

IMAGING THE BLADDER AND URETHRA OF  
INCONTINENT WOMEN BY TRANSRECTAL ULTRASOUND

Thesis submitted to the University of Edinburgh

for the Degree of Doctor of Medicine

by

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December 1986



ACKNOWLEDGEMENTS

This study has been made possible with the help, encouragement and patience of many people.

I am indebted to the Swann Morton Foundation, Sheffield without whose considerable generosity none of the equipment could have been purchased and the project realised.

I am grateful to the Department of Obstetrics and Gynaecology for the opportunity to carry out the work. I am indebted to the following: Professor John Beazley for his academic advice and general support, Mr. Derek Gardener and Mrs. Ailsa Forrester for their assistance with the computing and storage of information, Mr. Paul Nickson for his professional advice in the production of illustrations and to Miss Jane Walsh for her drawings. In particular, I offer my utmost thanks to Mr. John Sutherst, Reader in the Department of Obstetrics and Gynaecology who was my supervisor and friend. I am indebted to him for his stimulating discussions, enthusiasm and quiet confidence.

I am grateful to Dr. Malcolm Brown in the Institute of Medical and Dental Bioengineering at Liverpool University for his continually helpful suggestions and advice, in particular for assistance with the equipment modification and development of computer software.

Thanks are also due to Dr. G. Lamb in the Department of Radiology and Mr. K. Parsons in the Department of Urology at the Royal Liverpool Hospital for their advice.

To Mr. W. N. McDicken of the Medical Physics Department of Edinburgh Royal Infirmary I am indebted for his help with the evaluation of contrast agents for bladder ultrasound.

To Mr. C. R. West for his advice and help with statistical methods..

A word of thanks also to the nursing staff, in particular at the Urodynamic Unit of the Women's Hospital, Liverpool for their patience, good humour and continual support.

I am sincerely grateful to two secretaries: Mrs. Parveen Kelly who I am delighted to say had to relinquish her post to have a baby boy, and secondly Miss Elaine Rawlinson who not only produced the typed manuscript but provided an enormous feeling of professional competence borne from experience. Thank you to them both.

Finally I offer my sincere appreciation to my wife Maureen without whose sustained encouragement and the ability to keep my three young children at bay made all this possible.

DECLARATION

The work contained in this thesis was carried out in the Department of Obstetrics and Gynaecology at Liverpool University. Most of the clinical studies were performed at the Royal Liverpool Hospital and Women's Hospital, Liverpool. The local ethical committee approved the study and informed consent was obtained from all patients. I certify that the work contained in this thesis is my own. It has not been submitted for any other degree or diploma.

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ABSTRACT OF THESIS

There are a number of methods for investigating the incontinent patient. Cystometric measurement and radiological imaging techniques have stood the test of time. Individual tests are described and the cystographic methods reviewed in detail.

A transrectal ultrasound method of imaging the bladder and urethra is described. The basic technique, equipment modifications and the introduction of a computer software programme to display intravesical and intraabdominal pressures are discussed. The background to the use of contrast agents in ultrasound is described and the role of an iodine based agent for enhancing the image of the bladder and urethra is assessed.

The ultrasonic appearance of the bladder and urethra in continent women is contrasted with the image of incontinent patients. The effect of the transrectal ultrasound probe on standard urodynamic and electromyographic measuring techniques is discussed.

A comparative study of the methods for diagnosing stress incontinence and the imaging potential of ultrasonic and radiological techniques for examining the dynamic relationships of bladder and urethra during stress are described.

The clinical application of the ultrasound technique in the pre, intra and post operative investigation and treatment of the patient with stress incontinence is presented. The results from 59 patients are reported. A prospective series of operations for

stress incontinence is performed. The selection criteria for surgery are based on preoperative ultrasound and urodynamic assessment.

The results from this series are presented and a suggested algorithm based on anatomical and urodynamic examination is discussed. The advantages and disadvantages of this technique are described and future work is suggested.

SECTION 1

## INTRODUCTION

"There is no more distressing lesion than urinary incontinence - a constant dribbling of the repulsive urine soaking the clothes which cling wet and cold to the thighs making the patient offensive to herself and her family ostracizing her from society" was described by Kelly (Di Saia, 1981) and provides a vivid picture of the depressing and embarrassing position faced by the patient with urinary incontinence.

The initial radiological techniques for viewing the bladder and urethra have been complimented by bladder and abdominal pressure measurements over the last 25 years. The emphasis in the female has been based on identifying or excluding abnormal bladder contractions by cystometry, using X-rays to describe the anatomical relationships of bladder and urethra in relation to stress incontinence.

The purpose of this work is to evaluate a new ultr<sup>a</sup>sonic <sup>^</sup> imaging technique in the investigation and management of patients with urinary incontinence. The main component of the thesis was concerned with stress incontinence. X

A large number of patients were studied and several different tests were performed in each case. For reasons of clarity much of the urodynamic data are presented in the appropriate Appendix except when the results contributed to a greater understanding of the ultrasound study.

SECTION 2

## 2 ANATOMY AND PHYSIOLOGY

### 2:1 Embryology

Early in fetal life, at about 17-19 days of intrauterine existence the mesoderm at the side of the cloaca produces bilateral elevations called urethral folds. The upper part of each fold becomes fused as the clitoris and the lower area becomes the labia minora. When the fetus is 4-5 mm in crown rump length a septum grows caudally into the body of the cloaca pushing towards the intact cloacal membrane. This urorectal septum divides the cloaca into a ventral urogenital sinus with corresponding urogenital membrane and dorsal rectum with anal membrane. The vestibule is produced by involution of the urogenital membrane at 18 mm crown-rump length (Gosling, 1984).

At about the same time as the urorectal septum is pushing caudally two ducts approach the ventrolateral surface of the cloaca. These mesonephric ducts or Wolfian ducts are of mesodermal origin and will develop into ureter, trigone and proximal urethra in the female (Tanagho and Smith, 1968; Hutch, 1971; Packham, 1971; Gosling, 1984). These become incorporated into the posteroinferior aspect of the ventral cloaca (bladder) by the seventh week of life (Malvern, 1980). The mesonephric epithelium is replaced by bladder endoderm and develops into transitional epithelium around 12 weeks gestation (Gyllensten, 1949).

The urogenital sinus now has both allantoic and mesonephric ducts opening into it. With fetal growth the ventral portion of

the sinus increases in size as the dorsal wall is pulled backwards by the growth of the mesonephric ducts. The allantoic remnant is later called the urachus. When the urogenital membrane involutes, the tube like structure from the allantois to the caudal aspect of the urogenital sinus, the vesico-urethral canal, develops as the bladder and urethra.

The ureter develops on the dorso medial aspect of the mesonephric duct as a small outpouching close to the eventual bladder. This is the ureteric bud. Differential growth occurs as the ureteric bud moves cranially to the nephrogenic cord where it produces a condensation of mesoderm - the eventual kidney, as the mesonephric duct is dragged caudally. The mesoderm between these two develops as the trigone.

The trigone has a deep and superficial layer. The deep portion assumes a tube like configuration to cover the lower ureter (Tanagho and Pugh, 1963) and is sometimes described as Waldheyers sheath (Wesson, 1920).

## 2:2 Anatomy

The bladder is a hollow viscus lying anteriorly in the pelvis. It is basically a smooth muscle organ (detrusor muscle). It has an outer adventitial coat and a lining of transitional epithelium.

## 2:2:1 Detrusor muscle

The bladder comprises two anatomically separate contractile elements, the detrusor muscle and the trigone. The former is of endodermal and the latter of mesodermal origin. The detrusor muscle has three layers; an outer and inner longitudinal muscle with intermediate circular layer of smooth muscle. However, these are only apparent histologically close to the bladder neck (Hunter, 1954). Throughout the remainder of the detrusor muscle the layers intertwine to such an extent that there is no clear distinction. The bladder behaves as a viscoelastic structure as individual muscle fibres elongate during filling without any alteration in the structural linkages (Coolsaet et al, 1975). It contracts however, as a single unit (Donker 1976).

The outer longitudinal layer of muscle has anterior and posterior divisions and some of these fibres sweep around the urethra as a detrusor muscle loop. The middle circular layer extends to the bladder neck but not into the urethra and has attachments to the deep trigone (Hutch, 1971). There is still considerable controversy about the inner longitudinal layer. An extensive body of opinion states that there is communication with the urethra (Le Gros Clarke, 1883; Scher, 1950; Lapidès et al, 1960; Woodburne, 1960; Tanagho and Smith, 1966; Bro-Rasmussen et al, 1965). However, equally categorical statements to the contrary have been made by McNeal (1972), Drees (1974), Gosling and Dixon (1975), Donker (1976).

### 2:2:2 Trigone

This has a superficial and deep component. The deep trigone fuses with the ureter cranially but its apex is in doubt. Histologically its cells are undistinguishable from the detrusor (Gosling, 1985). Tanagho and Smith (1968) state that it terminates at the internal urethral meatus but embryologists have suggested that the lower border of the Wolfian duct is the junction with the Mullerian duct - i.e. the urethrovaginal junction in the female or verumontanum in the male. It lies between the superficial trigone and outer longitudinal muscle layer of the bladder, fusing with the middle circular layer at its lateral borders.

The superficial trigone is a continuation of the longitudinal layer of the ureter (Donker, 1976). The muscles of the two ureters join to form the cranial edge of the superficial trigone sometimes called Merciers bar. The lateral border (Bell's Muscle - Bell, 1812) may be important in initiating bladder neck funelling at the start of micturition. The superficial trigone passes over the urethrovesical junction and simply appears to fade out in the female urethra.

### 2:2:3 Urethra

In the adult female this is approximately 4 cm in length. It runs from the internal urethral meatus of the bladder to the external meatus, posterior to the clitoris. It perforates the urogenital diaphragm about two thirds of the distance along its

course. It is a tubelike structure <sup>of</sup> smooth muscle and elastic tissue but mainly collagen (Hickey et al, 1982).

The epithelium of the urethra is of two types. In the distal portion the urethra is covered by stratified squamous epithelium continuous with that of the vagina. The proximal portion is covered by transitional epithelium and is continuous with that of the bladder. The junction between the two different types is variable but stratified squamous epithelium has been reported over the trigone (Packham, 1971). The squamous cells are sensitive to oestrogen and may play a role in preventing ascending infection of the urethra and also helping to promote continence. The soft anterior and posterior mucosal surfaces are usually apposed and create a watertight seal except during micturition (Zinner et al, 1980).

The urethra has two smooth muscle layers, an inner longitudinal layer and an outer circular layer incorporated into a collagen and elastic matrix which contributes to passive closure by its circumferential configuration. It is likely that resting urethral tone depends to a large extent on the intrinsic striated muscle of the urethra (Rhabdosphincter) which has the bulk of its fibres in mid urethra. This has somatic innervation but which is different from the periurethral striated muscle of the pelvic floor (Gil Vernet, 1964), and which is morphologically separate (Gosling and Dixon, 1979).

Histochemical studies of both these muscles (Gosling et al, 1981) have shown that the intrinsic sphincter has Type I -

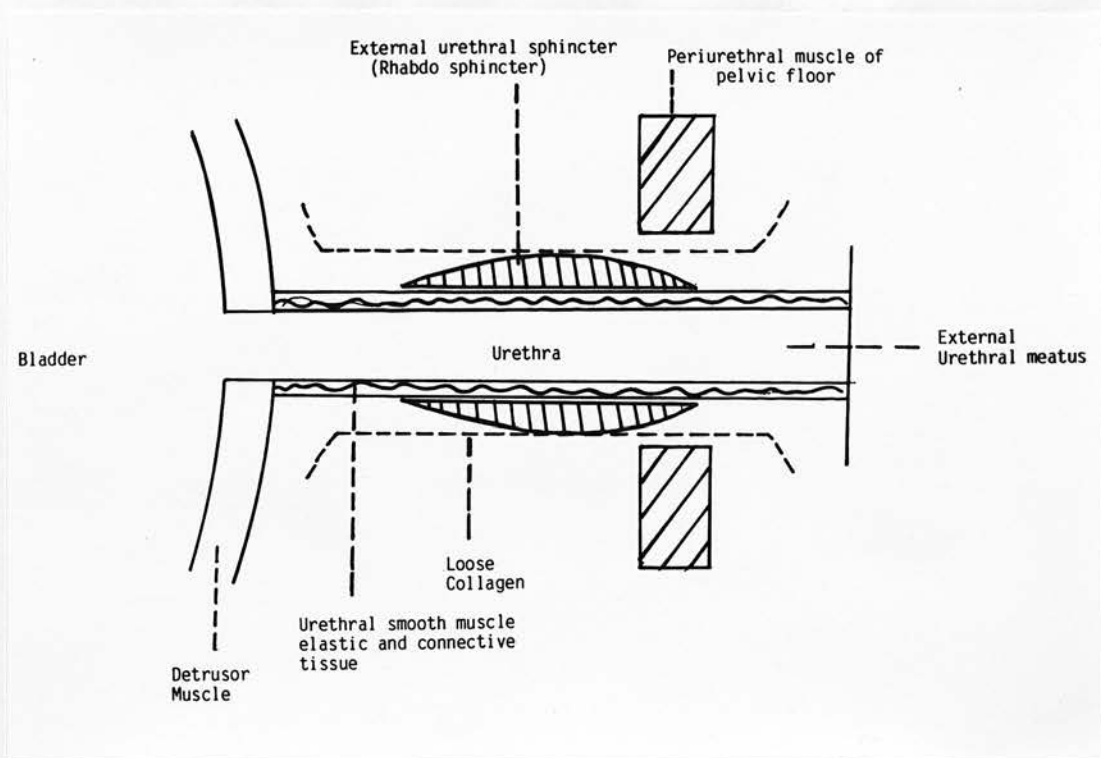


FIGURE 2:2:3(i) Coronal section of bladder and urethra to show anatomical components of the urethral "sphincter" mechanism.

i.e. slow twitch fibres and periurethral muscle has both Type I and II fibres i.e. both slow and fast twitch fibres. This would suggest that the external urethral sphincter maintains a degree of tonic contraction over long periods helping to produce passive urethral closure, whereas the Type II or fast twitch fibres of the periurethral muscle augments urethral closure pressure during moments of sudden stress such as coughing or sneezing.

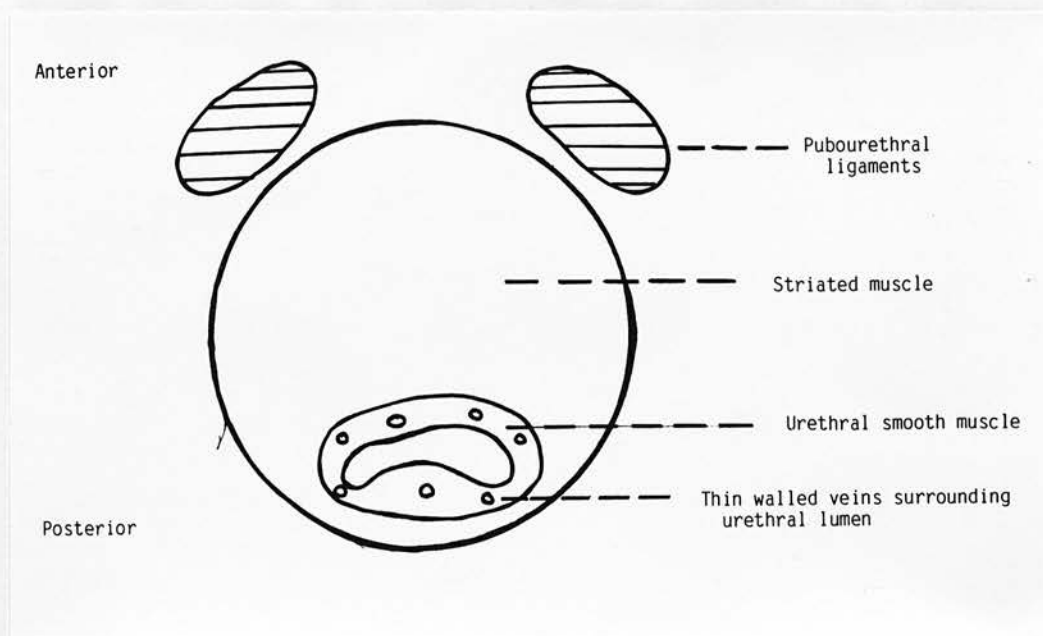


FIGURE 2:2:3(ii) Horizontal section of mid urethra.  
Pubourethral ligaments anterior to  
external urethral sphincter

#### 2:2:4 Ligaments

Ligamentous attachments of the bladder neck are probably of considerable importance in maintaining bladder neck position and also continence, acting as a stabilising influence on the urethrovesical junction during moments of stress (Zacharin and Gleadell, 1963). They comprise an anterior pubo-vesical ligament which is a continuation of the suspensory ligament of the clitoris and a posterior ligament. This splits into two arms from its origin on the posterior aspect of the symphysis pubis passing to the junction of the proximal one-third and distal two-thirds of the urethra. Histologically, the ligaments contain smooth muscle (Zacharin, 1977) which may contract simultaneously with the detrusor muscle (Gosling, 1985).

#### 2:3 Neurophysiology

At the end of the 19th century it was thought that the bladder and urethra were controlled by the will (Mosso and Pellacini, 1882; Rehfisch, 1897). Denny Brown and Robertson (1933) and Langworthy and Kolb (1933) believed that the brain created a continuous inhibitory state. Voluntary withholding of these impulses initiated micturition through a parasympathetic spinal reflex pathway (Learmonth, 1931). More recent evidence to the contrary suggests a net excitatory central function of the sacral micturition centre (Mahony et al, 1977).

The central control centre lies in the reticular formation of the pons. Sensory afferent fibres are difficult to define.

Proprioception is mediated by bladder wall tension receptors (Iggo, 1955). Afferents travel to the sacral parasympathetic outflow and also along sympathetic fibres.

Nathan (1976) indicated that all sensory afferents travel in the spinothalamic tracts despite the evidence of Hitchcock et al (1974). They showed residual sensation even after bilateral spinothalamic tractotomy to a depth of 3 mm suggesting posterior column involvement.

The day to day functions of the bladder and urethra are regulated at a peripheral level by the autonomic nervous system. The somatic innervation plays only a minor role. The parasympathetic nerve supply arises from the intermediolateral columns of the second (S2) third (S3) and fourth (S4) sacral segments of the spinal cord (Learmonth, 1931). In practice the majority of fibres arise from S3 and S4. Fibres pass as the pelvic splanchnics (*nervi erigentes*) to the pelvic ganglia. The sympathetic outflow arises from the thoracolumbar region of T11 to L2 (Learmonth, 1931) passing along the posterior abdominal wall as the hypogastric plexus of nerves, into the pelvis to synapse with the pelvic ganglia (Kluck, 1980). These are situated at the base of the bladder (Gosling and Thompson, 1977) and around the ureterovesical junction (Schulman et al, 1972). Their presence elsewhere is open to doubt. Dixon et al (1983) demonstrated intramural ganglia, by histochemical study, in the dome and lateral walls of the bladder where the cells were rich in acetylcholinesterase. There was no evidence of any

Noradrenergic activity associated with these ganglia. Others, (Ek et al, 1977; Sundin et al, 1977; Alm, 1978) however, have failed to demonstrate such ganglia in the human bladder.

Postganglionic cholinergic fibres pass to the bladder wall and urethra (Mobley et al, 1966). In the bladder they ramify to such an extent that almost every muscle cell has one or more cholinergic nerve ending (Gosling, 1979). These are excitatory fibres and produce detrusor muscle contractions. They may also be important in opening the urethra by contraction of the longitudinal muscle.

The role of the sympathetic nervous system is not as clear. It is attractive to believe that the functions of the two are directly opposite but unfortunately the anatomical and pharmacological evidence is not so convincing. Presumptive noradrenergic preganglionic nerves are thought to exert an inhibitory influence on detrusor muscle by their effect at the pelvic ganglia (De Groat and Theobald, 1976). Noradrenergic nerves do not seem to innervate individual bladder or urethral muscle fibres. The sympathetic nerves which do occur appear to accompany the vascular tree (Sundin et al, 1977). However, the pharmacological and histological information is confusing as much of the former work was experimental and performed on cats.

Cholinergic and beta adrenergic receptors have been identified in all parts of the urinary bladder and urethra. Alpha adrenergic receptors have only been identified at the base of the bladder and proximal urethra (Edvardsen and Setekleiv,

1968; Rohner et al, 1971; Raz and Caine, 1972; Nergardh and Boreus, 1972; Nergardh, 1974; Gosling and Dixon, 1975). The authors postulated that the sympathetic mechanism at the bladder neck and urethra was one of active contraction and relaxation whereas at the fundus of the bladder relaxation occurred.

Acetylcholine appears to influence adrenergic function at the neuromuscular junction. Alpha stimulation mediates a smooth muscle contraction probably of the urethral circular smooth muscle (Owman et al, 1971). This corroborates work by Elliot (1907) and Kleeman (1970) who demonstrated that electrical stimulation of sympathetic nerves led to a reduction of urine flow rate by bladder neck contraction and relaxation of the fundus. Beta stimulation led to smooth muscle relaxation. Nergardh (1974) reported that the amount of noradrenaline released at the neuromuscular junction determined the extent of alpha or beta activity. Todd and Mack (1969) showed that stimulation of Beta receptors in strips of detrusor muscle from the fundus of the bladder led to relaxation of an acetylcholine induced contraction. The extent of the relaxation was reduced in patients with detrusor instability. Pre (alpha 2) and post synaptic (alpha 1) neuromuscular receptors have been described by Eaton and Bates (1982). As alpha adrenergic agonists inhibit noradrenaline release while antagonists enhance the stimulatory effect of the neurotransmitter it has been proposed that the alpha 2 receptors control release of noradrenaline via a negative feedback loop (Langer et al, 1980). The two alpha receptors have

different pharmacological sensitivities (Langer, 1974; Wikberg, 1979) and in patients with detrusor instability the alpha 2 regulation of noradrenaline release may be altered. This results in less tonic inhibition of detrusor muscle and leads to excessive smooth muscle activity.

Recent work in patients with detrusor instability has shown a reduction in Vasoactive Intestinal Polypeptide (VIP) (Gu et al, 1983). This reflects a loss of inhibitory control of the detrusor muscle increasing the risk of unhibited detrusor contractions. The role of prostaglandins and the possibility of a third messenger in the autonomic nervous system (Ambache and Zar, 1970) which is non adrenergic and non cholinergic remains to be clarified.

The storage and voiding of urine are under voluntary control but the bladder and urethra are made up of involuntary smooth muscle. These paradoxical facts may be reconciled by further pharmacological work.

#### 2:4 Physiology

The two basic bladder functions are those of storage and emptying. The main argument surrounds the "sphincteric" function of the urethra during the storage phase and the reciprocal relaxation during micturition.

## 2:4:1 Storage and Continence

The normal bladder dilates passively to hold approximately 500 ml. The capacity alters if the viscoelastic properties of the bladder change, for example with interstitial cystitis or following pelvic irradiation. As the bladder becomes smaller the mural tension tends to rise during cystometry. Poor bladder compliance may result in urinary symptoms even incontinence. Normal detrusor function is dependent upon sensory (probably proprioceptive) afferent pathways acting via a central loop through the frontal cortex, mid brain reticular formation and interconnecting cerebellar pathways to the sacral outflow S2 S3 and S4. Sensation is influenced by conditions such as urethritis or cystitis, sudden cold, running water or local atrophic epithelial change for example in the menopausal woman. Impulses travel to the detrusor muscle along pelvic nerves as pre-ganglionic parasympathetic fibres. Lesions above the sacral outflow lead to hyper-reflexic detrusor changes. Lower motor neuron conditions result in an areflexic bladder, urinary retention and overflow incontinence.

There is no anatomical sphincter at the bladder neck in the female. However, the urethra does remain closed at this site even during stress (Constantinou and Govan, 1981). Continence is maintained because urethral pressure is always greater than bladder pressure. The components contributing to passive closure include smooth muscle tone, elastic and connective tissue and also a vascular element (Enhorning, 1961; Rud et al, 1980;

Herbert et al, 1982). Hilton and Stanton (1983) described a margin for continence for each patient. This was derived from the amplitude of maximum urethral pressure, its variation at rest (Ulmsten et al, 1982; Weil et al, 1984), pressure transmission to bladder and urethra, intraabdominal pressure fluctuation and the maintenance of maximum urethral pressure during stress, which all interact to maintain a state of continence. Deviation along any of these arms may result in incontinence. Maximum urethral pressure varies with age (Rud, 1980) is lower in patients with stress incontinence (Obrink and Bunne, 1978; Hilton and Stanton, 1983) but bears no relation to the extent of urine loss. Repeated operations for stress incontinence do however, lead to low urethral pressures.

Continence is also maintained during the storage phase by active components. Contraction of the striated pelvic floor musculature provides additional closure during stress but of primary importance is the position of the proximal urethra within the abdominal cavity. A sudden rise in abdominal pressure is therefore equally distributed to the bladder and urethra. The pressure differential is maintained (Figure 2:4:1).

Other features of continence have been derived from the anatomical changes observed following incontinence surgery. Although it is unlikely that urethral length (Lapides et al, 1960) or urethral calibre (Aldridge, 1952) play a major role in maintaining continence, the spatial relationships of bladder, urethra, symphysis pubis and pelvic floor are undoubtedly

important. These particular aspects will be described in detail later.

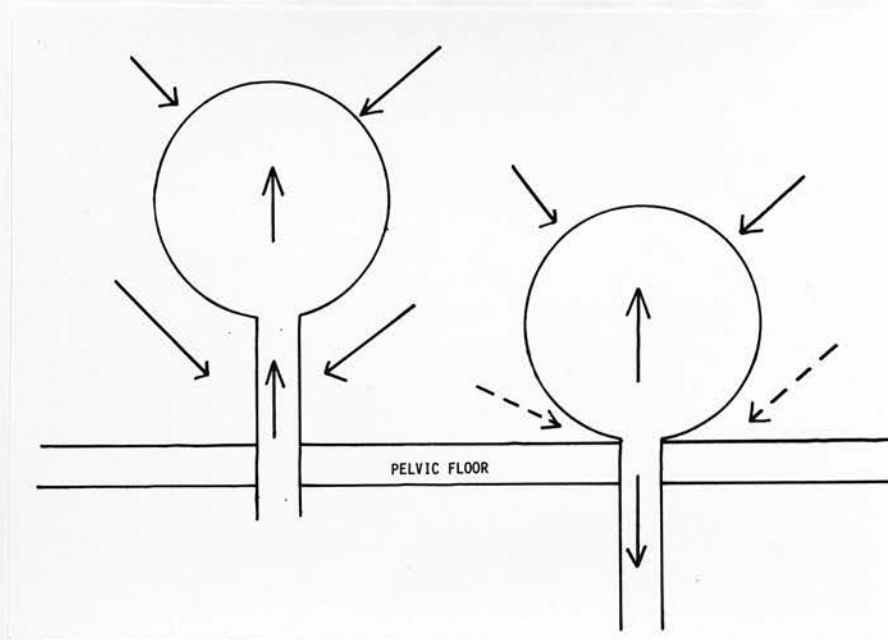


FIGURE 2:4:1 Abdominal pressure transmission to proximal urethra

#### 2:4:2 Voiding

For voiding to occur bladder pressure must overcome the elastic resistance of the bladder neck. A fall in urethral resistance occurs immediately prior to micturition as the rhabdosphincter relaxes due to central inhibition of its neurones in the sacral segments S2-S4. This is mediated by descending spinal pathways from higher centres (Gosling, 1985). At the same time other descending pathways in the posterior and lateral columns activate the preganglionic parasympathetic nerves of the bladder causing a detrusor muscle contraction (Blaivas, 1982).

## 2:5 Incontinence

Urinary incontinence results from a disturbance or dysfunction of the physiological mechanisms maintaining continence. It is a common problem especially in women but because the precise aetiology is obscure management is difficult.

### 2:5:1 Classification

In women the main causes of urinary incontinence are stress and urge incontinence or a combination of the two. Retention with outflow, fistulae or congenital causes result in less than 5-10 per cent of cases.

Stress incontinence was originally described by Sir Eardley Holland in association with exertion. Bonney (1923) called it diurnal incontinence because it was almost exclusively related to patients in the erect position. Berkow (1941) coined the phrase orthostatic incontinence. Youssef and Mahfouz (1956) were convinced of the basic pathology and described the condition as sphincter incompetence. The International Continence Society (ICS) have defined it as "the involuntary loss of urine per urethram where intravesical pressure exceeds intraurethral pressure in the absence of a detrusor contraction" and use the term Genuine Stress Incontinence (GSI).

It is important to differentiate the symptom, the sign and the diagnosis of stress incontinence.

Urge incontinence is defined as the involuntary loss of urine per urethram in association with a strong desire to void.

Motor urge incontinence is associated with uninhibited detrusor contractions where the intravesical pressure rise is  $>15 \text{ cmH}_2\text{O}$ . Sensory urgency is not associated with detrusor contractions. Characteristically the patient has frequency, urgency and nocturia with a small bladder capacity and an early first desire to void.

#### 2:5:2 Aetiology

Genuine Stress Incontinence is sometimes seen in nulliparous women but in general is confined to the older parous patient. It is more common in the caucasian female and is rarely encountered in the Far Eastern oriental woman (Zacharin, 1977). In the young nullipara incontinence is probably due to a congenital weakness of the bladder neck associated with the evolutionary change of assuming the erect posture (Hodgkinson, 1970).

Pregnancy declares a predilection for stress incontinence (Francis, 1960) which may be exaggerated by childbirth. Although Genuine Stress Incontinence is commoner in multiparous patients there are no data relating length of labour or type of delivery to the incidence and severity of urinary incontinence. Stress incontinence like all types of incontinence increases with age in both sexes and is particularly common in women after the menopause. In the incontinent patient resting urethral tone is lower than in normal controls (Edwards and Malvern, 1974) and with excessive mobility of the bladder neck during stress pressure transmission is less than in normal women.

There is some evidence to suggest that the striated muscle component of the "sphincteric" mechanism is abnormal in patients with stress incontinence (Snooks and Swash, 1984) and Smith and Warrell (1985) showed delayed nerve conduction times in patients with stress incontinence. These findings may be related to nerve damage at parturition. There is a frequently held belief that stress incontinence relates to prolapse and that cure of the latter will relieve the former. Their presence together is coincidental and probably due to the mutual antecedent insult of pregnancy. Often patients present with symptoms of prolapse only to complain of incontinence following vaginal repair. It is likely that a rectocele compresses and a procidentia kinks the urethra so that following surgical repair the masked urinary incontinence is revealed. Alternatively, post operative fibrosis may hold the urethra open and prevent the normal bladder neck closure mechanism from working. Common clinical associations include obesity, chronic bronchitis and poor abdominal or perineal musculature.

### 2:5:3 Prevalence of Urinary Incontinence

The prevalence of urinary incontinence is difficult to ascertain because of the embarrassing nature of the condition and the fact that many women deny they suffer at all. The problem very often only comes to light as a result of direct questioning. However, reports would suggest that it is common in the community with about 1 million people affected, particularly the older

woman who has had children. From a large postal survey of 22,430 patients over the age of 5, Thomas et al (1980) estimated that the prevalence of urinary incontinence in females between the ages of 15-64 years and in those patients more than 65 years of age as 8.5 per cent and 11.6 per cent respectively. Yarnell et al (1981) interviewed 1,060 women aged 18 or over, at home, in South Wales. Forty-five per cent of them described infrequent urinary incontinence (i.e. less than once per week). Only five per cent complained of a daily or continuous loss. These results are similar to those of Brocklehurst et al (1972) who studied a group of female patients aged 45-64 years in a general practice population. Fifty-seven per cent were incontinent. In 1972, Milne et al presented data for 272 Scottish patients between the ages of 62-90. Five per cent complained of severe incontinence, to the extent of bedwetting and 38 per cent had complained of severe incontinence. Of 1,327 American female students studied by Nemir and Middleton (1954), 5 per cent described frequent urine leaks and a surprising 52 per cent occasional loss. Similar studies of nulliparous student nurses by Scott (1969) showed that 40 per cent complained of urinary incontinence while Wolin (1969) found 16 per cent suffered daily incontinence and 50.7 per cent occasional urine leaks. Crist et al (1972) found that 30.4 per cent of 1,008 women admitted to some degree of urinary incontinence.

SECTION 3  
URODYNAMIC TESTS IN  
CURRENT USE

### 3 INTRODUCTION

During the last 25 years there has been a rapid growth of interest in urodynamic methods for studying bladder and urethral physiology. In certain clinical situations investigation is mandatory but with recognition of the poor correlation between symptoms and diagnosis urodynamic study has assumed increasing importance.

To facilitate comparison of results by different investigators using urodynamic methods a standard terminology of lower urinary tract function has been recommended by the International Continence Society (ICS). Abstracts from the First, Second and Fourth Reports (1976, 1977, 1981) are presented in the Appendix.

In our unit approximately 350 new female patients are seen for investigation each year with an additional 100 patients attending for repeat study after treatment. The history and examination findings are recorded on computer data sheets for storage (see Appendix).

The methods in current use are presented below with emphasis placed on the tests that we perform in our urodynamic unit.

### 3:1 TESTS IN CURRENT USE

The methods available for investigating the patient complaining of urinary incontinence vary from centre to centre. In our own urodynamic unit the investigation is divided into four broad areas:

- i) History, examination and exclusion of urinary tract infection
- ii) Identification and quantification of urine loss
- iii) Assessment of detrusor muscle function and detrusor pressure during cystometry
- iv) Measurement of urethral function

#### 3:1:2 Mid Stream Specimen of Urine

All patients attending the unit provide such a specimen. This helps exclude a urinary tract infection present in 2-3 per cent of patients attending the clinic. This compares with other reported series (Walter and Vijlsgaard, 1978). Diagnoses are made from routine culture and sensitivity assessments. In some units a Dip-Stick slide technique is used. Any positive results are received within 48 hours, and the patient and General Practitioner are notified for immediate antibiotic treatment.

### 3:1:3 Urethroscopy

This examination provides additional valuable information of the bladder and urethral mucosa. We perform this examination on all patients with symptoms of urge or urge incontinence using a rigid 30 degree paediatric cystoscope. Patients are asked to attend with a comfortably full bladder so it is rarely necessary to catheterise the patient to fill the bladder. Polyps, inflammation or malignancy can be diagnosed and in particular the trigone and ureteric orifices inspected for signs of infection. Occasional bladder calculi or diverticulae may be observed. The mucosa of the urethra is then inspected for inflammatory or atrophic changes which can contribute to the patient's urinary symptoms. In cases of motor or sensory urge incontinence it may be necessary to measure bladder capacity to differentiate between the small bladder due to fibrosis/interstitial cystitis from one where the bladder is hypersensitive. This is best performed under general anaesthetic when it is possible to stretch the bladder.

### 3:1:4 Assessment of urine loss

It is usually necessary to determine the extent of the disorder in patients with urinary incontinence. Some patients complain of excessive loss but only leak tiny quantities whereas others tolerate quite large amounts of urine loss without much complaint. The history may indicate the severity of loss and frequency/volume/incontinence charts are useful in this respect.

This account, however, is not always reliable and cannot be very accurate. Warrell (1969) indicated that incontinence could be demonstrated clinically at bladder volumes less than capacity. Others believe that clinical examination is an inferior method of assessing loss as incontinence is not always seen (Stanton and Ritchie, 1977; Tanagho, 1979; Robinson and Stanton, 1981).

The Urilos Nappy Test (James et al, 1971) is a pad which contains a dry electrolyte. As urine is absorbed by the diaper there is a change in electrical conductivity which can be recorded as a volume of urine loss (0-100 ml).

In our unit we have found that it is more convenient to use a perineal pad weighing method during a series of daily activities (Sutherst et al, 1981). A one litre fluid load is given and the patient then performs a series of exercises for one hour. The preweighed pads are removed every 10 minutes and reweighed to quantify the urine loss in mls. A full description of the pad test is presented in the Appendix.

In patients with extra urethral incontinence a three swab test is of value to diagnose a urinary fistula. Methylene blue dye is instilled into the bladder, the swabs are placed high in the vagina, mid vagina and urethra. A ureterovaginal fistula will stain the top swab with clear urine whereas a vesicovaginal or urethrovaginal fistula will stain the corresponding vaginal swabs blue.

### 3:1:5 Urine flow rate

This procedure has tended to be performed routinely for investigation of male patients attending incontinence clinics, but seems to be assuming more significance for investigating the incontinent female. A flow rate is important for patients with abnormal voiding symptoms arising de novo or following surgery for stress incontinence. It provides a simple non invasive method of measuring urine flow in the pre and post therapeutic phases. Flow rate measurements have been made regularly for over 40 years, although the measurement of voided urine by volume estimation was originally made by Rehfisch (1897). Several other methods have been described such as the measurement of urine voided by weight (Drake, 1948), the displacement of air from a closed vessel into which urine was voided (Gierup et al, 1969), or the measurement of rate of clearance of a radioisotope from the bladder during micturition (Winter, 1964). Von Garrelts (1956) designed an early electronic flowmeter as a tall cylindrical collecting device with a pressure transducer in the base. This measured the increased pressure exerted as urine was voided and since there was a correlation between pressure and volume the urine flow rate could be determined in respect of time. Others (Zinner et al, 1969; Ritter et al, 1977) have used a drop spectrometer to analyse flow rates. This technique remains a research project at present.

Methods in current use are similar to, or modifications of, the strain gauge relying on weight change but which was modified

by Von Garrelts and Strandell (1972). The patient voids into a cylindrical receptacle which sits on a strain gauge weighing transducer. The weight of fluid is measured and electronically displayed as a urine flow rate. An alternative, perhaps more sophisticated technique involves the use of a rotating disc, the speed of which is maintained by a servo-amplifier. The operation is based upon the theory that the amount of electrical energy required to maintain the disc at a constant speed while urine is being voided onto its surface is proportional to the flow rate (Rowan et al, 1977) (Figure 3:1:5i).



FIGURE 3:1:5i ROTATING DISC UROFLOWMETER

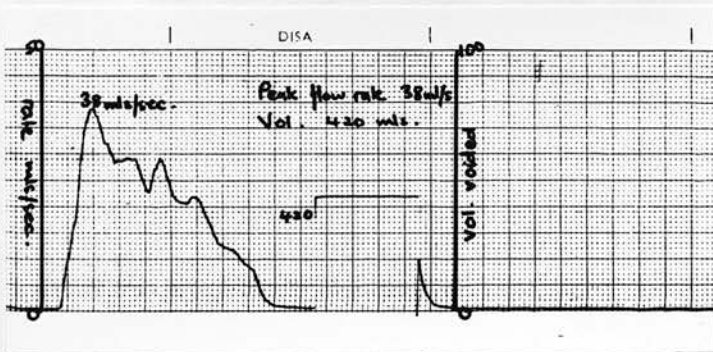
A further commonly used method involves a vertical dipstick suspended into a straight sided collecting vessel (James, 1977). The solute in urine conducts electricity across the capacitor and as the volume of urine voided increases the area of the capacitor decreases. As a consequence the capacitance diminishes and the change provides the voided urine volume, and the rate of change, the urine flow rate.

Ultrasonic measurements of flow rate (Rollema, 1976; Nishizawa et al, 1984) may prove practical, but are still confined to scattered research centres. Normal values for urine flow rate are difficult to obtain. They vary with age, sex and also the volume of urine that is voided. Nomograms for such parameters are available relating maximum flow and voided volume to age and sex (Backman, 1965; Siroky et al, 1979). By and large the volume of urine voided should be more than 200 ml and the peak flow rate at least 15 ml per second (Rowan et al, 1977). If the measurement is lower, despite repeated attempts this may suggest an abnormal detrusor function or perhaps partial obstruction of the outflow tract. Intermittent flow rates may be due to poor detrusor contractions or <sup>y</sup>dys<sub>^</sub>nergia of the coordination between bladder contraction and urethral relaxation. Measurements should certainly be made in private, preferably in the sitting position. Many patients find this a difficult task and in fact 25-30 per cent of female patients attending our clinic are unable to void in such circumstances.

In some centres simultaneous measurement of intravesical and intra-abdominal pressure is recorded during voiding as a routine. In our unit the procedure is reserved for patients with abnormal flow rates or voiding symptoms, especially those who have undergone previous incontinent surgery. It is time consuming and requires the use of a small epidural catheter to allow measurement of intravesical pressure which does not obstruct the urine flow.

In women, voiding studies will detect rare cases of obstruction and can assess detrusor function before surgery for stress incontinence. Detrusor sphincter dyssynergia may also be demonstrated.

Typical urine flow rate traces are shown below (Figure 3:1:5ii).



Normal trace



Obstructed flow rate following surgery

### 3:1:6 Cystometry

As a muscular organ the bladder has a unique viscoelastic property (Coolsaet et al, 1975; Maastrigt et al, 1976) for accommodating increasing volumes of fluid by a passive stretching of its fibres with minimal intravesical pressure rise, to a capacity of approximately 500 mls. Cystometry is the measurement of pressure versus volume and forms the most important urodynamic investigation of the incontinent female patient.

Mosso and Pellacini (1882) were the first to appreciate this peculiar property of the bladder when they used a primitive but effective single channel recorder to measure bladder pressure during incremental filling (Figure 3:1:6).

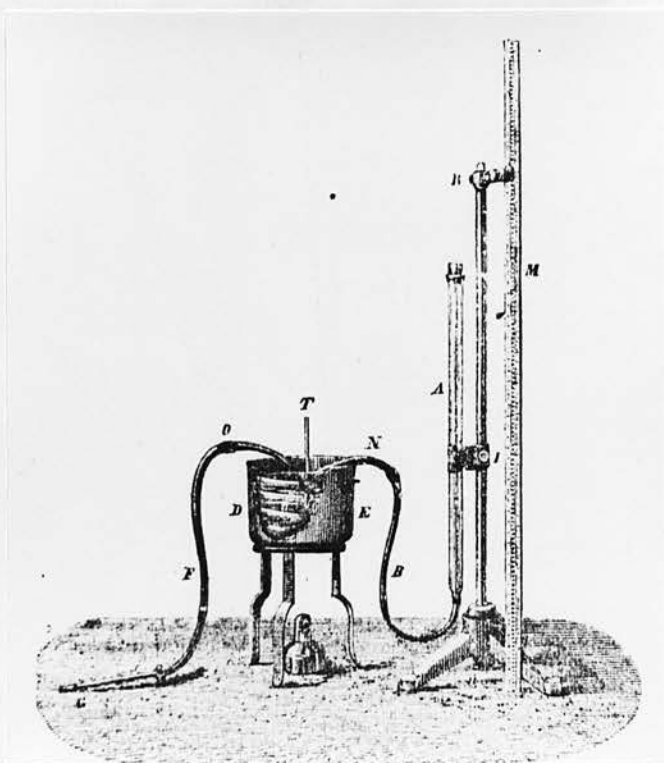


FIGURE 3:1:6 CYSTOMETRY EQUIPMENT (1882)

The aim of cystometry is to differentiate normal from abnormal detrusor function during the phases of filling, storage and voiding. For this investigation certain criteria must be described:-

- i) The mode of filling
- ii) The temperature of the filling medium
- iii) The type of filling medium
- iv) The rate of filling
- v) The measurement of pressures
- vi) The type of recording apparatus
- vii) The position of the patient during cystometry

i) The mode of filling

We use a 12 French gauge Portex double lumen urethral catheter so that one channel may be used for bladder filling while the other is used for intravesical pressure recording. There are two pairs of eyeholes along the side of the catheter set 6 cm apart (figure 3:1:6:i). Alternative methods for filling the bladder use a two catheter technique, one for filling which is then removed when capacity is reached allowing a much smaller epidural catheter to measure bladder pressure. Forced diuresis following administration of an oral diuretic drug, or physiological filling which is sometimes performed for patients with suspected neuropathic bladders are others. The latter is time consuming and impractical in a busy urodynamic unit. We find that by using a single double lumen catheter we are able to carry

out cystometric measurements and also urethral studies, and therefore cut down the ultimate cost of each investigation.



FIGURE 3:1:6:i      PORTEX DOUBLE LUMEN CATHETER

ii) The temperature of the medium

This is usually sterile water at body temperature, although minor variations are unlikely to influence detrusor function.

Iced water on the other hand can be used to assess the afferent loop of the detrusor reflex pathway in patients with a neuropathic bladder.

iii) Filling medium

We use sterile water for the bladder infusion during cystometry. In North America carbon dioxide is commonly used. This has the advantage of being quick and is less untidy. It is therefore more suitable as an office procedure (Raz and Kaufman, 1977). Patient acceptability however is limited due to the fast filling which may cause discomfort (Gleason et al, 1976) and also occasional mucosal irritation. Information about the effect of carbon dioxide upon cystometrographic reading is confusing. Most of the comparative studies discuss urethral pressure profile and functional length measurements with fluid and carbon dioxide. Torrens (1977) showed comparable results whereas Shower et al (1983) commented on average closure pressures and functional urethral lengths being lower with carbon dioxide than with water.

In X-ray cystography contrast medium is used. This does not alter the pressure recordings compared with more conventional filling media (Arnold et al, 1974).

iv) Rate of filling

Until transducers became widely available bladder pressures were recorded at 50 ml increments during filling. This is now continuous. The ICS have defined the following filling rates as shown below:

Slow fill cystometry	0 - 10	mls/min
Medium fill cystometry	10 - 100	mls/min
Fast fill cystometry	>100	mls/min

Slow fill cystometry which matches the normal physiological situation is usually required for investigation of the neuropathic bladder. Fast fill cystometry on the other hand may provoke a detrusor contraction or increase bladder tone of the hypocompliant bladder. Some authors would say this is grossly unphysiological filling while others feel that any detrusor contraction is abnormal and that cystometry should aim to be as provocative as possible. My own preference is for a medium fill cystometry of between 50-60 mls per minute. This allows time to speak to the patient, gain her confidence and give her time to get accustomed to the strange surroundings. As most bladders hold approximately 500 mls of fluid the bladder will take approximately 10 minutes to fill. If incremental filling is employed the volumes must be described and the intervals timed.

v) Measurement of pressures

Intravesical pressure is determined by the passive and also active properties bladder muscle, the effect of intra abdominal pressure changes and also gravity. The zero reference point is the upper border of the symphysis pubis and pressures are recorded in cmH<sub>2</sub>O. Water filled, or electronic microtransducers are used which have the advantage of eliminating zero error. Telemetric techniques have also been described (James, 1978; Bhatia et al, 1982). The information is stored on a paper trace or computer disc.

According to Ek and Bradley (1983), Dubois recorded bladder pressure during the investigation of bladder function in 1876. In his dissertation on the pressure in the bladder he measured bladder and rectal pressure simultaneously using a water manometer. Twin channel recording of bladder and abdominal pressure with a subtracted detrusor pressure is now the ideal technique (Hodgkinson, 1960; Enhorning, 1961).

Recently, we have attempted to measure abdominal pressure using a vaginal approach with a small balloon catheter inserted high in the posterior vaginal fornix (El Taher et al, 1985). The preliminary results have proved encouraging and the technique is certainly more acceptable to the patient.

The reliability of the rectal/vaginal pressure recording is checked by asking the patient to cough and then recording the pressure rise in the bladder and also abdominal pressure line which should demonstrate equal responses. Occasionally kinking

or the presence of air bubbles in one of the manometer lines produces a discrepancy in the readings but this can be rectified before formal investigation begins.

vi) The position of the patient

Cystometrographic recordings are made in the supine position during filling, in the erect position during provocative cystometry, then sitting or standing during voiding.

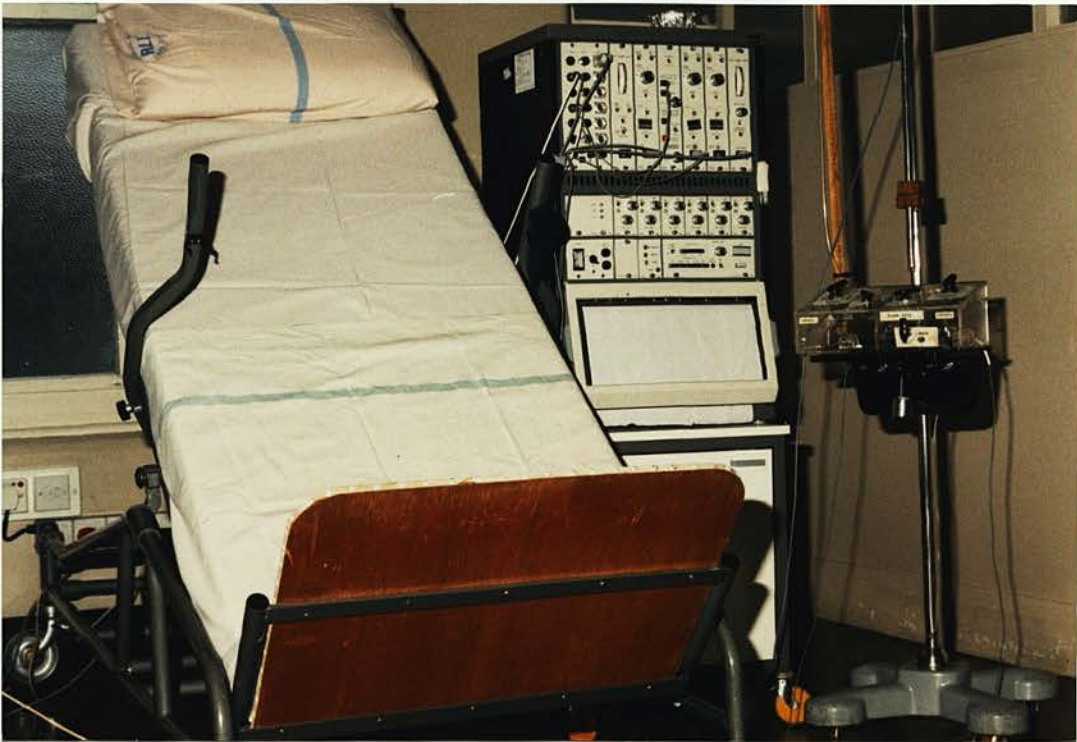


FIGURE 3:1:6:vi SIX CHANNEL RECORDER AND TILTING BED

### 3:1:7 Measurement of Urethral Function

In the normal situation, intraurethral pressure is greater than intravesical pressure at rest and during moments of stress. Therefore for the maintenance of continence the urethral occlusive forces outweigh the expulsive forces of the bladder itself and any influence arising from intraabdominal pressure transmission. This initial theory was conceived by Barnes (1940) but only expounded by Hodgkinson (1960) and Enhorning (1961) when intraurethral and intravesical pressures were measured simultaneously.

#### Urethral Closure Pressure Profile

The urethral closure pressure profile (UCPP) denotes the intraluminal pressure along the length of the urethra at rest. This is shown schematically in Figure 3:1:7:i.

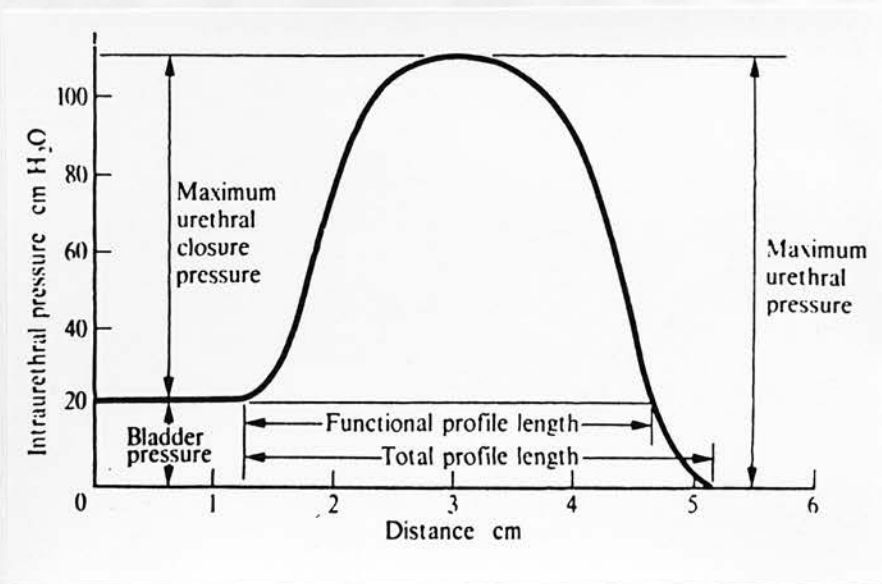


FIGURE 3:1:7:i URETHRAL CLOSURE PRESSURE PROFILE

Maximum urethral pressure (MUP) is the maximum pressure seen over the measured profile, whereas maximum urethral closure pressure is the difference between maximum urethral pressure and intravesical pressure. The functional length of the urethra is measured from the point where the urethral pressure exceeds intravesical pressure.

Much work has centred on the factors contributing to urethral pressure, but it would appear that a combination of smooth muscle, elastic tissue, a vascular component and also striated muscle influence the closure pressure profile. Maximum closure pressure relates to the striated muscle area of the external urethral sphincter which occupies the middle third of the urethra and tends to lie 1-1.5 cm from the internal urethral meatus (Enhorning, 1961). The presence of the proximal urethra within the abdominal cavity explains the equal transmission of pressure to bladder and upper urethra during stress exercises (Figure 2:4:1). A reduction of the pressure transmission ratio has been claimed as <sup>an</sup> aetiological factor in genuine stress incontinence (Henriksson et al, 1979; Hilton and Stanton, 1983) and a parameter that may be measured to assess the effect of surgery. X

The urethral pressure varies with age (Enhorning, 1961; Toews, 1967; Rud, 1980) and probably is influenced by the changing female hormonal milieu as postmenopausal women with mild stress incontinence often benefit from local oestrogen treatment



(Hiltor and Stanton, 1983). Although urethral pressure measurements are lower in patients with stress incontinence (Henriksson et al, 1979) there appears to be such a wide variation in normal values of functional length and maximum closure pressure (Edwards and Malvern, 1974) that using the UCPP as a diagnostic parameter has proved inaccurate. As a result other profile parameters have been used such as the area under the curve of the urethral profile (Mortenssen et al, 1977), the area under the curve to the point of maximum closure pressure and the rate of rise of the ascending limb of the profile in the proximal urethra (Constantinou and Govan, 1977) for diagnostic and prognostic purposes.

Recent interest in urethral pressure variability has resulted in the notion that pressure changes of 20 cmH<sub>2</sub>O are probably within normal limits (Kulseng-Hansen, 1983). Fluctuations are more common in patients with sensory urgency and when marked, pressure changes of 50-70 cmH<sub>2</sub>O may occur and result in urine leakage. The aetiology of this urethral pressure fluctuation is as yet unknown. The measurement of urethral pressure is now commonly carried out using one of two techniques described overleaf:

i) Fluid perfusion method - (Toews, 1967; Brown and Wickham, 1969).

In our own unit the fluid perfusion method is used. This measures the pressure required to perfuse a catheter at a constant rate of infusion (2-4 mls/min) which is maintained by using a gravity feed infusion system with a drip stand 3 metres high, or a pressure cuff sphygmomanometer. Occasionally an automatic syringe pump is used but this tends to have compliance problems which therefore interferes with accurate recording of pressures. The catheter is withdrawn from the bladder mechanically at 0.5 cm/second and the paper speed of the pen recorder is 1 cm/second. From the profile the requisite measurements are made. For all our urethral studies the bladder volume is standardised at 150 mls. Using an infusion rate of 1 drop/second (i.e. 4 mls/min) and a slow catheter withdrawal speed the response time for the fluid filled system appears adequate.

There are several inherent problems of a fluid filled system and artefacts due to air bubbles or leaks lead to a dampening of the urethral closure pressure profile. Other problems relate to the size of the catheter; if too large it may measure not only closure pressure but also an element of urethral elasticity. Eye hole number and position are important for adequate mucosal contact and catheter orientation respectively.

If carbon dioxide is used as the filling medium (Robertson, 1974) for UCPP measurements the infusion rate must be rapid and

catheter withdrawal extremely slow to achieve an adequate response which is also recordable. These pre-requisites make the procedure uncomfortable for the patient often leading to catheter movement artefacts.

ii) Catheter tip microtransducers - (Asmussen and Ulmsten, 1975; 1976)

These were developed in the early 1970s (Miller and Baker, 1973) and popularised in Sweden by Asmussen and Ulmsten. The catheters have the advantage of being small (6 French gauge), they are not prone to air bubble or leak artefacts. Due to a rapid response time, 2,000 cycles/second (Lindstrom and Ulmsten, 1978) sudden changes in pressure due to cough impulses can be recorded to construct a stress urethral pressure profile (Asmussen and Ulmsten, 1976; Hilton and Stanton, 1983).

The disadvantages are that the catheters are expensive and also the fact that some authors have expressed concern about errors arising from orientation of the catheter within the urethra (Hilton and Stanton, 1981; Anderson et al, 1983).

Two other methods are described for completion - but now rarely used.

iii) Balloon catheters - (Enhoring, 1961)

Soft balloons mounted on a catheter will transmit pressure along fluid filled lines to a transducer. They are accurate when calibrated correctly and have a rapid response time.

iv) Shelley Force Gauge

This consists of strain gauges bonded to the inner aspect of a small urethral device. It measures the radial force applied by the urethral walls and ignores hydrostatic pressure. Shelley and Warrell (1965) showed a reduction in radial force in women with stress incontinence.

3:1:8 Electromyography

All muscles have an electrical potential when contracting. The striated muscle electrical activity can be measured by using surface or needle electrodes. The former need to be in direct apposition to the muscle as skin surface electrodes are inaccurate. The anal plug electrode is the most widely used surface electrode although a similar type of device attached around a urethral catheter has been described (Takaiwa et al, 1983). Concentric or single fibre needle electrodes afford more direct measurement of muscle activity. They are however, much more painful to insert than the surface electrodes.

In the normal situation the electromyographic recording (EMG) signal increases with bladder filling and decreases or stops altogether on micturition. Abnormal responses are seen when persistent EMG signals occur during voiding as seen in cases of detrusor sphincter dyssynergia. A diminished or absent EMG trace may be due to denervation of the muscle to some extent assuming the needle has been correctly positioned.

The main indication for EMG is the investigation of patients with a neuropathic bladder. It is helpful to distinguish between smooth and striated muscle urethral obstruction seen on videocystourethrography. Single fibre EMG has been used to quantify the damage to nerves supplying the bladder as a result of childbirth. If a nerve is partially damaged the remaining axon will sprout to re-innervate the denervated muscle. This branching of nerves to many different muscle cells can be

quantified to assess the extent of the neuromuscular damage (Anderson, 1984).

### 3:1:9 SACRAL EVOKED RESPONSES

The function of this test is to measure and establish the function of the sacral reflex arc and therefore quantify the inaccurate bulbocavernosus reflex. The object is to measure the time taken for a nerve stimulus to produce an evoked response which is usually in the form of a muscle contraction (e.g. stimulation of the dorsal nerve of the clitoris produces a contraction of the bulbocavernosus muscle). The normal response shows an average conductance period of 35 milliseconds.

The analysis of the SER is more precise than an EMG recording (perhaps except single fibre measurement) as an indication of denervation. Such measurements are necessary to differentiate neuropathic, myopathic and functional disorders of the bladder and urethra.

My experience of electromyographic recordings has been very limited. I have personally found the results difficult to interpret. Insertion of the needles is often painful for the patient and time consuming in a busy urodynamic unit. I have no experience of SER but I feel that for both of these investigations they probably benefit only selected patients and that the investigation itself should be confined to centres where there is a specific interest in muscular or neuropathic disorders of muscle function.

### 3:2 Summary of Investigation - Urodynamic Unit, Women's Hospital, Liverpool

In our unit, therefore, following clinical examination we perform a pad test. The patient voids and urine flow rate is measured. Residual urine volume is then measured prior to medium fill water cystometry. The patient is instructed to report the first desire to void and when maximum capacity has been reached. Erect provocative cystometry is then performed. The patient is asked to cough and heel bounce as bladder and abdominal pressures are recorded.

A normal cystometrogram is as follows: sensation of bladder filling occurs at at 100-200 mls (F1); a desire to micturate follows at 300-400 mls (F2) and capacity is reached when a strong desire to void is experienced at approximately 500 mls (F3). This definition of capacity is not entirely satisfactory because some can be encouraged to hold more fluid after F3. The presence

of contractions exceeding 15 cmH<sub>2</sub>O indicates an unstable bladder or detrusor instability. For transient pressure changes <15 cmH<sub>2</sub>O clinical judgement needs to be exercised.

In certain situations described earlier voiding cystometry is performed otherwise the bladder is drained to approximately 200 mls for urethral pressure profile and fluid bridge test. In the presence of obvious stress leakage the urethral tests are not carried out.

As this thesis is based on the evaluation of a new imaging technique for studying the bladder and urethra I have separated the general methods of urodynamic investigation from the specific tests of bladder neck competence. These will now be described in greater detail.

3:3 TESTS OF BLADDER NECK COMPETENCE AND THEIR RELATION  
TO THE DIAGNOSIS OF STRESS INCONTINENCE

3:3:1 Introduction

It is notoriously difficult to make an accurate diagnosis from the history of an incontinent patient. The symptoms may not correlate with the physical signs and vice versa. Urine loss per urethram may not be visible due to distal closure mechanism preventing the escape of fluid (Farrar et al, 1975) or because of a reluctance on the part of the patient to fill the bladder to capacity, a volume at which the patient knows will lead to stress incontinence with provocation. Stress leaks are probably only seen during clinical examination in 50-60 per cent of patients with genuine stress incontinence. Quantifying the extent of the urine loss by Urilos Nappy test or pad test may give additional information. Further tests are often required to clarify the diagnosis especially in the incontinent patient with mixed symptoms or following surgery. Radiological screening, Fluid Bridge Test or Urethral Electrical Conductance Test will be described in relation to the diagnosis of patients with stress incontinence.

### 3:3:2 Radiological techniques

The bladder has been X-rayed for approximately the last 75 years. According to Johanson (1951), Cunningham performed urethrography on a male patient using contrast in 1910. Kehrer (1918) and Rubsamen (1920) used collargol and oxygen respectively to study the bladder. Unfortunately neither produced any pictures of their investigations. Norris and Kimborough (1928) studied antero-posterior X-rays of normal and also incontinent female patients in erect and supine positions. They appear to have been the first to comment on the cone shaped appearance of the urethrovesical junction often seen in patients with stress incontinence.

The antero-posterior radiological approach was criticised because the position of the bladder anterior to the urethrovesical junction often lay at a lower level and therefore obscured the true bladder neck. Thomsen (1930) initially attempted lateral views of incontinent patients before resorting to an oblique approach with the patient placed at 45 degrees. The still, lateral X-ray however, did not incur much favour until Malpas et al (1949) and Ball et al (1950) reintroduced the technique.

Fluoroscopy was extensively used by Muellner (1949, 1951) and also by Jeffcoate and Roberts (1952) in their early work. Interest in this particular method continued until Hinman et al (1954), Lund et al (1957) and later Gardiner et al (1961)

published details describing a cine fluorographic study of micturition.

Meanwhile, Adran et al (1956) performed a series of rapid fire, single, lateral X-rays to build up a picture of micturition using a speed of 3-4 frames per second.

The initial contrast agent used for successful cystography was iodine based (Norris and Kimborough, 1928, V. Mickulicz Radecki, 1931; Stevens and Smith, 1936; Ball, 1950; Bailey et al, 1954, 1956). Sometimes however, the urethra was difficult to visualise due to the dense bony architecture of the pelvis. A water emulsion of barium sulphate was introduced by Nordenstrom (1952) and tried later by Adran (1956) and Nilsen (1958). Instillation proved difficult and the information obtained was rarely superior to that of the iodine based medium. The technique is infrequently used except in the colpocystourethro-gram described later.

It is difficult to see the urethra and study its dynamic movements during stress unless urine leaks, the patient voids, or the urethra is outlined in some manner. Thomsen (1930) and Crabtree et al (1936) tried to visualise the urethra by squirting a radioopaque liquid in a retrograde fashion through the external urethral meatus. This proved impractical and was discontinued. V. Mikulicz Radecki (1931) used a catheter with a thin lead thread to outline the urethra before Stevens and Smith (1937) and later Barnes (1940) used a bead-chain technique (Figure 3:3:2). This had the advantage of matching the urethral contour more

closely and reduced the splinting effect catheters tend to produce.

The bead-chain technique is widely used in the United States (Hodgkinson and Doud, 1953; Steinhausen et al, 1970) and also Scandinavia (Ala-ketola et al, 1981). It has not achieved the same widespread use in the United Kingdom (Hertogs and Stanton, 1985).

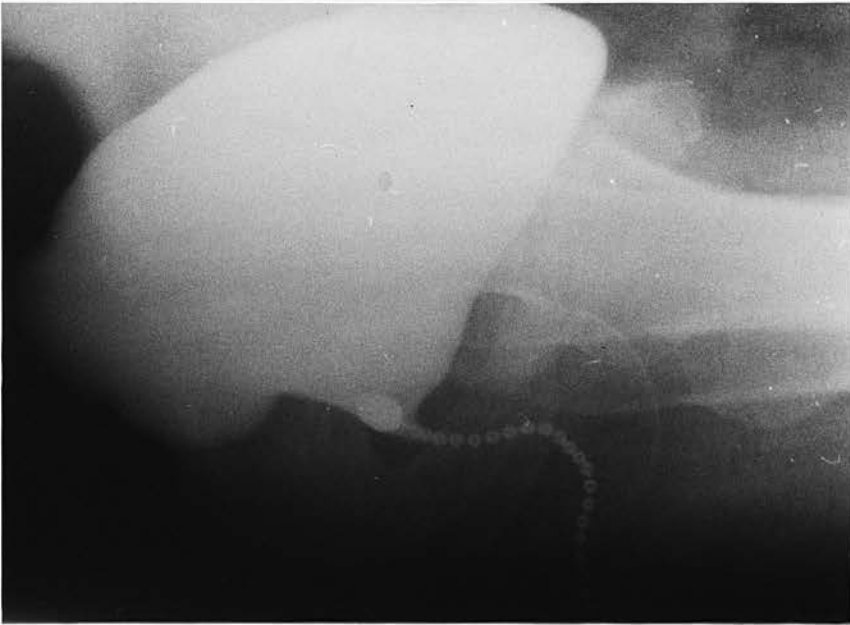


FIGURE 3:3:2 BEAD CHAIN LATERAL CYSTOGRAM

Renewed interest in cystometry followed the simultaneous recording of bladder and urethral pressure by Hodgkinson (1960) and Enhorning (1961). Several years later this technique was combined with a recording of the dynamic changes of the bladder and urethra on cine X-ray film (Enhorning et al, 1964; Tanagho et al, 1966; Bates et al, 1970). Today videocystourethrography (VCU) with pressure flow studies, which encompass the filling and voiding phases of micturition with simultaneous radiological screening of the bladder and urethra provides the most comprehensive investigation of the incontinent patient. The information can be stored on video tape for review later with appropriate sound commentary.

In an effort to demonstrate the morphological soft tissue changes seen in the incontinent patient during stressful provocation some workers have used barium paste to outline the vagina and urethra. The colpocystourethrogram was initially described by Ardran et al (1956) and later by Bethoux and Bory (1962). More recently Lazarevski et al (1975) and Oleson and Walter (1977) have demonstrated the value of this technique. It involves considerable patient preparation and must have limited value as a routine procedure.

By coating the vaginal walls with barium paste and using an iodine based medium in the bladder they were able to view the pelvic structures more closely. This technique seems excessive for routine use but does however, provide considerably more information concerning tissue movement around the bladder neck

area compared to the standard radiological screening technique of the VCU.

### 3:3:3 CURRENT RADIOLOGICAL TECHNIQUES

#### i) Static cystogram

This usually takes the form of a lateral view due to the restrictions of antero-posterior images mentioned earlier. A resting and also straining view are taken. In the absence of simultaneous pressure recording it is difficult to distinguish urine leakage due to (a) uninhibited detrusor contractions (b) bladder neck incompetence (c) voluntary voiding, or, (d) an open urethra held in position by surrounding fibrosis.

By using a bead-chain it is possible to observe the movements of the bladder neck in relation to the symphysis pubis and also to detect any urine loss. I think this particular technique still has a place in demonstrating the appearances of the bladder and urethra before and after surgery.

#### ii) Micturating cystography

This technique consists of screening the bladder and urethra during voiding. Static or cine recordings can be made and stored on video tape. The method may be used to show vesicoureteric reflux, vesical or urethral fistulae and bladder or urethral diverticuli. By asking the patient to perform a mid stream stop, milk back of urine can be observed and the effectiveness of the pelvic floor muscles in closing the urethra can be

ascertained. In the absence of pressure recordings however, misleading results and therefore diagnoses may be obtained (Rose and Eaton, 1983).

### iii) Videocystourethrography

At present this provides the most comprehensive investigation of urinary incontinence when combined with pressure recordings from the bladder and urethra or rectum (Figure 3:3:3:iii). It is of particular value for screening the dynamic changes of the bladder neck in patients following failed incontinence surgery, with abnormal voiding symptoms, or with a mixed picture of both stress and urge incontinence. It is of more value for the investigation of the incontinent male and some workers feel that routine radiological investigation is unnecessary for every female patient with urinary incontinence and should be reserved for selected patients (Massey and Abrams, 1985).

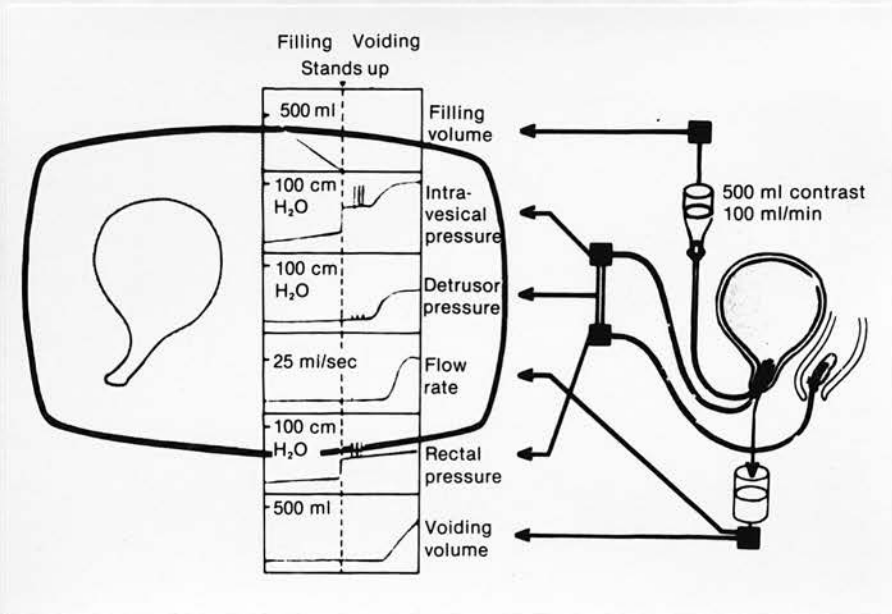


FIGURE 3:3:3:iii

SCHMATIC DIAGRAM OF TYPICAL VIDEOCYSTO-  
URETHROGRAPHY WITH PRESSURE/FLOW RECORDING

Although radiological techniques may demonstrate proximal urethral weakness or frank urine loss, many workers have described certain radiological parameters with which to describe patients with stress incontinence. These relate to the topographical appearances of the bladder and urethra in relation to the symphysis pubis, vagina and/or sacrum, but perhaps in particular the relation of the urethra to the bladder base at rest and during stress.

Jeffcoate and Roberts (1952) introduced the term posterior urethrovesical angle (PUV) into gynaecological parlance and drew attention to the relationship between the proximal urethra and urethrovesical junction in the continent and incontinent patient. They concluded that a normal PUV angle (90-100 degrees) was necessary for continence to be maintained. In patients with stress incontinence, loss of this angle was noted and often approximated to 180 degrees or more. Although their findings were corroborated by other workers (Hodgkinson, 1953; Dutton, 1960; Francis, 1960; Green, 1962) the belief that loss of the angle was diagnostic of stress incontinence is no longer so firmly held because of similar appearances in normal patients (Greenwald, 1967; Kitzmiller et al, 1972).

V. Mikulicz Radecki (1931) commented on the relationship between the urethra and symphysis pubis and described the angle subtended by drawing a line along the posterior surface of the symphysis pubis which bisected a line along the anterior wall of

the urethra (Figure 3:3:4:i). The angle is usually acute but becomes obtuse in patients with stress incontinence. Bailey (1954; 1956) and Green (1962) confirmed these findings and described the angle of urethral inclination between the urethra and the vertical as all important.

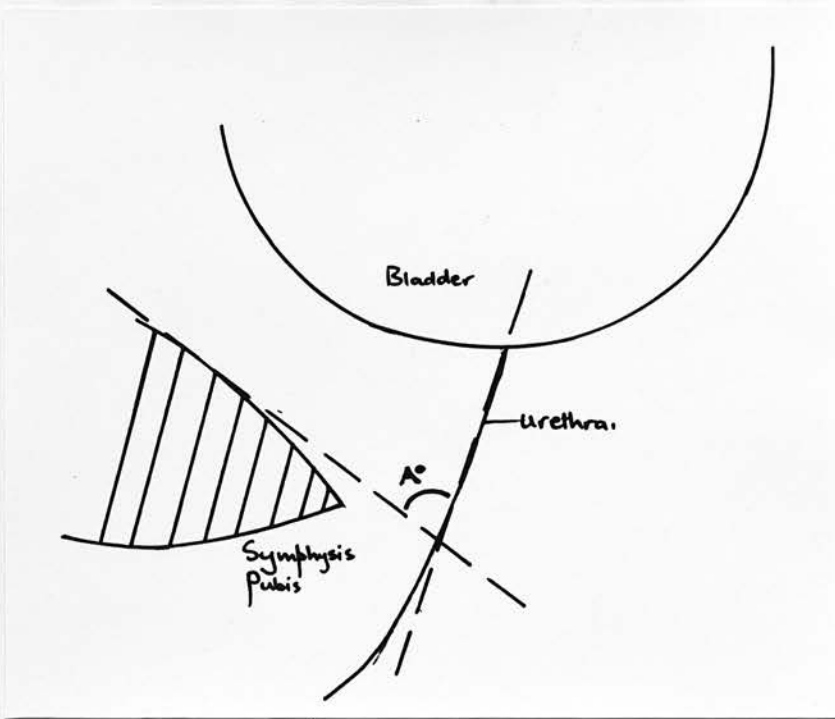


FIGURE 3:3:4:i

The latter author described two main radiological appearances of patients with stress incontinence and equated the PUV angle and urethral inclination to the degree of stress incontinence. From this radiological classification patients with stress incontinence were divided into those with Type I appearances i.e. complete loss of the posterior urethrovesical angle but a normal urethral inclination and those with the Type II appearance where not only was there complete loss of the posterior urethrovesical angle but also an increase and reversal of the normal axis of urethral inclination due to posterior rotation and descent of the bladder neck and proximal urethra (Figure 3:3:4:ii). Green (1962, 1975) based his surgical treatment upon these radiological findings. The patient with Type I appearance was operated on vaginally by anterior colporrhaphy and insertion of buttressing sutures at the bladder neck. Patients with Type II appearances were operated on abdominally by performing a Marshall-Marchetti-Krantz procedure.

Other radiological associations with stress incontinence include the distance between the symphysis pubis and urethrovesical junction (Olesen and Walter, 1977) and also the presence or absence of a flat bladder base. Whether these additional single measurements or observations have any bearing on the diagnosis or therapeutic outcome is open to question.

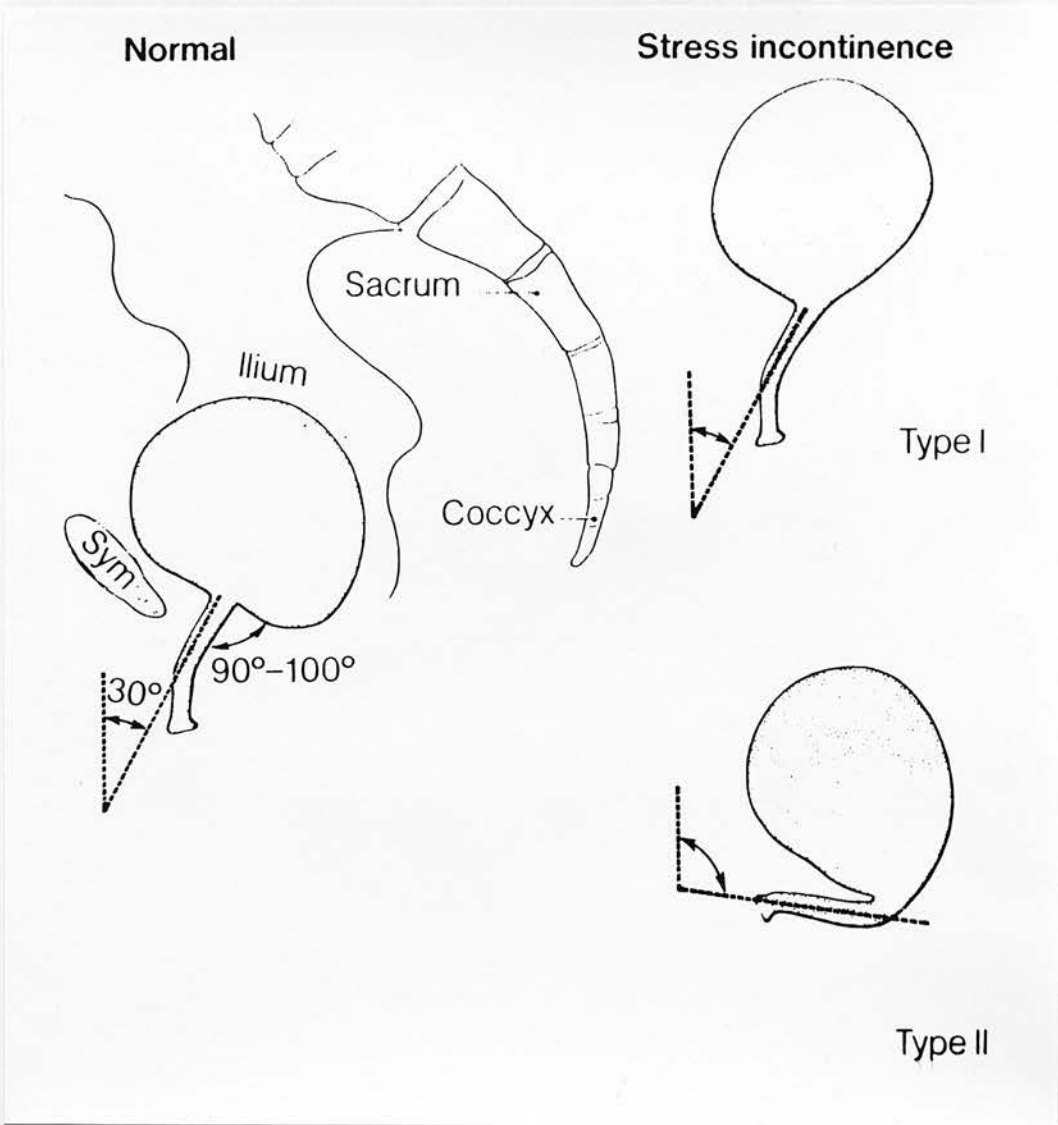


FIGURE 3:3:4:ii GREEN'S CLASSIFICATION

Bladder neck funnelling or beaking (Norris and Kimborough, 1928; Thomson, 1930; Aldridge, 1952; Nilsen, 1958) is a common finding in patients with urinary incontinence but is also seen in normal continent females. Although this may be suggestive of a functional bladder neck weakness, continence in these patients tends to be maintained distally, presumably at the level of the mass of striated muscle in mid urethra. It is not specifically diagnostic however, of stress incontinence (Versi et al, 1986).

### 3:3:5 Fluid Bridge Test

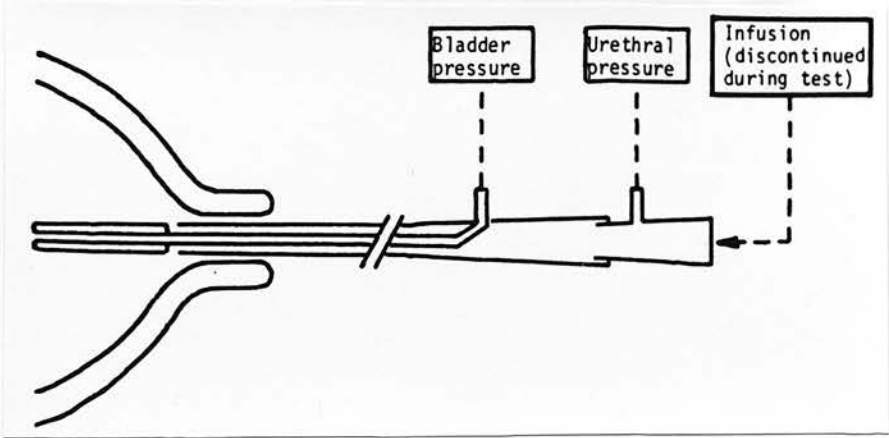
The Fluid Bridge Test (FBT) (Brown and Sutherst, 1979; Sutherst and Brown, 1980) detects urine entering the urethra and therefore competence or incompetence of the urethrovesical junction. Using a fluid infusion technique the test relies on the principle that a water infusion system does not permit an adequate speed of response to measure transmitted pressure. Therefore, urethral pressure transmission can effectively be ignored and the catheter will only respond to fluid entering the urethra from the bladder.

A double lumen bladder-urethral catheter is used to measure the respective pressures simultaneously (Figure 3:3:5:i). The bladder neck is identified by withdrawal of the infused catheter as for the UCPP method of Brown and Wickham (1969). The catheter is then positioned so that the eye holes lie at a selected distance from the urethrovesical junction. The position can be

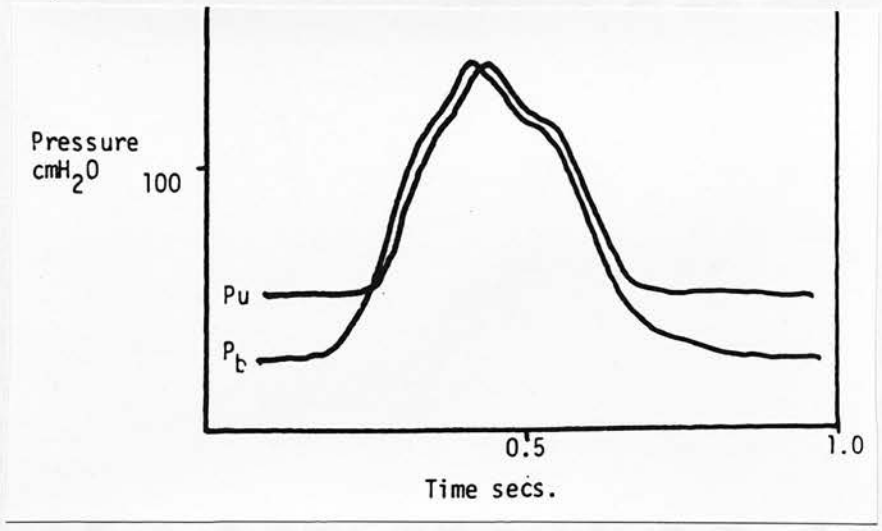
verified by turning on the infusion and referring back to the urethral profile, or more simply by observing the centimetre markings along the catheter. By asking the patient to cough, if the proximal urethra opens a fluid bridge is created from the bladder to the eye holes of the catheters within the urethra. This is therefore a positive fluid bridge test (Figure 3:3:5:ii).

The test can be performed sequentially down the urethra to establish the extent of the bladder neck incompetence. If the patient has a cough competent urethrovesical junction then the bladder channel will respond to the cough but the urethral channel recording will remain flat measuring urethral wall tone and a minimal degree of transmitted abdominal pressure (Figure 3:3:5:iii).

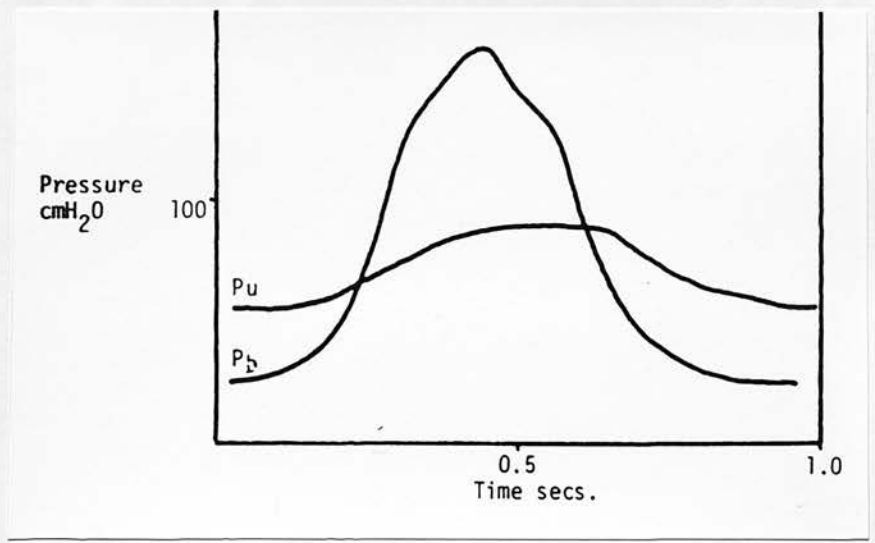
Criticism of the fluid bridge test has centred on the movement of the catheter during stress, orientation of the side eye holes and splintage of the urethra by the soft Portex catheter. However, I find this particular test useful when evaluating patients after surgery or in the absence of demonstrable leakage.



i



ii



iii

FIGURES 3:3:5i, ii, iii

### 3:3:6 Electric Fluid Bridge Test

An adaptation of the FBT by Plevnik et al (1983) involves the detection of fluid entry into the urethra by measuring the electrical impedance change. This was originally called the Electric Fluid Bridge Test (EFBT) although recently has been reintroduced as the Urethral Electrical Conductance test (UEC) (Plevnik et al, 1985). The impedance of the urethral wall is much greater than that of urine or saline. Fluid leaking into the urethra will therefore lower the impedance which can be recorded using a Plexiglass catheter with three pairs of gold plated electrodes set 0.5 cm apart (Figure 3:3:6). The impedance is measured at rest and then during coughing at 0.5 cm intervals down the urethra as for the original FBT. The UEC test however, appears to have the ability to detect small volumes of urine leakage; perhaps those missed on X-ray. It can also detect volume of loss by measuring the relative impedance change. The test itself is a variation on the theme of the water infusion FBT and requires much work to establish its place in the investigation of the incontinent patient. Many of the criticisms levelled at the original FBT will presumably apply to the UEC.

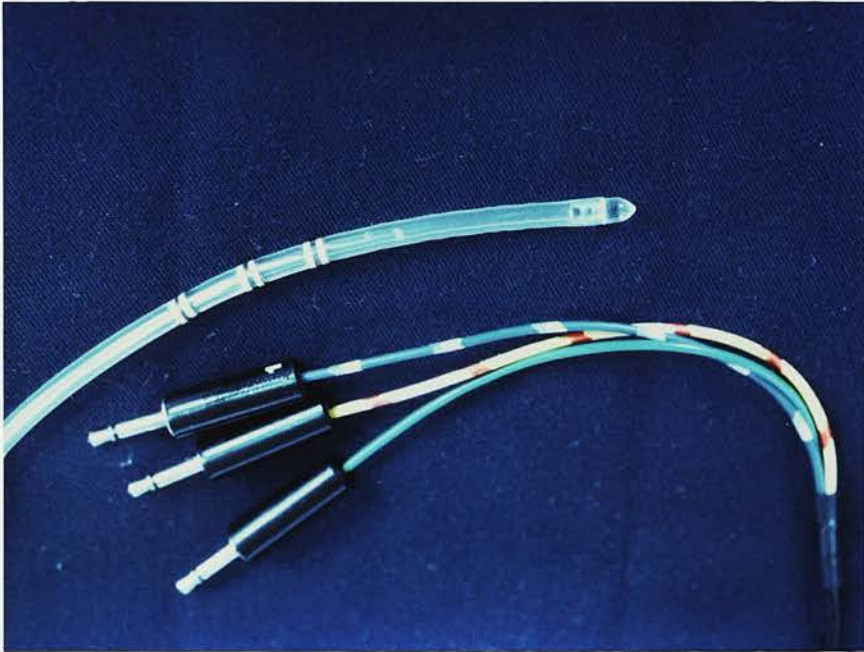


FIGURE 3:3:6 PLEXIGLASS CATHETER WITH GOLD PLATED  
ELECTRODES 0.5 CM APART

3:3:7 SUMMARY

In many cases the demonstration of urine leakage during physical examination is sufficient to provide a diagnosis. However, this is not always the case and further objective criteria are necessary to substantiate the diagnosis and help determine the correct surgical approach.

X-ray techniques have provided the standard imaging technique and many radiological signs have been associated with a diagnosis of stress incontinence. Surgical correction of these changes is assumed to be important for surgical success (Jeffcoate and Roberts, 1954; Hodgkinson, 1970; Green, 1975; Raz et al, 1979). However, many of these radiological signs have been studied on static X-rays and minimal credance has been attached to the dynamic relationships of bladder base and urethra during stress.

The FBT assesses competence of the bladder neck. It is repeatable and provides information about the extent of weakness at the urethrovesical junction in patients with stress incontinence. It acts as a useful postoperative guide to the success of surgery and provides more objective evidence for the mode of action of various surgical procedures. The drawbacks appear to be false positive results especially in the supine position close to the urethrovesical junction. This may be due to catheter movement. False negative results have occurred in patients who have had previous operations to relieve stress incontinence. This probably occurs because of urethral fibrosis and the FBT catheter occludes the lumen preventing urine leakage. The test is still a valuable tool and compliments other urodynamic investigations.

**SECTION 4**  
**HYPOTHESIS**

Transrectal ultrasound adds a new dimension to the investigation and management of the incontinent patient. I propose that this technique can provide an effective, cheap and safe alternative to the present radiological methods of studying the lower genital tract of the incontinent female.

Ultrasound is widely used in medical practice and most obstetricians and gynaecologists are conversant with the basic technique and its diagnostic potential. With the introduction of a transrectal probe to study the prostate other pelvic viscera have become accessible in particular the bladder and urethra. Using a linear array transrectal probe, the bladder and urethra can be screened, stress incontinence can be diagnosed and the anatomical relationships defined and measured at rest and in response to stress. Simultaneous pressure flow measurements can be displayed on the ultrasound screen and data recorded on videotape.

I shall outline the development of the technique and equipment modifications which were required for its incorporation into the urodynamic clinic. Finally its application in the pre, intra and post operative clinical setting will be assessed and a plan developed to select the particular surgical procedure prospectively.

SECTION 5

ULTRASOUND:

THEORY, EQUIPMENT AND REVIEW OF  
BIOLOGICAL EFFECTS OF ULTRASOUND

## 5:1 DEFINITION

Ultrasound is the term used to describe sound above the pitch audible to the normal human ear (i.e. 18 Hz - 20 KHz). It is the transmission of mechanical vibrations through matter. The echoes produced by the interaction of ultrasound and for this study the tissues of the pelvis provide information about the acoustic properties of these tissues and their surrounding milieu. It is therefore essentially different from X-radiography.

## 5:2 BACKGROUND

Ultrasound was developed between the Wars for locating submarines, depth sounding of waterways and channels and for pinpointing shoals of fish (Gramiak et al, 1969). Firestone (1945) used ultrasound to test the integrity of materials whilst Ludwig and Struthers (1950) introduced ultrasound into clinical medicine to detect gallstones.

Edler and Hertz (1954) introduced the technique to study heart valve motion, which was later developed into echocardiography. Donald et al (1958) described the value of ultrasound in gynaecological practice to differentiate abdominal masses.

The fluid filled bladder proved an excellent organ for study and by acting as an ultrasonic window other pelvic structures could be identified. Holmes (1967) and others (White et al, 1980; Nachtegaele et al, 1982) used a transabdominal approach. This technique is still used to measure residual urine volume

(West, 1967; Pedersen et al, 1975; McClean and Ecell, 1978), to visualise bladder calculi (Rosenfield et al, 1979), for the investigation and follow up of bladder tumours (Itzchak et al, 1981; Brun et al, 1984) and also to detect vesico ureteric reflux in children (Kessler and Altman, 1982). However, viewing the bladder base and urethra remained a problem due to the overlying symphysis pubis and often excess adipose tissue of the anterior abdominal wall. A transrectal probe which was initially developed to study the prostate (Watanabe et al, 1974; Resnick et al, 1977; Brooman et al, 1981; Okafor et al, 1983) has been used to study the bladder and urethra (Nishizawa et al, 1982, 1983; Perkash and Friedland, 1983; Shapeero et al, 1983; Richmond et al, 1984; Brown et al, 1985).

### 5:3 PRINCIPLES OF ULTRASOUND

For diagnostic purposes the frequency of ultrasound varies from 1-20 MHz. In this study I used a 5 MHz linear array transrectal probe. The generation of ultrasound from a transducer requires crystals which are capable of exhibiting the Piezo-electric effect. When a voltage is applied across a crystal it will expand slightly. When the voltage is stopped the crystal returns to normal size and will contract in size if the electrical polarity is reversed. This change in the crystal shape produces a pressure wave which when in contact with tissue produces rapid, minute vibrations or the generation of an ultrasound beam. When the reflected beam returns and strikes the

transducer, which now acts as a receiver, a small voltage is produced. The Piezo-electric crystal generates ultrasound in response to an applied voltage which in turn produces a potential from the reflected echo. The greater the amplitude of the echo the greater the voltage produced. The crystals are either naturally occurring e.g. Quartz or Lithium Sulphate or synthetic materials such as the ceramic crystals of lead zirconate or titanate. The characteristic frequency of each crystal and therefore each transducer is determined by the crystal thickness. Once the ultrasound frequency has been determined it is then possible to cut a crystal to the required dimensions.

For rapid ultrasound pulses to be created as short pulses each crystal vibration must be dampened soon after excitation and is therefore bonded to a backing material of plastic or tungsten. In some circumstances another material is bonded to the front of the transducer to reduce reflection of the transmitted pulse at the tissue-transducer interface.

Short bursts of ultrasound (1-2 microseconds) are generated by the transducer. Sound passes into the transducer to a varying extent depending upon the tissue's acoustic properties. The time taken from generation of the pulse to detection of the reflected echo is a measure of the depth of the reflecting surface from the transducer.

Different types of ultrasound wave can be generated by varying the exciting voltage to produce continuous, short or long pulses. For A scan, B scan and a Real Time ultrasound scanning

techniques rapid, quick fire bursts of electrical voltage produce short, pulsed ultrasound waves.

#### 5:4 TYPES OF ULTRASOUND DISPLAY

'A' mode display or amplitude modulation is the basic technique. It is a one dimensional scan. As an ultrasound pulse is transmitted the spot on a cathode ray oscilloscope screen begins to sweep at a fast, uniform speed across the screen from left to right. This is achieved by applying an increasing voltage across the X plates of a cathode ray tube. As echoes are received they are amplified and applied as voltage pulses to the Y plates (Figure 5:4:1). The bigger the echo the larger the upward deflection from the X axis. The position of the deflection is a measure of the time taken for pulse generation, reflection and reception.

'B' mode display (brilliance or intensity scanning) is the same as 'A' mode but instead of echo spikes the pulses are represented as dots.

'M' mode - this is the time motion form of scanning. Echoes appear as dots with varying degrees of brightness depending on the echo strength. The display sweeps across the screen at 90 degrees to the time base. This is the type of scanning used in echocardiography where the transducer is stationary but the tissue moves.

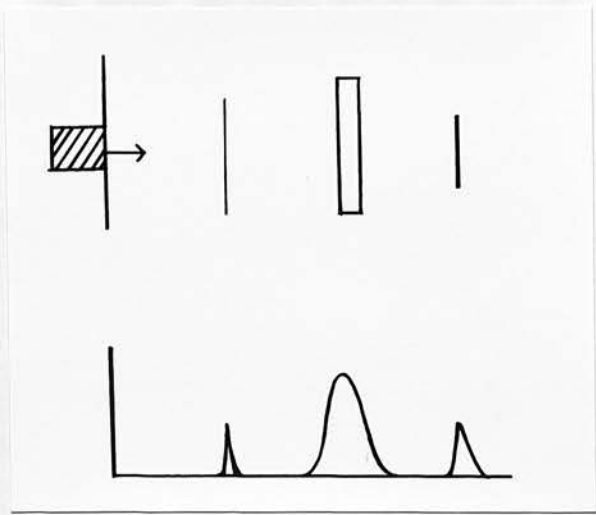
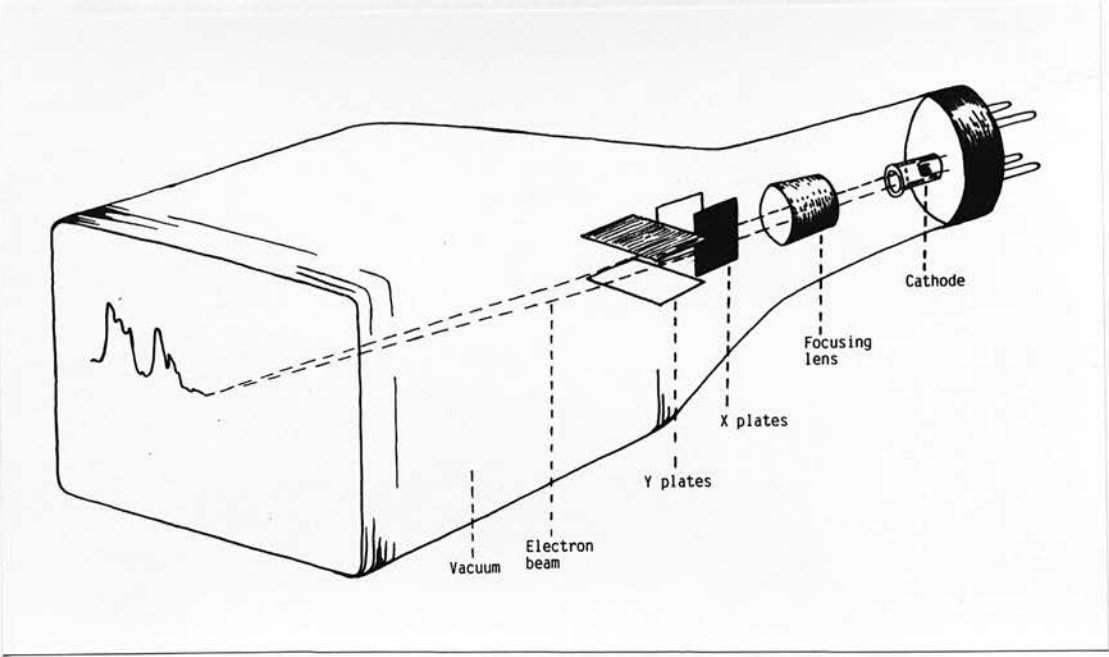


FIGURE 5:4:1 SIMPLE CATHODE RAY A-SCANNER WITH SCHEMATIC TRACE OF IMAGE FROM TISSUES OF VARYING THICKNESS AND DISTANCE FROM THE TRANSDUCER

'B' scanning - This developed because of difficulty interpreting the basic A scan pictures. The ultrasound beam sweeps in a plane through tissue and uses the B mode type of delivery. Reflecting tissue structures are located by determining the times for echoes to return and the direction of the beam. Two-dimensional pictures can then be constructed. The image is stored by photographing the picture as the spots appear by using an electronic scan converter to store the scan lines of information from the echoes and then displaying a composite grey scaled picture. The analog scan converter can store 32 levels of grey scale information in a matrix of 1000 x 1000. It receives spatial data, records and then displays the information after amplification. Digital scan converters record the voltage produced from each echo in numerical form and then display information on a screen in shades of grey. The new image is constructed from rectangular elements called pixels. Therefore the shade of grey for each pixel corresponds to the echo amplitude for each area scanned.

REAL TIME SCANNING

This is similar to cine photography. If images of tissue are generated very rapidly and also repeatedly it is possible to see motion of interfaces. The number of "frames" is approximately 25 per second (20-40 per second).

There are five types of Real Time Scanner:

- i) Mechanical
- ii) Linear array
- iii) Phased array
- iv) Water bath
- v) Compound

i) The two common varieties of mechanical sector scanner are the rotating wheel and the oscillating head type of transducer. In the former, four transducers are normally mounted on the head so that each ultrasonic beam scans through 90 degrees. Each transducer is activated as it passes through a quadrant and fires out of the transducer window in a wedge or fan shape (Figure 5:4:2).

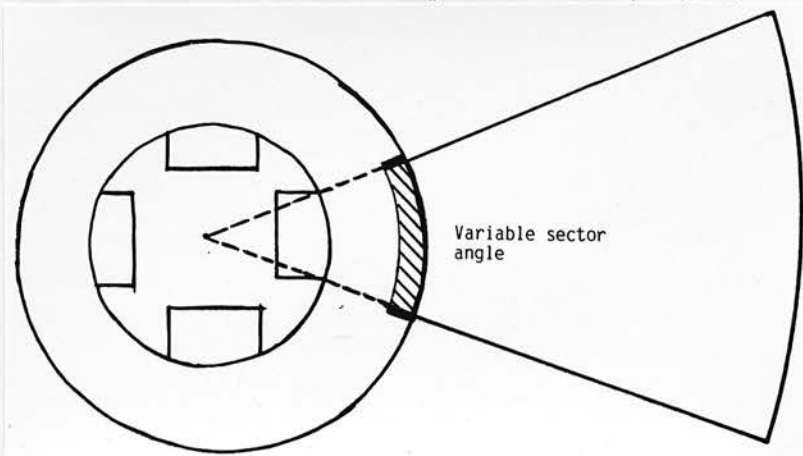


FIGURE 5:4:2 ROTATING WHEEL MECHANICAL SECTOR SCANNER

ii) In linear array scanning the transducer head is made from a number of crystal strips measuring for example 10 mm x 1.5 mm. The strips are grouped together such as 12345, 23456, 34567. The ultrasound beam then moves along at 1.5 mm intervals so that for 100 separate crystal strips 96 different scan lines would be produced. Some transducer crystals are grouped in unison as above or in an alternate sequence in an effort to improve picture quality. Usually the beam of sound is focused like the focal length of a camera using a lens or concave strip of crystals.

iii) In phased array real time scanning the transducer has a number of thin crystal strips laid side by side. The crystals are excited with slight time delays between each crystal so that the direction of each beam can be controlled electronically. With the appropriate number of crystals in each transducer a 90 degree sector can be scanned at a time.

iv) The water bath technique allows close tissue apposition with the transducer in difficult positions. It is of value when looking at structures close to the surface and thereby close to the transducer itself. By utilising this "stand off" approach clearer images of superficial tissues are possible.

v) The final type of real time scanner, the compound scan, operates by transmitting ultrasound from several different directions into the tissue or structure. The echoes produced from each ultrasound beam are then presented on screen as a compound image.

## 5:5 ULTRASOUND CHARACTERISTICS

### i) Ultrasound wavelength

The ultrasound beam is affected by two main factors, namely, the diameter of the piezo-electric crystal and the wavelength of the sound beam. The wavelength influences the width and length of the ultrasound phase. The velocity of ultrasound in tissue (C) = wavelength ( $\lambda$ ) x frequency (f) i.e.  $c = \lambda f$ . The ultrasound beam is divided into two definite areas of interest: the near zone (Fresnel zone) and far zone (Fraunhofer zone).

The depth of the near zone  $D = \frac{R^2}{\lambda}$

(D = depth of near zone. R = radius of transducer.  $\lambda$  = wavelength in cm). Therefore, for a fixed radius the depth increases as the wavelength decreases (or frequency increases). As the sound beam diverges at the end of the near zone the far zone begins. The spread of the beam in this zone is determined by  $\sin \theta = \frac{0.61\lambda}{R}$  ( $\sin \theta$  = angle of spread, R = radius of the transducer).

For a fixed transducer radius the smaller the wavelength (the greater the frequency) the lesser the spread of the ultrasound beam.

The crystal diameter and sound frequency are important variables to be considered for each area under investigation by scanning. As sound passes through tissue it becomes attenuated due to absorption by that tissue or reflection from its surface. The depth of ultrasound imaging varies inversely with the ultrasound frequency. For deep penetration a low frequency transducer is used and vice versa.

ii) Acoustic impedance

To establish the echo size of an ultrasound pulse the acoustic impedance of tissues on either side of an interface must be measured. The greater the difference in the acoustic impedance of neighbouring structures the bigger the echo and the more obvious the ultrasonic interface.

Acoustic impedance ( $Z$ ) is determined by the density ( $P$ ) of the tissue or material and the velocity ( $C$ ) of the sound through the material. Therefore  $Z = PC$ .

iii) Resolution

The axial resolution, or the differentiation of tissue structures along the path of the sound beam is determined by the duration of the ultrasound pulse. Lateral resolution is the ability of the transducer to produce separate pictures from structures/tissues lying side by side. Therefore, in general terms the higher the frequency of the ultrasound the better the

resolution. However, as a complication of the higher the frequency the greater the sound attenuation. A balance between the two is therefore essential.

The ability of a real time scanner to differentiate dynamic changes of tissues depends on the frame-rate. By increasing the frame-rate the time available to display scan lines of information is diminished and therefore once again a compromise has to be reached.

Since the introduction of ultrasound into medical practice for diagnostic and therapeutic purposes there has always been an element of concern about its safety for routine use. Although there is ample experimental tissue and animal data, the volume of evidence relating to human studies is small and at times contradictory.

The biophysical mechanisms of ultrasound include heating effects, cavitation effects, micro streaming and those of radiation forces.

i) Heat

The absorption of ultrasound energy by tissue or media results in heat production. The tendency in most media is for absorption to increase with intensity of ultrasound (Fry and Dunn, 1962). The actual rise in temperature depends upon the heat generated, the specific heat of the medium and the conductance of heat within the tissue. The heat generation depends on the intensity of ultrasound and the absorption coefficient (Goss et al, 1978). Lele (1975) reported no danger of ultrasonic teratogenicity from the effects of heat in man.

## ii) Cavitation

Local variations of pressure from an ultrasound wave produce oscillation of small gas bubbles. Stable and unstable types of transient cavitation are described and occur more commonly in liquids than soft tissues. Stable cavitation is due to the growth and then resonance of microgas bubbles. Transient cavitation describes the eventual collapse of the bubbles resulting in local temperature and pressure effects on surrounding tissues.

The evidence for mammalian tissue cavitation arises from using therapeutic ultrasound (ter Haar and Daniel, 1981; ter Haar et al, 1982) and has been suggested by Flynn (1982) using pulsed ultrasound.

## iii) Microstreaming

This describes the eddying effect produced around a bubble oscillating in a non-uniform manner leading to movement of particles of bubbles away from the transducer.

Radiation force is a steady force exerted on objects in a sound field with impedance or absorption different from their surrounding structures.

## iv) Biological effects

The vast amount of concern over the last 15 years has probably arisen from the report by MacIntosh and Davey (1970) of chromosomal aberrations after use of a fetal heart monitor and later (1972) the same authors concluded that there was a

relationship between the intensity of ultrasound and the extent of the chromosome abnormalities. Their results were based on a study of human blood cultures insonated with ultrasound of varying intensity (0-80 mw/cm). Liebeskind et al (1981) have reported sister chromatid exchanges in human lymphocytes exposed to ultrasound.

There is, however, overwhelming evidence contradicting these initial results from in vitro studies of lymphocyte cultures using both continuous wave ultrasound (Bernstine, 1969; Bobrow et al, 1971; Buckton and Baker, 1972). Similar contradictory work has been published when continuous and also pulsed ultrasound has been used (Boyd et al, 1971; Abdulla 1972; Watts et al, 1972). Coakley et al (1972) were unable to identify chromosome aberrations in human blood cultures despite using ultrasound of high intensity and even using a similar method to the South African pair MacIntosh et al (1975) were unable to reproduce their initial results. Six independent groups performing similar work to Liebeskind all reported negative findings (Jacobson-Kram, 1984).

Other experimental work by Lyon and Simpson (1974) confirmed that there were no effects of ultrasound on spermatogenesis and oocyte maturation of mice using pulsed and continuous wave ultrasound. Pulsed frequencies were either 1 msec or 30 msec and intensities ranging from 6.4-45 W/cm.

In vivo, Boyd et al (1971) showed no chromosome damage in blood from fetuses of mothers scanned at stages in pregnancy.

Lucas et al (1972) reported similar results from studies of fetal blood cultures after intrapartum fetal monitoring. Abdulla et al (1971) showed no increase in chromosome aberrations of maternal or fetal tissue obtained at hysterotomy for termination of pregnancy. These patients were insonated for one hour with pulsed ultrasound and ten hours of continuous ultrasound.

In other human studies, Hellman (1970) reported the safety of ultrasound in a collaborative study of 3,297 obstetric patients and concluded there was no increased risk of fetal abnormality arising from this technique.

#### 5:7 CONCLUSIONS

The experimental evidence to date and information from obstetric ultrasound departments suggests that there are no harmful biological effects from pulsed ultrasound at frequencies most commonly used for diagnostic purposes. Complete cystometry and ultrasound evaluation of the incontinent patient takes less than 20 minutes which is less than the comprehensive scan performed on the 16-20 week fetus in utero.

For the purposes of this study I used a 5 MHz probe which provided excellent tissue penetration, and adequate resolution. These were due to refraction, reverberation or shadowing. Refraction occurs because of a difference in the velocity of sound at different interfaces, for example between solids and liquids. Reverberation is due to multiple reflections between interfaces which are close to the transducer and shadowing occurs

when scanning structures with high attenuating properties such as bone. Hence, attempts at studying the bladder and urethra trans-abdominally proved unsuccessful due to shadowing by the pubis.

SECTION 6  
ULTRASOUND TECHNIQUE AND  
EQUIPMENT MODIFICATIONS

ULTRASOUND EQUIPMENT AND ITS MODIFICATIONS

The concept of imaging the bladder base and urethra in patients with stress incontinence is not new. However, examination by pelvic ultrasound is a relatively recent concept. The pilot study for this thesis involved a Toshiba scanner and rectal probe (3.5 MHz). However, for the purpose of this study an Aloka portable ultrasound scanner was purchased through the generosity of the Swann Morton Foundation, Sheffield.

6:1 ALOKA SSD 210 DX

This is a realtime scanner (Figure 6:1). It is portable and weighs 7 kgs without probe and cable. For equipment specifications see Appendix III. It has a freeze frame, push button numeric keyboard and two linear measurement facilities. The screen size is 5.5 inches diagonally.

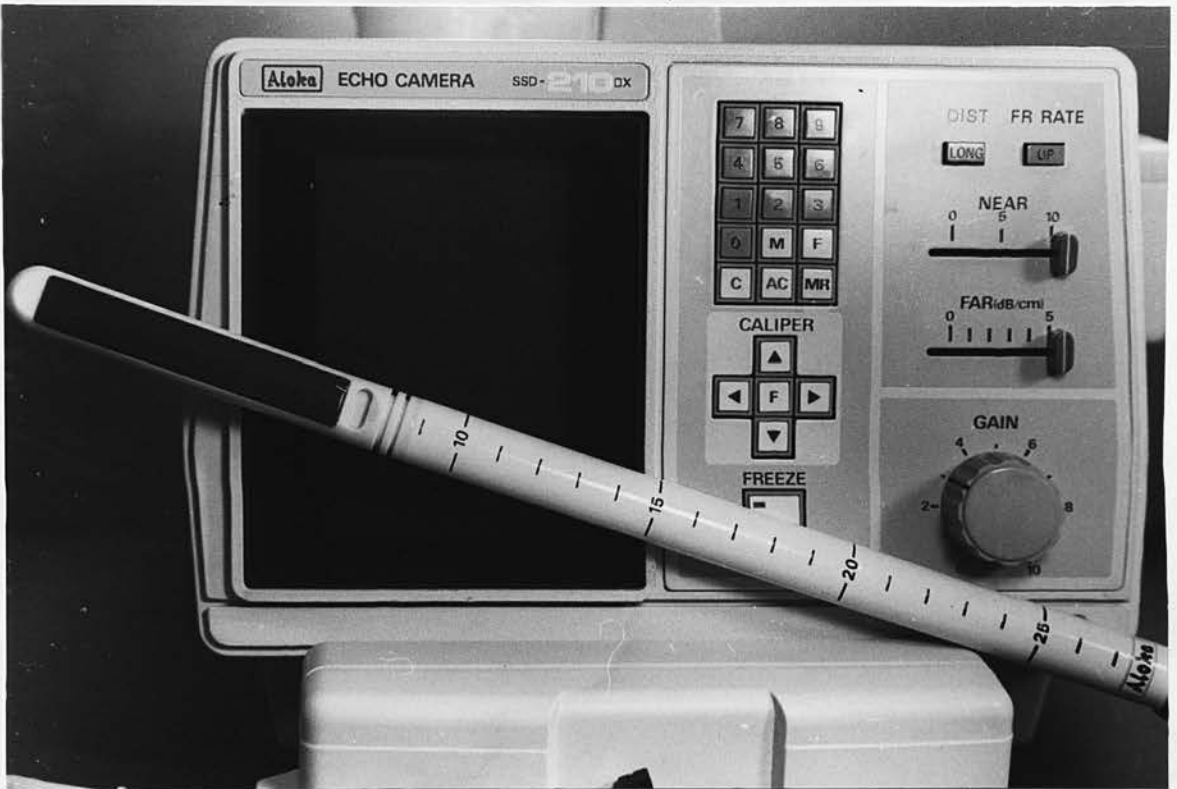


FIGURE 6:1

6:2 TRANSRECTAL PROBE (UST - 658-5)

This is a 5 MHz linear array probe with linear electronic scanning (Figure 6:2:i). The scan width is 56 mm (Figure 6:2:ii). The most important feature is the diameter of the probe head which is only 15 mm, and therefore at least 5 mm narrower than most of its competitors.

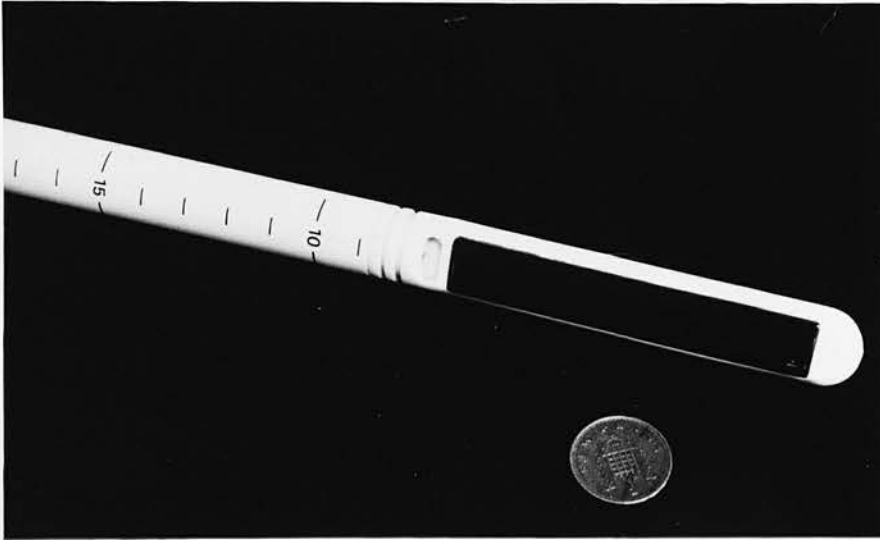


FIGURE 6:2:i TRANSRECTAL PROBE

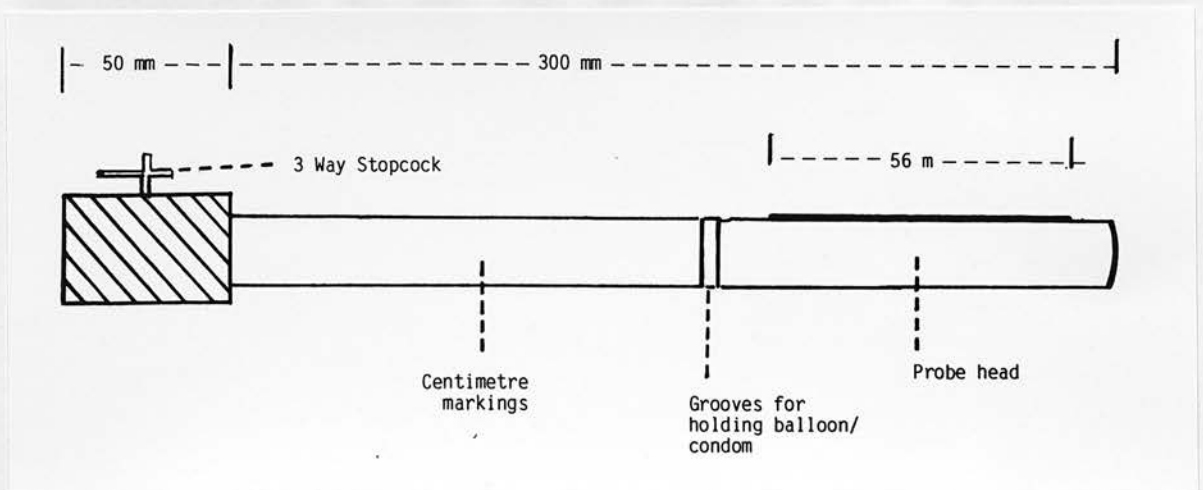


FIGURE 6:2:ii SCHEMATIC DRAWING OF ULTRASOUND PROBE

6:3 SCANNING PROCEDURE

The bladder is difficult to visualise unless filled with fluid. In abdominal ultrasound scanning particularly in obstetrics and gynaecology this structure provides a window through which the ovaries and uterus can be studied. However, because of the need to view the bladder outlet and urethra in patients with urinary incontinence the abdominal approach is often unsatisfactory. This is in part due to the symphysis pubis and the shadow this creates, but also the preponderance of adipose tissue at this site (Figures 6:3:i and 6:3:ii).

Therefore, the transrectal route was adopted to scan patients with urinary incontinence. This is obviously universally acceptable, although latterly we have tried the transvaginal route which tended to prove more acceptable to patients.

The probe head is covered with a condom or finger stall to prevent soiling and also to allow filling with degassed water to reduce artefacts. It is claimed by the manufacturers that this provides a better acoustic interface with the rectal or vaginal wall although in practice I found this unnecessary. However, by injecting 10-15 mls of water into the condom and then aspirating it is easier to suck out any air bubbles before insertion into the rectum. This is performed with the patient in the left lateral or dorsal position. Scanning can then take place with or without pressure flow recordings depending upon the nature of the investigation, in either the erect or supine positions or both.

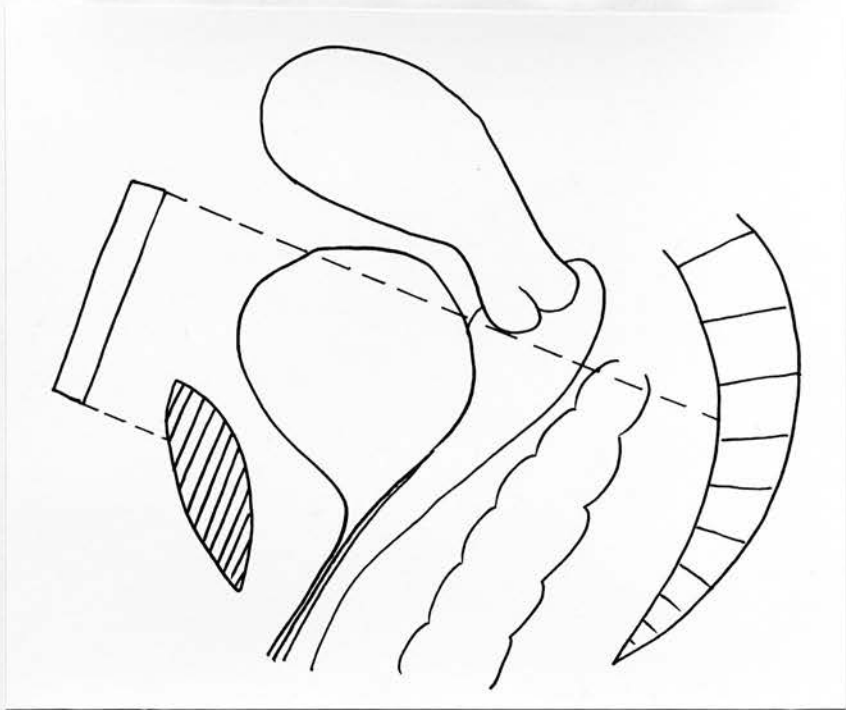
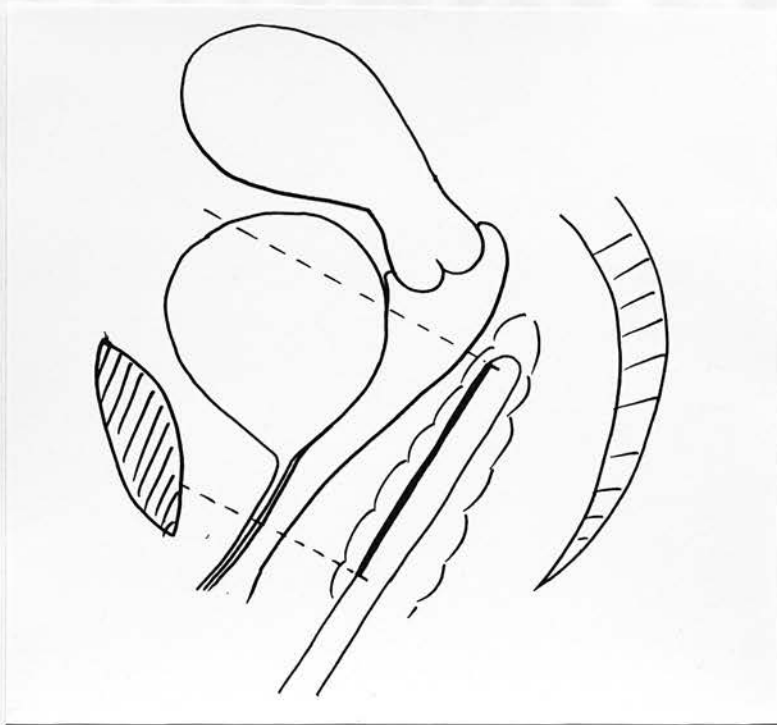


FIGURE 6:3:ii

TRANSRECTAL SCANNING



The conventional scan image appears from top to bottom of the screen irrespective of patient position. The picture is created in a left to right format as for television. Therefore whether the patient is supine or erect the image of the bladder and urethra is always the same and is shown in Figure 6:3:iii below. Further examples are presented in the clinical section.

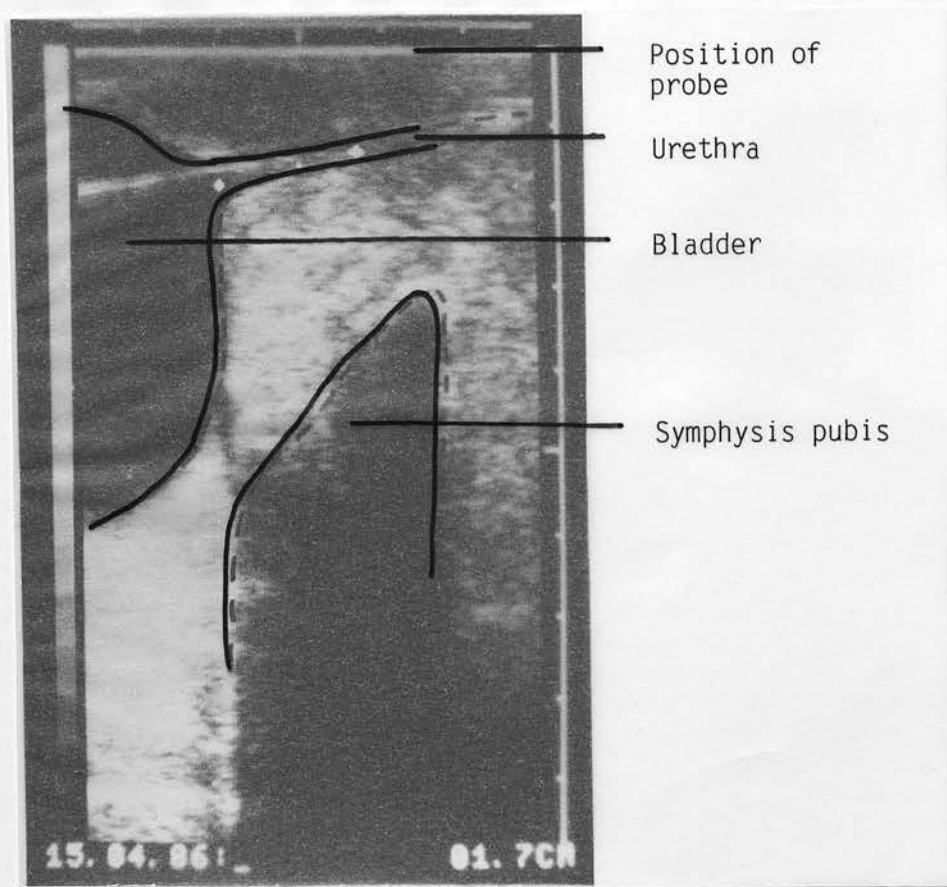


FIGURE 6:3:iii SCHEMATIC PICTURE OF BLADDER URETHRA AND PUBIS WITH ACTUAL POLAROID PRINT

The conventional scan image appears from top to bottom of the screen irrespective of patient position. The picture is created in a left to right format as for television. Therefore whether the patient is supine or erect the image of the bladder and urethra is always the same and is shown in Figure 6:3:iii below. Further examples are presented in the clinical section.

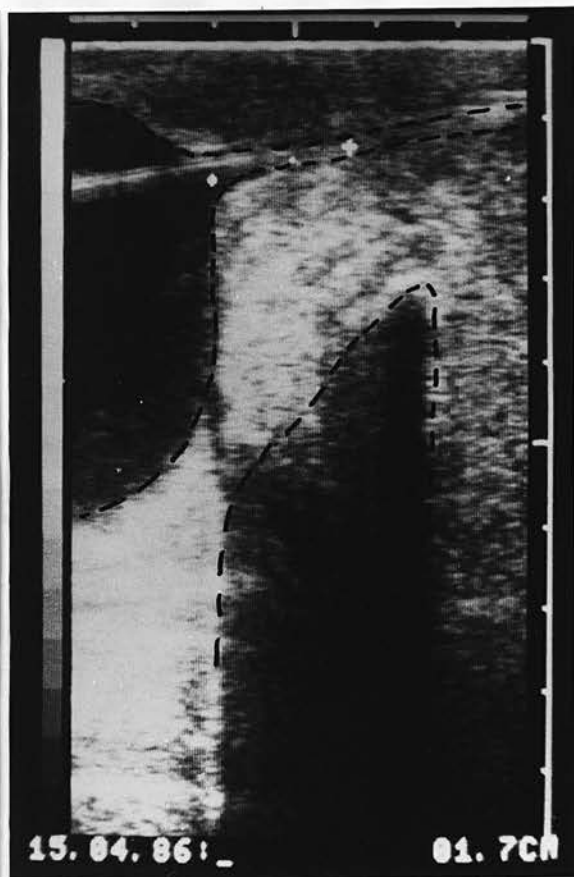


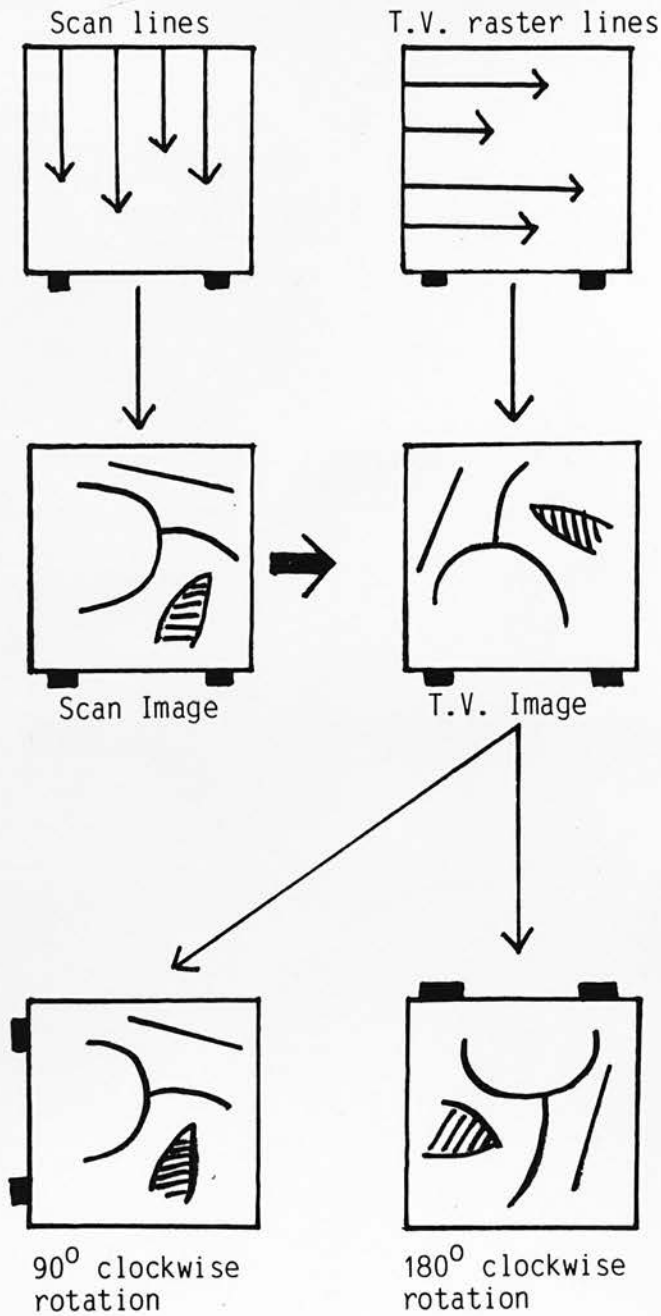
FIGURE 6:3:iii SCHEMATIC PICTURE OF BLADDER URETHRA AND  
PUBIS WITH ACTUAL POLAROID PRINT

6:4 MONITOR AND VIDEO MODIFICATIONS

The ultrasound screen measures 5.5 inches diagonally. This was enlarged to 12 inches by connecting to a standard monitor which needs to be placed on its side so that it conforms to the output signal of the scanner. The image proved easier to perceive and there was only minimal loss of picture quality and clarity. Orientation of ultrasound images is notoriously difficult but with larger static scanners conversion of the image to the more acceptable vertical position should be straightforward. With the portable Aloka scanner the monitor required to be rotated through 90 or 180 degrees for the best image (Figure 6:4).

The scan data for each patient was recorded on VHS video format with sound commentary for review later and also for comparison with similar investigations performed after treatment.

FIGURE 6:4 SCAN/MONITOR RELATIONSHIP AND NEED FOR ROTATION



6:5 ULTRASOUND SCREEN GRAPHICS - SIEL COMPUTER

The Aloka scanner has two basic linear measurement functions and a simple numerical keyboard for patient identification. In order to increase the capabilities of the scanner, a medical ultrasound computer (Siel ACV 4LS) was incorporated into the circuit. This has software dedicated for obstetric purposes and includes length, circumference, area, a drawing function as well as the basic obstetric measurements and computed ratios.

The standard keyboard allows greater detail to be printed on the scan screen for patient identification and also for the labelling of anatomical structures. The measurements and drawn outlines are made with a simple joystick function. The basic layout of the ultrasound equipment is shown in Figures 6:5:i and 6:5:ii.

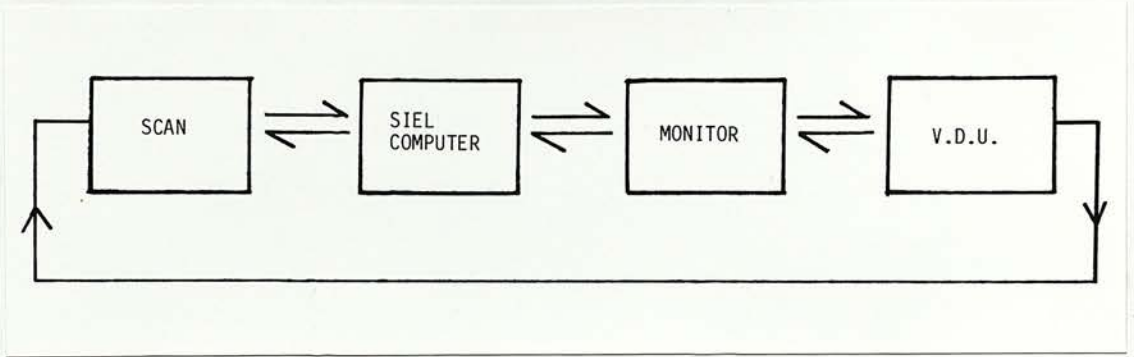


FIGURE 6:5:i BLOCK DIAGRAM OF BASIC SCAN EQUIPMENT



FIGURE 6:5:ii ULTRASOUND EQUIPMENT LAYOUT

6:6:1 BACKGROUND

There are a limited number of reports describing the use of contrast agents for ultrasound scanning. Much of the work is theoretical and the emphasis has been primarily on blood flow and blood vessel enhancement for doppler purposes. The ultrasonic tumour marking technique to monitor therapeutic response shows promise.

Gramiak and Shah (1969) reported that indocyanine green opacified areas of blood vessels and heart chambers which were being scanned. Ziskin et al (1972) showed experimentally in animals that the rapid instillation of fluid enhanced the ultrasonic image by production of minute gas bubbles. Goldberg (1976) injected a water-soluble X-ray contrast which contained microscopic air bubbles along a "T" tube to demonstrate the common bile duct. Carroll et al (1980) and Gobuty (1984) have used gelatin encapsulated microbubbles for the tumour rim enhancement of rabbits with V2 carcinoma. Recently perfluorocarbons have shown similar experimental properties in dogs (Mattrey, 1984). Microparticulates in solution (Ophir et al, 1979), collagen microspheres (Ophir et al, 1980), chelating agents and amino acids (Tyler et al, 1981) have been injected intravenously to selectively localise the tissue under observation. The echo enhancement appears due to an impedance