integration of palaeopathological data, historical contextualisation, and modern anatomical, kinesiological and medical literature into interpretations regarding functional adaptation of bone facilitate understanding of gendered activities in past populations?

- There is a general agreement between EC and CSG results.
- Males showed a relationship between EC and DJC at the right shoulder suggesting a similar aetiology between the two methods.
- Subscapularis EC may be an early indicator of RCD in younger age groups.
- Females had greater prevalence of EC at the elbow, the common extensor (CEO) and common flexor (CFO,) while males were higher at the shoulder (subscapularis, supraspinatus, and infraspinatus).
- EC for the younger middle adult age group (30-39 years of age) appears to be the most indicative of biomechanical gendered allocations of labour.
- EC at the shoulder, primarily the subscapularis, may be more indicative of activity in younger age groups than other arm entheses.
- EC for muscles of elbow flexion (biceps brachii, brachialis, and triceps brachii) are far less indicative of activity than those of the humerus.
- Females with higher Solid J also had indicators of repetitive use of the elbow flexors and extensors.
- Males with higher Solid J also showed evidence of repetitive use of the shoulder.
- Lower rates of dental enamel hypoplasia (DEH) were seen in Old Town Edinburgh and Leith.
- Rates of vitamin D deficiency (rickets) were similar across all Burgh groups.
- No evidence of tuberculosis was found in any Burgh group.

The comparison between EC and DJC identified only one notable relationship, in males at the right shoulder which is consistent with a similar aetiology between the two methods. This is likely related to the development of rotator cuff disease (RCD) in this population, probably from more frequent heavy lifting and work at or above shoulder level. This work also identifies subscapularis EC as a potential early indicator of RCD in younger age groups. The higher prevalence of EC in males at the right shoulder supports this assertion. Modern medical literature describing the aetiology of RCD lends support to the conclusion drawn from EC and DJC data.

Differences reflecting social allocations of labour were seen in the patterns of EC rather than in prevalence at any single enthesis. In the youngest group (20-29 years of age), there were few sex differences, but the 30-39 years of age group began to show some clear changes between the sexes at nearly every enthesis. There were a number of differences between the sexes in the 40-49 years of age group, however, a high degree of variability obscured the results. The integration of sociohistorical context shows a highly gendered society with vastly different daily activities between women and men in medieval Scotland.
Shoulder EC developed more in younger age groups suggesting these EC are more useful for determining activity. While EC at the CEO/CFO were more strongly correlated with age, agonist/antagonist relationships and within individual scores for asymmetry show this is still a valuable area of EC study for activity. The lack of clear gendered differences at EC on the radius and ulna (biceps brachii, brachialis, and triceps brachii) indicate these EC are less valuable in studying activity. Knowledge of kinesiology, muscle contraction, the function of joint complexes aided the conclusions drawn from the agonist/antagonist relationships and EC data.

The patterns found between CSG robusticity and EC suggest a general agreement between the two methods that appear to record different patterns of activity throughout the lifecycle. Indicators of repetitive use of flexors and extensors of the elbow combined with a high Solid J in females suggest both measures may be affected by behaviours involving lifting weight with the hands and forearms and carrying loads close to the body. Muscle movements of the shoulder with a higher Solid J in males may indicate lifting heavy loads and working at or above shoulder level. The kinesiological lens and interpretation through joint complexes allowed these conclusions to be made.

Method comparisons between CSG and DJC yielded no useful information. While this may have been due to small sample sizes or low prevalence of DJC in this population, it is likely that there is no comparable relationship between CSG and DJC when studied in archaeological populations. Both EC and CSG appear to be far more reliable as indicators of activity.

Lower rates of dental enamel hypoplasia, often linked with a healthier population in Old Town Edinburgh and Leith may indicate a highly stratified society around Scotland’s capital city. Similar rates of vitamin D deficiency (rickets) across all Burgh groups may be due to the effects of reduced daylight due and latitude rather than differences in diet and social status. A lack of evidence for tuberculosis in Scotland during this period may be consistent with a smaller population and less crowding, or potentially more outdoor activity with good ventilation when compared to similar size urban areas in England. Palaeopathological data, when combined with sociohistorical context, allowed for a richer, integrated interpretation that led to conclusions about social status and gendered allocations of labour.
7.5 Summary

The explorations of degree and variety of manual labour and social status between females and males offered broadly similar conclusions about life in urban medieval Scotland. The only contradictory result was that females were more asymmetrical for EC but more symmetrical for CSG, while males were the reverse. Aetiological differences in EC and CSG adaptations and lifecycle changes can account for this.

Lifestyle indicators support other conclusions indicating a highly stratified society particularly in and around Edinburgh, a lower population density, and outdoor activity with sufficient ventilation. Women performed strenuous labour that was often bimanual, but asymmetrical, with a wide variety. They were lifting light or medium loads and carrying them close to the body and below shoulder level. Women’s work was similar for both high and lower status Burghs and may have had a broadly lower social status as evidenced by levels of manual labour.

The high variety of women’s work can be explained by frequent changes throughout the lifecycle: learning the father’s trade, then the husband’s, running a business and household, caring for children, or working in the marketplace. Women’s work, at least in medieval Scotland, changed by the rhythm of days and weeks, which may not have left distinct markers of specialisation or repetition on their bones.

Men were also labouring but with unimanual, specialised tasks and less variety. Men’s work also differed notably based on status. High status educated men performed more sedentary tasks that required fine, detailed work of the forearms and hands and fewer large movements at the shoulder. Lower status men lifted heavy loads and often worked at or above shoulder level. While men’s work changed throughout the lifecycle, such as apprentice to master craftsman, these changes were less frequent than those of women. Men’s work tended to be seasonal and varied by months and years which may have provided more opportunity for their bones to show evidence of their labours.

7.6 Significance and Contribution

EC data obtained with the new Coimbra Method adds to the number of comparable female populations and continues the process of fine-tuning the application of EC in archaeological populations. EC data from this study aid in the evidence of which age group
(younger middle adults) show the clearest evidence of gendered labour, and that EC on the humerus are more indicative of activity may be key to future EC and activity research designs. This study on EC also explores the value of framing EC within functional joint complexes to address movement patterns rather than lone enthesis and specific occupations.

Conclusions around DJC were not as noteworthy but did allow for comparability to other Scottish populations in previous literature. The relationship between EC and DJC of the shoulder in males contributes to a greater understanding of the development of RCD and to diagnostic criteria of RCD in palaeopathology.

The high CSG robusticity scores in females counters the dominant narrative that males are biologically determined to develop stronger upper limbs while performing the bulk of the manual labour in societies with gendered allocations of labour. The EC/CSG relationships found here offer further hints of muscle-bone interactions that can be observed on the skeleton and suggest the value of delving into this area in the future.

The novel method for processing 3D scans with free and open-source software developed in this project contributes to the growing field of virtual anthropology by improving accessibility to CSG research and encourages data sharing and collaboration in the digital realm.

The inclusion of anatomical, clinical, and kinesiological perspectives has shown the value of approach interpretations of bone adaptation through functional joint complexes, biomechanics, and with sophisticated insight into multifaceted human movement. This thesis illustrates the importance of interdisciplinary perspectives and a broad knowledge base when interpreting functional bone adaptation, especially EC and CSG.

The new data on Scottish skeletal collections adds to a comparatively little researched archaeological population, emphasises the effects of social stratification and gendered society on human bone, and contributes to the understanding of urbanisation and the development of specialisation of labour in the medieval Scottish Burgh. This thesis highlights the remarkable and unique contribution of Scottish women to the economies of medieval urban Scotland and adds to the growing body of feminist historical and archaeological literature.
7.7 Future Research Directions

As with any statistical analysis increasing the sample sizes are a key to future research. The second half of Whitefriars Perth and the collection known as Logie’s Lane (St Andrews), both curated by the University of Aberdeen, would be essential inclusions. Any other collections from Aberdeen, Glasgow, or Inverness would aid the study of the medieval Scottish Burgh. Additional collections from rural Scotland may offer interesting comparisons to urban populations. Future studies could incorporate chemical and microbiological work such as aDNA, pathogens, radiocarbon dating, and isotopic analysis.

Detailed EC data with eight traits for each enthesis were recorded and could be further analysed. Bone formation and porosity at the enthesis appear to have different aetiological processes which could be further explored in the context of tissue degeneration, inflammation, and repetitive stress injuries.

More detailed EC analyses of the shoulder complex may help decipher the complexities of RCD and other shoulder pathologies. EC of the medial and lateral epicondyles also appear to be valuable tools to understanding human behaviour in the past. Recent work on EC of carpals and metacarpals exploring the intrinsic muscles of the hand could be compared to the elbow and shoulder to expand the discussion around occupation and activity (Karakostis et al. 2017). Palaeopathological work on functional complexes could offer valuable insights to modern occupational medicine by helping to understand acute and repetitive injuries.

The non-destructive and low-cost method developed in this project to orient and slice the 3D scans in open-source software needs to be tested and compared with other established methods. While only one slice of the humerus was studied in this project, further slices could be studied alongside the EC data which could help determine some of the biomechanical influences on both EC and measures of CSG.

Further work is needed to ascertain the effects of multiple biomechanical variables on the development of EC and measures of CSG. Animal studies that test loading, frequency, and repetition are already underway and may help illuminate the aetiologies of EC and CSG (Rabey et al. 2015). Medical imaging like CT has been used to explore muscle size and force on long bone geometry (Ireland et al. 2013, Murray and Stock 2020).
Experimental bioarchaeologists could recreate ancient tasks or occupations to the movements and forces associated with them. Electromyography and motion capture are two technologies that can be used with living subjects to help understand human movements associated with ancient technologies, crafts, or specific occupations (Shaw et al. 2012, Sládek et al. 2016, Shippen et al. 2017). A small motion-capture-based study of textile manufacture was originally part of this project, but it could not be completed due to insufficient funding. All this clinical data can be directly or indirectly applied to functional bone adaptation studies on archaeological materials. The keys to discerning human activity in the past lie not only with the dead but also with the living.
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## Appendices

### Appendix 1

#### 1.1 Basic Skeletal Analysis Data Collection

| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z |
| 1 | St Giles | G1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | Cathedral | G4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |

#### Right

| AA | AB | AC | AD | AE | AF | AG | AH | AI | AJ | AK | AL | AM | AN | AO | AP | AQ | AR | AS | AT | AU | AV | AW | AX | AY | AZ |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 4  | 1  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 4  | 4  | 4  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |

#### Left

| BA | BB | BC | BD | BE | BF | BG | BH | BI | BJ | BK | BL | BM | BN | BO | BP | BQ | BR | BS | BT | BU | BV | BW | BX | BY | BZ |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 0  | 0  | 4  | 3  | 3  | 0  | 6  | 0  | 0  | 4  | 0  | 0  | 2  | 0  | 2  | 0  | 0  | 0  | 0  | 4  | 4  | 4  | 4  | 7  |
| 0  | 0  | 4  | 0  | 0  | 0  | 1  | 0  | 0  | 4  | 4  | 4  | 4  | 4  | 4  | 4  | 4  | 4  | 4  | 4  | 4  | 4  | 4  | 4  | 9  |

#### Right

| CA | CB | CC | CD | CE | CF | CG | CH | CI | CJ | CK | CL | CM | CN | CO | CP | CQ | CR | CS | CT | CU | CV | CW | CX | CY | CZ |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1  | 0  | 0  | 1  | 0  | 0  | 4  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 1  | 1  | 0  | 0  | 0  | 0  |
| 0  | 0  | 4  | 4  | 4  | 4  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 4  | 4  | 1  | 4  | 4  | 4  | 4  |

#### Left

| DA | DB | DC | DD | DE | DF | DG | DH | DI | DJ | DK | DL | DM | DN | DO | DP | DQ | DR | DS | DT | DU | DV | DW | DX | DY | DZ |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 4  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 4  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 4  | 4  | 4  | 4  | 4  | 4  | 0  |
### 1.2 Pathology Data Collection

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>D</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1=absent</td>
<td>2=osteophytes</td>
<td>3=soft tissue</td>
<td>4=joint space</td>
<td>5=joint contour</td>
<td>6=porosity of joint surface</td>
<td>7=Schröder’s nodes</td>
<td>8=present/unaffected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
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<th>Skeleton</th>
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<th>Glenohumeral Joint</th>
<th>A/C Joint</th>
<th>Glenohumeral Joint</th>
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</thead>
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<td>G1</td>
<td>acromion</td>
<td>lateral clavicle</td>
<td>R/A/C</td>
<td>glenoid fossa</td>
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<tr>
<td></td>
<td>G4</td>
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<td>9</td>
<td>9</td>
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<th>S</th>
<th>T</th>
<th>U</th>
<th>V</th>
<th>W</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>=not present</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
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<th>Left Elbow</th>
</tr>
</thead>
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<tr>
<td><strong>Humerus</strong></td>
<td><strong>Radius</strong></td>
</tr>
<tr>
<td>trochea</td>
<td>capitulum</td>
</tr>
<tr>
<td>radial head</td>
<td>trochelear notch</td>
</tr>
<tr>
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<td>0</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Right Wrist</th>
<th>Left Wrist</th>
<th>Hips</th>
<th>Knees</th>
</tr>
</thead>
<tbody>
<tr>
<td>radius</td>
<td>radius</td>
<td>radius</td>
<td>radius</td>
</tr>
<tr>
<td>carpalis</td>
<td>carpalis</td>
<td>carpalis</td>
<td>carpalis</td>
</tr>
<tr>
<td>radius medialis</td>
<td>radius lateralis</td>
<td>scaphoid</td>
<td>lunate</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>
1.3 Data Collection New Coimbra Method

286


### Description of Method

Entheses should be observed without additional magnification (apart from the use of magnification to determine whether there is post-mortem damage) and should be approximately 20-30 cm from the eye, rotating the bone to view all aspects. Lighting should be good, ideally observation should take place in daylight otherwise oblique lighting is recommended. To avoid observer fatigue, frequent breaks are recommended.

This table is a summary of the method. Absence of changes should be scored as zero. Score the maximum extent of the enthesis footprint. Please consult photographs in conjunction with this table.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Feature</th>
<th>Abbrev.</th>
<th>Definition</th>
<th>Degrees of expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>Bone Formation</td>
<td>BF (Z1)</td>
<td>See degrees of expression. Normal morphological smooth rounded or mound-like (check by touching) margins, even if the margin is elevated, should be scored as 0.</td>
<td>1= distinct sharp demarcated new bone formation along the margin or other enthesophyte which does not meet the criteria for stage 2 in terms of size or extent</td>
</tr>
<tr>
<td></td>
<td>Erosion</td>
<td>ER (Z1)</td>
<td>Depressions or excavations of any shape involving discontinuity of the floor of the lesion greater in width than depth with irregular margins. Only erosions &gt;1 mm, where you can clearly see the floor, were recorded. This does not include pores (i.e. rounded margins). Score erosions if they occur on bone formation.</td>
<td>1= &lt;25% of margin 2= ≥25% of margin</td>
</tr>
<tr>
<td></td>
<td>Textural change</td>
<td>TC</td>
<td>A non-smooth, diffuse granular texture (with the appearance of fine grained sandpaper) or a vertically aligned striated surface.</td>
<td>1= covering &gt;50% of surface</td>
</tr>
<tr>
<td>Zone 2</td>
<td>Bone Formation</td>
<td>BF (Z2)</td>
<td>Any bone production from roughness of surface to true exostoses (e.g. distinct bone projections of any form, like bony spurs, bony nodules and amorphous bone formation).</td>
<td>1= distinct bone formation &gt;1 mm in size in any direction and affecting &lt;50% of surface 2= distinct bone formation &gt;1 mm in size in any direction and affecting ≥50% of surface</td>
</tr>
<tr>
<td></td>
<td>Erosion</td>
<td>ER (Z2)</td>
<td>Depressions or excavations of any shape (but not covered by the definition of macro-porosity) and involving discontinuity of the floor of the lesion greater in width than depth with irregular margins. Only erosions &gt;2 mm were recorded. MPO or EPO occurring within an erosion should not be recorded separately. Bone formation is only scored if it exceeds the height of the depression (do not score woven bone). Score erosions if they occur on bone formation.</td>
<td>1= &lt;25% of surface 2= ≥25% of surface</td>
</tr>
<tr>
<td></td>
<td>Fine Porosity</td>
<td>FPO</td>
<td>Small, round to oval perforations with smooth, rounded margins &lt;1 mm. These should be visible to the naked eye and be in a localised area. Do not score if they are at the base of an erosion or if they occur as part of woven bone.</td>
<td>1= &lt;50% of surface 2= ≥50% of surface</td>
</tr>
<tr>
<td></td>
<td>Macro-porosity</td>
<td>MPO</td>
<td>Small, round to oval perforations with smooth, rounded margins about 1 mm or larger in size with the appearance of a channel, but the internal aspect is rarely visible. Do not score if they are at the base of an erosion.</td>
<td>1= one or two pores 2= ≥2 pores</td>
</tr>
<tr>
<td></td>
<td>Cavitation</td>
<td>CA</td>
<td>Subcortical cavity with a clear floor which is not a channel. The opening should be ≥2 mm and the whole floor must be visible.</td>
<td>1= 1 cavitation 2= &gt;1 cavitation</td>
</tr>
</tbody>
</table>
Appendix 3

3.1 Mesh Lab Alignment and Slicing Step by Step

1. Open Mesh Lab v133
2. File -> Import Mesh
3. View -> Show Layer Dialog
4. Filters -> Smoothing -> Laplacian Smooth
   a. Check 3
   b. Click Apply
5. Render -> Show Axis
6. Filters -> Normals, Curvatures, Orientation -> Transform: Move, Translate, Centre
   a. Check “translate centre of bbox to origin”
   b. Click Apply
7. Filters -> Normals, Curvatures, Orientation -> Transform: Align to Principal Axis
   a. Check “use vertex”
8. Render -> Show Quoted Box
9. Filters -> Quality Measure and Computations -> Compute Geometric Measures
   a. Calculate 35% of distal measurement from origin (0)
10. Filters -> Quality Measure and Computations -> Compute Planar Section
    a. Dropdown menu “Plane Perpendicular to z axis”
    b. Cross plane offset - enter 35% calculation as a whole or negative number
    c. Check “create also section surface”
    d. Click Apply
11. In layer dialogue box highlight polyline then
    a. File -> Export Mesh As -> Assign name and location -> File type (*.dxf)
12. In layer dialogue box highlight section surface (mesh)
    a. File -> Export Mesh As -> Assign name and location -> File type (*.stl) or (*.dxf)
13. Highlight and copy text in dialogue box and paste into word doc
    a. File -> Save Project As -> assign name and location -> File type MeshLab Project (*.mlp)

3.2 File Conversion and Preparation (Convert *.dxf to *.tif)

1. Open online file converter at https://www.zamzar.com/
   a. Two free conversions a day or £8 for a month for unlimited
2. Click Add Files (drag and drop files)
3. Convert to Tiff
4. Click Convert Now
5. Wait
6. Download
7. Wait
8. Move to Folder
   (duplicate .tif files)

3.3 Reduce File size in Preview

1. Open all files in one Preview window to batch convert
2. **Tools-> Adjust Size**
   a. Resolution: 30 (will give web quality image)
   b. Check Scale proportionally and resample image
   c. Click OK
   (Change preferences back to open groups of files in the same window)

### 3.4 Image J and MomentMacroJ Step by Step Process

1. **Open ImageJ**
2. **Install Macro (do only once per day)**
   a. Plugins-> Macro-> Install-> navigate to MomentMacro
3. **File-> Open then navigate to file**
4. **Convert to 8-bit greyscale**
   a. Image-> Type-> 8-bit
5. **Choose Density Threshold**
   a. Image-> Adjust-> Threshold
   b. Default will suffice but check for % close to 100
6. **Select region of interest**
   a. Wand Tool-> click on polyline (whole shape should be highlighted)
7. **Run Macro**
   a. Plugins-> Macros-> Moment Calculation (only once per day needed)
   b. Reset Scale
      i. Click No (Only needs to be done once a day)
   c. Draw principal axes
      i. Yes (This didn’t work)
8. **Name sample**
9. **Enter high and low threshold (clicking low begins the calculation)**
10. **Log text box will pop up and ask to be saved. Name it the file name.**
    a. It saves cumulatively so at the end of the day the last saved log will be all the processed files.
11. **Open Excel**
    a. File-> Import
       i. Check Text File then click Import to navigate file directory
       ii. Click Get Data
       iii. Click Next, next, finish
       iv. Confirm location of data, click OK
Appendix 4 Single Enthesal Change Data

Entheseal changes (EC) were analysed by single enthesis for age and sex, and later by joint complex to compare geographical location of all individuals, females, and males. EC true prevalence rate (TPR) for single entheses were analysed between adults and older adults and by three adult age groups. Single entheses were also studied by sex and by side.

Statistically significant differences between individuals aged under 50 ($n = 136$) and those over 50 ($n = 68$) were seen on the right side at the common flexor and extensor, triceps brachii, brachialis, biceps brachii, and the hamstring group (Table 48, Figures 125). On the left side, significance was evident on the common flexor and extensor, brachialis, and biceps brachii (Figure 126). TPR and visualisation show that for all entheses adults over 50 years of age had higher rates than adults under 50 years of age.

<table>
<thead>
<tr>
<th>Enthesis</th>
<th>N</th>
<th>n</th>
<th>Ct</th>
<th>TPR</th>
<th>n</th>
<th>Ct</th>
<th>TPR</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Right</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subscapularis</td>
<td>79</td>
<td>59</td>
<td>35</td>
<td>59%</td>
<td>20</td>
<td>15</td>
<td>75%</td>
<td>.323</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>78</td>
<td>55</td>
<td>4</td>
<td>7%</td>
<td>23</td>
<td>2</td>
<td>9%</td>
<td>.705</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>88</td>
<td>63</td>
<td>11</td>
<td>17%</td>
<td>25</td>
<td>5</td>
<td>20%</td>
<td>.767</td>
</tr>
<tr>
<td>Common Flexor</td>
<td>126</td>
<td>83</td>
<td>6</td>
<td>7%</td>
<td>43</td>
<td>27</td>
<td>26%</td>
<td>.012*</td>
</tr>
<tr>
<td>Common Extensor</td>
<td>114</td>
<td>75</td>
<td>18</td>
<td>24%</td>
<td>51</td>
<td>38</td>
<td>51%</td>
<td>.006**</td>
</tr>
<tr>
<td>Triceps Brachii</td>
<td>131</td>
<td>88</td>
<td>29</td>
<td>33%</td>
<td>46</td>
<td>27</td>
<td>33%</td>
<td>.003**</td>
</tr>
<tr>
<td>Brachialis</td>
<td>153</td>
<td>102</td>
<td>56</td>
<td>55%</td>
<td>43</td>
<td>11</td>
<td>75%</td>
<td>.024*</td>
</tr>
<tr>
<td>Biceps Brachii</td>
<td>152</td>
<td>106</td>
<td>50</td>
<td>47%</td>
<td>39</td>
<td>20</td>
<td>74%</td>
<td>.004**</td>
</tr>
<tr>
<td>Hamstring Group</td>
<td>109</td>
<td>65</td>
<td>12</td>
<td>18%</td>
<td>44</td>
<td>18</td>
<td>41%</td>
<td>.023*</td>
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<tr>
<td>Calcaneal Tendon</td>
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<td>45</td>
<td>22</td>
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<td>22</td>
<td>16</td>
<td>73%</td>
<td>.277</td>
</tr>
<tr>
<td><strong>Left</strong></td>
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<td>6</td>
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*p < .05, **p < .01, ***p < .001, Ct.- Case Counts
Figure 125 Right Side Enthesal Change Prevalence in Adults vs Older Adults
*p < .05

Figure 126 Left Side Enthesal Change Prevalence in Adults vs Older Adults
*p < .05
For all adults under 50 (n = 136, 79 females, 57 males) there were no significant differences between females and males at any enthesis (Table 49). Males had higher TPR for the right and left subscapularis, biceps brachii, and calcaneal tendon, while females had higher rates for most other entheses. Right and left sides were generally similar, but some differences were noted when comparing the graphs (Figures 127 and 128) for the CEO, CFO, and the hamstring group.

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<td>52%</td>
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<td>36%</td>
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*p < .05, **p < .01, ***p < .001, Ct. - Case Counts
Figure 127 Right Side Prevalence by Single Enthesis and Sex
*p < .05

Figure 128 Left Side Prevalence by Single Enthesis and Sex
*p < .05
All adults under 50 \((n = 136)\) subdivided into age groups were found to have statistically significant differences in the true prevalence rate of entheseal changes between the age groups (Tables 5). On the right side, significant age-related differences were seen at the supraspinatus, common extensor, brachialis, and biceps brachii, and on the left at the common extensor, triceps brachii, and biceps brachii. A slight trend was noted at the left brachialis. Visualisation of the TPR revealed an overall positive trend when compared to age (Figures 9 and 10). For most entheses, older middle adults frequently had higher rates than younger middle adults, who then had higher rates than young adults.

### Table 50 Prevalence by Single Enthesis and Age

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*p < .05, **p < .01, ***p < .001, Ct.- Case Counts*
Figure 129 Right Side Prevalence by Single Enthesis and Age
*p < .05

Figure 130 Left Side Prevalence by Single Enthesis and Age
*p < .05
Females under 50 ($n = 79$) were compared by age group. Females showed statistically significant differences between age groups for the right biceps brachii and triceps brachii and biceps brachii on the left (Table 51). Visualisation shows that, while not as evident as when the sexes were combined, several entheses show a broad trend toward higher rates of EC presence compared with increased age (Figures 131 and 132).

### Table 51 Female Prevalence by Single Enthesis

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<td>2</td>
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<tr>
<td></td>
<td>Biceps Brachii</td>
<td>58</td>
<td>9</td>
<td>0</td>
<td>12%</td>
<td>18</td>
<td>5</td>
<td>24%</td>
<td>5</td>
<td>2</td>
</tr>
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<td></td>
<td></td>
<td>18</td>
<td>92%</td>
<td></td>
<td>5</td>
<td>2</td>
<td>33%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hamstring Group</td>
<td>26</td>
<td>7</td>
<td>0</td>
<td>0%</td>
<td>13</td>
<td>3</td>
<td>23%</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>40%</td>
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<td>3</td>
<td>1</td>
<td>17%</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Calcaneal Tendon</td>
<td>21</td>
<td>5</td>
<td>2</td>
<td>40%</td>
<td>11</td>
<td>7</td>
<td>64%</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>28%</td>
<td></td>
<td>7</td>
<td>35%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001, Ct.-Case Counts*
Figure 131 Female Right-Side Prevalence by Single Enthesis
*p < .05

Figure 132 Female Left Side Prevalence by Single Enthesis
*p < .05
Males under 50 ($n = 57$) were compared by age group. Males showed statistical significance on the right at the common extensor and brachialis, and on the left only at the brachialis (Table 52). Two trends in males were seen at the right supraspinatus and biceps brachii. Similar to the females (but not as evident in the combined sexes), most entheses show a broad trend toward higher rates of EC presence compared with increased age (Figures 133 and 134).

Table 52 Male Prevalence by Single Enthesis

<table>
<thead>
<tr>
<th>Side</th>
<th>Enthesis</th>
<th>20-29</th>
<th></th>
<th>30-39</th>
<th></th>
<th>40-49</th>
<th></th>
<th>p value</th>
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<tr>
<td></td>
<td></td>
<td>N</td>
<td>n</td>
<td>Ct</td>
<td>TPR</td>
<td>n</td>
<td>Ct</td>
<td>TPR</td>
</tr>
<tr>
<td>Right</td>
<td>Subscapularis</td>
<td>27</td>
<td>9</td>
<td>5</td>
<td>56%</td>
<td>8</td>
<td>5</td>
<td>63%</td>
</tr>
<tr>
<td></td>
<td>Supraspinatus</td>
<td>30</td>
<td>10</td>
<td>0</td>
<td>0%</td>
<td>9</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Infraspinatus</td>
<td>30</td>
<td>10</td>
<td>1</td>
<td>10%</td>
<td>9</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Common Flexor</td>
<td>32</td>
<td>12</td>
<td>0</td>
<td>0%</td>
<td>8</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Common Extensor</td>
<td>31</td>
<td>11</td>
<td>0</td>
<td>0%</td>
<td>9</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Triceps Brachii</td>
<td>41</td>
<td>15</td>
<td>5</td>
<td>33%</td>
<td>11</td>
<td>2</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td>Brachialis</td>
<td>39</td>
<td>14</td>
<td>4</td>
<td>29%</td>
<td>9</td>
<td>3</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td>Biceps Brachii</td>
<td>44</td>
<td>15</td>
<td>5</td>
<td>33%</td>
<td>12</td>
<td>6</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>Hamstring Group</td>
<td>31</td>
<td>8</td>
<td>1</td>
<td>13%</td>
<td>7</td>
<td>1</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>Calcaneal Tendon</td>
<td>24</td>
<td>5</td>
<td>3</td>
<td>60%</td>
<td>10</td>
<td>4</td>
<td>40%</td>
</tr>
<tr>
<td>Left</td>
<td>Subscapularis</td>
<td>25</td>
<td>8</td>
<td>3</td>
<td>38%</td>
<td>7</td>
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<td>43%</td>
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<tr>
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<td>28</td>
<td>11</td>
<td>1</td>
<td>9%</td>
<td>7</td>
<td>0</td>
<td>0%</td>
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<tr>
<td></td>
<td>Infraspinatus</td>
<td>29</td>
<td>12</td>
<td>1</td>
<td>8%</td>
<td>7</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Common Flexor</td>
<td>28</td>
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<td>5</td>
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<td>9</td>
<td>2</td>
<td>0%</td>
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<tr>
<td></td>
<td>Common Extensor</td>
<td>24</td>
<td>14</td>
<td>3</td>
<td>0%</td>
<td>14</td>
<td>7</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Triceps Brachii</td>
<td>38</td>
<td>9</td>
<td>2</td>
<td>38%</td>
<td>4</td>
<td>8</td>
<td>22%</td>
</tr>
<tr>
<td></td>
<td>Brachialis</td>
<td>42</td>
<td>6</td>
<td>0</td>
<td>21%</td>
<td>9</td>
<td>0</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>Biceps Brachii</td>
<td>37</td>
<td>5</td>
<td>0</td>
<td>22%</td>
<td>8</td>
<td>0</td>
<td>57%</td>
</tr>
<tr>
<td></td>
<td>Hamstring Group</td>
<td>23</td>
<td>6</td>
<td>0</td>
<td>0%</td>
<td>7</td>
<td>1</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>Calcaneal Tendon</td>
<td>23</td>
<td>5</td>
<td>3</td>
<td>60%</td>
<td>9</td>
<td>5</td>
<td>56%</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001, Ct.- Case Counts
Figure 133 Male Right Side Prevalence by Single Enthesis
*p < .05

Figure 134 Male Left Side Prevalence by Single Enthesis
*p < .05
To visualise this data (Tables 51 and 52) in another way, the TPR for females and males are shown for each age group for those under 50. The young adult group (20-29 years of age) appears to be quite similar with males having higher rates at the right subscapularis while the standout for females is the left brachialis (Figure 135). Much of the variation is centred around the flexors and extensors of the elbow (triceps brachii, brachialis, and biceps brachii).

![Figure 135 Female and Male Enthesal Change Scores for Young Adults (20-29 years of age)](image)

The young middle adult group (30-39 years of age) show more clear divergence between the sexes especially at the infraspinatus, CFO, CEO, and the biceps brachii (Figure 136). Females also have higher TPR at seven of the ten entheses. Both sexes show very similar bilateral patterns.
Figure 136 Female and Male Enthesal Change Scores for Young Middle Adults (30-39 years of age)

The older middle adult group (40-49 years of age) shows a lot more variation between the sexes but also bilaterally (Figure 137). Males have higher TPR on the right in every case, but females have more variety depending on the enthesis.
Figure 138 shows that males had a high ratio at all joint complexes apart from the left elbow (which was equal) when compared to females.
Figure 138 Female and Male Ratios for Agonist/Antagonist Relationships