SOME FACTORS INVOLVED IN MECHANICAL INSTRUMENTATION IN THE ROOT CANAL OF A PERMANENT TOOTH

by

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CONTENTS

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This investigation arose as a direct result of certain questions which posed themselves during the course of a prolonged interest in Endodontia. There has always been, since qualification, a pleasurable preoccupation with endodontic problems mainly because of the meticulous and painstaking attention which must be given to the stages of mechanical instrumentation and obturation of the central space of a pulpless tooth. During the period of many years clinical experience it became obvious that questions arose which, while being imponderable in the clinical situation, might be answered by an 'in-vitro' investigation. The problems posed are entirely of mechanical preparation - no investigation being carried out on the physical properties of the instruments concerned since it was considered that the problems of mechanical instrumentation were more related to the cutting action of these instruments than to their physical properties. The problems posed and the results obtained from 'in-vitro' studies form the basis of this thesis.

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C H A P T E R 1

Introduction.

Endodontics can best be defined in the words of the preface of the Bulletin on Endodontics prepared by the University of Toronto Dental School. This states that "endodontics is the union of two Greek words 'endo' within and 'odontos' a tooth. The English equivalent of these two Greek words encompasses the practice of all therapeutic and surgical procedures relating to the protection of the vital pulp, biomechanical and biochemical treatment of the pathologically involved pulp and the material obliteration of the space formerly containing that pulp". This investigation is, however, only involved with one of these factors, namely, biomechanical instrumentation.

The human dentition is made up of 20 deciduous and 32 permanent teeth, each tooth being composed of three calcified tissues - cementum, dentine and enamel - together with a highly specialized connective tissue, the dental pulp. With the exception of enamel, the tissues that go to make up the human tooth are of mesodermal origin. Enamel, ectodermal in origin, is a highly specialized tissue; is the hardest and most densely calcified tissue in the human body. It is unique among calcified tissues in that once it reaches its functional state it is completely devoid of contact with any cellular elements and is, therefore, unlike cementum, dentine or bone, unable to react to injury.

Dentine, cementum and bone are, by virtue of the cellular elements with which they are in intimate contact, able to react over a considerable range to injury. Formation of dentine and cementum can continue throughout life by, in the case of dentine, additions to its pulpal surface and in the case of cementum, to depositions to its external surface. Additions to the pulpal surface of dentine are particularly pertinent to the present work in that, with continuing age, there is a physiological diminution in the size of the pulp cavity of the human tooth.

From the embryological point of view, the first indication that teeth will be present in the human oral cavity is at the 6th week of foetal life when the primary epithelial band begins to form as a localised band of proliferation of the oral epithelium (Scott & Symons 1964). During the 7th week each primary epithelial band begins to divide into two processes - the vestibular band which later on forms the lips and cheeks, and a band called the dental lamina from which will be formed the teeth. Along the length of the dental lamina small rounded swellings begin to form which go to make up the enamel organs of the deciduous teeth. In relation to each enamel organ the underlying cells of the mesodermal tissue begin rapidly to proliferate forming a dense mass of cellular tissue which later on develops into the dental papilla or primitive dental pulp and the follicular sac of each developing tooth germ. The term 'tooth germ' describes both the ectodermal and mesodermal elements which go to make up the human tooth. The dental papilla continues its development from a localised mass of cells through a 'cap stage' and later on into the typical 'bell stage' (Fig. 1.1).

Permanent teeth with deciduous predecessors are formed from a further downgrowth or lamina which appears on the lingual side of the developing deciduous enamel organ. This will later on proliferate to

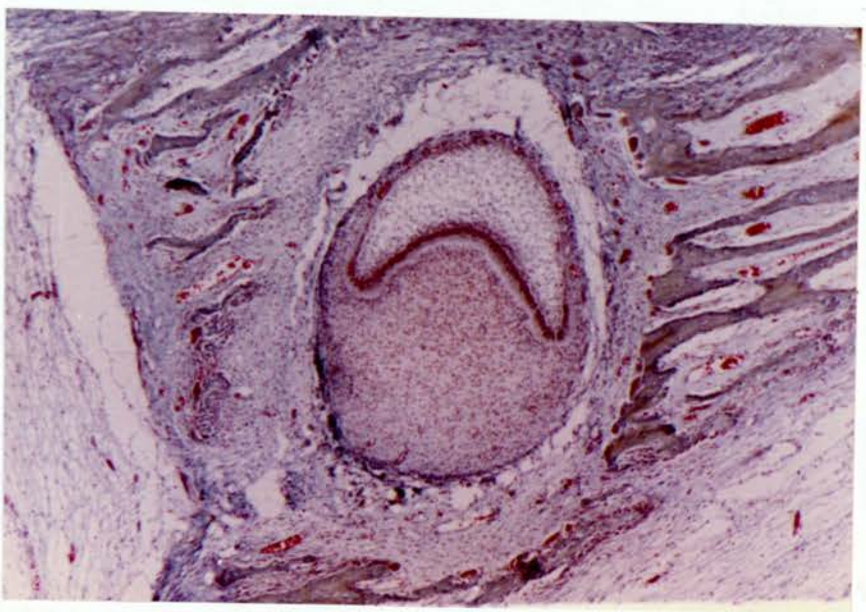


Fig. 1.1

form the successional permanent teeth. Posterior teeth with no deciduous predecessors are formed from a continuous proliferation of the primary dental lamina in a ventral direction. From this ventral projection the enamel organs of these teeth are formed.

It is at the bell stage of development of the dental papilla that changes become evident, pointing to the approaching formation of dentine which is laid down between the mesodermal surface of the basement membrane and the inward retreating odontoblasts, the thickness of dentine depending on how far these odontoblasts have retreated from the basement membrane. Formation of the dentine is, however, controlled by the presence of the internal enamel epithelium and Hertwig's Sheath (a continuation of the internal and external enamel epithelium layers). Odontoblasts can only be differentiated from the cells of the dental papilla if these elements are present. The root portion of a tooth is mapped out by Hertwig's Sheath which in the case of a single rooted tooth is a simple tubular structure but in the case of multi-rooted teeth is more complex in nature.

Unlike enamel, dentine formation is continuous throughout the life of the tooth (Stanley & Ranney 1962). Once the external form of the tooth has been established and the primary dentine thickness laid down, a further but slower deposition of secondary dentine takes place within the pulp cavity gradually diminishing the size of this cavity (Figs. 1.2 and 1.3). The cells of the dentine, the odontoblasts, possess extremely long protoplasmic processes usually referred to as Tomes' Fibres (sometimes as long as 5 mm or 5,000 μ

Fig. 1.2

Fig. 1.3

long). These fibres pass through the entire thickness of dentine within a tubule whose diameter ranges from 1 to 5 microns.

The dental pulp, the portion of the dental papilla remaining after dentine formation is completed, is an extremely delicate, highly vascular tissue composed of odontoblasts, fibroblasts and defence cells. It occupies the central cavity of the tooth, that is, the pulp chamber in the coronal portion of the tooth and the root canal in the root portion and morphologically corresponds roughly in shape to the external form of the tooth. By virtue of its developmental connection with the dentine it has a function other than formative, sensory and nutritional, namely, a defence function. In this respect it is intimately involved with any stimulus applied to the dentine. Moderate stimulation will cause the pulp to produce secondary dentine, while severe irritation will cause pulp tissue to undergo inflammatory changes. The defensive function of the pulp is of great importance in conservative dentistry in that it gives the dental pulp the power to recover after an assault has been made upon it; for example, after cavity preparation, where the mechanical stimulus in such a procedure has been shown by Beveridge & Brown (1956), Wynn et al (1963) and Scheinin (1963) to produce an actual rise in blood pressure within the pulp itself. It is interesting to note that in the investigation carried out by Beveridge & Brown (1956), it was found that whenever the pulp was frankly exposed, no rise in blood pressure occurred following the application of the usual stimuli thus demonstrating that the rise in pressure is, in the final analysis, due to the rigid walls of the cavity containing the pulp tissue.

If the applied stimulus is great, whether this is mechanical or chemical, then an inflammation is induced in the pulp tissue (Brännström (1961) and Stanley & Swerdlow (1959)) and because the pulp tissue is enclosed within hard unyielding walls the intense pressure within the tooth leads to self-injury (Orban (1944) and Scheinin (1963)) which, in some cases, may be so severe that necrosis of the pulp occurs due to stasis of the blood supply.

Stasis of the blood supply, therefore, arises from an increased internal pressure in the central cavity due to hyperaemic and exudative changes accompanying an inflammation, and since it has been demonstrated that pulp tissue does not tolerate inflammation well and has no collateral circulation (Ingle (1965); Lewin-Epstein & Silbermann (1962)) and since pulp tissue is enclosed within hard unyielding dentine walls, the great increase in pressure compresses and eventually occludes the blood vessels, especially in the apical region of the root, to such an extent that the pulp tissue becomes necrotic.

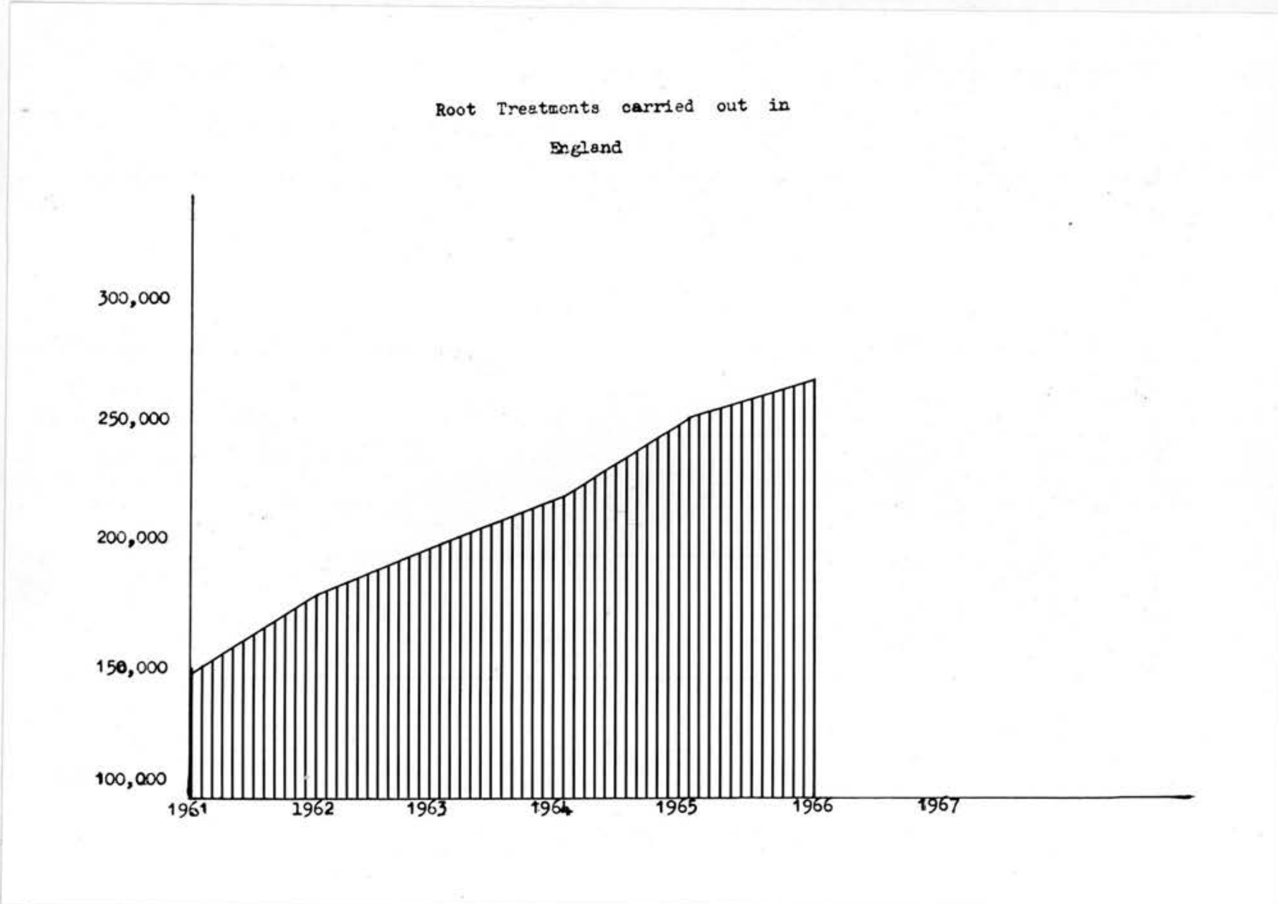
The fact that a dead space is left within the central cavity of the tooth whenever necrosis of the pulp occurs is of great importance to the endodontist. The cliche that nature abhors a vacuum is certainly true in root canal therapy and it is the ultimate aim of endodontic procedures to 'sterilise' and eliminate the central cavity formerly occupied by pulp tissue. Another factor of importance to the endodontist is the fact that the young tooth has a large central cavity requiring the use of large diameter instruments in the mechanical preparation of the root canal whereas in the old tooth, due to the deposition of secondary dentine within the central cavity, the diameter of the root canal is very much reduced permitting much smaller instruments to be used in the final preparation of the root canal.

Root canal therapy is a recognised technique in the armamentaria of the practising dentist for the retention of a tooth in the dental arch, whose pulp shows evidence of pathologic changes. It is, however, but one aspect of the wider term - endodontics.

Root canal therapy is not a modern technique since this particular procedure was described by Pierre Fauchard in his 'Treatise on the Teeth' published in the year 1746. In recent years root canal therapy has become more and more popular with the dental profession and with the general public alike, probably because of the present emphasis placed on Dental Health Education, and the dispelling of the old belief in focal infection. Figures kindly supplied by the Ministry of Health (1968), the Scottish Home and Health Department (1968) and by the Northern Ireland Health Services Board (1968) show that root treatments are increasing over the years while the number of extractions carried out is steadily decreasing; shown in the table. The following graphs show that the number of root treatments completed by general practitioners in England and Wales (Fig. 1.4), Scotland (Fig. 1.5) and Northern Ireland (Fig. 1.6) under the National Health Service is on the increase. The figure for England in the year 1961 was 164,250 while the number carried out in 1967 shows an increase of 78% (292,000). This large increase in a relatively short space of 6 years shows that this facet of dental

	Scotland		England & Wales		Northern Ireland	
	Root Treat-ments	Extractions	Root Treat-ments	Extractions	Root Treat-ments	Extractions
1961	13,250	1,337,900	151,000	9,774,000		
1962	11,130	1,353,320	184,000	9,138,000		
1963	13,610	1,282,940	205,000	8,696,000		
1964	14,735	1,284,300	225,000	8,845,000	6,310	354,180
1965	14,375	1,126,210	257,000	8,182,000	6,510	332,290
1966	15,952	1,286,486	272,000	7,585,000	6,820	302,580
1967	20,537	1,309,932	292,000	7,494,000	7,680	305,800

Table.



Root Treatments carried out in
England
300,000
250,000
200,000
150,000
100,000
1961
1962
1963
1964
1965
1966
1967

Fig. 1.4

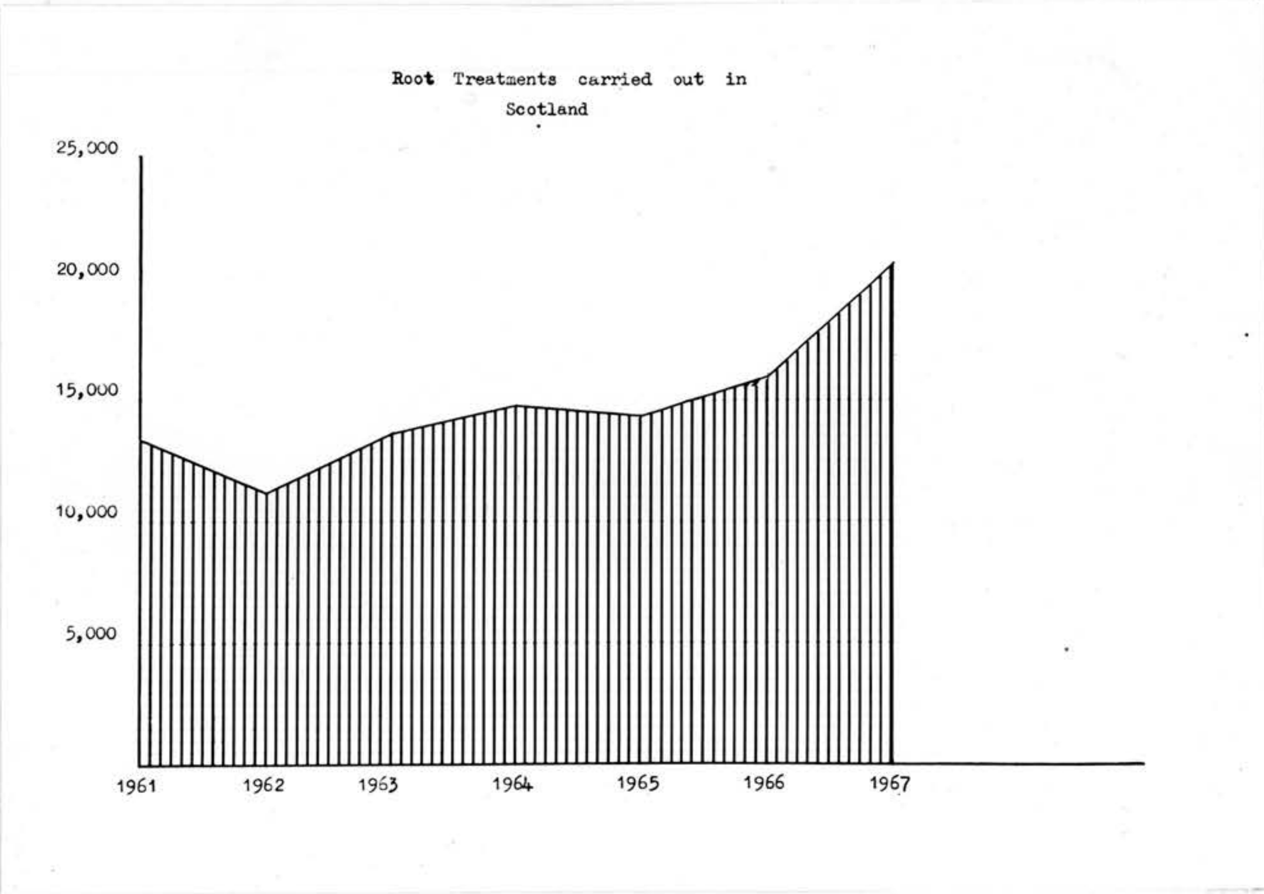

Root Treatments carried out in
Scotland
25,000
20,000
15,000
10,000
5,000
1961
1962
1963
1964
1965
1966
1967

Fig. 1.5

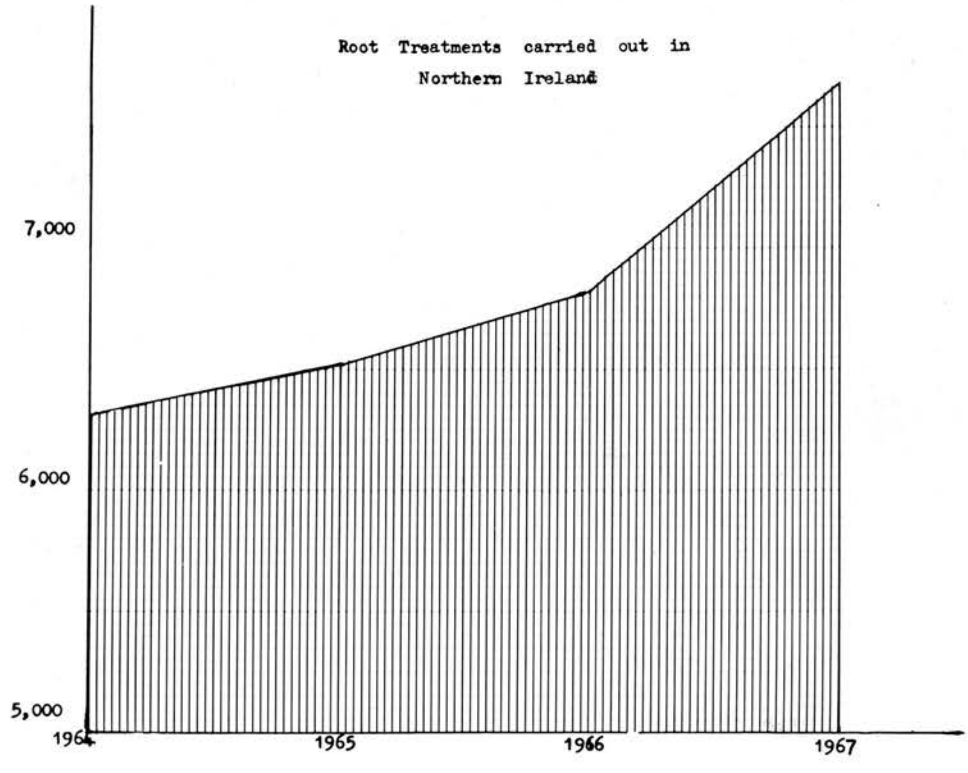

Root Treatments carried out in
Northern Ireland
7,000
6,000
5,000
1964
1965
1966
1967

Fig. 1.6

procedures is becoming more and more important than it has been in the past.

The early methods applied to root canal therapy had, of necessity, certain limitations placed upon them due to a lack of instruments and materials. As a result of these basic deficiencies great emphasis and dependence was placed on the role of potent antiseptics such as paraform (Frahm (1911)), pure phenol (Crane (1911 and Tileston (1914)) and sulphuric acid (Johnson (1922)) in the control of infection and in the hope that the root canal would remain relatively clean after treatment, the operators failing to recognize that hermetic sealing of the apical foramen is a 'sine qua non' in endodontic therapy. Unfortunately, even today, a similar dependence appears to be placed on antiseptics in the final phase of root canal therapy - namely - the stressing in the literature of root canal sealers with antiseptic qualities.

Longbothom was the first to recommend in the year 1802 that root canals should be permanently filled after initial treatment had been completed. Apparently it was only then recognized that the space left in the tooth, after the pulp tissue had been removed or was already destroyed, had to be obliterated. However, it was not until 1867 that Bowman used gutta percha as a root filling material - the material most commonly used today as the obturator of the empty space remaining in the tooth after initial treatment.

To obtain rigidity in this rather flexible material (gutta percha) Beust in 1901 introduced a gutta percha point which had been reinforced with a central core of silver wire. In 1929 Greve went a stage further and introduced a metal point as the permanent filling material for root canals, which was in the form of a precision gold cone manufactured to fit accurately a root canal prepared by means of special engine reamers.

In the same year (1929) Trebitsch pointed out that since silver particles in a petrie dish were generally surrounded by an area of sterility, he was inclined therefore to the view that some form of silver should be used in root canal therapy. In support of this theory he pointed out that silver was being used more and more in surgery and that this metal was well tolerated by the tissues since it remained in place over a long period without any obvious damage to the host cells. More recent work by Fieldman and Nyborg (1966) bears out the findings of Trebitsch.

It was not until 1933, however, that Jasper used silver points which corresponded in diameter and taper to the root canal reamer or file.

With the introduction in 1955 of matched points, that is, matched in diameter and taper to the root canal instrument, it was thought that this approach would result in a more precise and more accurate method of permanently filling the root canal. Clinical experience has shown that even using the most meticulous and painstaking technique, it is not always a simple matter to completely obliterate the central space. As a result of this clinical experience it became obvious that it was desirable to assess whether or not the various matched points did in fact match the instrument in diameter, as was stated by the manufacturer.

Again it was thought necessary to evaluate the final shape of the root canal after instrumentation. It was decided therefore that some investigation was required for the following points :-

(i) Does the instrument leave the final shape of the root canal with the desired diameter which corresponds to, or very closely approaches that of, the diameter of the root filling point at specific points along its long axis?

(ii) Do the instruments leave the dentine walls or the root canal rough or smooth after instrumentation, and is there any variation in the smoothness of the wall of the canal in relation to the type of instrument used? Roughness has a decided bearing on the sealing potential of the root canal point. The final filling point has a smooth surface and if the canal wall is rough, then the irregularities that are present must of necessity be taken up by root canal sealer which is used to cement the point in place. Obviously it is ideal to have a smooth canal wall and a root filling point which accurately fits the prepared canal.

(iii) Another question which requires clarification is the possibility of expelling material from the root canal through the apical foramen into the periapical space during instrumentation. The principle, frequently reiterated in endodontic textbooks and research literature (Black (1917), Curson (1966), Grossman (1950), Ingle (1965), Kürer (1966), Marshall (1909) and Moffitt (1913), that one should avoid, at all times, expelling material through the apical foramen during instrumentation within the root canal, is biologically sound. It has been stated by these authors that the danger of this occurring is ever present and likely to take place. The statement that material is expelled through the apical foramen during mechanical instrumentation is one which is an intuitive assumption since, to my knowledge, no experimental proof has been put forward that this is true. If this intuitive assumption is correct, does it hold good in equal proportions for the root canal reamer and for the root canal file? Ingle and Grossman state that the root canal file is more liable to push material ahead of the instrument into the apical part of the root canal thus increasing the liability of expelling this material through the apical foramen into the periapical space. Is there, therefore, a quantative relationship with the type of instrument used?

If the assumption that material is always liable to be expelled through the apical foramen is correct, then it involves the question of 'sterility' of the root canal before instrumentation is commenced. There can be little doubt that it is desirable that infected material should never be expelled through the apical foramen into the periapical tissues (Black (1917), Brady (1920), McGehee (1951), Moffitt (1913), Sommer (1966) and Sciaky (1961)). At best, this only prolongs the course of treatment and, at worst, involves the patient in an acute exacerbation of what otherwise might be a chronic condition.

It has become apparent, from what has been said, that investigation into some aspects of root canal therapy has still to be undertaken and it is the purpose of this thesis to set out an evaluation of the following points :-

1. Do matched points, provided by the manufacturer, correspond in diameter at specific distances along their long axis to the reamers and files? This is a most important consideration since it not only affects the fit of the point in the canal but it also indirectly affects the dentist's attitude to root fillings in general. When a root canal is instrumented to a given instrument size, and a corresponding numbered point inserted into the prepared canal, it should fit accurately. If the operator can be assured that this is so then this one consideration alone will reassure him that the technique is scientifically sound and, at the same time, will in all probability encourage him to carry out an increasing number of root treatments. The more root treatments a practitioner undertakes the more proficient he should become in his technique. One of the things that discourages practitioners in this branch of their general practice is the fact that all too often they have to waste time trying to find a point which accurately fits the prepared root canal - a position which should never be tolerated in a technique requiring meticulous and painstaking accuracy.
2. The form that the prepared canal takes after instrumentation

also requires investigation and, at the same time, some assessment should be made as to whether or not there is any significant difference in form between reaming and filing. Is it true to say that the shape of the prepared root canal has a decided bearing on the fit of the root filling point? As has already been pointed out by Sommer, the root canal must be hermetically sealed, otherwise space between the point and the canal wall will act as a dead space in which tissue fluids stagnate, break down and react by eliciting a foreign body reaction (Rickert & Dixon (1931)). The canal, therefore, must be prepared with a shape which corresponds to the root filling point; in other words, round in cross-section and with a taper corresponding to the taper on the root filling point. Ovality in the final shape of the prepared canal can only lead to a loss of hermetic sealing. It was presumed that there might be some difference in the final shape produced by means of the root canal reamer as against that produced by the root canal file. This possibility has been investigated.

3. The question of substance in the intuitive assumption that material is expelled through the apical foramen during instrumentation within the root canal was also investigated. In connection with this question was the probability that there might be a quantitative relationship between the amount of material expelled and the type of instrument employed; this too was the subject of an experiment. It has already

been stated that it is always hoped that expulsion of material through the apical foramen can be avoided. Many references to this occurrence are reported in the literature (Sommer (1966) and Ingle (1965)), together with photographs of this actually occurring whenever a tooth is reamed in the hand (Fig 1.7), that it was felt that this particular phenomenon should be investigated. It was also hoped that it could be shown experimentally whether or not there was a quantitative relationship with the type of instrument used in the preparation of the root canal.

Finally, it was considered that measurements obtained for the diameter of the root filling points and the root canal instruments should be correlated to ascertain if the 'matched' points would form the basis for a good hermetic seal. It was also intended that the various measurements obtained would be correlated to the diameter of the prepared root canal so that in this way an indication of the degree of sealing would be obtained. There can be no doubt that an efficient seal of the central space of a pulpless tooth is of the utmost importance and to see how effective this was being carried out in the clinical situation, a radiographic study of completed root fillings would be required.

Fig. 183. Poisonous canal contents forced beyond apical foramen when instruments are used in an up and down motion.

Fig. 1.7

CHAPTER 2

Instruments used in the Preparation of the Root Canal.

Introduction

It has already been shown that the central space in a human tooth is occupied by the dental pulp and ample evidence (Beveridge & Brown (1956), Seltzer Bender & Zionts (1963), Brännström (1961), Gardner (1963), Ingle (1965), Langeland (1959), Orban (1944), Stanley (1962) and Zander (1951)) has been produced to show that this tissue reacts to stimuli applied to the dentine. When the stimulus is great or of long duration, then the pulp tissue will eventually succumb and lose its vitality. The central space in the tooth will then be occupied by necrotic tissue, providing an ideal nidus for any infection that finds its way to this dead space (Via (1955) and Fish (1948)).

The organisms that infect the dental pulp may be derived from a carious cavity (Chirnside (1961)). Although the calcific barrier of secondary dentine laid down in response to the carious process (Corbett (1962) and Nygaard-Ostby (1955) has been demonstrated by Fish to be impermeable to bacterial products, this is only a temporary measure since the barrier of secondary dentine does not resist the softening effects of acids produced by acidogenic bacteria. Therefore, whenever a carious lesion is left untreated, infection of the pulp will eventually occur. There are, however, two defense mechanisms to be passed before infection of the pulp tissue actually occurs -

1. First of all, it has been shown (Canby & Bernier (1936) and Canby & Burnett (1963)) that the deep layers of carious dentine are acid in reaction (ph 5.5 - 4.7) and they believe that this acidity prevents the organisms contained in carious

dentine gaining access to pulp tissue.

2. The defensive function of the pulp tissue will, to some extent, ensure that this tissue is not immediately infected, although infection will undoubtedly eventually occur if the lesion is left untreated.

The infecting organism may be derived from a frank exposure of pulp tissue, the oral fluids being in direct communication with the pulp tissue - this tissue becoming automatically infected.

Infection of the pulp tissue may also occur by way of the periodontal membrane which can become detached as a result of trauma, allowing organisms from the oral cavity to gain access to the periapical tissue by way of the surrounding support tissues. These tissues, because of injury, do not permit the body defence mechanisms to exert their full potential and so the organisms are not completely eliminated.

On the other hand, in rare instances, the infecting organisms may be blood borne, the organisms gaining entrance to the root canal by way of the apical vessels (Burkett & Burn (1937)). Some form of injury is usually presupposed at the actual site of infection when dealing with blood borne infection because it has been shown that organisms can only survive for a short time (10 - 30 minutes) in the blood stream of a healthy individual (Okell & Elliott (1935), Kerr (1955), Burkett & Burns (1937) and Fish (1948)). Also, it is known that blood borne organisms are in any case usually of low virulence and organisms of low virulence do not, as a rule, produce infection in normal tissue.

From whatever the source of infection, if the central cavity of a tooth becomes infected, it must be dealt with before obliteration of this cavity is undertaken. On the other hand, the central cavity may be sterile (Hayes (1943), Morse & Yates (1941), Macdonald Hare & Wood (1957) and Ingle & Zedlow (1958)). These workers have shown that approximately 25% of all pulpless teeth with intact crowns gave a negative culture before any treatment was commenced; nevertheless, preparation of the root canal is essential in either case, on two counts :-

1. Mechanical cleansing of the walls of the central cavity;
2. Preparation of these walls to receive the final root filling.

It is indeed fortunate that both those goals are accomplished in one sequence of instrumentation (Hatton et al (1928)).

Mechanical instrumentation is still the most effective method of removing debris and bacteria from the central cavity of a tooth (Berger (1926)). During this phase of root canal therapy, it is hoped that all necrotic tissue attached to the dentine wall of the root canal will be removed, together with most of the bacteria and debris which finds its way into the dentinal tubules. Möller (1966), Dorfman et al (1943) and Shovelton (1964), have shown that bacteria do not penetrate the dentinal tubules to any great depth so that it is assumed that mechanical instrumentation will eliminate the majority of infecting organisms. These workers, together with Besic (1943) consider that organisms remaining in the dentinal tubules after root canal preparation, are only of secondary importance in root canal therapy.

However, the mechanical preparation of the root canal to receive the final root filling point is by no means of secondary importance in the success of the root filling. Too much emphasis cannot be given to this aspect of endodontic therapy for, in the final analysis, the whole success of any root filling depends on the final shape of the prepared canal. At the present time all the commercially available points used in the obliteration of the root canal in a tooth are circular in diameter and tapering from the apical end towards the base. It follows, therefore, that if the desired hermetic sealing is to be obtained, the root canal itself must be prepared in a similar fashion.

In the mechanical preparation of the root canal of a tooth to receive the final root filling, two types of instrument are in common usage in Britain. They are root canal reamers and root canal files (Fig. 2.1). It is pointed out that the European terminology for root canal instruments does not correspond to the American nomenclature. A comparison of the two types of instrument is as follows :-

British	American
Root canal reamer	Root canal reamer
'K' type file	Root canal file
Root canal file*	Hedstrom file

*Very infrequently referred to as the Hedstrom file in Britain.

It is pointed out that the 'K' type file is not in common use

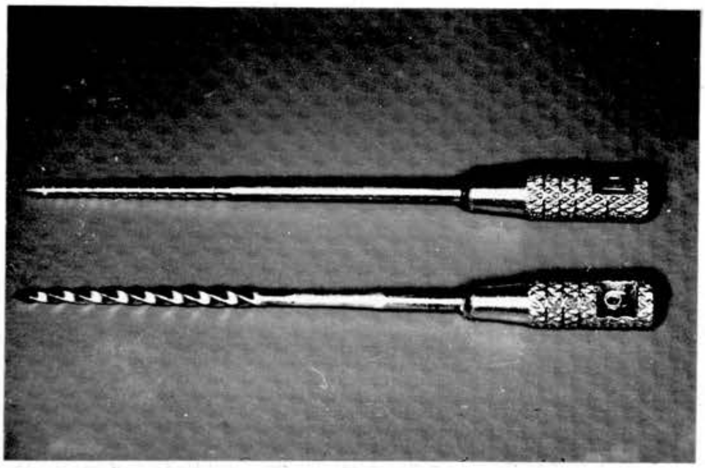


Fig. 2.1

in Britain. Only those instruments in common use in Britain were subjected to investigation and since information has shown that instruments produced by Produits Dentaire (Vevey, Switzerland) are used more often that instruments produced by other manufacturers, these instruments were selected for the various investigations (Fig. 2.1).

From the manufacturer's data (Fig. 2.2), it will be seen that root canal reamers, root canal files, gutta percha points and silver points are all standardized in taper and in diameter. However, clinically, it is very apparent that there is some discrepancy since it is often clinically obvious that a matched gutta percha point does not fit the prepared root canal as accurately as one would hope. The question therefore poses itself - where does the fault lie? Is it that the instruments are not manufactured to the standards laid down in the manufacturer's technical data, or is it that the gutta percha points used in the obliteration of the root canal are not matched to the instrument size?

It is pointed out that, in this study, no account is taken of the various physical properties (stress, stiffness, torque etc.) of the instruments under investigation. While these are important considerations in the quality and type of instrument used, nevertheless it behoves the operator to employ the greatest possible skill in mechanical preparation of the root canal irrespective of the physical properties of the instrument. It is considered by the author that the actual diameter of the instrument and its relationship to the diameter of the gutta percha or silver point and to the diameter of the prepared canal are the essential features that require investigation.

Technical Data

Instrument Number	Diameter at 1 mm from tip	Diameter at 15 mm from tip
No. 1	0.15	0.45
No. 2	0.20	0.50
No. 3	0.25	0.55
No. 4	0.30	0.60
No. 5	0.40	0.70
No. 6	0.50	0.80
No. 7	0.60	0.90
No. 8	0.70	1.00
No. 9	0.80	1.10
No.10	0.90	1.20
No.11	1.00	1.30
No.12	1.10	1.40

Fig. 2.2 Diameter in millimetres of Silver, Gutta Percha and Absorbent Paper Points, Reamers and Hedstrom Files.

Measurement of Instruments

Method

It was thought that the first question that required investigation was whether or not the instruments corresponded to the technical data supplied by the manufacturer (Fig. 2.2). Each instrument was therefore measured at selected points along its long axis (Fig. 2.3). It wasfelt that measurements carried out by means of an engineer's micrometer would fail in accuracy and anyhow it would be difficult, if not impossible, to choose the various points for measurement visually. To be certain that each measurement point along the long axis of the instrument was accurately chosen and that measurements would be accurate to within 0.001 mm, it was decided that all measurements should be carried out by means of a microscope fitted with a 'Filar' head (Fig. 2.4).

This method is basically similar to the method advocated by Green (1957) in which he measured root canal reamer and file widths using a measuring microscope. By mounting the various instruments on a piece of card and drawing lines on the card at 1 mm, 6 mm and 15 mm from the tip of the instrument he measured the diameter of each instrument at these three specific points. It appears to the author that the disadvantage of Green's method is that, with the 32 times magnification which he used, it would seem to be impossible to accurately pinpoint the various measurement lines because of the magnification of the original reference lines drawn on the card. In this investigation the use of the vernier scale on the mechanical stage of the microscope ensures that more precise points of reference are possible.

Method:

Each instrument was pressed into a small piece of plasticine attached along one side of a glass slide (Fig. 2.5). The glass

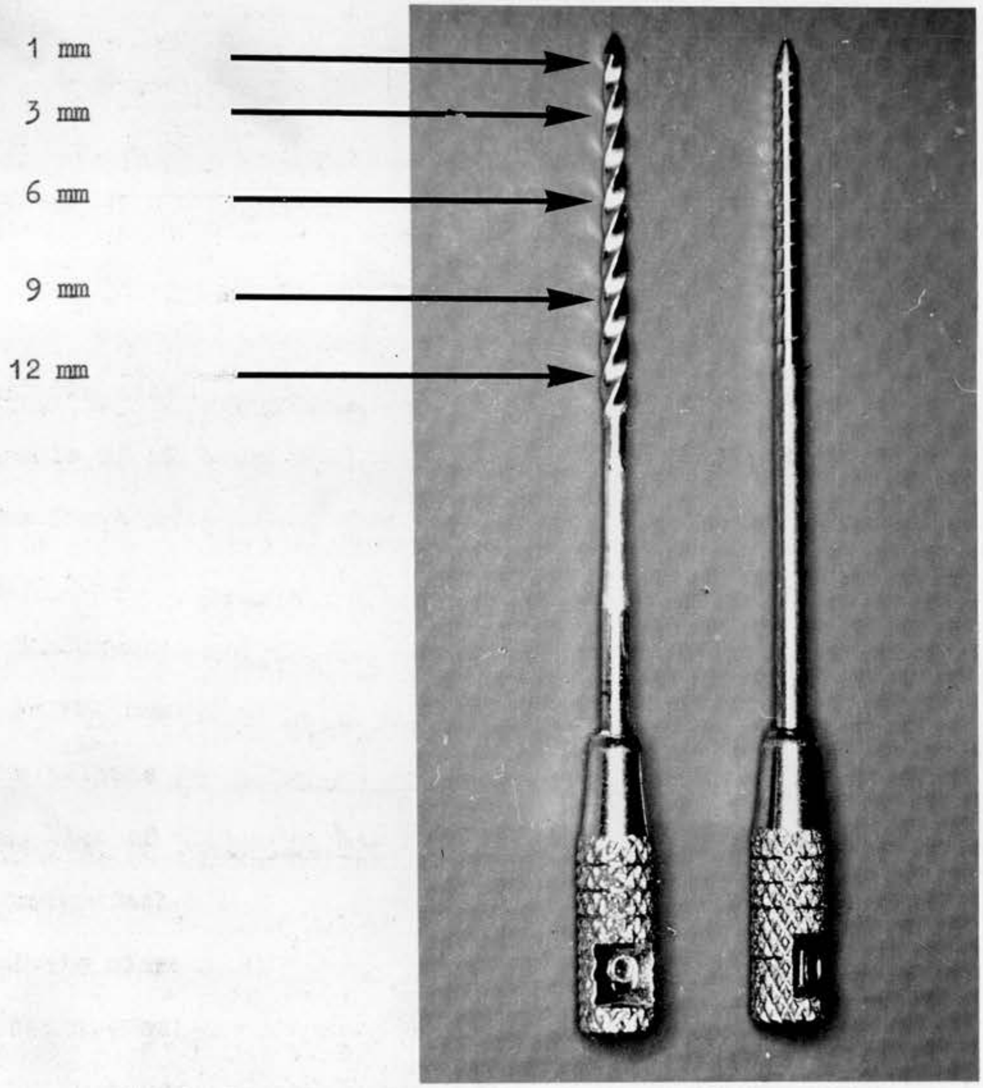


Fig. 2.3

Fig. 2.4

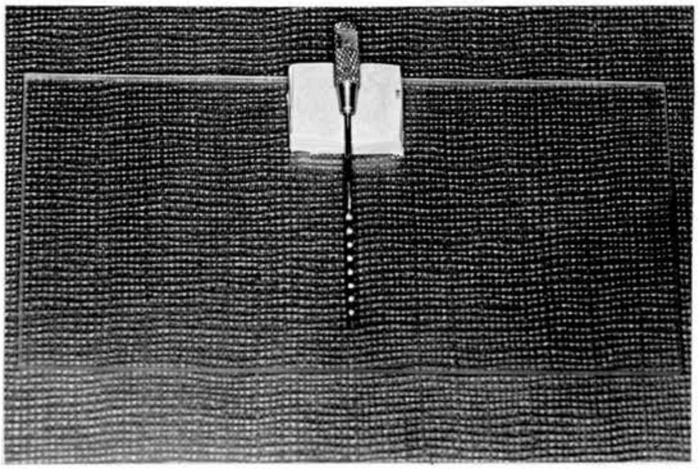


Fig. 2.5

slide was placed on the mechanical stage of a microscope (Watson & Son Ltd., London) using an objective 'X 10'. Fitted to the microscope was a 'Filar' head (Breck & Sons, London. 'X 10'). Measurements were made at various points along the long axis of the instrument as set out in the tables (Figs. 2.6 to 2.13). It was possible to focus the microscope until the largest diameter of the instrument was apparent and this was measured. A cross check was carried out on the circular shaft of one of the instruments, by measuring with the microscope and with an engineer's micrometer and the readings compared. It was obvious that they agreed in detail and that the measuring microscope was the more accurate in that it was capable of giving measurements to three decimal points.

The first point for measurement (1 mm) was chosen because it was found in the larger sized instruments that the bevel on the tip of the instrument was, in some cases, longer than 0.5 mm as was stated in the manufacturer's technical data.

The extreme tip of each instrument was orientated level with the base line of the Filar head and the reading on the vernier scale of the mechanical stage of the microscope noted. By moving the stage of the microscope exactly 1 mm as read off on the vernier scale, measurements were made. This was repeated for 3 mm, 6 mm and so on in increments of 3 mms until the 12 mm length was reached. Since the total length of the cutting edge of most instruments was 14.5 mm, the 15 mm diameter was omitted.

One or two points about the measurements in the larger sized instruments are given in elucidation of the figures quoted. It will be seen that for Nos. 11 and 12, in both reamers and in files, the readings for the 1 mm mark do not agree with the technical data.

This occurred because the bevel on these instruments was longer than the stipulated 0.5 mm so that the measurement was in fact obtained on the bevel itself. In the case of the 12 mm reading, for No. 11 reamers and files it was impossible to obtain a microscope reading due to the fact that the microscope was only capable of reading up to 1.250 mm. It would have been possible to reduce the objective lens magnification and obtain a reading in this way but it was thought that might have led to inaccuracies in that different magnifications were being used to obtain the readings; hence these particular measurements were omitted. For a similar reason, the readings for the 9 mm and 12 mm mark were also omitted in the case of the No. 12 reamers and files. Where the readings for the shank diameter of the No. 11 and No. 12 instruments are shown, these were obtained by means of an engineer's micrometer - this was possible since the shank of these instruments is circular in cross-section.

Results.

R e a m e r s

No.	1 mm	3 mm	6 mm	9 mm	12 mm	Shank
1	0.151	0.190	0.261	0.325	0.439	0.463
	0.164	0.221	0.288	0.380	0.456	0.460
	0.175	0.226	0.260	0.314	0.428	0.455
	0.157	0.189	0.274	0.316	0.431	0.462
	0.177	0.220	0.265	0.321	0.432	0.465
	0.152	0.196	0.255	0.311	0.440	0.467
	0.158	0.202	0.277	0.336	0.429	0.460
	0.166	0.227	0.290	0.384	0.452	0.458
2	0.207	0.220	0.288	0.400	0.462	0.508
	0.211	0.247	0.299	0.416	0.471	0.511
	0.190	0.256	0.335	0.428	0.463	0.515
	0.196	0.262	0.320	0.411	0.472	0.513
	0.202	0.260	0.280	0.345	0.454	0.516
	0.201	0.216	0.274	0.395	0.466	0.507
	0.213	0.251	0.317	0.338	0.488	0.508
	0.199	0.244	0.286	0.407	0.452	0.515
3	0.277	0.302	0.376	0.449	0.527	0.509
	0.269	0.307	0.381	0.452	0.514	0.508
	0.260	0.310	0.404	0.451	0.510	0.507
	0.271	0.313	0.408	0.460	0.514	0.516
	0.260	0.316	0.400	0.457	0.525	0.511
	0.277	0.324	0.405	0.468	0.521	0.508
	0.273	0.315	0.413	0.450	0.510	0.507
	0.264	0.312	0.399	0.459	0.522	0.517

Fig. 2.6

R e a m e r s

No.	1 mm	3 mm	6 mm	9mm	12 mm	Shank
4	0.321	0.362	0.417	0.490	0.540	0.607
	0.304	0.355	0.406	0.489	0.552	0.609
	0.280	0.367	0.434	0.497	0.564	0.612
	0.318	0.383	0.444	0.472	0.597	0.611
	0.314	0.374	0.441	0.467	0.601	0.609
	0.297	0.365	0.428	0.482	0.584	0.606
	0.315	0.347	0.452	0.493	0.561	0.607
	0.302	0.339	0.438	0.481	0.577	0.610
5	0.395	0.446	0.534	0.591	0.668	0.713
	0.416	0.458	0.544	0.588	0.661	0.712
	0.396	0.448	0.549	0.578	0.659	0.715
	0.424	0.452	0.530	0.589	0.660	0.717
	0.439	0.471	0.519	0.582	0.665	0.714
	0.434	0.462	0.515	0.576	0.665	0.712
	0.425	0.421	0.504	0.569	0.664	0.717
	0.408	0.432	0.526	0.578	0.667	0.713
6	0.475	0.544	0.635	0.696	0.782	0.809
	0.457	0.541	0.618	0.689	0.767	0.802
	0.403	0.538	0.635	0.684	0.754	0.805
	0.478	0.551	0.622	0.696	0.789	0.807
	0.446	0.544	0.624	0.683	0.756	0.803
	0.438	0.561	0.624	0.688	0.773	0.805
	0.424	0.563	0.600	0.683	0.782	0.806
	0.466	0.559	0.618	0.687	0.779	0.807

Fig. 2.7

Reamers

No.	1 mm	3 mm	6 mm	9 mm	12 mm	Shank
7	0.621	0.671	0.741	0.789	0.867	0.911
	0.550	0.603	0.742	0.785	0.865	0.916
	0.604	0.642	0.692	0.703	0.906	0.915
	0.616	0.649	0.699	0.713	0.820	0.912
	0.584	0.618	0.686	0.708	0.800	0.910
	0.621	0.681	0.719	0.768	0.843	0.918
	0.543	0.586	0.671	0.714	0.854	0.917
	0.579	0.638	0.696	0.781	0.855	0.917
8	0.602	0.679	0.858	0.918	0.934	1.010
	0.634	0.685	0.824	0.917	0.935	1.025
	0.623	0.686	0.798	0.830	0.948	1.025
	0.710	0.724	0.806	0.859	0.959	1.024
	0.716	0.768	0.852	0.918	0.972	1.016
	0.664	0.696	0.841	0.917	0.952	1.012
	0.681	0.727	0.843	0.918	0.964	1.016
	0.704	0.728	0.826	0.894	0.992	1.021
9	0.774	0.804	0.940	0.989	1.065	1.110
	0.856	0.911	0.927	0.945	1.039	1.109
	0.835	0.899	0.930	0.953	1.046	1.114
	0.783	0.852	0.918	0.942	1.092	1.114
	0.764	0.795	0.937	0.989	1.052	1.114
	0.761	0.863	0.937	0.963	1.049	1.109
	0.755	0.824	0.941	0.979	1.056	1.106
	0.832	0.845	0.892	0.921	1.002	1.114

Fig. 2.8

R e a m e r s

No.	1 mm	3 mm	6 mm	9 mm	12 mm	Shank
10	0.880	0.964	1.040	1.100	1.204	1.212
	0.822	0.907	1.013	1.094	1.209	1.215
	0.850	0.892	1.001	1.098	1.192	1.210
	0.927	0.954	1.036	1.084	1.176	1.221
	0.844	0.976	1.044	1.096	1.153	1.211
	0.863	0.895	1.019	1.121	1.162	1.210
	0.868	0.917	1.012	1.113	1.181	1.219
	0.845	0.968	1.033	1.098	1.178	1.235
11	0.934 x	1.068	1.128	1.205	x	1.290 +
	0.907 x	1.072	1.129	1.208	x	1.285 +
	0.902 x	1.066	1.111	1.203	x	1.290 +
	0.827 x	1.080	1.189	1.209	x	1.290 +
	0.964 x	1.017	1.184	1.201	x	1.295 +
	0.928 x	1.053	1.124	1.181	x	1.285 +
	0.964 x	1.062	1.125	1.191	x	1.295 +
	0.802 x	1.062	1.130	1.204	x	1.295 +
12	1.005 x	1.129	1.206	x	x	1.405 +
	0.983 x	1.162	1.211	x	x	1.410 +
	0.929 x	1.056	1.136	x	x	1.400 +
	0.924 x	1.020	1.186	x	x	1.405 +
	0.970 x	1.049	1.207	x	x	1.400 +
	0.992 x	1.036	1.174	x	x	1.405 +
	1.006 x	1.126	1.194	x	x	1.400 +
	0.916 x	1.155	1.244	x	x	1.405 +

Fig. 2.9

F i l e s

No.	1 mm	3 mm	6 mm	9 mm	12 mm	Shank
1	0.145	0.180	0.259	0.362	0.444	0.459
	0.163	0.249	0.317	0.421	0.474	0.465
	0.159	0.227	0.298	0.392	0.455	0.451
	0.146	0.212	0.306	0.370	0.446	0.460
	0.153	0.220	0.290	0.386	0.461	0.447
	0.167	0.235	0.308	0.411	0.469	0.455
	0.161	0.227	0.302	0.407	0.471	0.460
	0.149	0.186	0.278	0.394	0.451	0.458
2	0.190	0.210	0.327	0.427	0.468	0.516
	0.207	0.223	0.339	0.441	0.479	0.512
	0.211	0.260	0.341	0.427	0.499	0.509
	0.218	0.280	0.342	0.439	0.523	0.506
	0.212	0.271	0.338	0.431	0.487	0.510
	0.204	0.270	0.333	0.428	0.521	0.519
	0.215	0.268	0.342	0.425	0.518	0.509
	0.199	0.217	0.339	0.436	0.514	0.511
3	0.224	0.311	0.384	0.482	0.580	0.562
	0.222	0.309	0.378	0.477	0.551	0.558
	0.207	0.301	0.341	0.470	0.546	0.551
	0.216	0.313	0.366	0.484	0.549	0.557
	0.226	0.303	0.371	0.480	0.547	0.562
	0.222	0.314	0.382	0.479	0.553	0.560
	0.218	0.306	0.364	0.477	0.549	0.559
	0.220	0.300	0.347	0.481	0.552	0.562

Fig. 2.10

F i l e s

No.	1 mm	3 mm	6 mm	9 mm	12 mm	Shank
4	0.276	0.354	0.434	0.541	0.626	0.620
	0.281	0.353	0.427	0.532	0.635	0.616
	0.320	0.341	0.403	0.514	0.595	0.611
	0.309	0.351	0.430	0.528	0.627	0.617
	0.263	0.284	0.424	0.541	0.643	0.613
	0.296	0.338	0.419	0.540	0.628	0.618
	0.289	0.360	0.432	0.536	0.618	0.618
	0.313	0.356	0.424	0.529	0.641	0.620
5	0.394	0.447	0.532	0.645	0.741	0.719
	0.401	0.456	0.528	0.637	0.712	0.718
	0.409	0.492	0.558	0.634	0.707	0.713
	0.399	0.446	0.527	0.599	0.692	0.714
	0.371	0.443	0.523	0.632	0.729	0.713
	0.407	0.472	0.546	0.618	0.726	0.716
	0.400	0.437	0.515	0.587	0.687	0.718
	0.408	0.475	0.532	0.607	0.711	0.717
6	0.510	0.560	0.633	0.730	0.801	0.815
	0.500	0.562	0.628	0.727	0.811	0.810
	0.492	0.550	0.611	0.716	0.820	0.814
	0.499	0.561	0.622	0.720	0.818	0.817
	0.527	0.565	0.629	0.719	0.806	0.815
	0.523	0.559	0.624	0.723	0.816	0.809
	0.517	0.556	0.627	0.707	0.817	0.809
	0.499	0.554	0.623	0.721	0.809	0.817

Fig. 2.11

F i l e s

No.	1 mm	3 mm	6 mm	9 mm	12 mm	Shank
7	0.614	0.679	0.727	0.827	0.893	0.922
	0.608	0.663	0.719	0.789	0.922	0.922
	0.606	0.660	0.725	0.818	0.897	0.920
	0.618	0.689	0.749	0.844	0.925	0.918
	0.610	0.667	0.728	0.815	0.899	0.914
	0.599	0.682	0.760	0.862	0.923	0.912
	0.620	0.693	0.764	0.834	0.879	0.915
	0.616	0.680	0.739	0.841	0.896	0.921
8	0.702	0.783	0.847	0.892	0.984	1.005
	0.709	0.771	0.851	0.939	0.995	1.005
	0.699	0.762	0.841	0.927	0.985	1.005
	0.687	0.761	0.830	0.919	0.986	1.005
	0.680	0.753	0.800	0.865	0.941	1.009
	0.715	0.769	0.821	0.889	0.985	1.010
	0.708	0.760	0.809	0.884	0.966	1.006
	0.710	0.758	0.832	0.907	0.984	1.002
9	0.783	0.904	1.027	1.087	1.125	1.125
	0.763	0.885	0.970	1.050	1.117	1.130
	0.777	0.888	0.940	1.054	1.125	1.124
	0.782	0.907	1.000	1.045	1.120	1.120
	0.751	0.889	0.973	1.063	1.112	1.122
	0.799	0.884	0.969	1.066	1.106	1.118
	0.772	0.913	0.976	1.082	1.131	1.125
	0.784	0.926	0.981	1.077	1.123	1.120

Fig. 2.12

F i l e s

No.	1 mm	3 mm	6 mm	9 mm	12 mm	Shank
10	0.834	0.977	1.056	1.125	1.197	1.209
	0.895	0.980	1.081	1.121	1.200	1.201
	0.896	0.982	1.054	1.123	1.186	1.200
	0.884	0.968	1.044	1.112	1.184	1.208
	0.881	0.953	0.992	1.108	1.191	1.203
	0.815	0.971	1.036	1.129	1.203	1.215
	0.862	0.977	1.041	1.116	1.187	1.207
	0.844	0.962	1.037	1.115	1.201	1.204
11	0.763 x	1.070	1.140	1.219	x	1.260 +
	0.774 x	1.110	1.157	1.209	x	1.270 +
	0.730 x	1.087	1.106	1.172	x	1.280 +
	0.732 x	1.080	1.139	1.193	x	1.295 +
	0.740 x	1.068	1.119	1.211	x	1.295 +
	0.738 x	1.002	1.140	1.199	x	1.290 +
	0.751 x	1.056	1.131	1.187	x	1.295 +
	0.734 x	1.078	1.112	1.203	x	1.285 +
12	0.912 x	1.099	1.239	x	x	1.380 +
	0.861 x	1.044	1.244	x	x	1.385 +
	0.920 x	1.102	1.239	x	x	1.400 +
	0.893 x	1.007	1.236	x	x	1.400 +
	0.760 x	1.135	1.227	x	x	1.410 +
	0.877 x	1.168	1.241	x	x	1.410 +
	0.872 x	1.156	1.233	x	x	1.405 +
	0.903 x	1.101	1.256	x	x	1.405 +

Fig. 2.13

Discussion of Results

As a result of a visit to Switzerland to the company who produce the root canal instruments used in this investigation, it was ascertained that only random tests are carried out on products to assess conformity to definite tolerance limits in manufacture. As far as root canal instruments are concerned - prior to twisting the steel rod into reamer shape, flutes are cut along its long axis; this is precisely carried out, the permitted tolerance limit in this particular operation is $\pm$ 0.005 mm. After these flutes are cut, the steel rod is then subjected to twisting so as to form the reamer blade itself and this, it should be pointed out, is a much less precise operation. The stated tolerance in this case is $\pm$ 0.025 mm.

When these two tolerances are added together, the final tolerance in instrument diameter is arrived at. Thus a tolerance of $\pm$ 0.03 mm should be added to the diameter quoted in the literature. From the technical data supplied by the manufacturer (Fig. 2.2), the diameter of the instrument along its long axis (3 mm, 6 mm, 9 mm and 12 mm) was arrived at in the following manner.

It is accepted that the taper of these instruments is uniform along their long axis. If this is so, then by using the formula

$$\Delta y = \frac{h(x - y)}{l}$$

it is possible to find the diameter of the instrument at any position along its long axis, where -

Δy - is the increase in diameter over y

h - is the distance from y to the new position

x - is the diameter of the apex of the taper

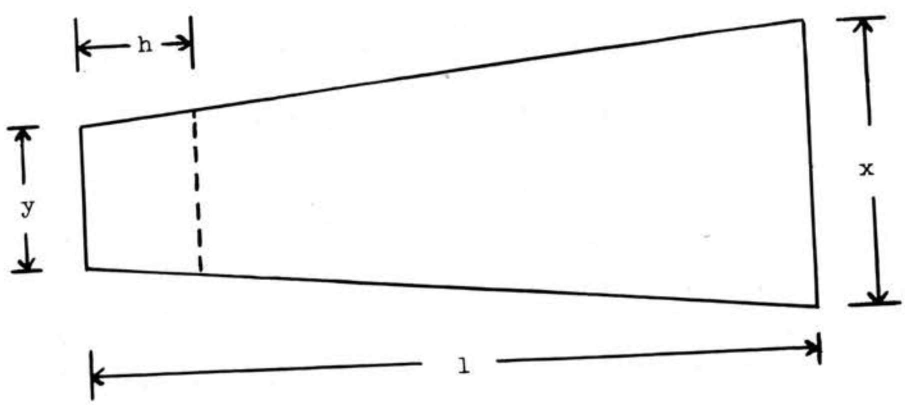


Fig. 2.14

y - is the diameter of the base of the taper

l - is the length of the tapered portion.

In a typical example (Fig. 2.14), where the diameter of the instrument is required at a position 2 mm from the apex of the taper -

$$\Delta y = \frac{h(x - y)}{l} = \frac{2(0.30)}{14} = 0.043 \text{ mm}$$

thus 0.043 mm should be added to the diameter of the apex of the taper, giving a diameter of 'y' + 0.043 mm at a position 2 mm from the tip. Measurements obtained by this means are set out in the tables in Fig. 2.15 and Fig. 2.16.

Instrument Number	Manufacturer's stated diameter in mms	Distance from tip mm	Range in mms allowing for tolerance limits
1	0.150	1	0.18 - 0.12
	0.193	3	0.22 - 0.16
	0.257	6	0.29 - 0.22
	0.321	9	0.35 - 0.29
	0.386	12	0.42 - 0.35
2	0.200	1	0.23 - 0.17
	0.243	3	0.27 - 0.21
	0.307	6	0.34 - 0.27
	0.371	9	0.40 - 0.34
	0.436	12	0.47 - 0.40
3	0.250	1	0.28 - 0.22
	0.293	3	0.32 - 0.26
	0.357	6	0.39 - 0.32
	0.421	9	0.45 - 0.39
	0.486	12	0.52 - 0.45
4	0.300	1	0.33 - 0.27
	0.343	3	0.37 - 0.31
	0.407	6	0.44 - 0.38
	0.471	9	0.50 - 0.44
	0.536	12	0.57 - 0.50
5	0.400	1	0.43 - 0.37
	0.443	3	0.47 - 0.41
	0.507	6	0.54 - 0.48
	0.571	9	0.60 - 0.54
	0.636	12	0.67 - 0.61
6	0.500	1	0.53 - 0.47
	0.543	3	0.57 - 0.51
	0.607	6	0.64 - 0.58
	0.671	9	0.70 - 0.64
	0.736	12	0.77 - 0.71

Fig. 2.15

Instrument Number	Manufacturer's stated diameter in mms	Distance from tip mms	Range in mms allowing for tolerance limits
7	0.600	1	0.63 - 0.57
	0.643	3	0.67 - 0.61
	0.707	6	0.74 - 0.67
	0.771	9	0.80 - 0.74
	0.836	12	0.87 - 0.81
8	0.700	1	0.73 - 0.67
	0.743	3	0.77 - 0.71
	0.807	6	0.84 - 0.77
	0.871	9	0.90 - 0.84
	0.936	12	0.97 - 0.91
9	0.800	1	0.83 - 0.77
	0.843	3	0.87 - 0.81
	0.907	6	0.94 - 0.87
	0.971	9	1.00 - 0.94
	1.036	12	1.07 - 1.01
10	0.900	1	0.93 - 0.87
	0.943	3	0.97 - 0.91
	1.007	6	1.04 - 0.97
	1.071	9	1.10 - 1.04
	1.136	12	1.17 - 1.11
11	1.000	1	1.03 - 0.97
	1.043	3	1.07 - 1.01
	1.107	6	1.14 - 1.07
	1.171	9	1.20 - 1.14
	1.236	12	1.27 - 1.21
12	1.100	1	1.13 - 1.07
	1.143	3	1.17 - 1.11
	1.207	6	1.24 - 1.17
	1.271	9	1.30 - 1.24
	1.336	12	1.37 - 1.31

Fig. 2.16

In the last column of these tables is the range of measurement between which all instrument diameters should fall when due allowance has been given to the diameter of the instrument ± the accumulated tolerance (0.03 mm).

In the year 1929 Grove, and again in 1955, Ingle, made a plea for standardization of root canal instruments made by all manufacturers. According to Ingle these instruments were, in fact, made to conform to a standardized set of measurements in the year 1955. This has been denied by two Swiss manufacturers (Produits Dentaire and Maillefer), both companies stating that they have produced standardized root canal instruments since about 1949. The instruments used in this investigation (Produits Dentaire) were measured and the readings obtained set out in the tables (Figs. 2.6 to 2.13). Fig. 2.17 and Fig. 2.18 show the number of different sized instruments which conform to the manufacturer's technical data, while Fig. 2.19 and Fig. 2.20 show these numbers graphically. In Fig. 2.21 and Fig. 2.22, the number of instruments which have a smaller diameter than the stated diameter is shown.

As Sommer (1966) and Ingle (1965) point out, it is essential to the success of a root filling that the canal should be hermetically sealed so that nothing whatsoever can escape through the apical foramen and cause damage to the periapical tissues, thus ensuring that the tooth will remain in the dental arch as a fully functional unit for many years.

To accomplish the desired hermetic seal, the root canal diameter after preparation should correspond very closely to the diameter of

Root Canal Reamers

Instrument Number	1 mm from tip	3 mm from tip	6 mm from tip	Total Instruments Measured
1	8	5	8	8
2	8	8	8	8
3	8	7	2	8
4	8	6	5	8
5	6	7	6	8
6	2	8	8	8
7	6	4	6	8
8	4	4	4	8
9	2	6	7	8
10	2	4	7	8
11	X	6	6	8
12	X	4	6	8

Fig. 2.17 Number of Root Canal Reamers whose diameter conforms to the manufacturer's data.

Root Canal Files

Instrument Number	1 mm from tip	3 mm from tip	6 mm from tip	Total Instruments Measured
1	8	4	2	8
2	8	6	5	8
3	5	8	8	8
4	7	8	8	8
5	8	5	6	8
6	8	8	8	8
7	8	3	5	8
8	8	6	5	8
9	6	0	1	8
10	4	3	3	8
11	X	4	7	8
12	X	5	5	8

Fig. 2.18 Number of Root Canal Files whose diameter conforms to the manufacturer's data.

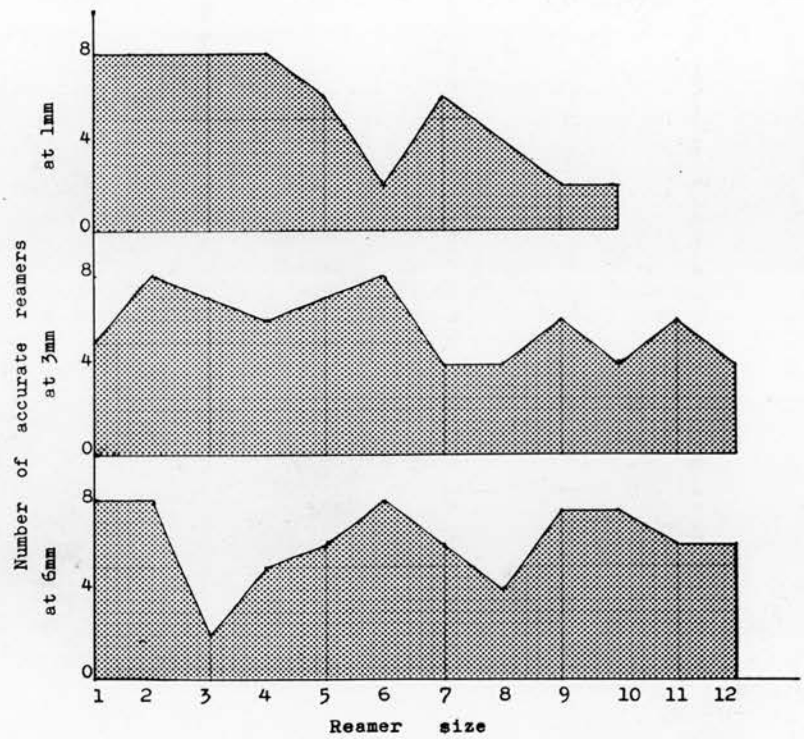

Number of accurate reamers
at 1mm
at 3mm
at 6mm
8
4
0
1 2 3 4 5 6 7 8 9 10 11 12
Reamer size

Fig. 2.19

Root Canal Reamers

Instrument Number	1 mm from tip	3 mm from tip	6 mm from tip	Total Instruments Measured
1	0	0	0	8
2	0	0	0	8
3	0	0	0	8
4	0	0	0	8
5	0	0	0	8
6	6	0	0	8
7	2	2	0	8
8	4	4	0	8
9	3	2	0	8
10	6	3	0	8
11	X	0	0	8
12	X	4	1	8

Fig. 2.21 Number of Root Canal Reamers whose diameter is less than that stipulated by the manufacturer.

Root Canal Files

Instrument Number	1 mm from tip	3 mm from tip	6 mm from tip	Total Instruments Measured
1	0	0	0	8
2	0	0	0	8
3	3	0	0	8
4	1	1	0	8
5	0	0	0	8
6	0	0	0	8
7	0	0	0	8
8	0	0	0	8
9	2	0	0	8
10	4	0	0	8
11	X	1	0	8
12	X	3	0	8

Fig. 2.22 Number of Root Canal Files whose diameter is less than that stipulated by the manufacturer.

the root filling point. However, when gutta percha is used as the root filling material, it is desirable that the diameter of the root canal should be slightly less than the diameter of the gutta percha point. This would ensure that the gutta percha point fitted the canal tightly, since this material is capable of being compressed to some extent. It is clinical practice to recommend that when fitting a gutta percha point into a root canal, it should require some force to place it in the canal and carry it to the desired length so that as good a seal as possible is obtained.

The question of filling the entire root canal or merely the apical third portion poses itself. It is recommended by Sommer (1966), Strindberg (1956), McElroy & Wach (1958) and Kuttler (1958) that the entire root canal should be obturated with the root filling point (Fig. 2.23). It is, however, thought that full root filling is unnecessary since a sectional root filling is a generally accepted technique in the case where it is proposed to place a post crown restoration on a root filled tooth (Fig. 2.24).

One can, however, carry out either the sectional technique when root filling a tooth, or cut back an existing full root filling to accommodate the post portion of the restoration. It cannot be overemphasized that the apical third of the root canal must be accurately and hermetically sealed. There is agreement between Sommer (1966) and Möller (1958) when they state that the apical third of the root canal is more apt to contain organisms than the remainder of the canal. Clinical experience has shown that the apical third area must be included when taking a culture to ascertain the bacteriologic

Fig. 2.23

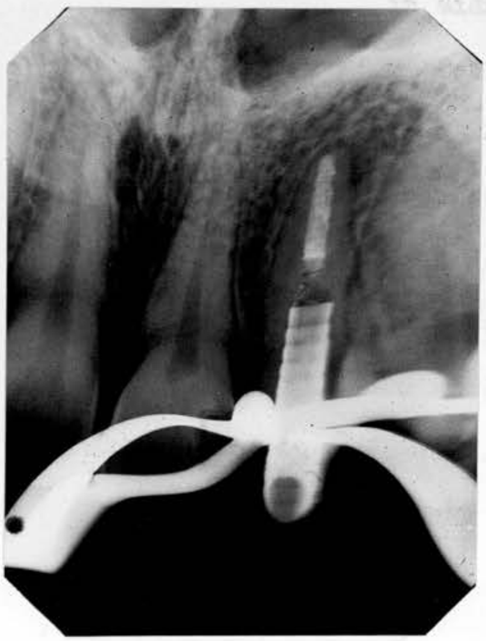


Fig. 2.24

status of the root canal (Sommer (1966) and Möller (1966)). Hence, if continued irritation of the periapical tissues is to be prevented, it is obvious that the apical third of the canal and the apical foramen should be really tightly sealed. Once the apical third is adequately filled, it is thought that the filling, or otherwise, of the remainder of the root canal is of no great consequence. It is pointed out, however, that the opening for access in the lingual fossa of the tooth must always be adequately sealed off from the oral fluids (Chanoch (1966)).

Referring again to the table (Fig. 2.17 and Fig. 2.18), it was thought that if the number of instruments recorded as being within the tolerance limits was expressed as a percentage of the total number of instruments measured in each column, this would give an overall indication of the degree of accuracy of the root canal reamer vis-á-vis the root canal file. As an example of how these figures were obtained - taking the figures in column 2 as being the number of reamers that were within the tolerance limits and expressing this as a percentage of the total number of instruments measured (80), it is found to be 68%. Similar calculations were carried out for the remaining columns (Fig. 2.25). From the figures obtained it will be seen that the efficiency of the Hedstrom file falls off the larger the diameter of the cutting surface. This is set out graphically in the histogram (Fig. 2.26).

Again, taking the length 1 mm to 6 mm from the tip of the instrument as being the most important region in relation to accurate

	Percentage of Reamers falling within tolerance limits	Percentage of Files falling within tolerance limits
At 1 mm	66	73
At 3 mm	72	63
At 6 mm	76	65
At 9 mm	70	13
At 12 mm	56	4
Mean percentage of all positions on the instrument	68	44

Fig. 2.25 Percentage of instruments falling within the tolerance limits laid down by the manufacturer.

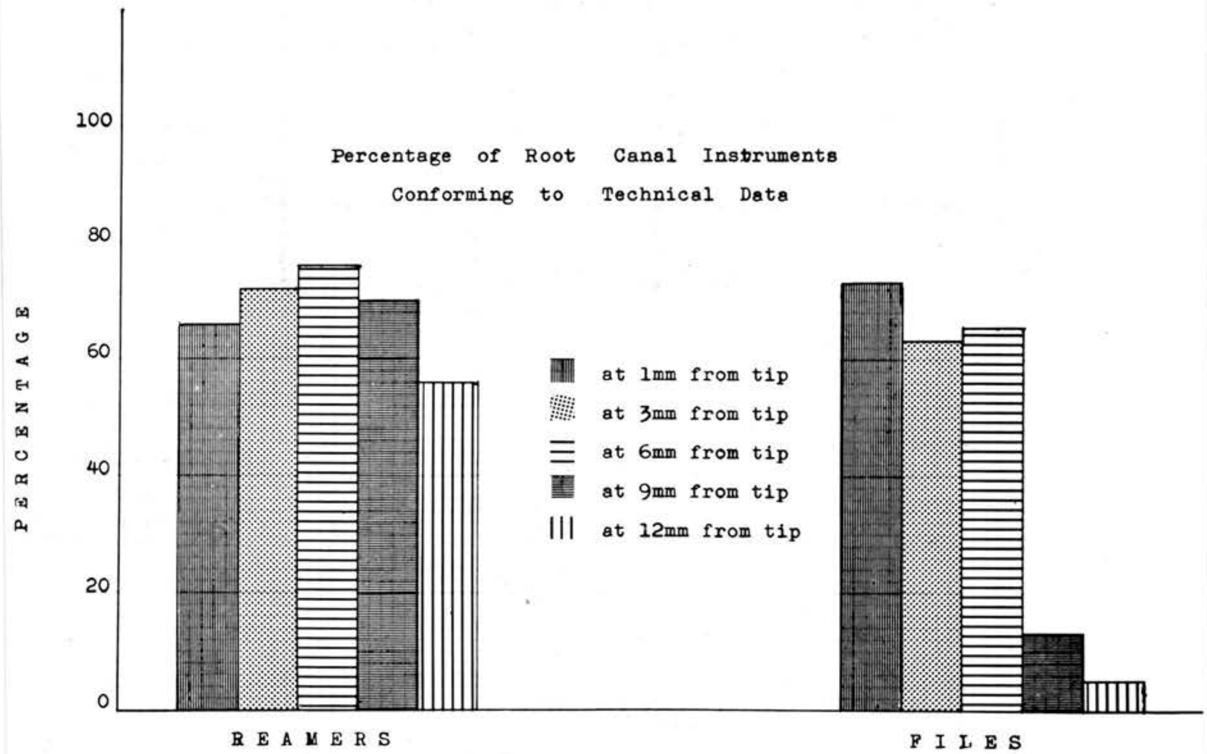

Percentage of Root Canal Instruments
Conforming to Technical Data
PERCENTAGE
100
80
60
40
20
0
at 1mm from tip
at 3mm from tip
at 6mm from tip
at 9mm from tip
at 12mm from tip
REAMERS
FILES

Fig. 2.26

preparation of the root canal (Fig. 2.27), it will be seen from the percentages that the reamer would appear to be a more suitable instrument than the Hedstrom file. Added to this is the fact that if the percentages in all columns are averaged, it is found that 68% of the reamers and 44% of the Hedstrom files used in this investigation can be said to be suitable for the mechanical preparation of a root canal. The reading at 9 mm and 12 mm is less important than the apical region (1 mm to 6 mm) in relation to preparation of the canal since the larger diameter of the instrument will correspond to the coronal third of the root canal which is rarely circular anyhow and so is of less importance than the apical region as far as mechanical preparation is concerned. This fact is fortuitous in that root canal instruments have been shown by this investigation to be less accurate in conforming to manufacturer's stated tolerance limits in their larger diameters.

Even though it has been stated that the regions 9 mm and 12 mm are of less importance than the apical region of the instrument, it is interesting to average the number of instruments which fall within the tolerance limits over all the regions measured. From this it is found that 68% of the root canal reamers measured in this investigation were within the tolerance limits, while only 44% of the Hedstrom files measured were within similar limits. Therefore, ignoring other factors, it is apparent from these figures that the root canal reamer more accurately conforms to specification than does the Hedstrom file.

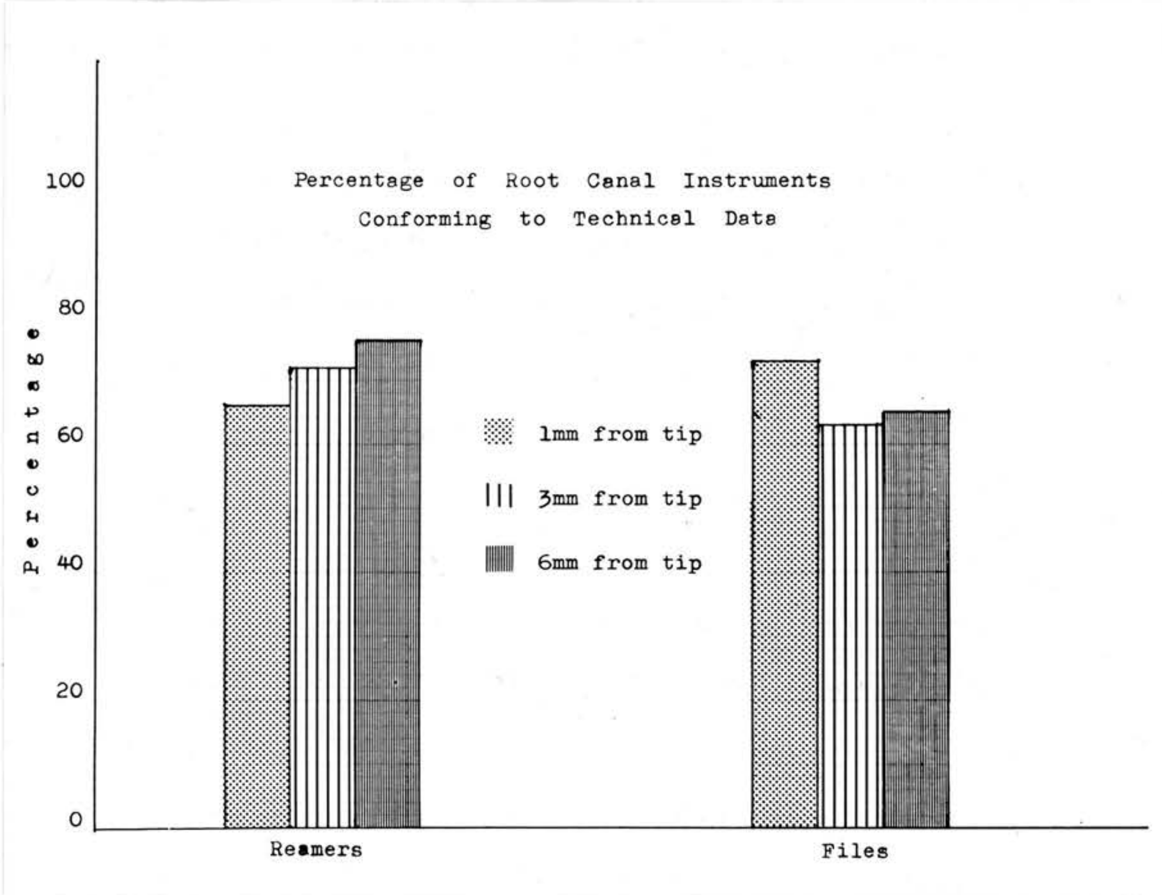

Percentage of Root Canal Instruments
Conforming to Technical Data
100
80
60
40
20
0
Percentage
1mm from tip
3mm from tip
6mm from tip
Reamers
Files

Fig. 2.27

The view is held that accurate preparation of the apical third of the canal is of the utmost importance. If it is found that it is possible to prepare the root canal in this region in such a manner that the gutta percha point is a tight fit, this in itself would ensure an adequate seal. That this view is so has been shown by Strindberg (1956) who states that the first filling cone should cork the apical portion of the canal tightly. Marshall & Massler (1961), Dow & Ingle (1955), Sausen (1962), Crawford & Larson (1956) and Going et al (1960), all used radio-active isotopes to test the effectiveness of root canal obturation. Marshall & Massler state quite dogmatically that a root canal can be completely sealed 100% of the time against marginal ingress of isotopes. Since Going et al (1960) and Trail & Sausen (1962) have also shown that isotopes have a greater penetrating power than bacteria, it follows that it is possible to seal the apex of a tooth against the egress of bacteria.

To be certain that an adequate seal does in fact occur, the instrument used in the preparation of the canal should ideally have a diameter slightly smaller than that of the root filling point, or, conversely, that the root filling point should be wider in diameter than the instrument. From the table (Fig. 2.27) it will be seen that in the main the diameter of the reamer over the first 6 mm of its length generally tends to conform to the calculated tolerances and is slightly more accurate in this respect than the root canal files. Should it be seen, when the gutta percha points are investigated that their diameters are larger than the stated sizes, then this indeed would be admirable. On the other hand, if the gutta percha points have diameters smaller than the stated size and, in fact, smaller than the reamer diameter, then it is obvious that a poor seal will be obtained with the matched point; great dependence would therefore have to be placed on the root canal sealer to ensure the requisite seal. When the root canal files were examined the diameters were found, by and large, to be larger than that given in the technical data; this would result in a consequent loss of adequate seal in the apical portion of the root canal when a matched point is used. Again, dependence would be placed on the root canal sealer in effecting an adequate hermetic seal. This is bad practice, since it is impossible to be absolutely certain that air bubbles are not introduced into the mix during spatulation or when spinning the sealer into the root canal prior to introducing the root filling point. Air bubbles in the cementing medium will undoubtedly mar the sealing properties of the final root filling.

The manufacturer states that the difference in diameter between incremental sized root canal instruments is 0.05 mm for No. 1 to No.4 and thereafter the increase in diameter is said to be 0.1 mm for No. 5 to No.12. This stated increase in diameter is represented by the broken line in the graphs in Figs. 2.28, 2.29 and 2.30.

The incremental difference in sequential sized instruments measured in this investigation, at 1 mm, 3 mm and 6 mm from the tip, is set out in the graph as a continuous line. It will be seen from these three graphs that the difference in diameter found in this investigation does not adhere to the manufacturer's stated difference.

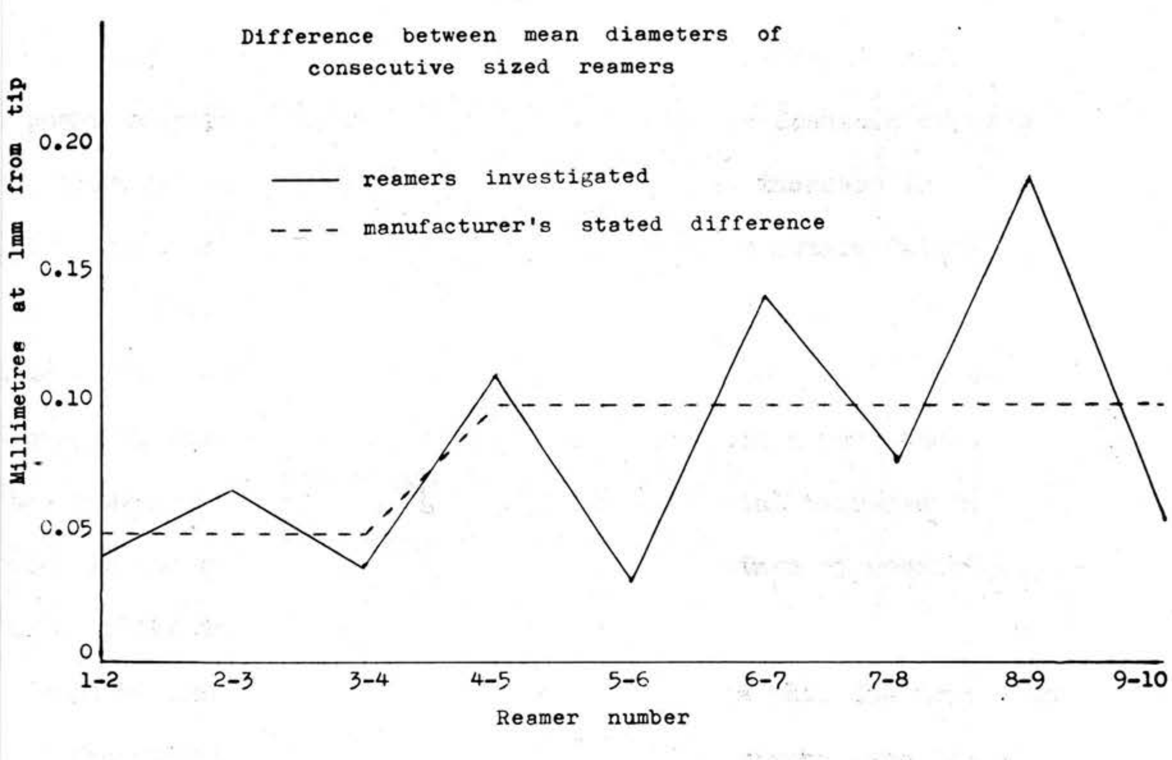
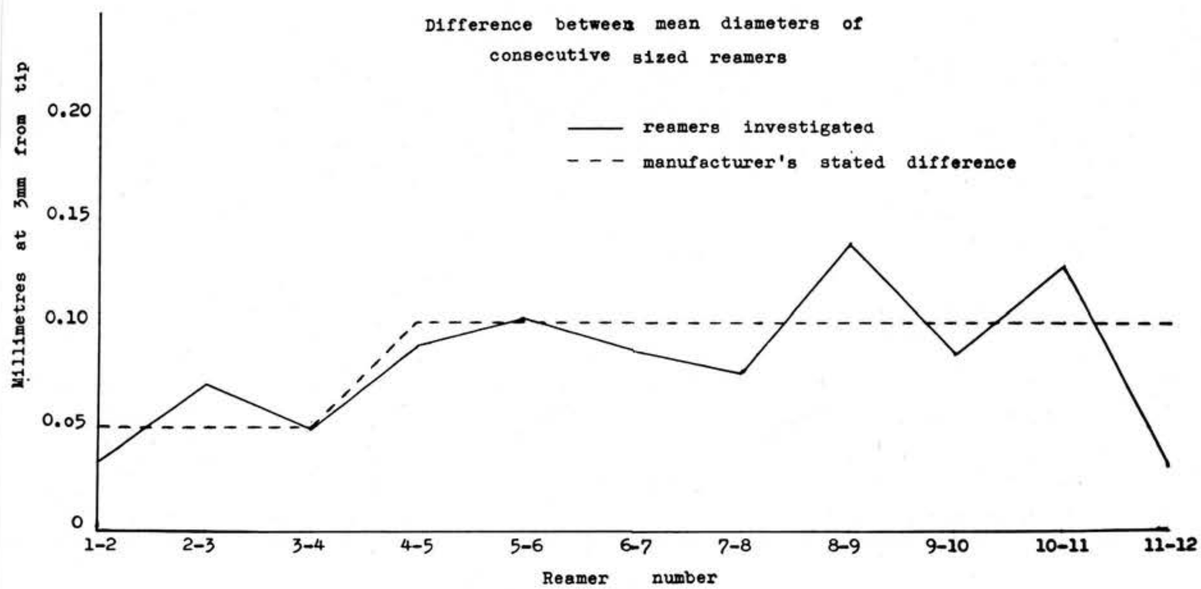

Difference between mean diameters of consecutive sized reamers
reamers investigated
manufacturer's stated difference
Millimetres at 1mm from tip
0.20
0.15
0.10
0.05
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
Reamer number

Fig. 2.28



Difference between mean diameters of
consecutive sized reamers
reamers investigated
manufacturer's stated difference
Millimetres at 3mm from tip
0.20
0.15
0.10
0.05
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-11
11-12
Reamer number

Fig. 2.29

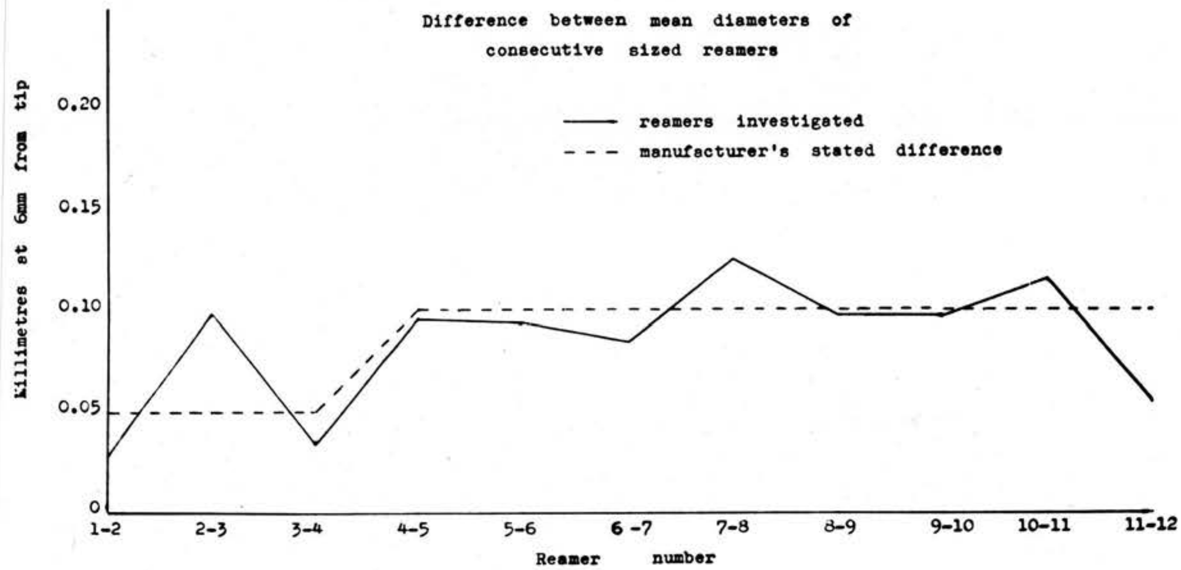

Difference between mean diameters of
consecutive sized reamers
reamers investigated
manufacturer's stated difference
Millimetres at 6mm from tip
0.20
0.15
0.10
0.05
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-11
11-12
Reamer number

Fig. 2.30

The difference in diameter was found to range from 0.03 mm to a maximum 0.18 mm. The significance of this discrepancy in uniformity is that when using root canal reamers in the mechanical instrumentation of a root canal of a permanent tooth, great care must be exercised when changing from one sized reamer to the next. In some cases the increase in diameter is small, therefore no great difficulty will be experienced but in other cases, where the increase in diameter is great, extra care must be exercised to ensure that the next larger size instrument does not bind in the canal with the inherent danger of fracture of the instrument. Lilley & Smith (1966) have shown comparable results in their work on the fracture of root canal reamers. They demonstrated that where the increase in diameter was greatest, the risk of fracture due to rotary fatigue was at its highest, while the smaller sizes showed a much greater fatigue life. Care, of course, should be exercised at all times when carrying out mechanical instrumentation within a root canal but the operator should realize that the incremental increase in diameter is not uniform and should think at all times of possible fracture of the instrument.

Since it has been stated on several occasions that the important area of the root canal is the apical third area, graphs were drawn showing the incremental increases in diameter in the 1 mm, 3 mm and 6 mm region from the tip of the reamers and files (Fig. 2.31 and Fig. 2.32). These two graphs show that there is no great discrepancy between the mean diameter of the root canal reamer and the root canal file, both graphs tending towards linear. These results are in agreement with the work carried out by Green (1957) and by Bucher as indicated in Sommer, Ostrander & Crowley (1966).

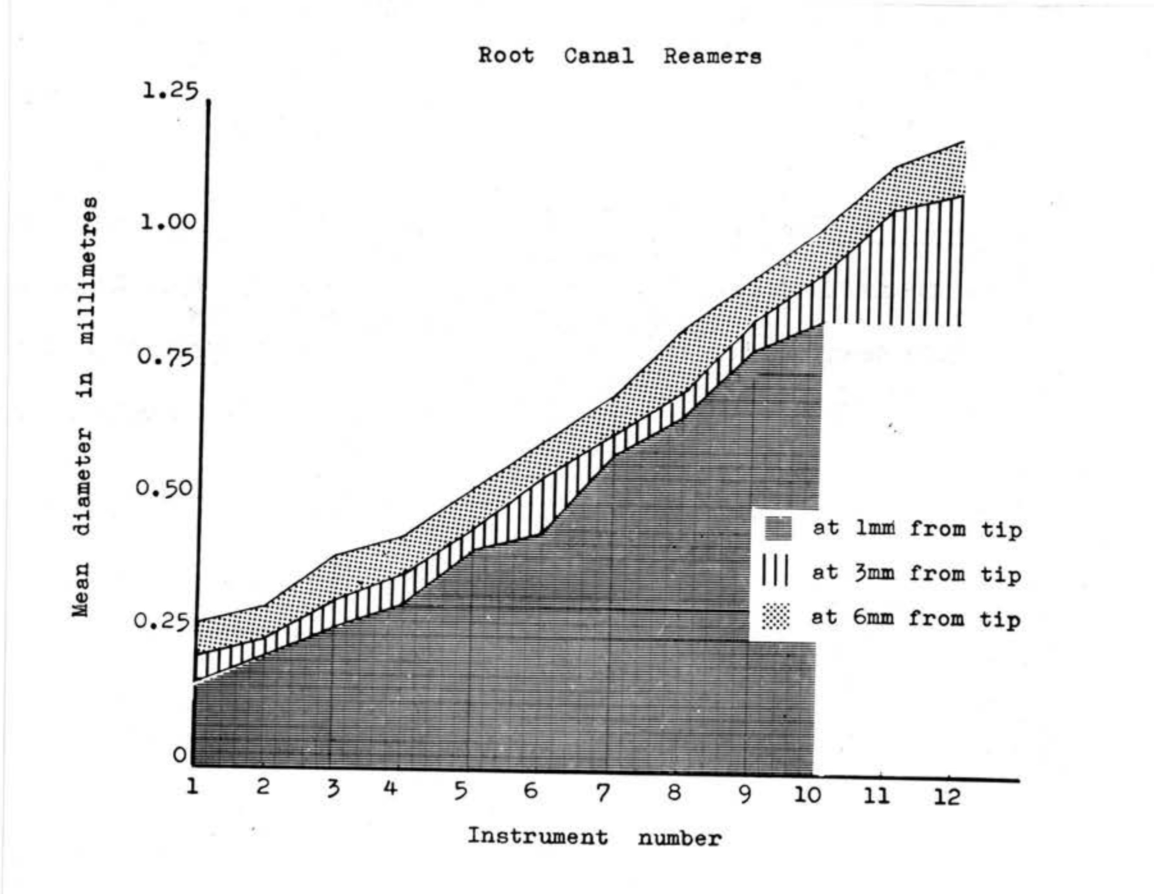

Root Canal Reamers
Mean diameter in millimetres
1.25
1.00
0.75
0.50
0.25
0
1
2
3
4
5
6
7
8
9
10
11
12
Instrument number
at 1mm from tip
at 3mm from tip
at 6mm from tip

Fig. 2.31

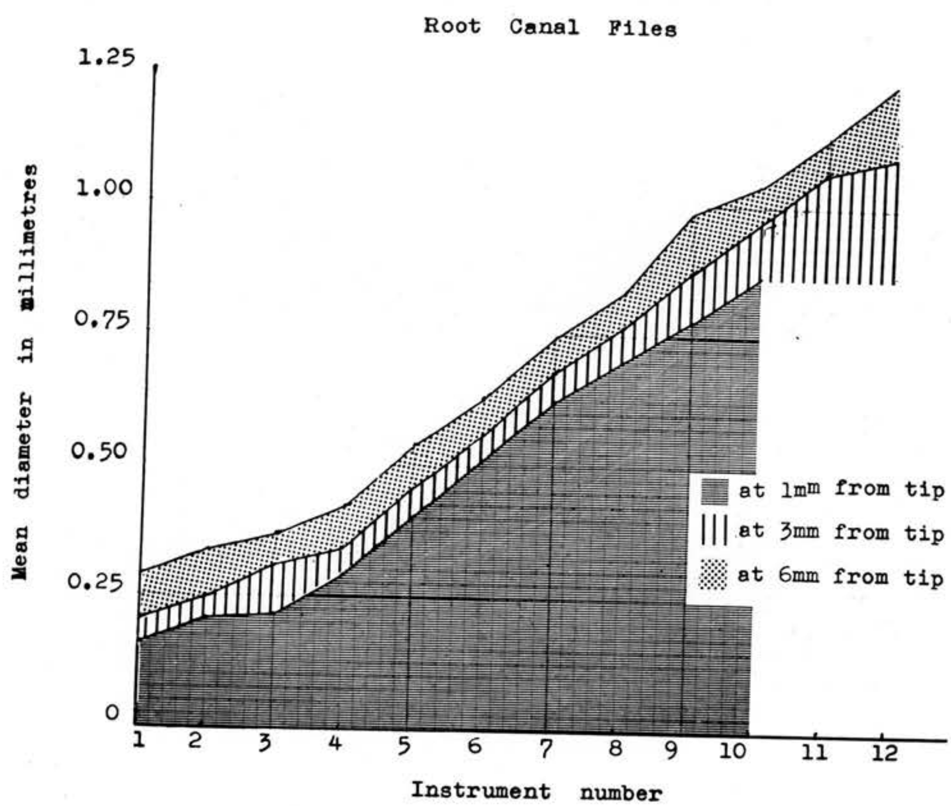

Root Canal Files
1.25
1.00
0.75
0.50
0.25
0
Mean diameter in millimetres
at 1mm from tip
at 3mm from tip
at 6mm from tip
1 2 3 4 5 6 7 8 9 10 11 12
Instrument number

Fig. 2.32

Omission of the 1 mm region for No. 11 and No. 12 instruments is for the reason stated on Page 22.

In summary - from the information obtained in this investigation, it would appear that the root canal reamer corresponds more closely to the technical data provided by the manufacturer than the Hedstrom file and is, therefore, from the mechanical aspect, the instrument of choice when carrying out mechanical instrumentation within the root canal. If the matched gutta percha points are found to correspond to or to be slightly greater in diameter than the reamer, then this would ensure a more adequate seal in the apical third region of the root canal. There are other reasons for this statement than the one propounded above, but these will be enlarged upon later on in this thesis (Chapter 3).

CHAPTER 3

Preparation of the Root Canal

Introduction

It has already been stated that one important facet of root canal therapy is the manner in which the root canal reamer and the root canal file prepare the dentine wall of the root canal during mechanical instrumentation within the canal. Endodontists agree that a very important factor, if not the most important factor, in the success of a root filling is the accuracy with which the root canal can be prepared to receive the final root filling itself. Nicholls (1960) states that "the more precisely cleansing approaches the narrowest part of the canal, the easier it is to obliterate the prepared part of the canal." Chanoch (1966) states that "the ideal prepared canal form should be perfectly round, tapering and with a minute foramen", while Ingle (1965), Bender et al (1964) and Grossman (1943) give as the most common cause of root canal failures "incorrectly filled canals" stating that "anything short of total obturation is not to be tolerated." It is felt that Nicholls' phrase - "precise cleansing" - is surely the operative phrase in mechanical instrumentation within the root canal of a tooth.

Precise cleansing can be interpreted as meaning the removal of necrotic tissue and infected dentine from the walls of the root canal so that the canal walls are left in a reasonably clean condition, thus permitting the drugs which are inserted into the canal to exert their maximum effect (Grossman (1943)). The dentine which is removed during mechanical instrumentation should be removed in such a manner that the walls are left straight, tapering and smooth. It also means that the canal should be prepared in a circular fashion, that is, with a circular cross-section, avoiding any tendency to ovality and that the canal should present a uniform taper from the apex to the coronal portion. If the root canal can be prepared with the ideal circular cross-section which corresponds to the matched root filling point, then the certainty of complete obturation is assured. It would appear, therefore, that 3 questions have to be investigated :-

1. What is the final configuration of the root canal after instrumentation with reamers?
2. What is the final configuration of the root canal after instrumentation with files?
3. Is there any difference in the final shape of the canal when the preparation made by these two instruments is compared?

Method

It was thought that if the cross-section of the root canal of permanent maxillary anterior teeth was examined before and after instrumentation, this would answer the three questions which have been posed. Extracted caries free permanent maxillary incisors were selected, without regard to specific age groups. They were placed in formalin for an undetermined period, but before being used in the investigation they were transferred to a solution of 50% glycerine and 50% hydrogen peroxide, the glycerine rendering them less friable and the peroxide removing all stains and making them more pleasant to handle. They were kept in this solution for about 7 days.

Each tooth, prior to subjecting it to examination, was removed from the stock solution, dried and then mounted in a sectional plaster block with the cingulum of the tooth just appearing at the edge of the plaster block (Fig. 3.1). The block was opened and the tooth removed, the length recorded and the junction of the apical and middle thirds of the tooth marked by scoring the root surface with a sharp edged instrument followed by marking the groove with a sharp pointed lead pencil so that this line appeared more obvious. In this section of the thesis a total of 9 reamed teeth and 15 filed teeth have been investigated.

A conventional triangular shaped opening for access to the root canal was cut in the lingual fossa and the pulp tissue, or what remained of it, removed with a barbed broach. Great care was taken over this aspect of the investigation since any residual pulp tissue adhering to the root canal wall tended to mask the canal outline when

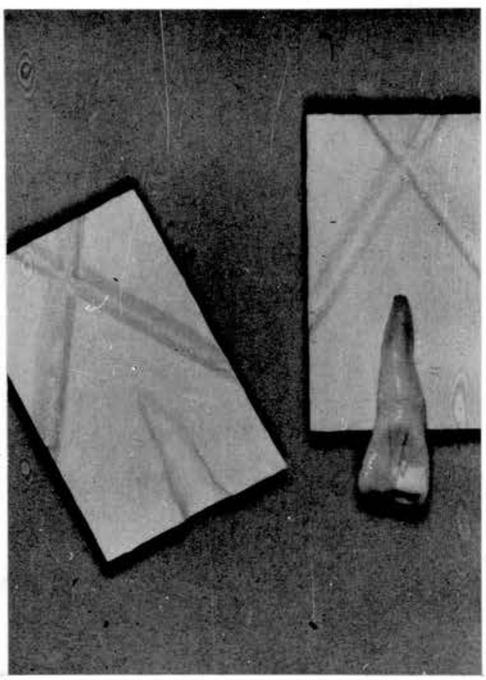


Fig. 3.1

viewed under the microscope. With a carborundum disc the root was almost severed at the junction of the apical and middle thirds, at right angles to the long axis of the tooth, by cutting at the reference line previously made (Fig. 3.2). The cut was not carried completely through the root, the final 1 mm or so being left so that it could be fractured in a similar manner to that employed in indirect inlay work. By employing this method of cutting it was possible to ensure that the apical portion of the root kept its original position, relative to the rest of the tooth, in the plaster block as it was being subjected to instrumentation. So that the outline of the root canal in the apical portion would stand out in relief, thus making measurement under the microscope much easier, it was swabbed with picric acid and left for one minute, washed and then stained with Mallory stain for one minute and finally washed with water to remove excess stain.

The apical portion was pressed into plasticine mounted on a glass slide (Fig. 3.3). Great care was taken to see that the cut surface was parallel to the glass slide, otherwise difficulty in focusing along the whole diameter of the canal outline would have resulted. Reference lines were made with a sharp pointed lead pencil, at right angles to each other, running from the canal periphery on the surface of the apical portion of the root, in order that the specimen could be returned to the same position under the microscope every time a reading was necessary. Having chosen a suitable scale on graph paper, the outline of the root canal in this apical portion of the tooth was drawn, after transferring many

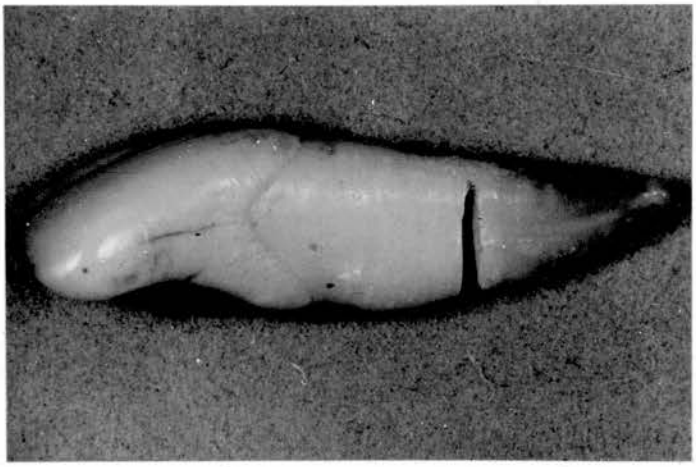


Fig. 3.2

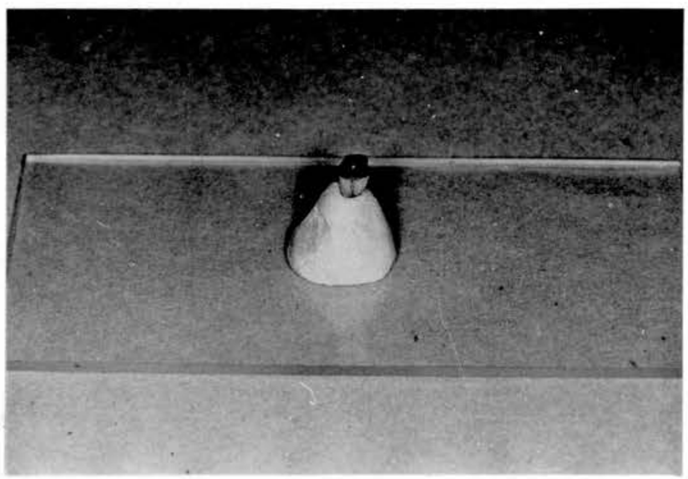


Fig. 3.3

reference points from a squared graticule eyepiece on the microscope to the graph paper. A magnification of 60 was obtained by means of a X10 ocular lens and a X6 eye piece.

Having recorded the outline of the root canal in the apical portion of the root before instrumentation, the complete tooth was returned to the plaster block and instrumentation with a root canal reamer was carried out in the usual manner (Fig. 3.4). Reamers were used in sequential sizes commencing with a small number (usually No. 2 or No. 3) and proceeding to the maximum size chosen for the particular tooth, not necessarily the same final size in all cases. This will be elaborated on later in this chapter.

Filing was also investigated, this method of instrumentation being performed in two distinct ways. The first method was to pass the smallest file into the root canal until it impinged on the canal wall, reference being made to the tooth length so that the instrument did not pass through the apical foramen. The file was then given a quarter to a half turn so that its spirals bit into the dentine, the file then being withdrawn with a pull stroke.

The second method was to use the file in what is thought to be its true connotation, that is, by inserting the file into the root canal until it impinges on the dentine wall, but, in this case, no attempt was made to bite the spirals into the dentine; the file being then withdrawn using lateral pressure against the side wall of the root canal. By this means one small segment of the canal periphery is filed at a time, the file being reinserted and another segment of the canal wall filed on the next withdrawal stroke. Again in this method the files were used in sequential sizes until the canal was considered finally prepared.

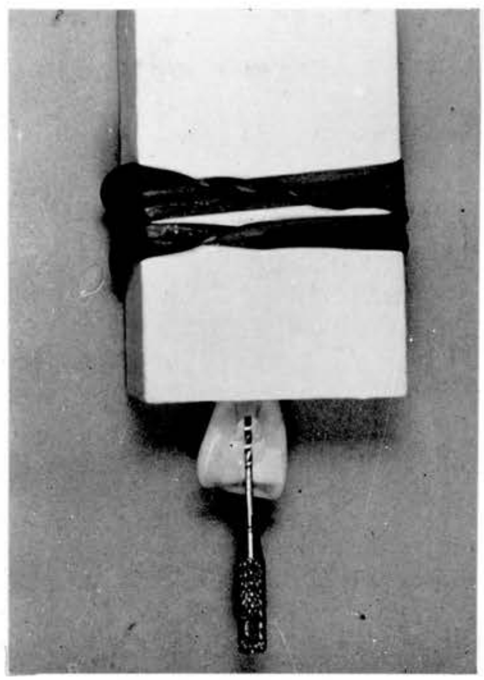


Fig. 3.4

Results.

Drawings of the various root canals, at the junction of the apical and middle thirds of the <u>tooth</u>, before and after instrumentation, are shown in the following diagrams. This area was chosen rather than the apical and middle third of the <u>root</u> because preliminary investigation had shown that the statement (Curson (1966), Sommer (1966) and Ingle (1965)) that root canals tend to be round in the apical region, was correct. Fig. 3.5 shows tracings of 5 root canals of permanent central incisors. These examples are taken out of a series of 100 teeth sectioned at 1 mm and 5 mm from the apex. In this figure the configuration of the root canal is shown when sectioned at 1 mm and at 5 mm from the apex.

The tables in Fig. 3.6 and Fig. 3.7 give the root canal diameter of 10 maxillary centrals and 10 laterals at the same two distances from the apex. It will be observed that the readings are in multiples of three because the graticule eye piece recorded in this particular division. The magnification used in obtaining these readings was X16.5.

Fig. 3.6 shows that 9 out of 10 maxillary central incisor root canals measured are round in the apical 1 mm, while only 2 out of 10 are round in the region 5 mms from the apex. Similarly, in Fig. 3.7, 9 out of 10 root canals of maxillary lateral incisors are seen to be circular in the region 1 mm from the apex while only 3 out of 10 were circular in the region 5 mms from the apex.

Therefore, if it is found possible to prepare the root canal with the ideal circular outline in the apical third region of the <u>tooth</u>, the outline of the canal in the apical third region of the <u>root</u> will be correspondingly prepared.

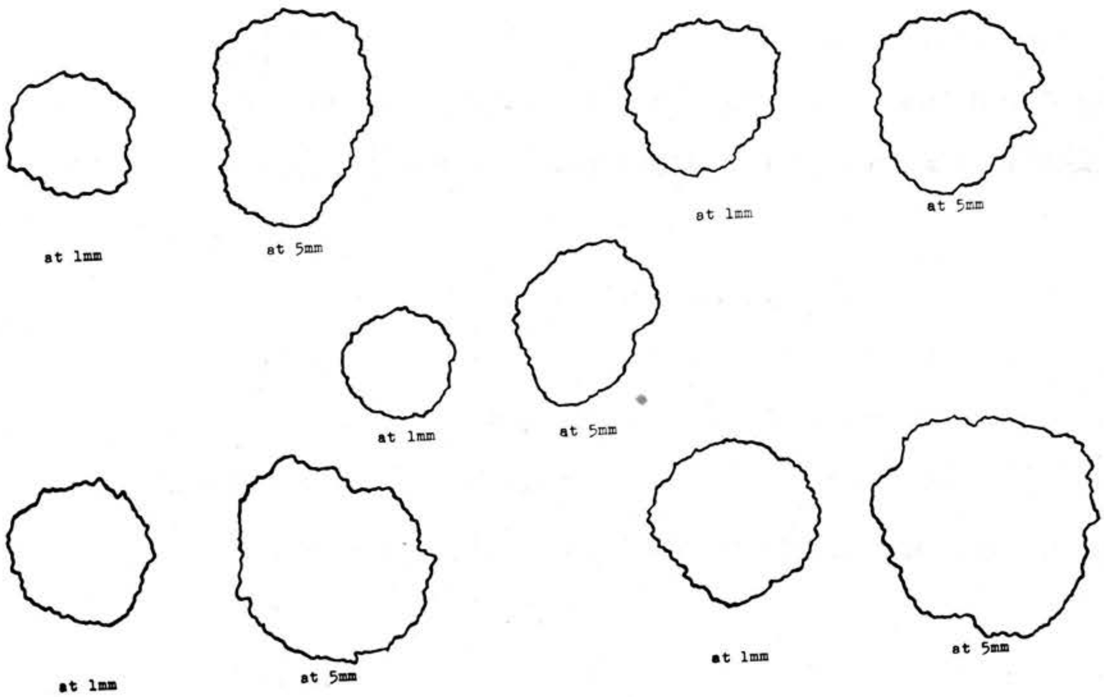

at 1mm
at 5mm
at 1mm
at 5mm
at 1mm
at 5mm
at 1mm
at 5mm
at 1mm
at 5mm

Fig. 3.5

MAXILLARY CENTRAL INCISORS					
Tooth	Length mm	Diameter at 1 mm from apex		Diameter at 5 mm from apex	
		Minimum mm	Maximum mm	Minimum mm	Maximum mm
/1	25	0.396		0.528	0.594
/1	24.5	0.495		0.627	0.759
1/	24	0.495		0.528	0.627
1/	23	0.429		0.627	0.759
1/	24	0.278	0.495	0.495	0.727
/1	21.5	0.495		0.627	0.660
1/	21.5	0.528		0.528	0.627
1/	24	0.429		0.528	0.759
1/	21.5	0.396		0.660	
1/	21	0.528		0.726	

Fig. 3.6

MAXILLARY LATERAL INCISORS					
		Diameter at 1 mm from apex		Diameter at 5 mm from apex	
Tooth	Length mm	Minimum mm	Maximum mm	Minimum mm	Maximum mm
2/	19	0.297		0.297	0.660
2/	22	0.330		0.462	0.759
/2	23.5	0.561		0.627	0.957
/2	22	0.330	0.462	0.396	0.957
/2	23.5	0.330		0.594	
/2	22	0.330		0.495	0.726
2/	20	0.330		0.396	
/2	24	0.396		0.561	1.055
/2	23	0.330		0.561	0.957
/2	24	0.330		0.495	

Fig. 3.7

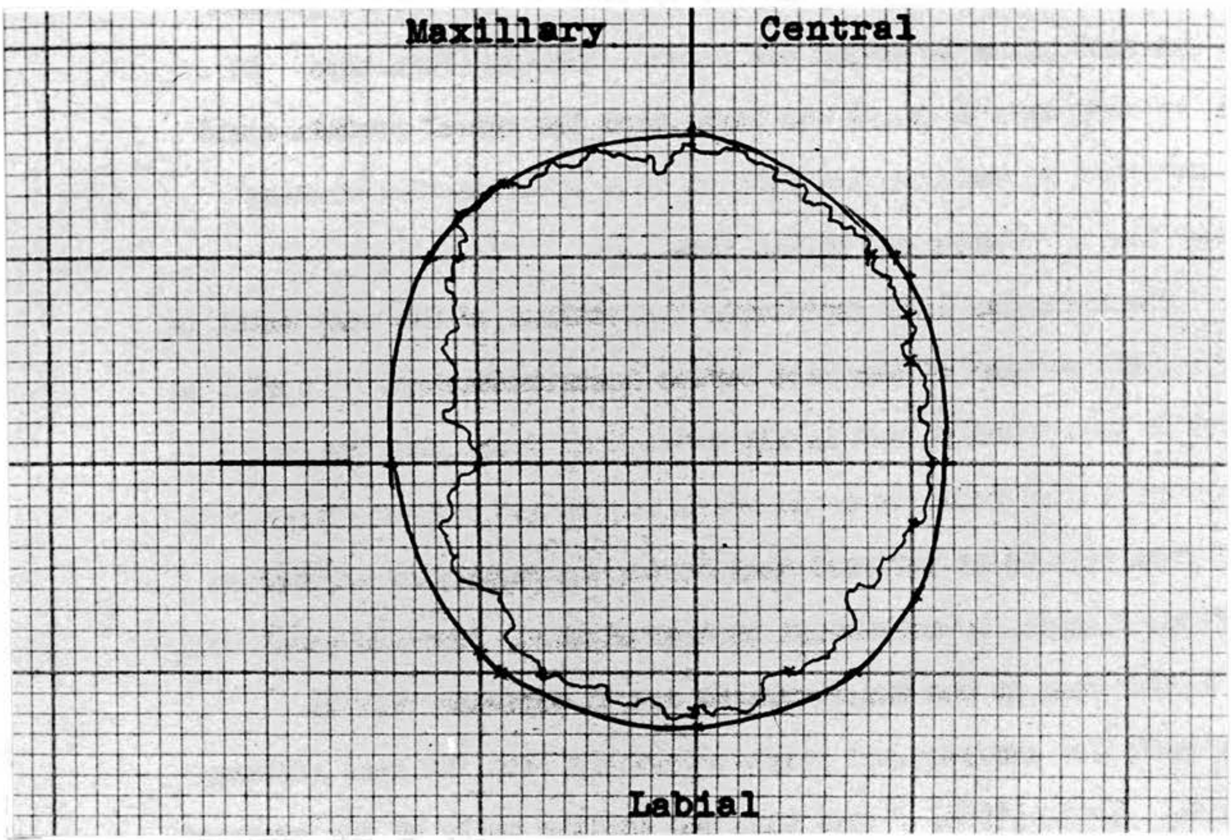


Fig. 3.8

An explanation of the various parts of the following drawings is given. Fig. 3.8 represents the tracing of a root canal of a maxillary central incisor sectioned in the apical third region of the tooth, that is, 7 mms from the apex. The two lines, one at the top of the diagram and other at the left are the two reference lines which were marked on the cut surface of the apical portion of the root prior to making the initial tracing (Page 42). It was by reference to these two lines that the apical portion could be returned to the same position on each occasion when viewing under the microscope was called for.

The irregular line represents the outline of the root canal in the apical portion of the root before instrumentation. It will be seen in this tracing, and in all subsequent ones, that the periphery of a root canal is by no means smooth and regular in outline and from this it is inferred that during preparation some dentine must be removed, by mechanical instrumentation, from the canal wall to ensure that it has the requisite smooth circular wall so necessary for accurate and complete sealing with the root filling point. Ingle (1965) states that the dentine walls of the prepared root canal must feel "glassy smooth" before proceeding to final obliteration of the central space.

The more even line, outside the original tracing of the root canal, represents the canal outline after instrumentation with, in this particular case, a reamer. It will be seen that the diameter is practically circular and appears completely smooth. This is the ideal configuration of a root canal in the apical third of the root, a shape so necessary if complete and accurate obliteration of the central space is to be ensured.

It is pointed out that a small area of the original root canal surface has not been included in the instrumentation with the reamer - the top left hand area in the diagram. This deficiency would, of course, have to be filled with root canal sealer and, as has already been pointed out, this is not a particularly certain method of obturation. This deficiency in mechanical preparation can, however, be overcome by enlarging the canal diameter with a larger reamer. In fact, this was carried out in this particular case and the root canal prepared with a final size of No. 12 reamer, two sizes above the initial final size.

It is proposed to go through all the teeth that were instrumented with reamers first of all, although this was not the order in which they were instrumented in this investigation. This will be followed by drawings of the teeth that were instrumented with the root canal file. A description of each drawing will be given and a final assessment of the results will end this chapter.

It is stressed that the tracings are not drawn to a particular scale but that they are all drawn in relation to the squares on the graticule eye piece. Some of the original root canal outlines were rather small and some quite large. Since the teeth were not selected according to age groups, this may account for the variation in diameters but this is only conjecture. It is thought that it would be more useful to concentrate on the final prepared shape and to omit all reference to the correlation of canal diameter to age.

R E A M E D   T E E T H

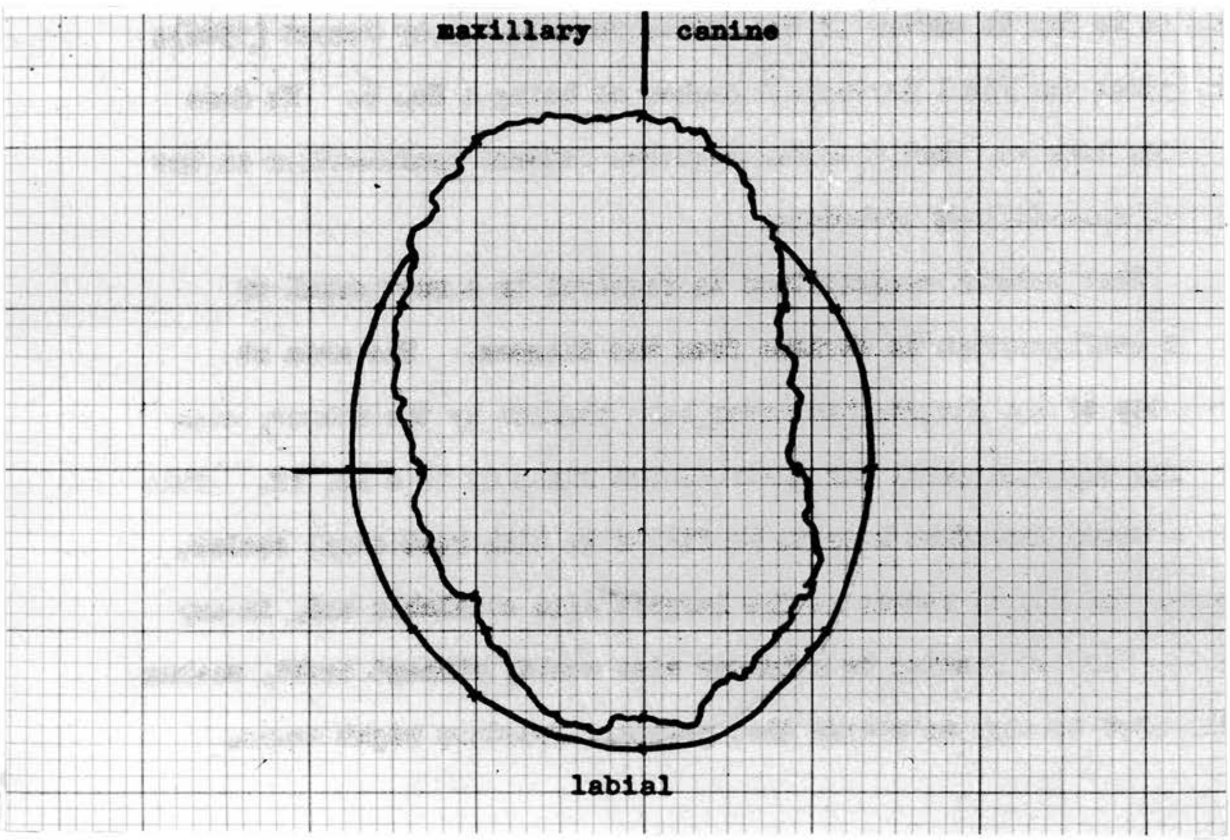


Fig. 3.9

Figure 3.9 shows the outline of a maxillary canine sectioned at 9 mm from the apex. The diameter of the canal is, as would be expected, wider in a labio-lingual diameter than it is in a mesio-distal diameter. This tooth was reamed up to a No. 12 reamer which is far in excess of the number recommended by Sommer (1966); he gives the final instrument number as being a No. 6. He does state, however, that a canine requires lateral condensation in the final root filling technique.

That lateral condensation is required in a root canal of this configuration is obvious from the diagram. The area at the top of the diagram has never been touched by the reamer, even though the root canal was instrumented right up to a No. 12. This area would therefore have to be filled in with root canal sealer. Also, the No. 12 reamer is the largest size available and, in any case, further reaming to a larger size would, without doubt, weaken the root to such an extent that possible fracture might occur.

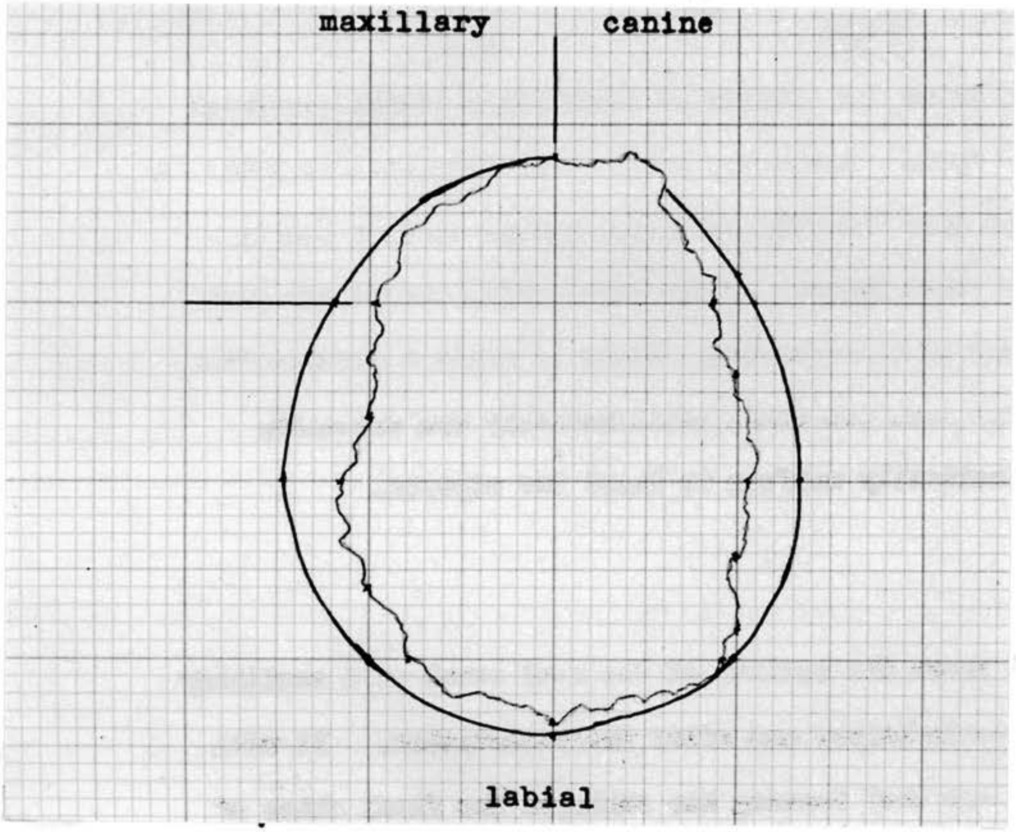


Fig. 3.10

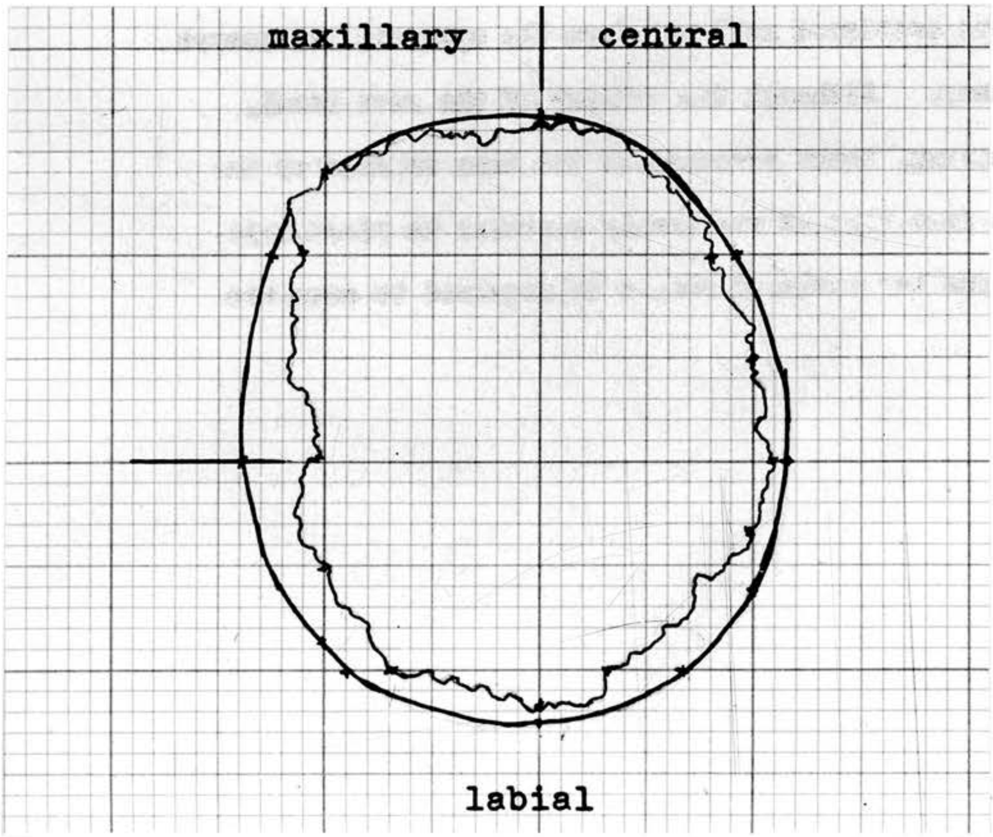


Fig. 3.11

Figure 3.10 shows the outline of a maxillary canine sectioned at 8 mm from the apex. Again the diameter of the canal is ovoid in shape but in this case the root canal was reamed up to a No. 10 reamer which has taken in most of the canal wall, except one small segment at the top of the drawing. There is quite a considerable removal of dentine from the canal walls mesially and distally, removal being practically uniform in these two aspects.

Figure 3.11 shows the outline of the root canal of a maxillary central incisor tooth before and after instrumentation. It will be seen in this case that reaming has rendered the final shape of the canal virtually circular in cross-section - the ideal shape for the final root filling point.

This tooth was sectioned at 7 mms from the apex and was reamed up to a No. 8 reamer. Although the outline of the root canal, before instrumentation, looks practically the same in area as the previous one, the fact that it was nearly circular to start with has meant that a smaller numbered reamer is required to complete instrumentation.

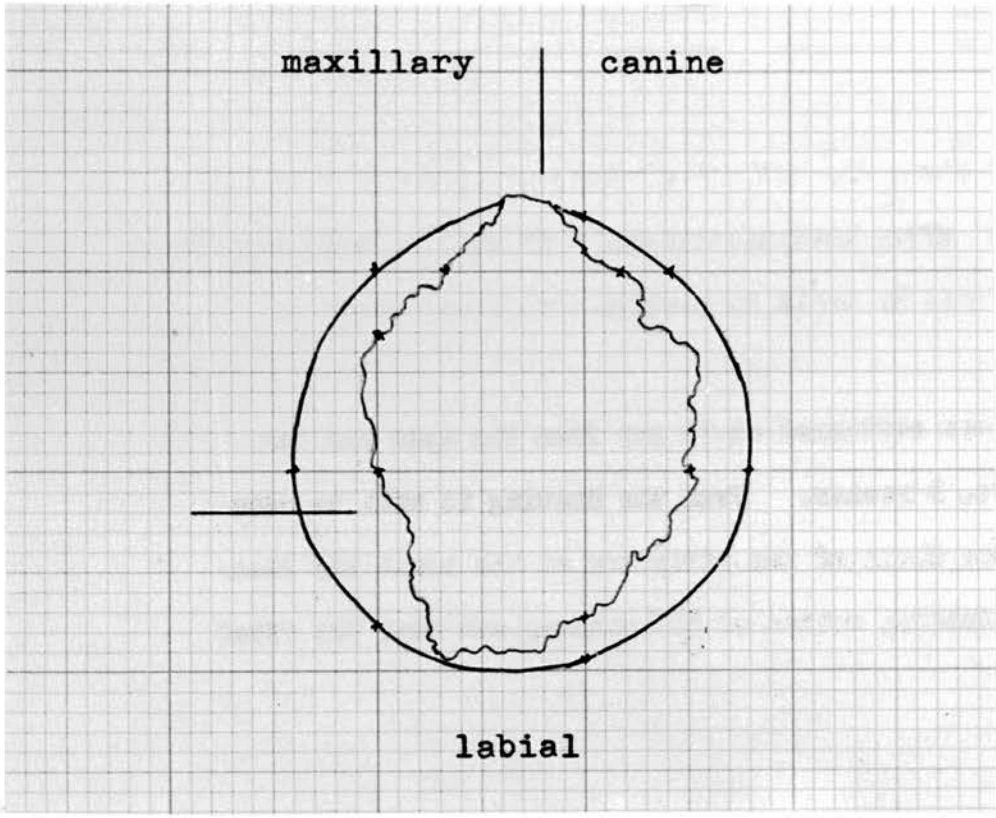


Fig. 3.12

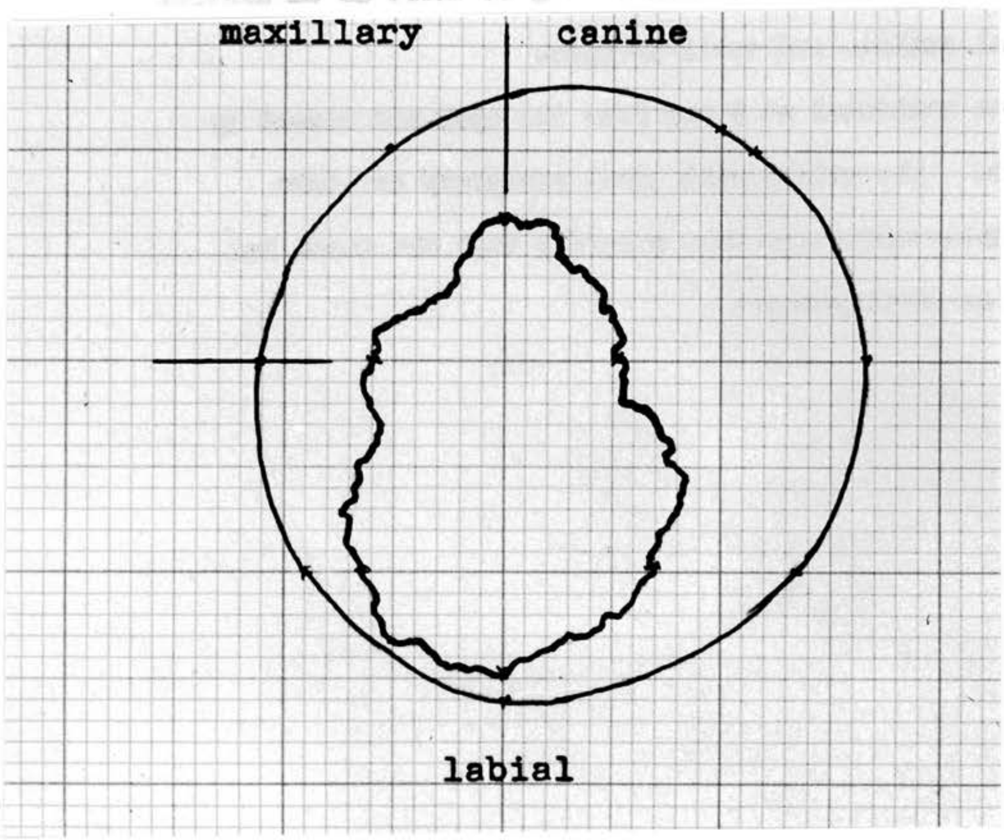


Fig. 3.13

Figure 3.12 shows the outline of the root canal of a maxillary canine before and after instrumentation. It will be seen that this is a root canal that is ovoid in section and rather small in diameter.

This tooth was sectioned at 10 mms from the apex and was reamed up to a No. 8 reamer. From the drawing it will be seen that virtually the whole of the periphery of the canal has been included in the cutting action of the reamer, and that the final shape is ideal.

Figure 3.13 shows the outline of the root canal of a maxillary canine before and after instrumentation. Again there is an initial ovoid shaped canal outline and small in size.

The tooth was sectioned at 9 mms from the apex and reamed up to a No. 9 reamer. The entire root canal periphery has been included in the instrumentation thus ensuring that the canal has been prepared in an ideal manner.

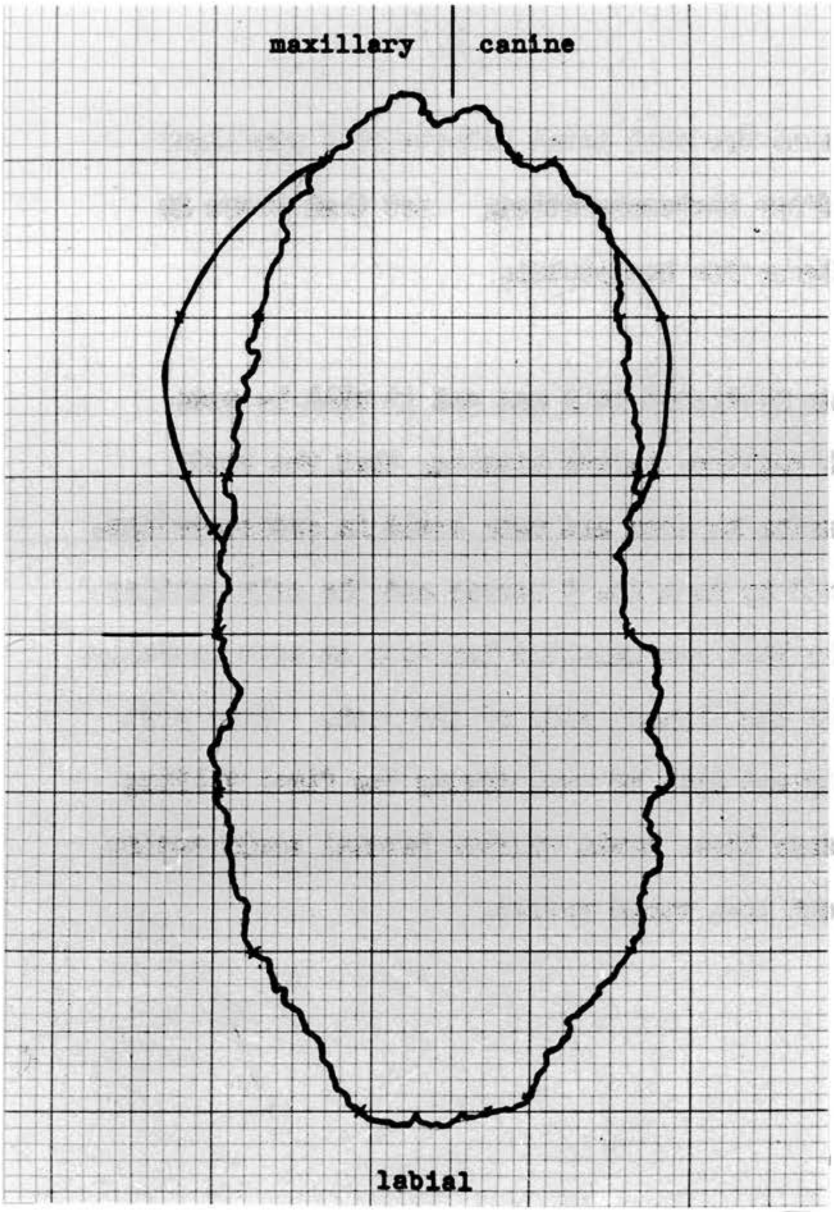


Fig. 3.14

Figure 3.14 shows the root canal outline of a maxillary canine before and after instrumentation; not that there is much difference between the two states.

This canine was sectioned at 9 mms and it will be seen from the root canal outline, before reaming, that the root canal is very extensive in area and very ovoid in cross-section. This tooth was reamed up to a No. 9 reamer and the only cutting of the dentine walls that has resulted has been an area mesially and distally towards the lingual side of the root. This root canal would need a great deal of care during the final filling stage and, at the same time, would require lateral condensation to ensure that a good seal would result.

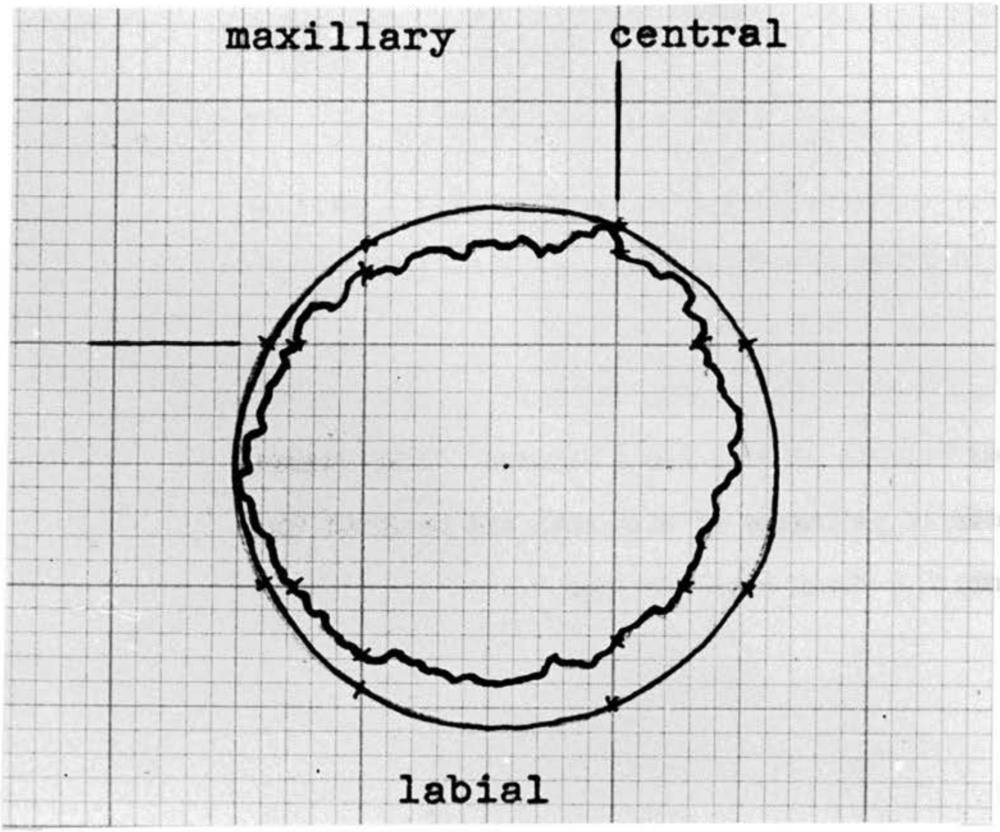


Fig. 3.15

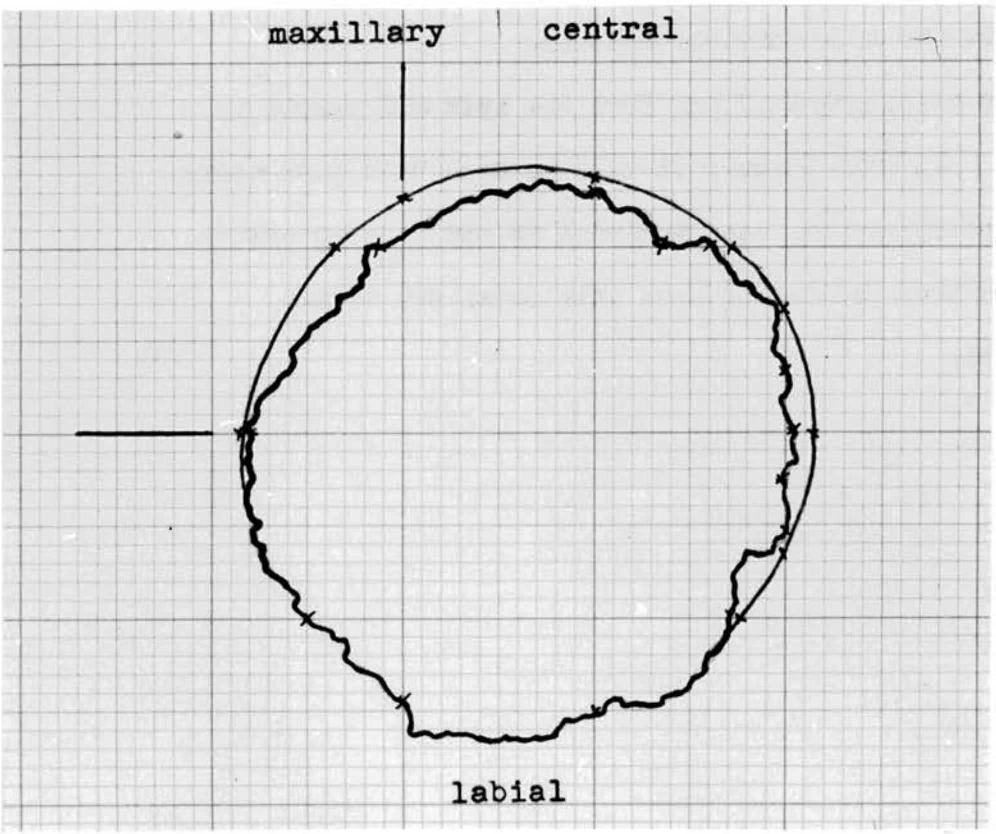


Fig. 3.16

Figure 3.15 shows the outline of a root canal of a maxillary central sectioned at 8 mms from the apex, before and after instrumentation.

It will be seen that in this tooth there is a small root canal which only required reaming up to a No. 6 reamer. This reamer size took in the entire periphery of the canal and rendered the canal in a fit state for final root filling.

Figure 3.16 shows the root canal outline of a maxillary central incisor tooth before and after instrumentation.

This tooth was sectioned at 7 mms from the apex and reamed up to a No. 8 reamer. In this diagram it will be seen that just about half of the canal periphery has been included in the reaming action. It would require further reaming to open this canal out to the ideal circular shape.

FILED TEETH

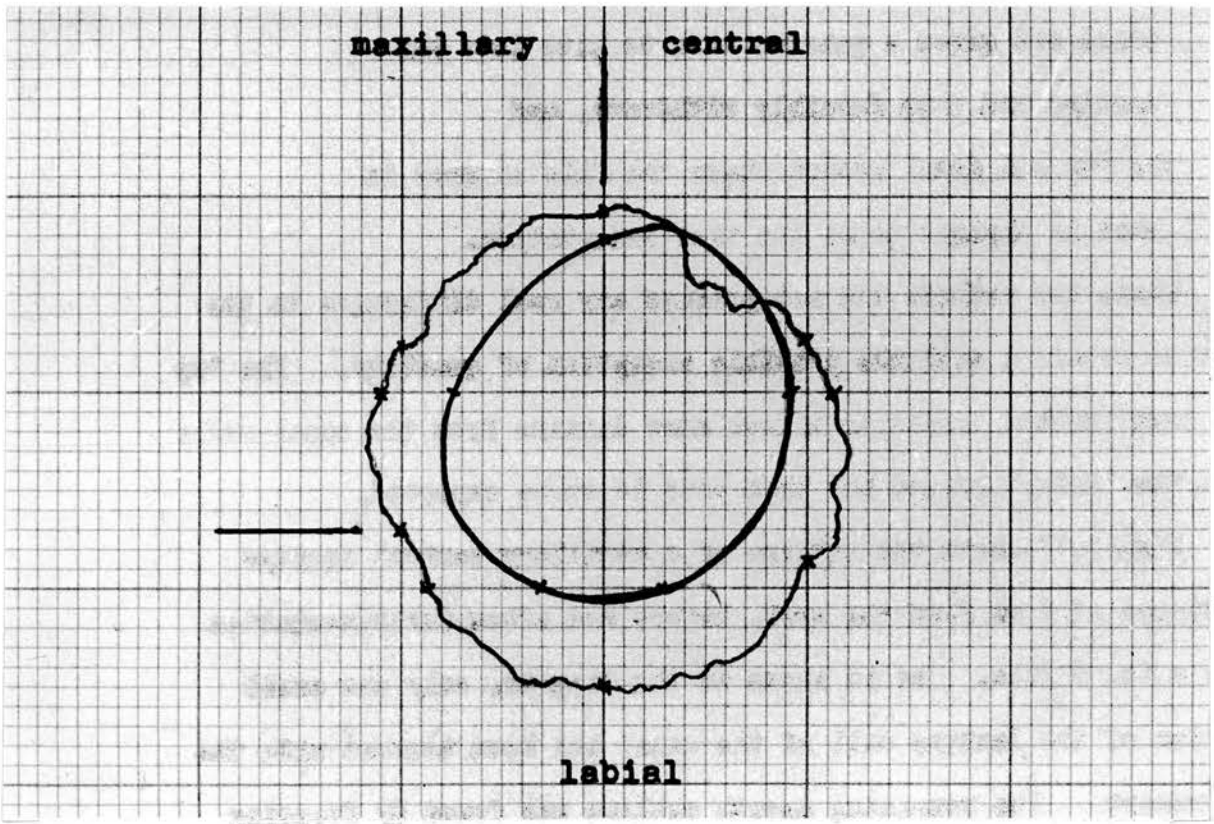


Fig. 3.17

In this section the results of filing within the root canal are observed. Again it is pointed out that the 'file' in this connection is the 'Hedstrom File' and not the American type file.

As was stated on page 43, the file was used in two different ways :-

the 'entry' method where the file is entered into the canal and given a quarter turn to bite into the dentine and then forcibly withdrawn, and

the 'up and down' method where the file is used in what is thought to be its true connotation.

These two methods did not produce any real difference in the results obtained with the possible exception of quantity. The 'up and down' method tended to remove more dentine from the canal walls than the 'entry' method but then this is to be expected.

Fig. 3.17 shows the outline of a maxillary central incisor sectioned at 5 mm from the apex, before and after instrumentation with a No. 6 file. As is shown in the diagram, only one small portion of the dentine wall of the canal has been touched with the instrument. The remaining smooth outline was found by focusing the microscope down the root canal so that this outline represented a point nearer the apex than the 5 mm mark where the root was sectioned.

In this particular root it was felt that filing should be carried out to a larger instrument number. This was done and the results shown opposite page 68.

It has been decided to report the two methods of filing separately and in the following 11 figures the method of 'up and down' filing is recorded, followed by 4 diagrams of the 'entry' method.

FILING

Carried out by the 'up and down' method.

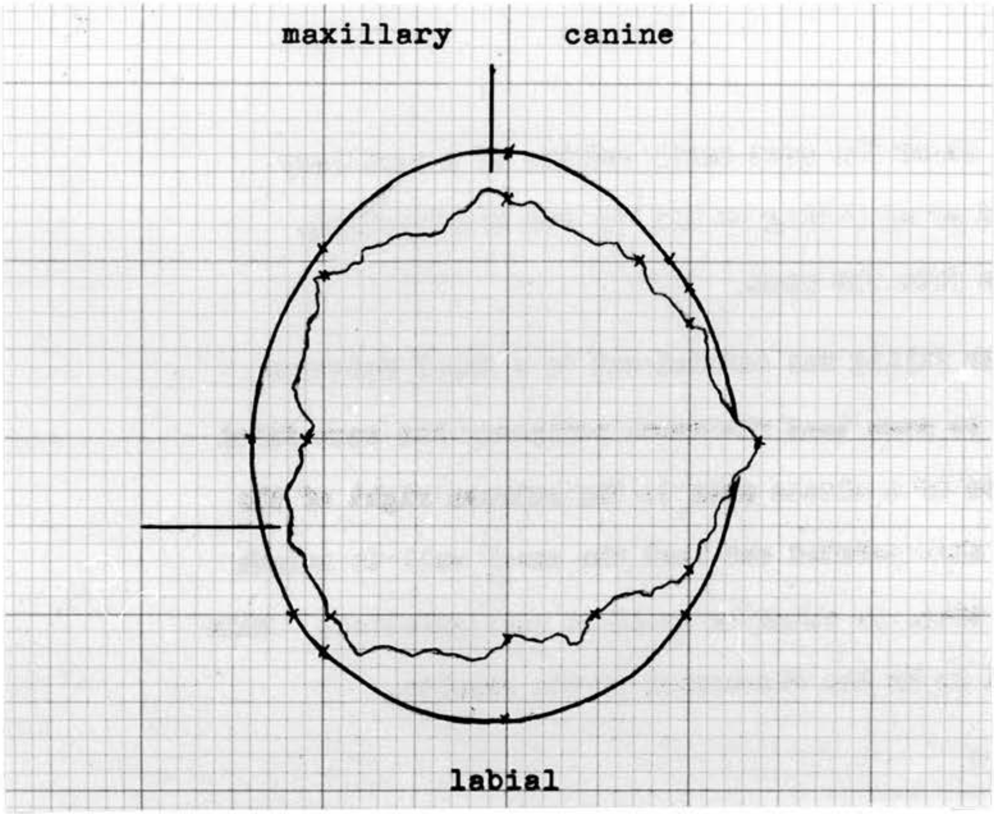


Fig. 3.18

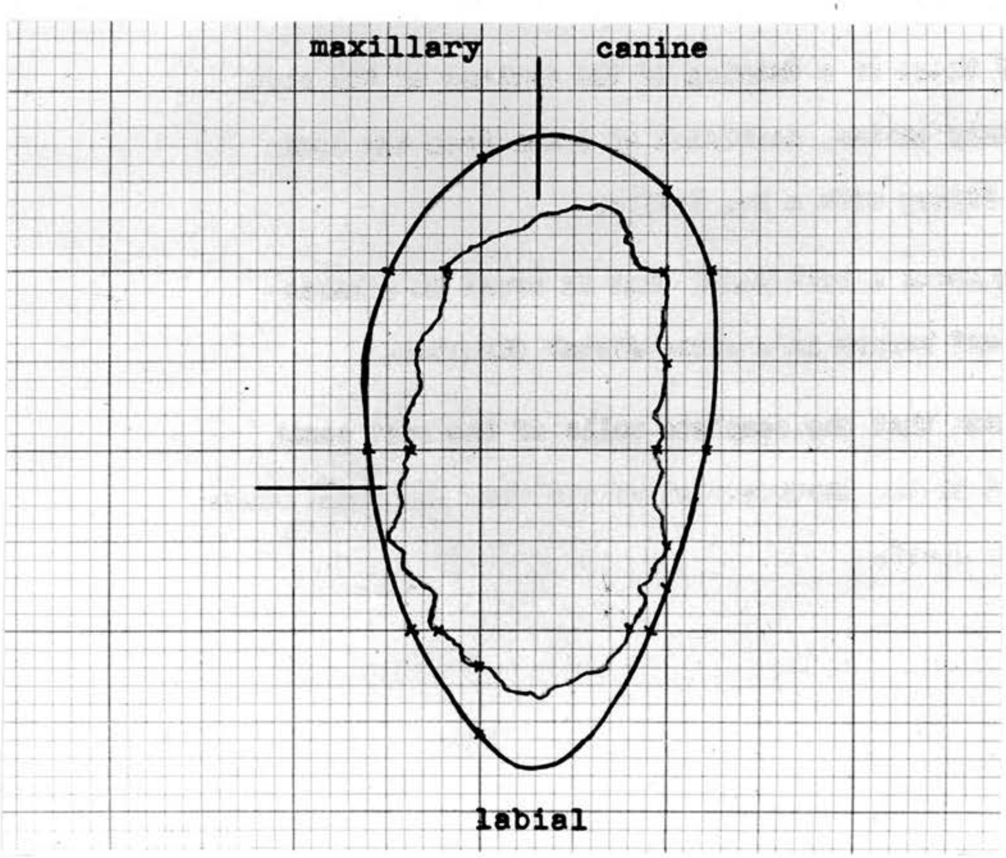


Fig. 3.19

Figure 3.18 shows the root canal outline of a maxillary canine before and after filing by the 'up and down' method, sectioned at 9 mm from the apex.

In this tooth filing was carried out to a No. 7 Hedstrom file and it will be seen that the canal periphery has been filed with the exception of a minute area to the extreme right of the drawing. It is also pointed out that the canal wall is smooth and, at the same time, is slightly ovoid in configuration. This will be commented on in the discussion of the results.

In Fig. 3.19 there is a drawing of the outline of the root canal of a maxillary canine, sectioned at 9 mms from the apex before and after filing with a No. 6 file.

This section shows a root canal that is broad in a labio-lingual diameter and narrow in a mesio-distal diameter.

It will be seen that the complete walls of the root canal have been involved in the instrumentation and that the final shape is very definitely ovoid.

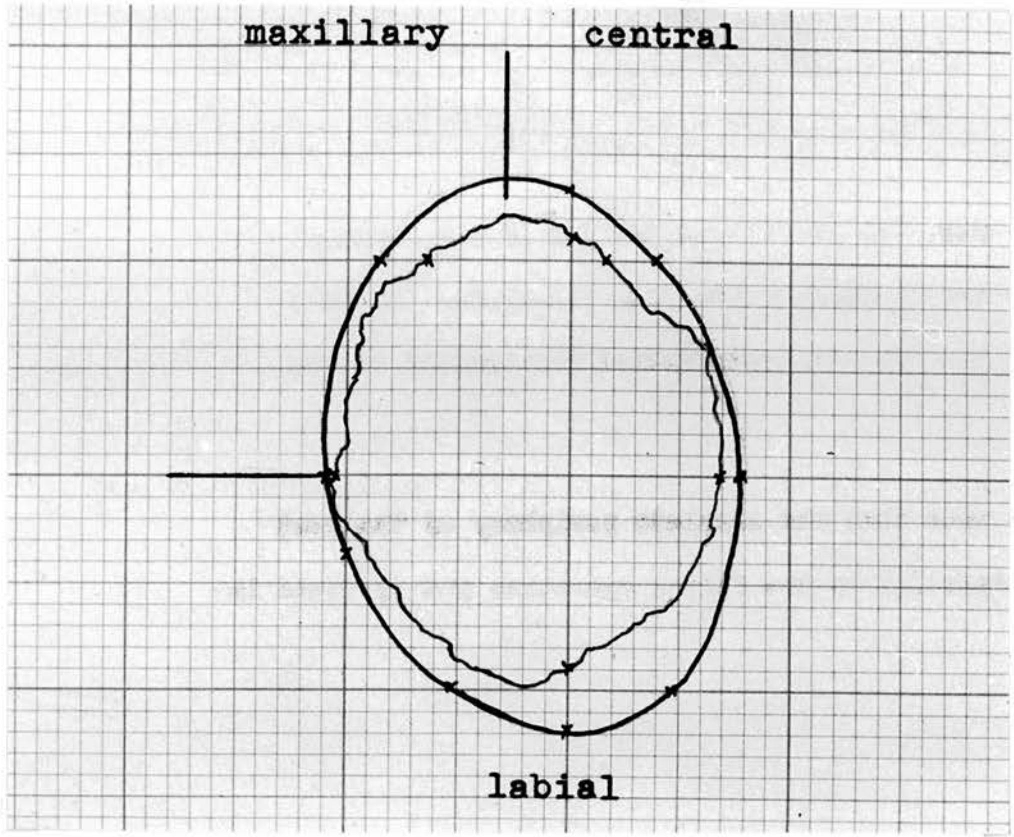


Fig. 3.20

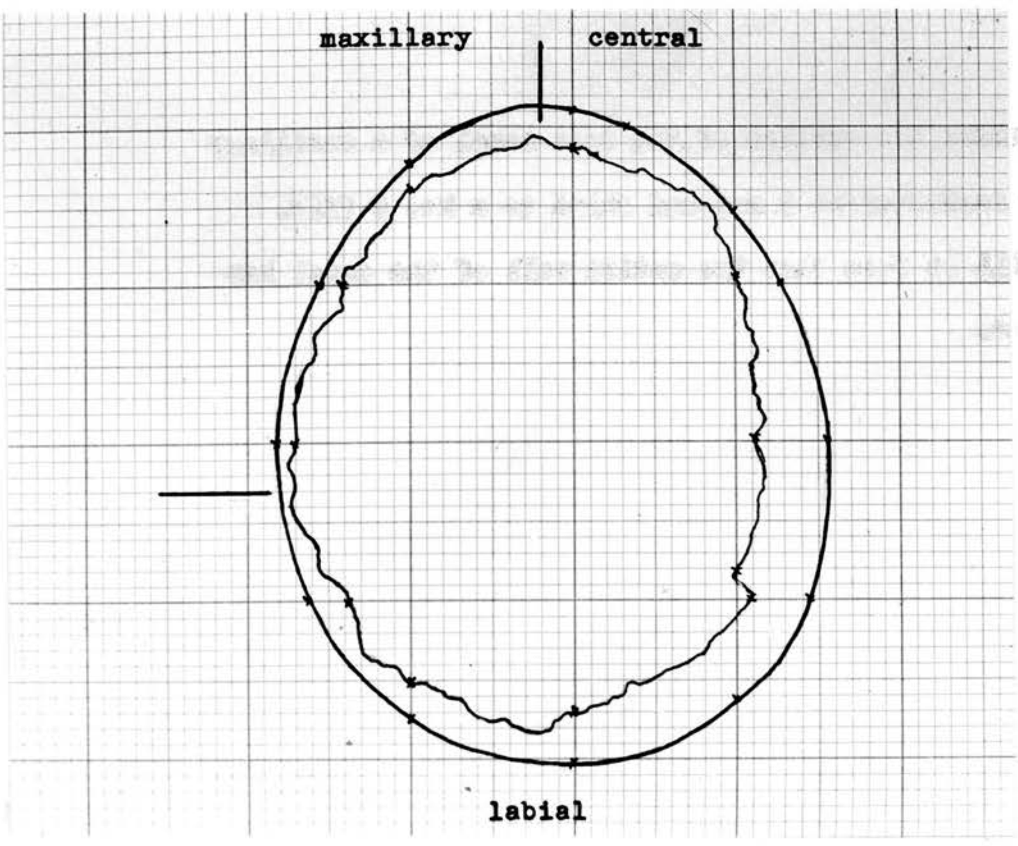


Fig. 3.21

Fig. 3.20 shows the root canal outline of a maxillary central incisor sectioned at 8 mms from the apex. In this tooth filing by the 'up and down' method was carried out to a No. 6 file.

It will be seen that the complete periphery of the root canal has been included in the filing operation and is ovoid in shape.

Fig. 3.21 shows the outline of the root canal of a maxillary central incisor sectioned at 9 mms and filed to a No. 8 file.

Again it will be seen that the entire wall of the canal has been instrumented.

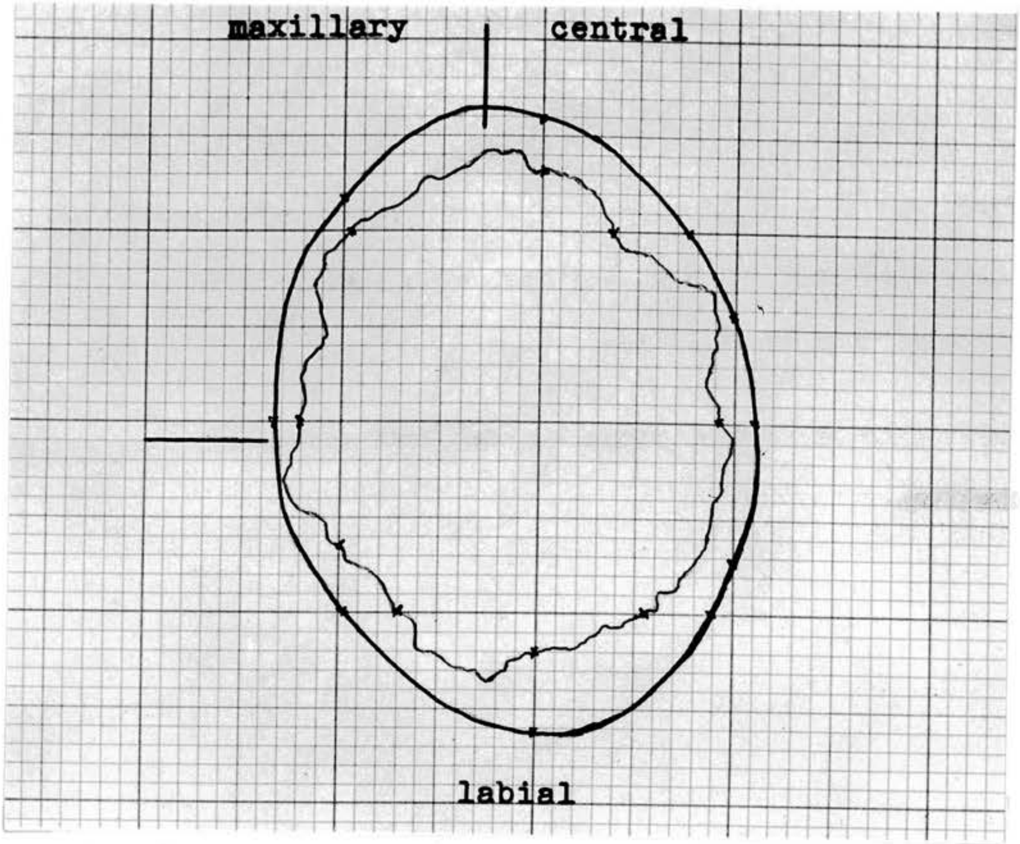


Fig. 3.22

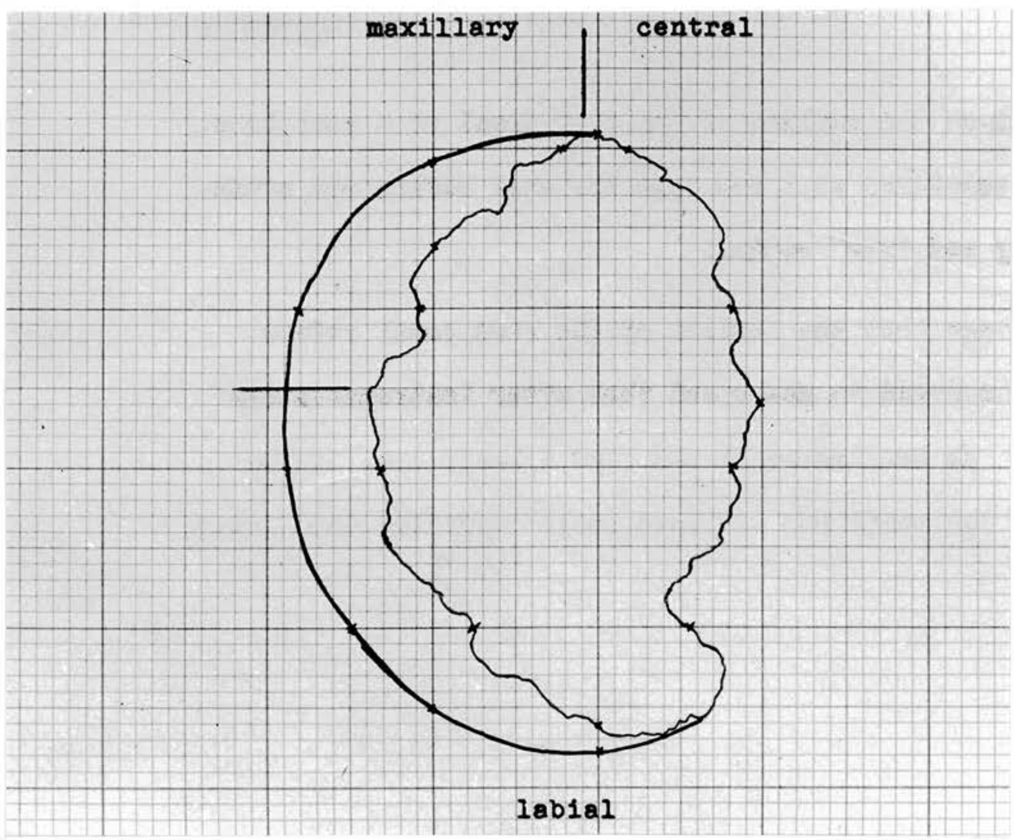


Fig. 3.23

Fig. 3.22 shows the outline of a root canal of a maxillary central incisor sectioned at 8 mms from the apex and filed in the 'up and down' method up to a No. 6 file.

It will be seen that the entire periphery has been included in the instrumentation.

Fig. 3.23 shows the outline of the root canal of a maxillary central incisor sectioned at 8 mms from the apex before and after filing in the 'up and down' method.

It will be seen that the outline of the root canal before instrumentation is ovoid in shape and that after instrumentation it is still ovoid in configuration and that a large area of the dentinal wall of the canal has not been included during the filing operation.

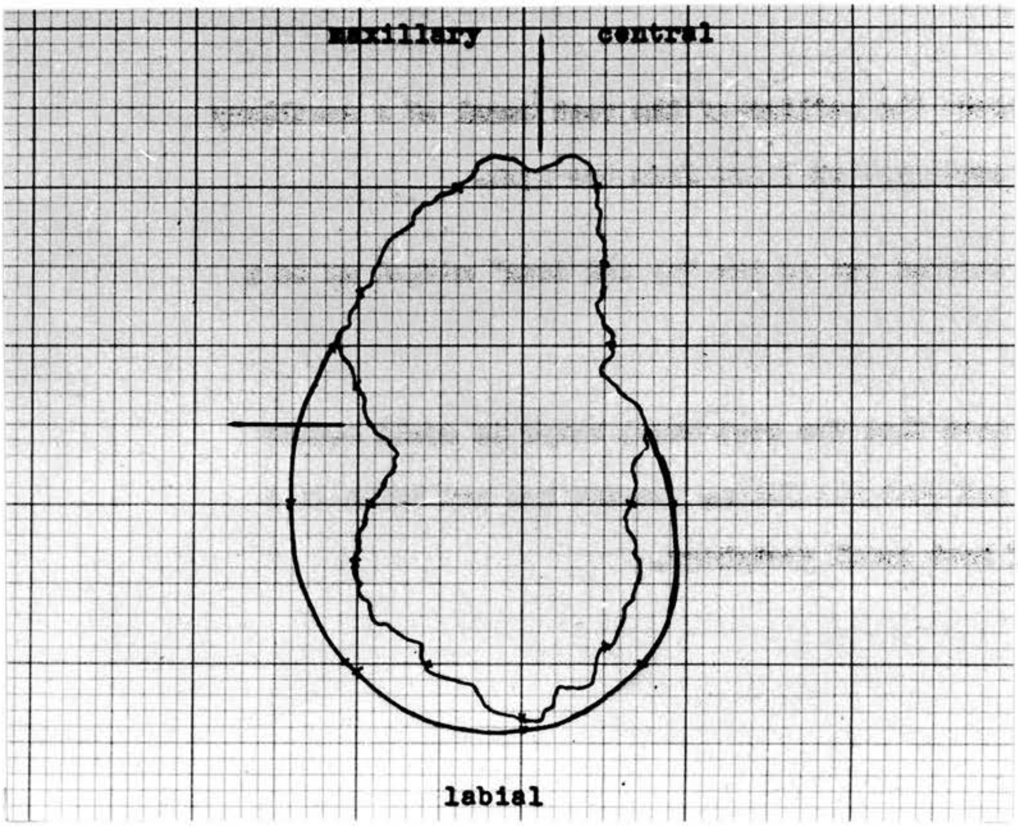


Fig. 3.24

Fig. 3.24 shews the outline of the root canal of a maxillary central inciser sectioned at 7 mms from the apex.

Filing was carried out in the 'up and down' method up to a No. 7 file.

It will be seen that the root canal shape is ovoid before instrumentation and that the filing process has not taken in a large portion of root canal periphery.

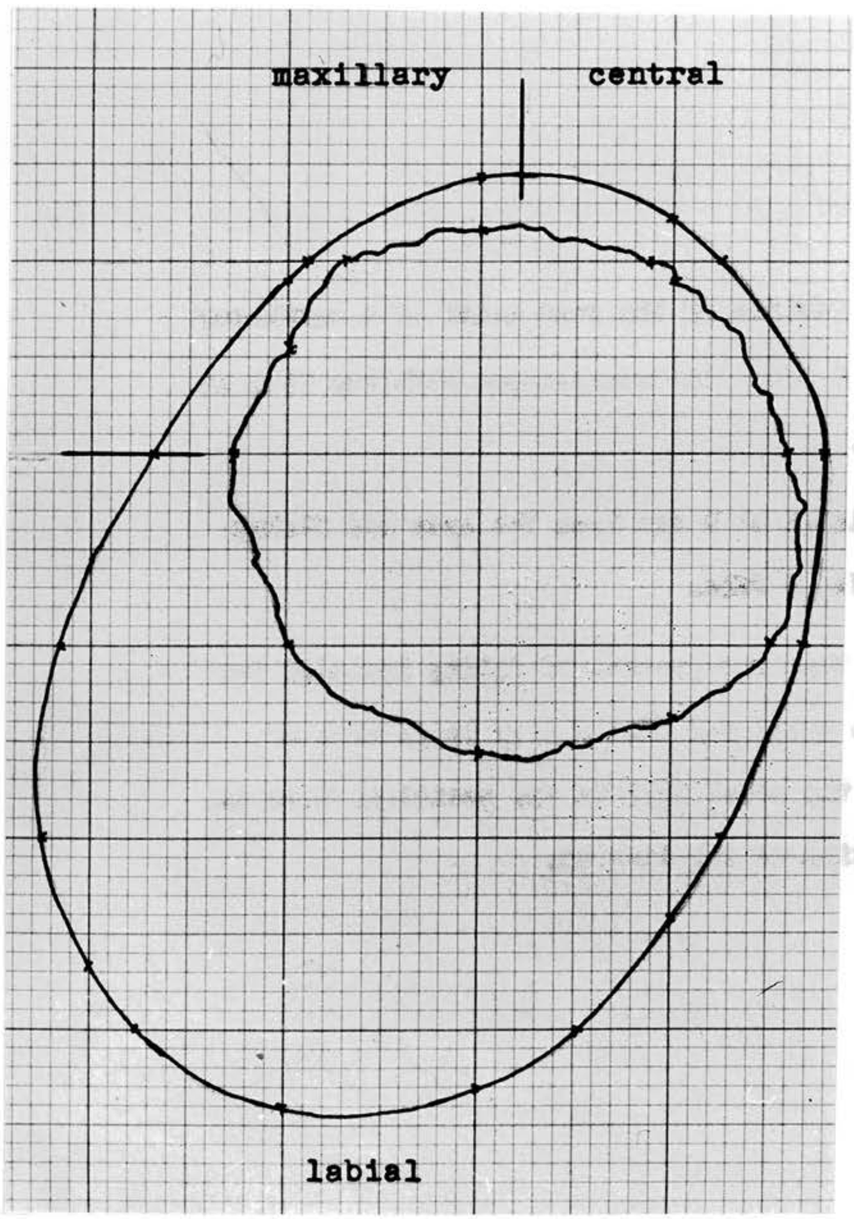


Fig. 3.25

Fig. 3.25 shows the outline of the root canal of a maxillary central incisor before and after instrumentation with the file in the 'up and down' method.

This tooth was sectioned at 6 mms from the apex and filing was carried out up to a No. 9 file.

It will be observed that the process of filing included the complete periphery of the canal and that a very large area of dentine was removed from the canal wall in one position, that is, the bottom left hand portion of the diagram.

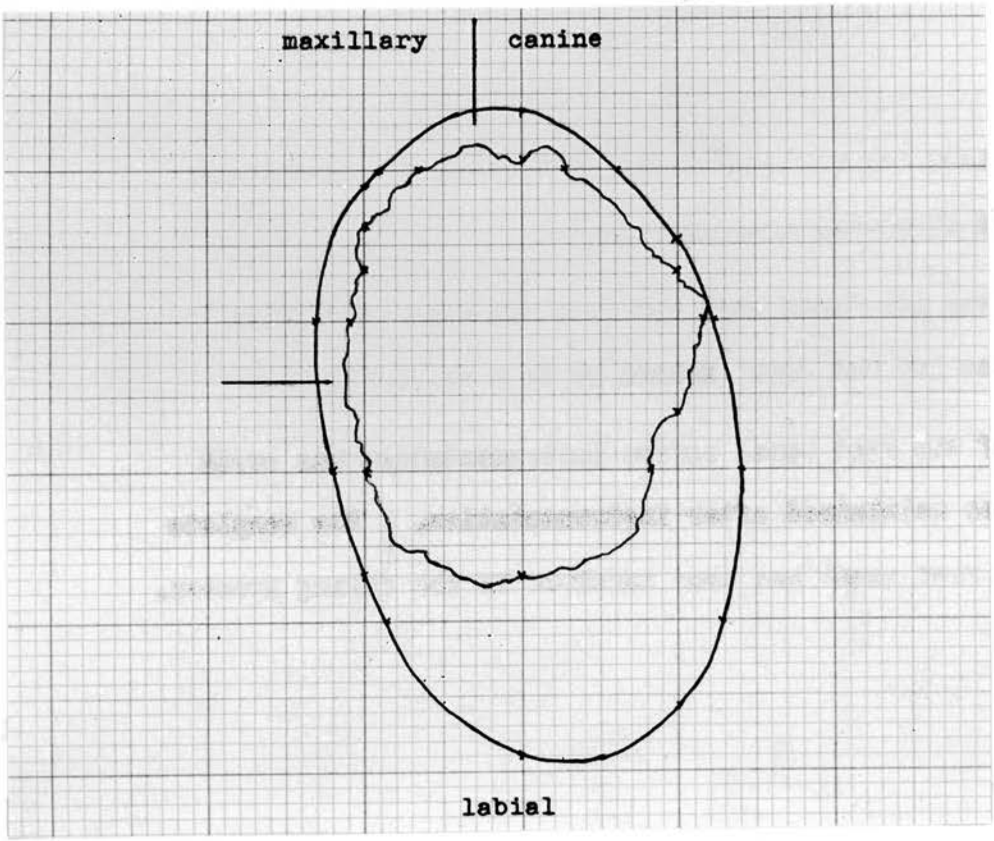


Fig. 3.26

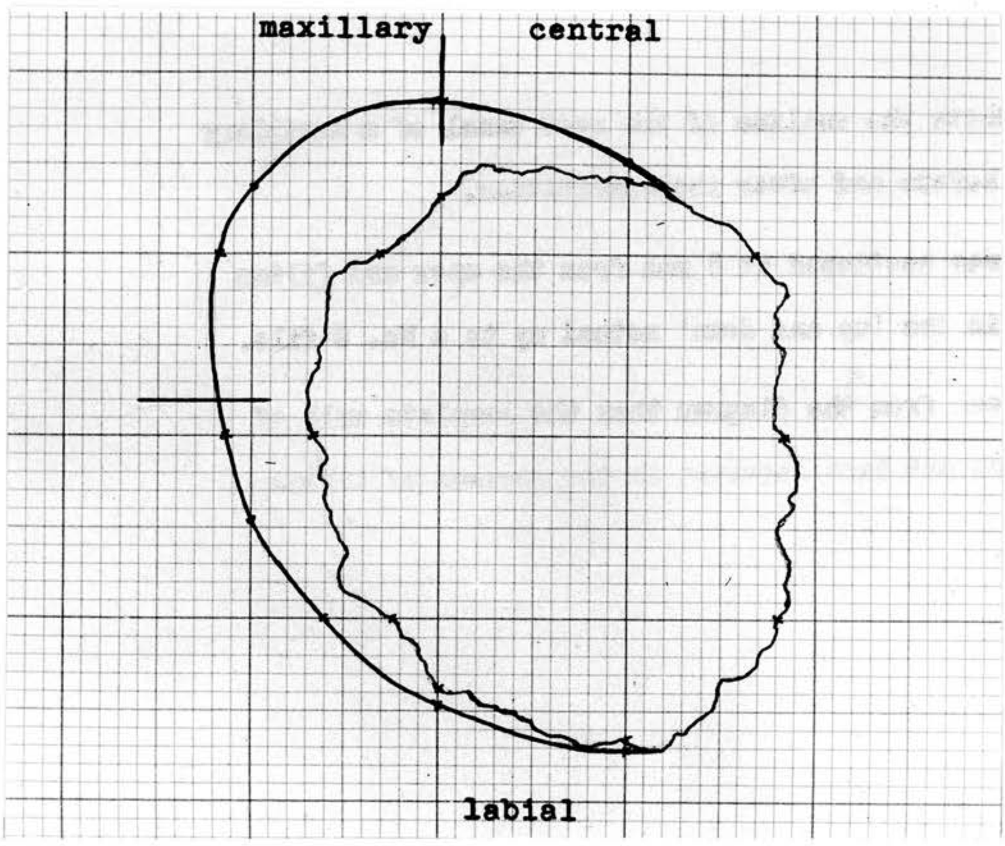


Fig. 3.27

Fig. 3.26 shows the outline of the root canal of a maxillary canine before and after instrumentation.

This tooth was sectioned at 9 mms from the apex and filing was carried in the 'up and down' method up to a No. 6 file.

The shape of the root canal before instrumentation was ovoid and this shape was maintained after instrumentation. The complete periphery of the root canal has been involved in the filing process.

Fig. 3.27 shows the outline of the root canal of a maxillary central incisor before and after instrumentation.

This tooth was sectioned at 8 mms from the apex and filing was carried out in the 'up and down' method up to a No. 6 file.

It can be seen from the diagram that the complete wall of the root canal has not been involved in the process of instrumentation.

F I L I N G

Carried out by the 'entry' method.

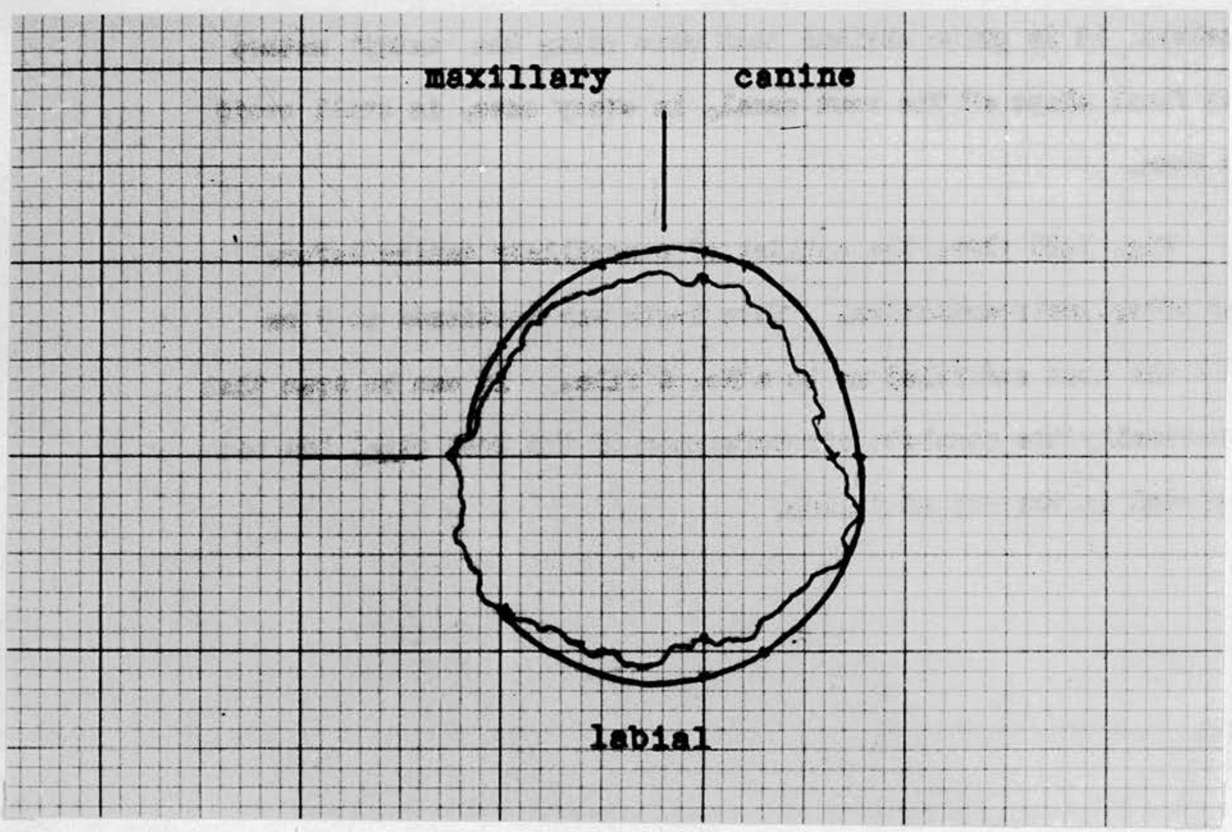


Fig. 3.28

The following 4 diagrams illustrate the results of filing in what has been described as the 'entry' method.

It will be seen that the final shape of the root canal is not as grossly elliptical as in the 'up and down' method, nevertheless, it is quite obvious that when using the 'entry' method the final shape of the root canal, in every case, is still ovoid in form.

Fig. 3.28 shows the outline of a maxillary canine before and after instrumentation. This tooth was sectioned at 9 mm from the apex and filed up to a No. 6 file. It can be seen that practically the complete circumference of the root canal has been included in the act of filing.

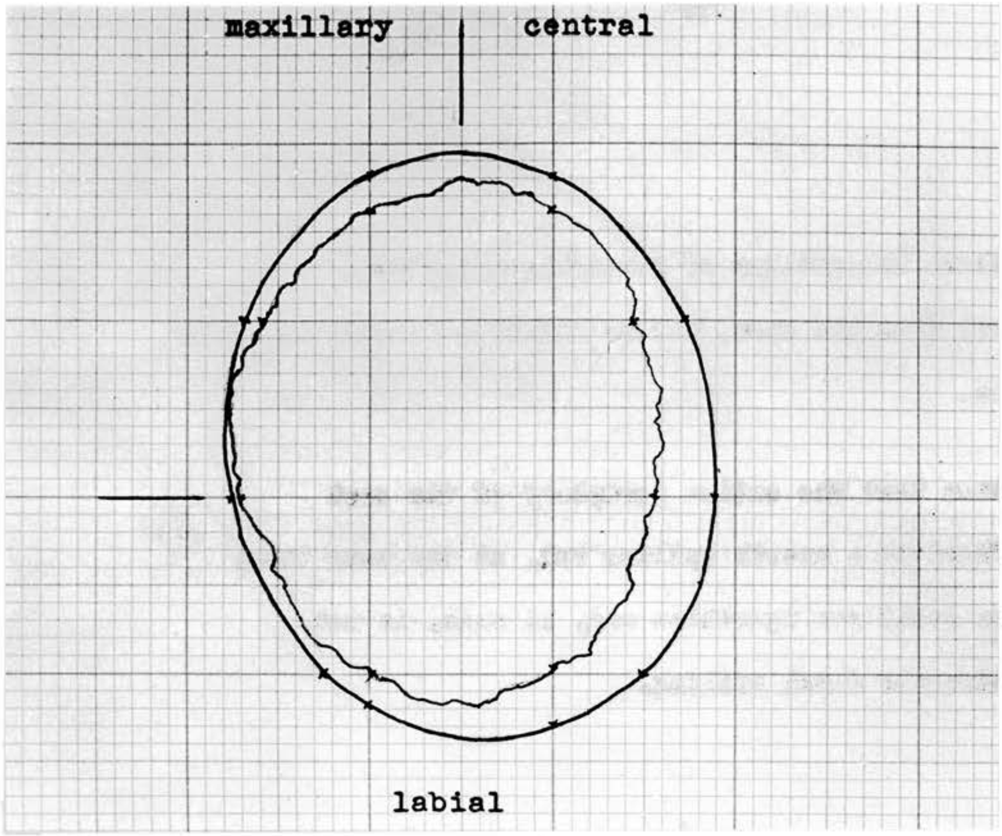


Fig. 3.29

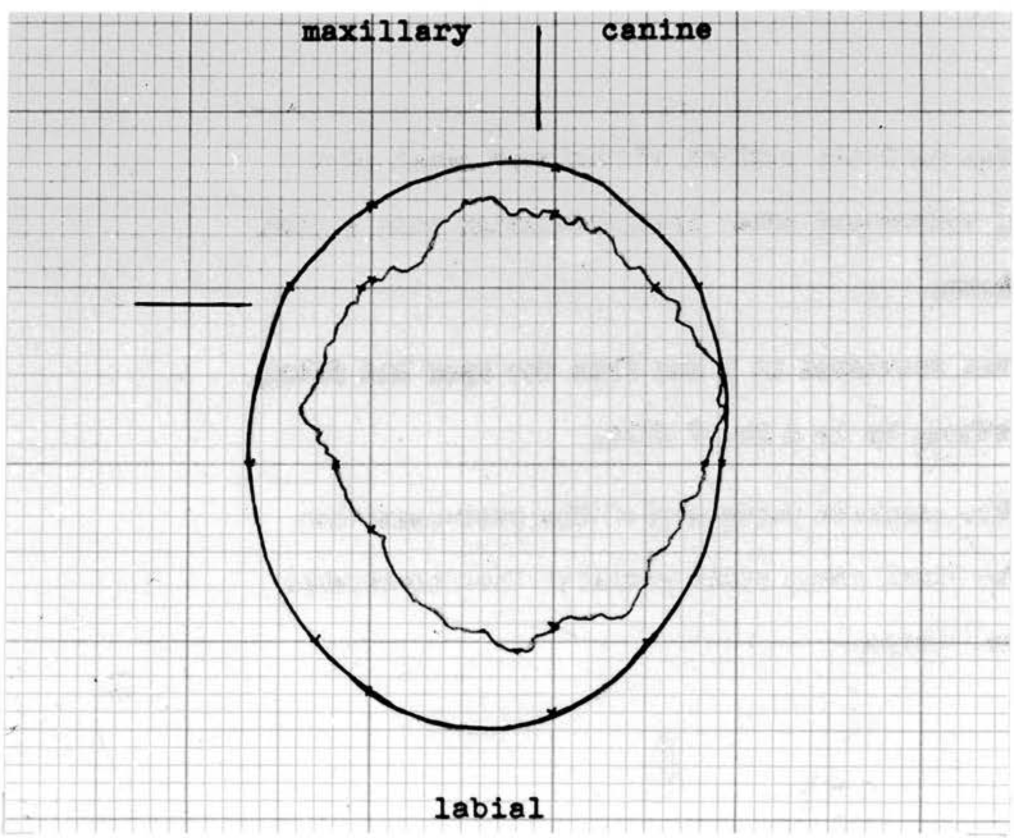


Fig. 3.30

Fig. 3.29 shows the outline of a maxillary central, sectioned at 9 mms from the apex, before and after instrumentation with a No. 8 file.

It can be seen that the entire periphery of the root canal has been filed to a smooth outline but, at the same time, this canal has an ovoid configuration and, as such, is not acceptable for adequate final sealing.

Again, in Fig. 3.30 the outline of the root canal of a maxillary canine, before and after instrumentation with a root canal file, is shown.

This tooth was sectioned at 9 mms from the apex and filed, by the 'entry' method, up to a No. 8 file.

Here again the complete periphery of the root canal has been filed and the final shape still presents the undesirable ovoid or elliptical shape.

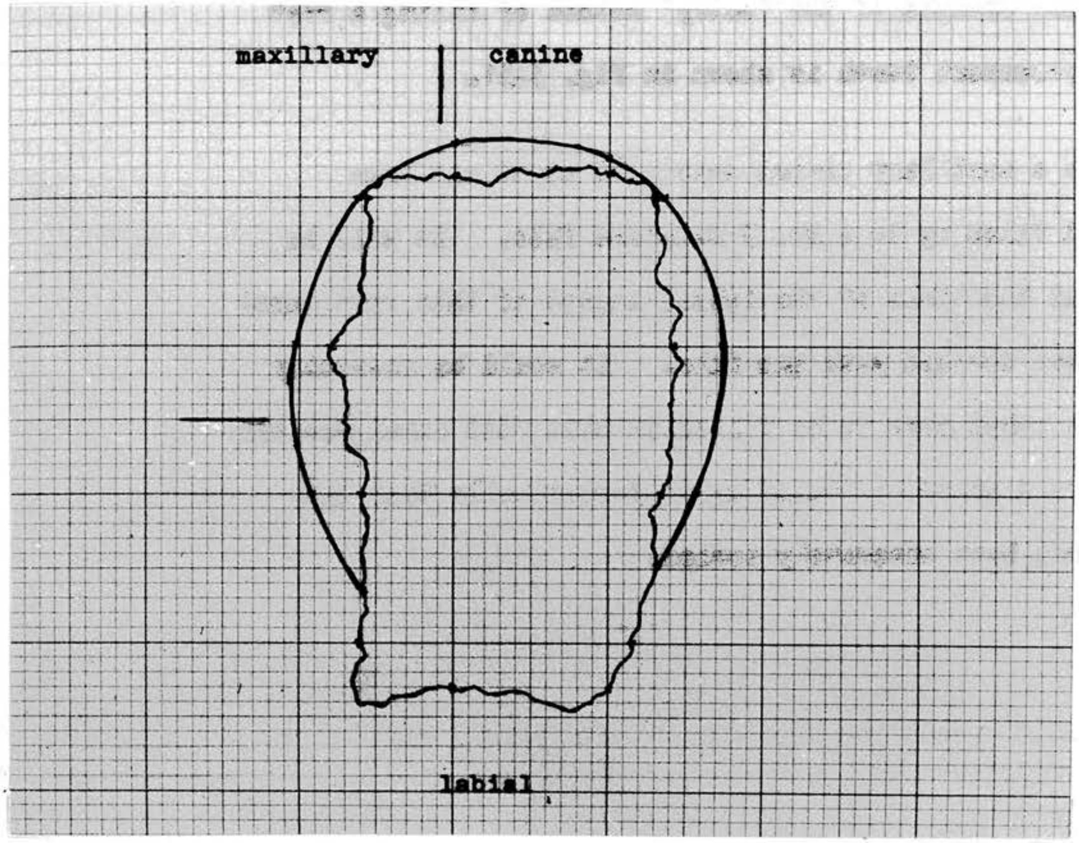


Fig. 3.31

The final example of the 'entry' method of filing a root canal of a permanent tooth is shown in Fig. 3.31.

This is a maxillary canine sectioned at 10 mms from the apex and filed up to a No. 7 Hedstrom file. It will be observed that the whole of the labial aspect of this root canal has never been touched with the file. It would be necessary for this untouched area to be filled in with root canal sealer and so it could never be stated quite dogmatically that this root canal has been adequately sealed.

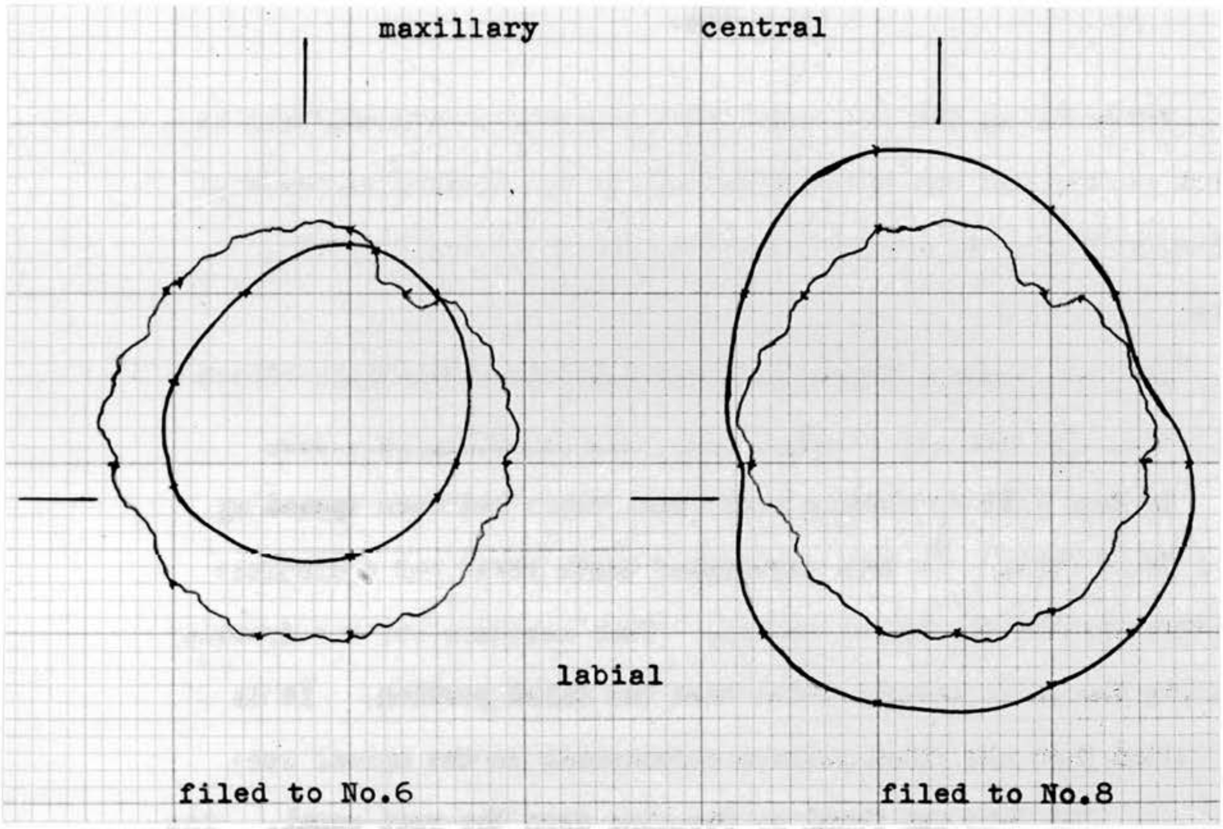


Fig. 3.32

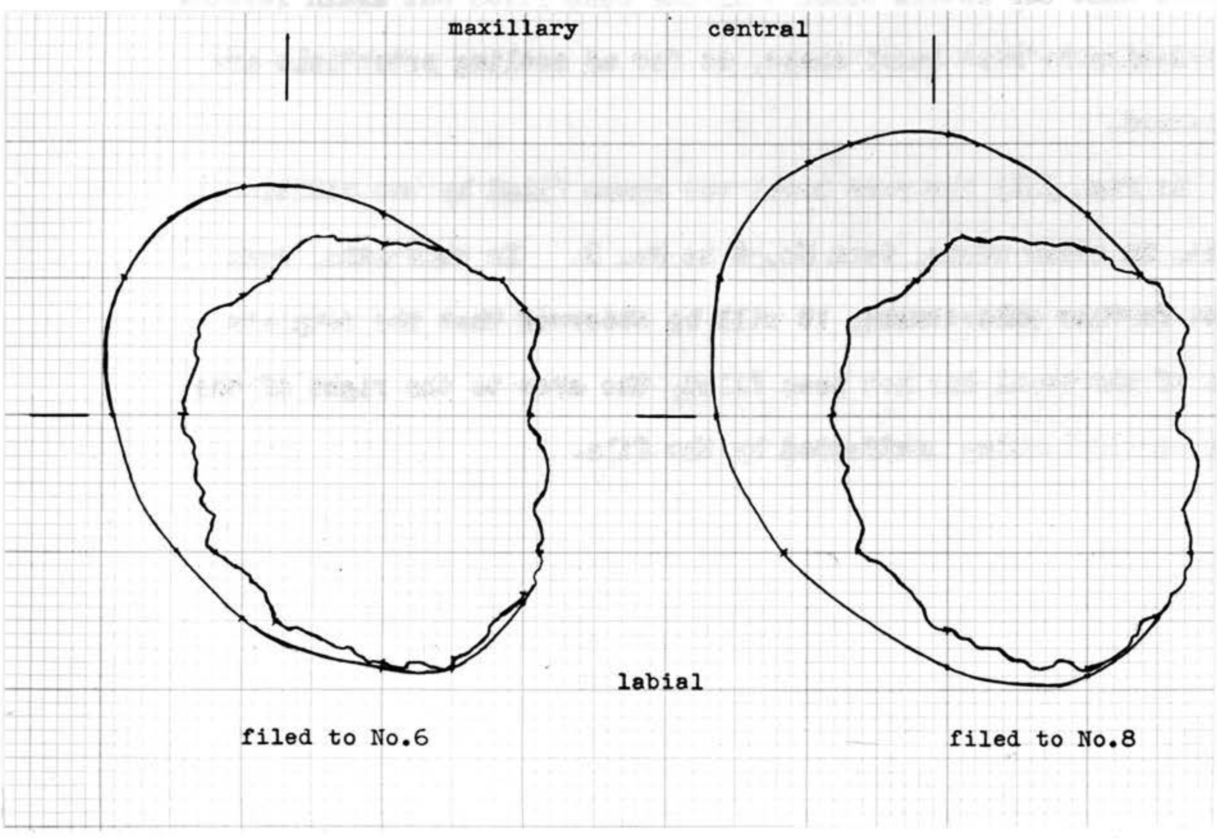


Fig. 3.33

Since filing the root canal of a permanent tooth did tend to leave portions of the wall unaffected, it was decided to see what effect filing to a larger size would have on the walls of the canal (Page 55).

The two diagrams (Figs. 3.32 and 3.33) show the final effect of filing the canal to a larger size than initially recorded.

In Fig. 3.32 is shown a root canal which had been opened up to a No. 6 file. In this particular tooth there was a distinct constriction in the apical region. This accounts for the drawing showing the canal outline wider than the filed portion. It is suggested that the filed portion corresponds to the apical constriction and this was found by focusing down the root canal. The canal was eventually enlarged to a No. 8 Hedstrom file. It will be seen that the entire canal wall has been filed but again leaving an undesirable root canal shape, as far as sealing potentials are concerned.

In Fig. 3.33 the root canal was again filed by two additional sizes, in other words, from No. 6 to No. 8. In this case, even after further enlargement, it will be observed that the complete wall of the canal has not been filed, the area to the right of the diagram still being unaffected by the file.

Discussion of Results.

In this section discussion will be divided into four separate parts :-

1. Reaming canals which had a circular outline before instrumentation.

2. Filing canals which had a circular outline before instrumentation.

3. Filing canals which had an elliptical outline before instrumentation.

4. Reaming canals which had an elliptical outline before instrumentation.

1. **Reaming canals which had a circular outline before instrumentation.**

It will be seen from Fig. 3.5, which shows tracings of actual root canal configurations taken from teeth sectioned in the apical third of the root, that the root canal in the region 1 mm from the apex is round in outline, whereas, in the region 5 mm from the apex it can be seen that the outline is elliptical or ovoid in shape.

Taking the round configuration first of all, it has been demonstrated that when reaming was carried out on a tooth with this shape, the circular outline is maintained (Fig. 3.12). This is in agreement with Pickard (1966) and, it is argued, is apparent since the reamer itself is circular in cross-section and is used with a circular cutting action being 'twirled' between the finger and thumb. Therefore, the cutting of the dentine walls should be circumferential in shape. Obviously, if larger and larger reamers were used in the preparation of the root canal then the complete walls would eventually be instrumented however irregular or large the root canal was initially, always providing the root was straight along its long axis.

Observations on certain teeth (Fig. 3.16) showed that where the outline was roughly round to begin with, nevertheless there still remained a portion of the wall of the canal which had not been subjected to the cutting action of the instrument. At first this was difficult to understand since the area of the canal wall that had been cut by the instrument was quite extensive in quantity or depth, while the area uncut seemed small by comparison. Was there a difference in dentine hardness that could account for this phenomenon,

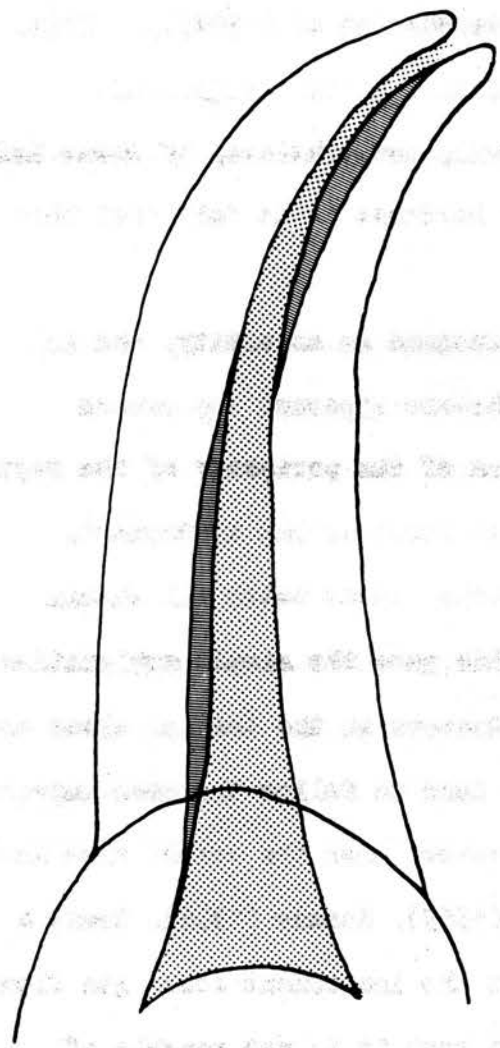


Fig. 3.34

that is, differing areas of hardness in the dentine of the canal outline? No visible difference in dentine appearance was apparent when viewed by naked eye or when viewed under the microscope, that is, the dentine did not appear to be hypercalcified (Hampson & Atkinson (1964) and Nalbandian et al (1960)). This, of course, is not proof that the dentine in this region was similar to the rest of the canal wall, nevertheless, if there had been a local difference in dentine hardness it is felt that this would have shown up visually.

When the complete tooth was examined as an entity, and in particular its long axis, it then became apparent why excess cutting occurred in one local region of the periphery of the root canal and why there remained an area uncut by the instrument. Where this irregular cutting did occur, these teeth all showed slight curvature of the root and this gave the simple explanation why irregular cutting occurred. Reamers in the smaller sizes are flexible and, as such, will always tend to follow the root curvature and so cut circumferentially. However, when the reamer size increases it has been shown by Luks (1959), Sommer (1966), Craig & Peyton (1962) and Shoji (1965) that the instrument loses its flexibility and becomes more rigid. As such it is not capable of following the root canal curvature and so cuts in a straight line. In Fig. 3.34 it can be demonstrated that the area cut by a rigid instrument in a curved canal is as indicated by the lined area. It is argued that this is, in fact, what has happened in Fig. 3.16 and why the whole root canal periphery has not been subjected to uniform

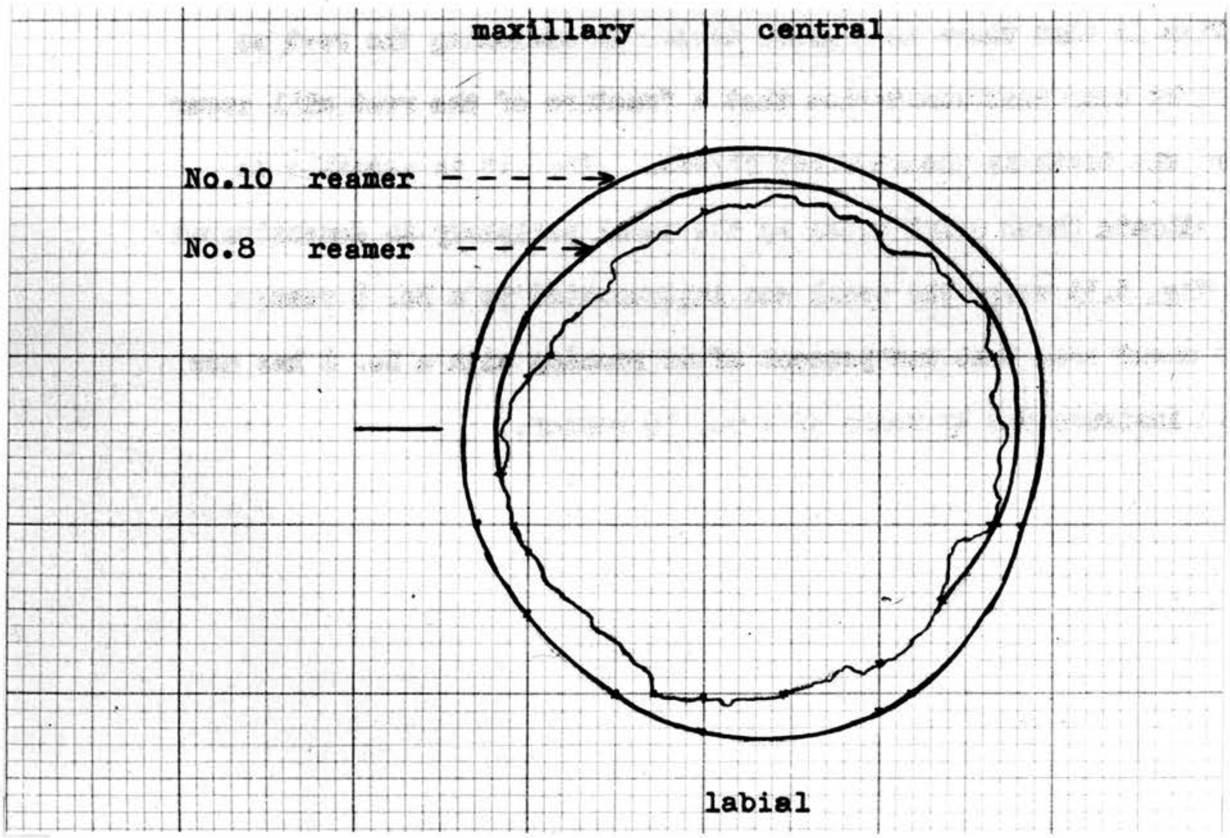


Fig. 3.35

cutting by the reamer. The greater the curvature of the root of the tooth together with large sized reamers, the more certain it is that uneven circumferential cutting will occur. It will be appreciated that where the curvature of the root is slight, it is still possible to cut around the canal periphery by using larger and larger instruments. The disadvantage in this course of action is that there is a grave danger in weakening the root so much by over instrumentation that a fracture of the root will occur when the tooth is placed under stress. That it is possible to eradicate these uncut areas in the canal periphery is demonstrated in Fig. 3.35 where the canal was instrumented to a No. 8 reamer. The uncut area that was present after reaming with a No. 8 has now been instrumented by means of a No. 10 reamer.

2. Filing canals which had a circular outline before instrumentation.

In Fig. 3.18 the root canal outline is again roughly circular in shape. This tooth was subjected to the cutting action of the Hedstrom file. As was pointed out on page 55, it did not appear to make any fundamental difference to the end result whatever the manner these instruments were used, the basic difference being one of quantity of dentine removed from the root canal walls. It will be seen from the drawing that, after instrumentation with a file, the final configuration of the canal outline is not circular but rather ovoid or elliptical in shape. This was not at all unexpected since these instruments work on the principle of a rat tail file. In engineering practice it is very difficult, if not impossible, to open out a circular hole in a sheet of metal to a larger diameter and, at the same time, maintain the hole in perfect circular form. Hence, for this reason, it was felt that it would be impossible to prepare a completely round canal with a Hedstrom file.

It can be postulated that these instruments should file a root canal with a circular cross-section whenever it was circular to begin with, since the cutting action of the file is in a downward direction and since the file must be entered into the canal to enable it to be withdrawn with its downward cutting stroke. Against this, however, it is argued that the file will tend to follow the walls of the canal on its downward stroke and since the root canals are rarely circular in cross-section in the middle and coronal thirds, it is thought that the file will tend to follow this elliptical shape and so produce an ovoid form to the apical portion of the root canal.

3. **Filing canals which had an elliptical outline before instrumentation.**

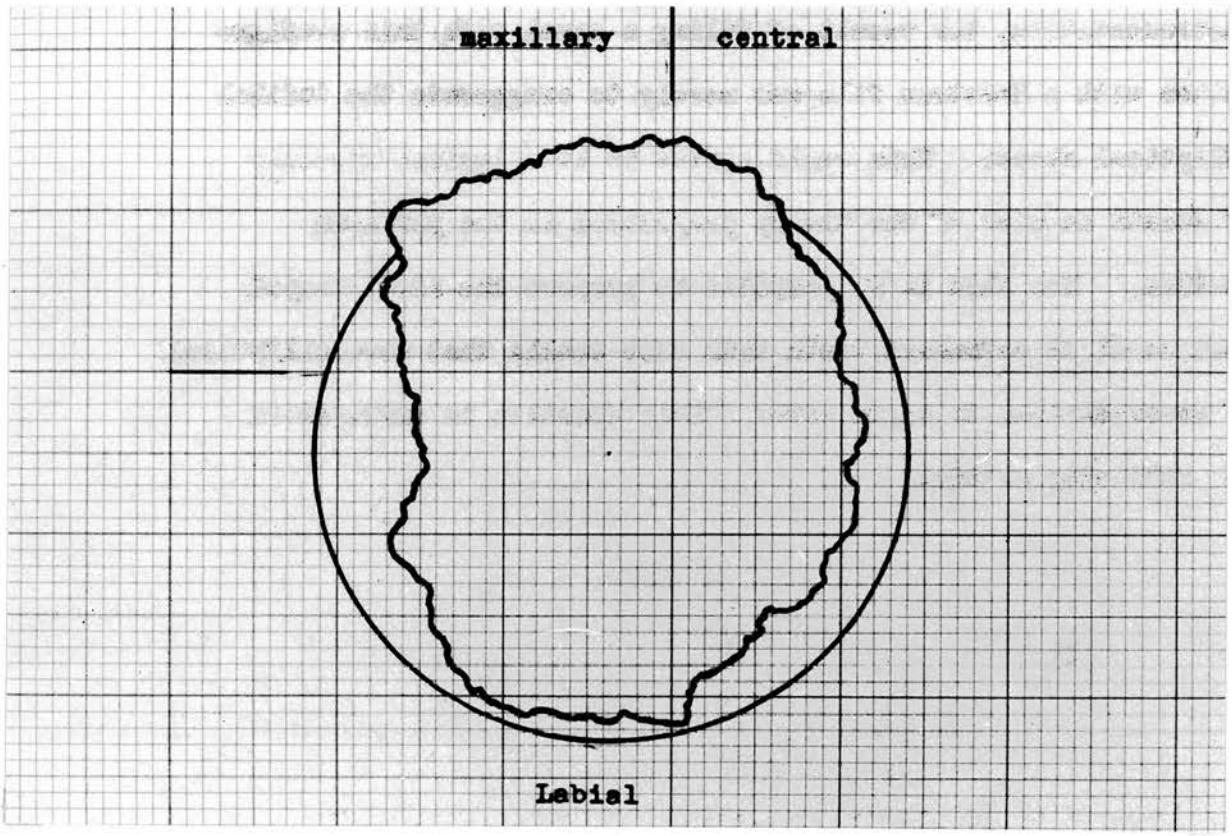


Fig. 3.36

The effect of filing a root canal which has a circular outline has been demonstrated. It was decided to see what effect was obtained by filing a root canal which was elliptical to begin with.

From Fig. 3.26 it can be demonstrated that when the root canal was ovoid in cross-section in the apical region before instrumentation, the result of filing a canal with this configuration with a Hedstrom file was merely to exaggerate the initial elliptical shape. This would appear to be a logical sequence of events in view of the theory propounded in the previous section. How then is it possible to prepare the ideal shaped root canal in permanent teeth with root canals that were elliptical in cross-section to begin with? This question is answered in the following section.

4. **Reaming canals which had an elliptical outline before instrumentation.**

The effect of reaming a root canal with a circular outline has already been demonstrated. Is it possible to obtain the desired circular configuration by means of a reamer whenever the root canal initially was elliptical? This section demonstrates this particular operation.

In Fig. 3.36 it will be seen that the ideal shaped canal has been obtained by using the root canal reamer. This instrument has almost completely smoothed out the original canal eccentricities and by so doing has provided a root canal that is circular in cross-section. It is apparent, therefore, that since it is impossible to obtain the ideal circular shape with the Hedstrom file, only root canal reamers should be used in the preparation of the apical portion of the root canal. Hedstrom files, it is argued, should only be used to smooth off rough edges on the root canal periphery at the junction of the root canal and the pulp chamber. When filing is carried out by the 'up and down' method there is a further disadvantage, to those already discussed, which does not appear obvious at first sight.

It has been shown by Möller (1966) and Strindberg (1956) that pumping within the canal of a tooth by the instrument used in bacteriologic sampling of canal contents gave considerably improved results as far as positive samples were concerned. This would lead one to suspect that the pumping action stirred up the canal contents to such an extent that it was easier to obtain a sample of the organisms within the canal on the paper point used. If this is so then it would mean that it is also easier for these organisms

Instrument and Filling Chart

(after Sommer)

Tooth	Instrument	Inclusive Instrument Numbers	Name of Canal	Filling material
Maxillary central incisor	long handle file	1 - 6	central	No.6 silver point alone or + gutta percha
Maxillary lateral incisor	long handle file	1 - 5 or 6	central	No.6 silver point alone or + gutta percha
Maxillary canine	long handle file	1 - 6	central	No.6 silver point alone or + gutta percha

Fig. 3.37

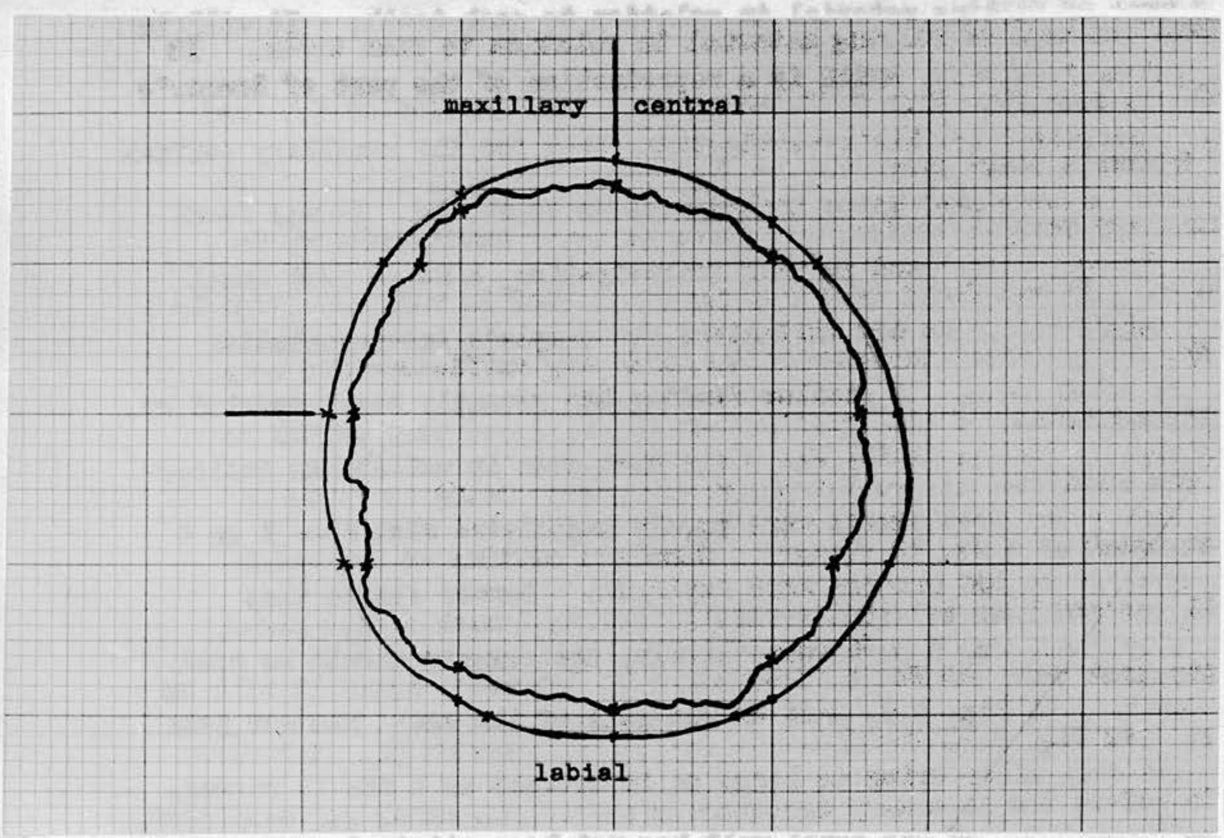


Fig. 3.38

to be expelled through the apical foramen into the periapical space during instrumentation by the 'up and down' method, something which, if possible, should be avoided at all costs.

One other interesting observation has been made during the course of this investigation. Sommer (1966) provides an 'Instrumentation and Filling' chart which sets out instrument sizes and type of filling material in relation to each tooth. It will be seen from Fig. 3.37, which is a reproduction of the part of Sommer's chart pertinent to this investigation, that for the maxillary central incisor he advocates using instruments up to No. 6. It was found that for the tooth used in this investigation, a No. 6 root canal instrument was in no way sufficient for complete instrumentation of the canal wall. A similar finding has recently been reported by Gutierrez & Gracia (1968) who state that even in mandibular incisor and canine the root canals were poorly negotiated when Nos. 1 to 6 and Nos. 25 to 100 reamers were employed. Sommer states that No. 4 or 5 and No. 5 or 6 respectively, instruments should be used on teeth. In Fig. 3.9. part of the wall of the canal has not been touched even after using as large an instrument as a No. 12 reamer. Complete cutting of the canal wall has not been attained even after using a much larger sized instrument than the No. 6 recommended by Sommer. Again it will be seen from Fig. 3.38 that reaming was carried out to No.12 reamer size before the necessary instrumentation of the canal was completed.

In the following two figures incomplete canal wall instrumentation is demonstrated. Fig. 3.39 is a photomicrograph (X14) of an apical third portion of the root of a permanent central incisor tooth before instrumentation 'in vitro'. It can be

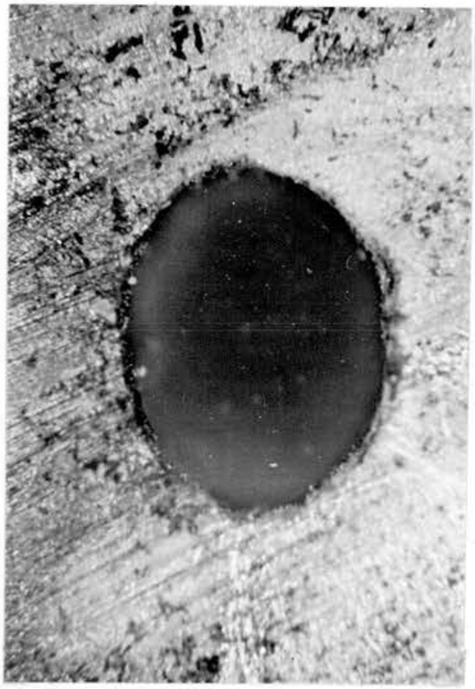


Fig. 3.39

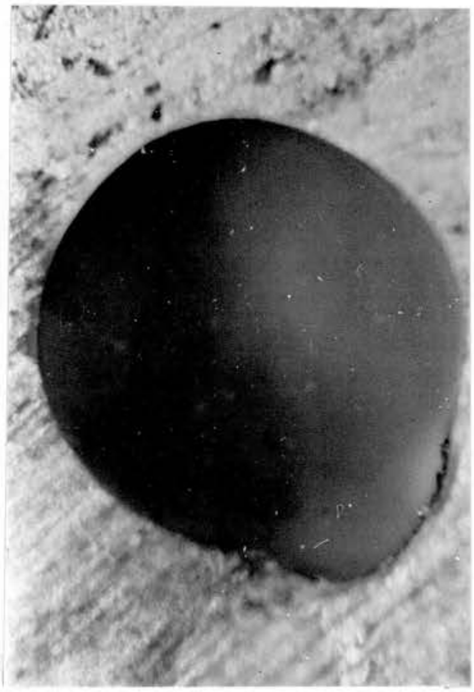


Fig. 3.40

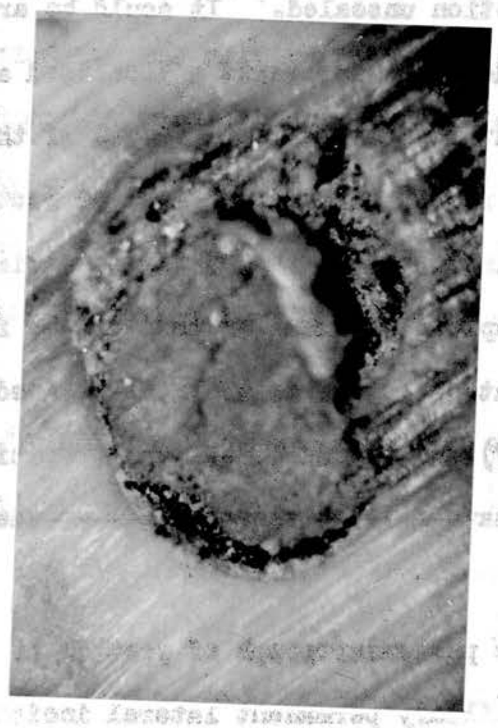


Fig. 3.41

observed that in the region at the bottom of the photograph on the periphery of the root canal there is a projection into the dentine wall. In Fig. 3.40 it can again be observed that this projection has not been instrumented even after reaming with a No. 10 reamer. There is no doubt that this projection would have been greater in extent if reaming had only been carried to Sommer's recommendations (No.6). Had this particular operation been carried out 'in-vivo' then this area would, of necessity, have had to be filled with root canal sealer, since the final point is circular in shape and, as a result, would leave this projection unsealed. It could be argued that this projection into the dentine represents a localised area but it could also be argued that it runs the full length of the canal wall and, as such, would result in a larger area of root canal sealer than necessary being in contact with the periapical tissue. Obliteration of the apical foramen, or part of the foramen, by means of root sealer, of whatever type, is to be deprecated as it has been shown by Rowe (1967) and Parris (1964) that practically all root canal sealers in use have a deleterious effect on the periapical tissues.

Finally, in Fig. 3.41 is a photomicrograph of portion of the apical end of the root of a maxillary permanent lateral incisor which was removed during an apicectomy. This tooth had been reamed to a No. 9 reamer (Sommer - No. 5) and root filled with a gutta percha point and root canal sealer prior to apicectomy. It can be seen that the point used for obliteration of the central space does not, in fact, fill the root canal entirely, root canal sealer being visible in certain areas of the root cross-section, particularly at the top right and left of the periphery of the canal.

This is an excellent clinical example of the 'in vitro' findings shown on page 49 where the reamer used (No. 9) has not included the complete periphery of the root canal wall in its cutting action, leaving a space between the canal wall and the point to be filled with root canal sealer. Had it been possible to increase the final instrument size in this clinical case then, no doubt, the complete canal wall would have been instrumented (Fig. 3.35). At the bottom of the photomicrograph (Fig. 3.41) there is a space due to what appears to be lack of root canal sealer or what may be taken as an air bubble introduced into the sealer whenever it was being placed in the root canal - a hazard which is ever present. That these air bubbles do occur in root filled canals will be demonstrated later in this thesis (Chapter 6).

SUMMARY OF RESULTS

It has been demonstrated in the preceding section that when root canals were prepared with the root canal reamer it made little or no difference to the final shape of the prepared canal what the configuration of the canal was initially. When the canal was round to begin with the reamer maintained the original shape and whenever the canal was elliptical reaming produced the ideal round cross-section which is so important to success in the final stage of obliteration of the central space.

When filing a root canal with the Hedstrom file it has been shown that this instrument always produces an elliptical configuration whatever the initial shape of the canal. When the canal was round to begin with the file tended to make the prepared shape oval in cross-section and when it was elliptical to begin with the final configuration was even more elliptical in cross-section. This particular configuration is to be avoided at all costs if good sealing is to be attained with the final root filling point. This is particularly important when silver points are used as the final filling since these points are rigid and cannot take up small irregularities in canal shape as can be accomplished to some extent by gutta percha. That this is possible with gutta percha is due to the physical properties of the material itself. It has a certain degree of elasticity and can be compressed to some extent and would therefore tend to take up some ovality in form. Nevertheless, this particular property should never be exploited or relied upon; it would be preferable to prepare the root canal in a circular fashion and so avoid excess root canal sealer taking up the empty space at the extremes of the oval shape.

In conclusion then, it can be stated that in the stage of mechanical preparation of root canals the root canal reamer should always be used in preference to the Hedstrom file because of its ability to produce the correct circular configuration. This shape will result in a good fitting point, with a minimum of root canal sealer being used to cement the final point in position. It is pointed out that Gutierez & Garcia (1968) found, as a result of their study, that there was no noticeable difference in the canal walls whenever the root canal reamer was used alone or when it was used in conjunction with a file. While they examined the surface of the canal walls, they did not report on the configuration of the root canal diameter - a facet which the author feels is of the utmost importance in the attainment of perfect sealing of the central space. The Hedstrom file, it is thought, should be used only as a smoothing instrument, not for preparation of the canal. It is most useful whenever irregularities require smoothing, especially at the junction of the root canal and the pulp chamber since a step is often formed at this site due to the action of the bur whenever opening for access is carried out.

CHAPTER 4

The effect produced by Mechanical Instrumentation within the Root Canal on the Periapical Tissues of a Permanent Tooth

Introduction

It has been shown that instrumentation within the root canal of a permanent tooth with root canal reamers produces the desired round tapering root canal so essential in obtaining the requisite hermetic seal in the apical third of the canal.

So far nothing has been said about any possible effect that this reaming is liable to produce on the periapical tissues, due to expulsion of material from the root canal through the apical foramen, if this occurs. If expulsion of material does occur, then the tissue reaction produced will depend on the state of the root canal at the time the reaming process was carried out (Blaney 1927, Burkett (1942) and Crabb (1965)). If the root canal contents are infected the result will be grave indeed, for an acute exacerbation will undoubtedly occur. If, on the other hand, the root canal has been 'sterilised' the trauma inflicted on the periapical tissues by material expelled through the apex will be greatly reduced (Howe, (1919), Grove (1916), Crane (1911), Pearson & Goldman (1964) and Winkler & Amerongen (1959)).

It is generally implied in the literature that material is expelled through the apical foramen during mechanical instrumentation within the root canal. Black (1917) states that there is a danger of pushing fluid from the root canal beyond the apex during instrumentation and Brady (1920) says that every precaution should be used to prevent the forcing of infection through the apex and involving the periapical tissue. Grayston (1909) and Kürer (1966) maintain that it is difficult to avoid some particles from the root canal contents being forced through the many foramina in the apex of a tooth and Moffitt (1913) states that there is a danger of carrying infection from the pulp into the apical area. Sommer (1966), Ingle (1965) and Curson (1966) all state that there is a great danger of forcing material from the root canal during mechanical instrumentation within the root canal, while Grossman (1950) and McGehee (1951) merely limit themselves to the statement that every endeavour should be made to avoid forcing material through the apical foramen into the periapical tissues. Kennedy et al (1967) state that a pumping action with the instruments could send infected material up through the root apices.

It is evident from this selection of the many references available that the statement regarding the avoidance of expelling material from the root canal during mechanical instrumentation has virtually become one of the principles of endodontic therapy. While it is agreed that it is the aim of every endodontist to avoid this situation, it is also true to say that this statement has, in effect, become an intuitive assumption since it has not been found possible to turn to anything in the literature that would show that this concept has been substantiated by experimental proof.

In this section of the thesis it is proposed to investigate this statement experimentally to see whether or not it is true and, at the same time, to observe if there is a quantitative relationship with the type of instrument employed in the preparation of the root canal. It has been shown that the instrument of choice for mechanical preparation of the root canal is a reamer and this is manufactured with a fluted cutting edge in the shape of a spiral

(Fig. 4.1). Since it is a spiral, and since it is revolved between the finger and thumb to enable it to cut into dentine, it would appear logical to assume that dentine debris will fill up the flutes of the instrument and once these are filled, then some debris will undoubtedly be pushed towards the apex. This will either block the apical constriction or will result in some debris being expelled through the apex. On the other hand, when the Hedstrom file, with its much closer spirals, is used as the cutting instrument it would seem that these instruments are much more liable to push debris towards the apex of the tooth. It is pointed out that in both methods of employing the Hedstrom file in this investigation (Page 43) the instrument is inserted into the root canal as far as possible before any cutting action is commenced, therefore, before long the root canal will contain a certain amount of dentine debris, and since the instrument is pushed through this to reach its desired position, it is logical to assume that some debris will be carried in front of the instrument and so either block the foramen or be expelled through the apex into the periapical space. It would appear that the question of relative traumatic effect of Hedstrom Files v Reamers must be investigated.

With these thoughts in mind the aim of this section of the thesis was :-

(i) to devise a model assembly for 'in-vitro' studies;

(ii) to assess whether or not material from the root canal did in fact pass through the apical foramen of a permanent incisor tooth during mechanical preparation

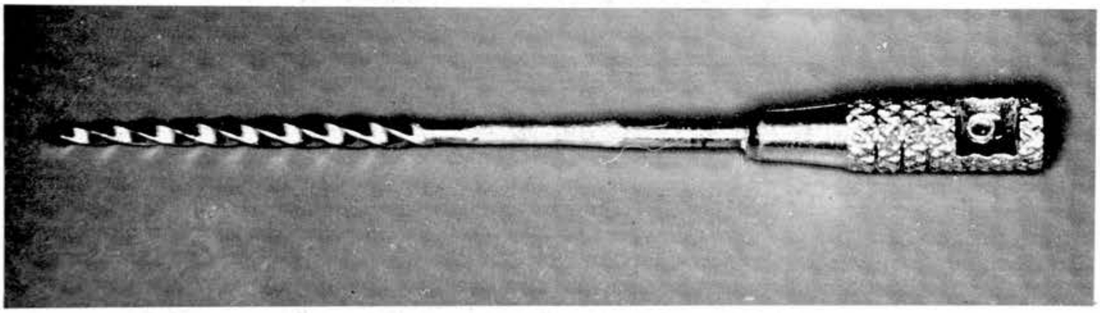


Fig. 4.1

of the root canal; and

(iii) to determine whether there is a quantitative relationship with the type of instrument employed in the preparation of the root canal.

Materials

It was essential that teeth were chosen whose root canals were easily instrumented. The root canal must be capable of presenting a direct line of access to instrumentation and they should be root canals of a reasonable diameter where instruments of a fairly robust character could be used. Consequently, extracted permanent maxillary incisors and canines were chosen for this investigation.

In attempting to trace whether or not material from the root canal was expelled beyond the apex during instrumentation, it was essential that some form of indicator be used. It was thought that two types of indicator were available :-

(i) a chemical indicator:

(ii) an indicator organism.

It was considered that the chemical method of indicating passage beyond the apex of the tooth would require rather precise chemical analysis, far beyond the knowledge and scope of the investigator. For this reason it was thought that an organism would present less problems and, in the final analysis, would be likely to lead to more accurate results in the hands of the investigator.

It would be possible and reasonable to use, as the indicator, those organisms that are commonly found in the root canals of infected teeth, namely streptococcus or coliform bacillus (Marshall & Savois (1967)). For reasons of pathogenicity or suitability for viable counts, these organisms were ruled out. The organism eventually chosen was Serratia marcescens. This is a small pleomorphic organism which is easily grown on simple media; it is virtually non-pathogenic; it is non-sporing and is readily destroyed. It is not commonly found in large numbers as a contaminant of the materials that were to be examined and its colonies have a distinctive pigmentation which distinguishes it from the common flora of the mouth or contaminants of extracted teeth. It did not produce chains or clumps under the conditions of the present investigation. It is therefore a suitable organism for use as an indicator and since it was shown by a pilot experiment that its colonies were readily counted by the method devised by Miles and Misra (1938), it was eventually chosen as the indicator organism.

Further materials required during this investigation were well dried nutrient agar plates, bijou bottles containing nutrient broth and an inoculum of S. marcescens.

It has already been stated that S. marcescens was found to be a suitable organism for this investigation by carrying out a pilot experiment. This pilot study was carried out as follows :-

Pilot experiment:

An overnight culture of S. marcescens held at 37°C in Oxoid nutrient broth was serially diluted in tenfold dilutions of from 10^{-1} to 10^{-7} in 5 ml amounts of nutrient broth. Miles and Misra viable counts were performed with all dilutions by dropping 7 drops per dilution on to well dried nutrient agar plates. Counts were carried out immediately after dilutions were made (10 a.m.) and again after dilutions had stood at room temperature for 5 hours (20°C).

Fig. 4.2 shows a table of viable counts for S. marcescens and

Log dilutions	Counts immediately after dilutions were made	Counts 5 hours after dilutions were made
-1	uncountable	uncountable
-2	uncountable	uncountable
-3	uncountable	uncountable
-4	uncountable	uncountable
-5	220	600
-6	1, 1, 1, 2, 3 5, 6 = 19	9, 15, 16, 13, 13, 15, 15 = 96
-7	3	3

Fig. 4.2

it will be seen from the results obtained with the $\log^{-6}$ dilution that it is possible to use S. marcescens as a good indicator organism for the experiment envisaged in that counts will be reasonably reproducible. From the increase in numbers of organisms over the 5 hour period it is also stressed that delay in counting should be avoided. From this pilot study it was possible to make the following prediction regarding the investigation proper.

Prediction:

Using an inoculum containing 2×10^8 organisms per ml as the indicator, it was surmised that the volume of inoculum introduced into the root canal on the instruments would be approximately 0.02 ml. That this supposition was reasonably correct is shown by the table in Fig. 4.3 where the amount of inoculum carried on the instruments was calculated. From the total number (2×10^8) of organisms per ml, 0.02 ml would contain 4×10^6 organisms. While it is not known whether or not material from the root canal is expelled through the apex of the tooth during instrumentation within the canal, if we suppose that material is in fact expelled and that if only one thousandth part of this volume (0.02 ml) is expelled, this would be equivalent to 4×10^3 organisms. This number of organisms will then be displaced into the bijou bottle which contains about 4 ml of culture medium, therefore, 1 ml of this medium will contain 1×10^3 organisms. This is explained as follows.

The inoculum of S. marcescens used as the indicator in this investigation contained 2×10^8 organisms per ml. Assessment of

Instrument numbers	Volume carried to root canal on reamers ml	Volume carried to root canal on files ml
1 - 6	0.00392	0.00484
1 - 8	0.00860	0.00870
1 - 9	0.01126	0.01174
1 - 10	0.01580	0.01580
1 - 12	0.02706	0.02520

Fig. 4.3

the number of organisms carried to the root canal on the different instruments can be calculated by the following method :-

the accumulated dose of inoculum carried to the root canal on instruments Nos. 1 to 6 inclusive is 0.004 ml (Page97).

0.004 ml will contain 0.004 (2×10^8) organisms = 800,000 organisms.

For the remaining instruments the number of organisms carried to the root canal is set out in the table below :-

Volume of inoculum carried to canal on instruments numbered	Calculated number of organisms
1 to 6	800,000
1 to 8	1,800,000
1 to 9	2,200,000
1 to 10	3,200,000
1 to 12	5,400,000

It will be seen that the number of organisms carried to the root canal during mechanical instrumentation with the various instruments can be approximated to :-

Nos. 1 to 6 = 1,000,000 organisms

Nos. 1 to 8 = 2,000,000 organisms (there being such a small
Nos. 1 to 9 difference in volume between the accumulated dose on 8 instruments and 9 instruments)

Nos. 1 to 10 = 3,000,000 organisms

Nos. 1 to 12 = 5,500,000 organisms.

If it is supposed that 1/1,000 part of the volume of inoculum carried to the root canal on the instruments is expelled through the apical foramen of the tooth during mechanical instrumentation, then this would be equivalent to :-

Nos. 1 to 6 $= 1/1,000(1 \times 10^6) = 1,000$ organisms

Nos. 1 to 8
Nos. 1 to 9 $= 1/1,000(2 \times 10^6) = 2,000$ organisms

Nos. 1 to 10 $= 1/1,000(3 \times 10^6) = 3,000$ organisms

Nos. 1 to 12 $= 1/1,000(5.5 \times 10^6) = 5,500$ organisms.

It is assumed therefore that this number of organisms would be expelled through the apical foramen, during in-vitro studies, into the bijou bottle which contains approximately 4 ml of culture medium. It follows that one pipette drop of the culture medium, which is used in Miles and Misra's method of quantitation, will contain :-

5 organisms for instruments Nos. 1 to 6

10 organisms for instruments Nos. 1 to 8 and 9

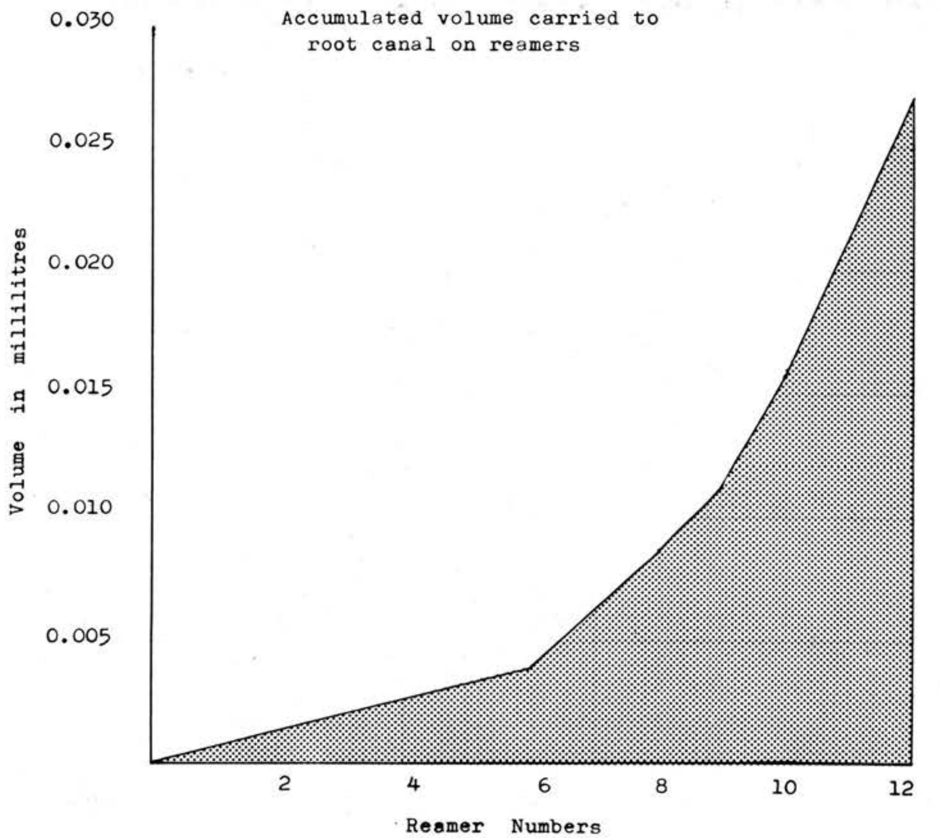
15 organisms for instruments Nos. 1 to 10

27 organisms for instruments Nos. 1 to 12.

This number of organisms, contained in each pipette drop, should be quite adequate to assess very small quantities of expelled material for the root canal into the bijou bottle and should provide a very good assessment of whether or not material is expelled through the apex of a permanent tooth during mechanical instrumentation within the root canal and, at the same time, it should be possible to gain some assessment of quantity of material expelled.

It is interesting to note that the estimation of volume of inoculum carried to the root canal on the instruments, which was subsequently verified by accurate weighing experiments (Fig. 4.3) bears a very close relationship to the volume of the pulp cavity of maxillary central incisors as estimated by Stewart (1948) and by Churchill (1932).

In the investigation carried out by these two workers it was found that the volume of a maxillary permanent central incisor central space was 0.0163 ml. In the present investigation the volume of inoculum carried to the tooth was found to be 0.0158 ml when reamed to a No. 10 reamer. This is shown graphically in Fig. 4.4.



Accumulated volume carried to root canal on reamers
0.030
0.025
0.020
0.015
0.010
0.005
Volume in millilitres
2
4
6
8
10
12
Reamer Numbers

Fig. 4.4

Method

Method of investigation:

Sterile extracted permanent maxillary incisors and canines were individually fixed in the metal cap of a bijou bottle with the apical region of the root bathed in a culture medium so that, when an instrument that had been infected with a known organism (S. marcescens) was used in the preparation of the root canal, we could show beyond all reasonable doubt whether or not the infecting organism passed beyond the apical foramen of the tooth into the culture medium in the bijou bottle.

Sterilisation of the Extracted Teeth.

It was first of all essential that the tooth was sterile so that contaminants would not mask the results of the investigation. Sterility was obtained by placing extracted maxillary incisors and canines into 10% formalin immediately after extraction, where they were kept for about 7 days. Thereafter they were transferred to a stock solution of 50% glycerine and 50% hydrogen peroxide (10 vols.) and stored in this solution until required. That this solution did render the tooth sterile was proved by prior experiments in which 2 teeth were instrumented in a typical aseptic situation, reaming each tooth up to a No. 9 reamer size. In each case the medium in the bijou remained sterile after incubation. After overnight incubation smears were made from the medium and aerobic and anaerobic subcultures were made on horse blood agar plates. These were incubated for 48 hours. Subcultures were repeated and the results confirmed that no contamination resulted from this aseptic mechanical preparation of the root canal, the media remaining absolutely sterile.

It can therefore be assumed that either there was no expulsion of material through the apex of the tooth or that the stock solution had rendered the experimental tooth sterile. Also no contamination had occurred during the act of mechanically preparing the root canal of these teeth.

Since it was assumed that material is expelled through the apex during instrumentation, it was considered that the stock solution, which had been proved to have sterilising properties, would tend to lead to false negative results unless all traces of it were removed from the tooth. Using the indicator organism, prior experiments confirmed that the glycerine/peroxide solution was bacteriostatic to this organism down to dilutions of 1 in 640 but not in a dilution of 1 in 1280. These experiments were carried out by preparing tenfold dilutions of 0.5 ml volumes of the stock solution in 4.5 ml volumes of Oxoid nutrient broth. 0.02 ml samples of a 10^{-3} dilution of a stationary phase nutrient broth culture of S. marcescens diluted in nutrient broth 4% in saline were then inoculated into these tenfold dilutions of the stock solution. Dilutions ranged from 1 in 100 down to 1 in 1,000.

A further extension of this experiment showed that the glycerine/peroxide solution was bacteriostatic for the test strain of S. marcescens in dilutions up to 1 in 640 but not bacteriostatic when diluted to 1 in 1280. From these experiments it has been demonstrated that, to avoid false results, it will be necessary to dilute any residue of the stock solution of glycerine/peroxide associated with a test tooth to at least 1 in 1280 before the experiment.

Therefore in the experiment proper, all that was required was for the tooth to be removed from the stock solution, drained as free as possible from this solution and then placed in about 6 ml of sterile distilled water and left in the sterile water for at least 24 hours in order that the stock solution is diluted well beyond 1 in 1,000.

Preparation of the Model Assembly:

It was essential that the tooth should be rigidly held during instrumentation to avoid leakage around the tooth and possible contamination of the medium in the bijou bottle. To ensure rigidity of an object with a tapering external surface, it is first of all essential that the tapering surface be rendered parallel sided (Fig. 4.5). Parallel sides to the root of the tooth were obtained by means of a modified diamond shoulder cutting instrument produced by one of the dental manufacturing companies (Fig. 4.6). The tooth with part of the root surface prepared with parallel sides was then inserted into a collet (Fig. 4.7) which was turned in very thin section brass having an internal diameter which corresponded to the internal diameter of the shoulder cutting instrument (Fig. 4.8b). The vertical portion of the brass collet was sawn through diametrically so that when the tooth was inserted into the collet a brass clamp (Fig. 4.8c) could be placed over the collet and tightened by means of small set screws, to hold the tooth rigidly in position.

The metal cap of a bijou bottle was drilled to take the brass collet accurately (Fig. 4.8d) and the rubber disc of the bijou was similarly pierced so that the tooth apex would protrude into

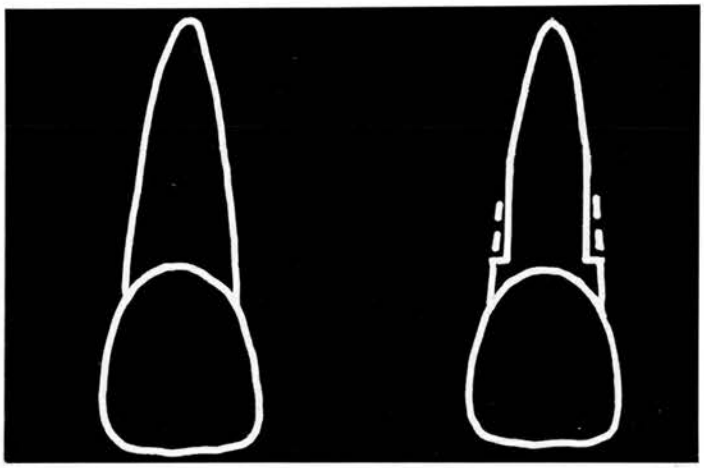


Fig. 4.5

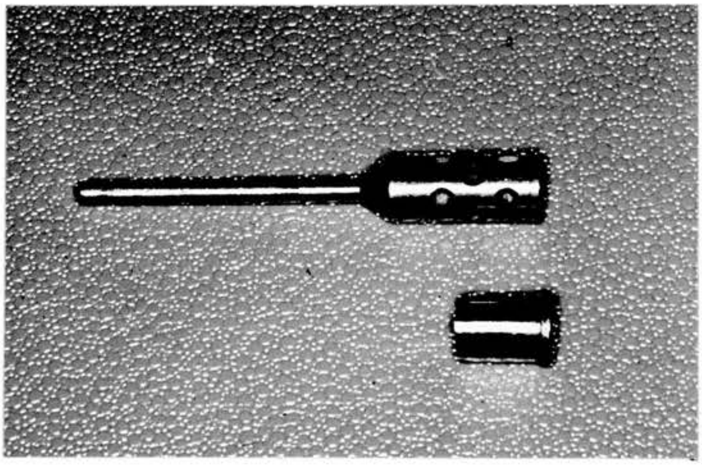


Fig. 4.6

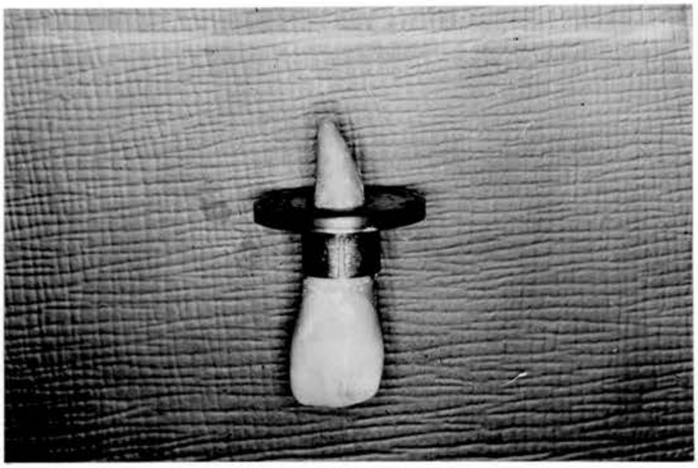


Fig. 4.7

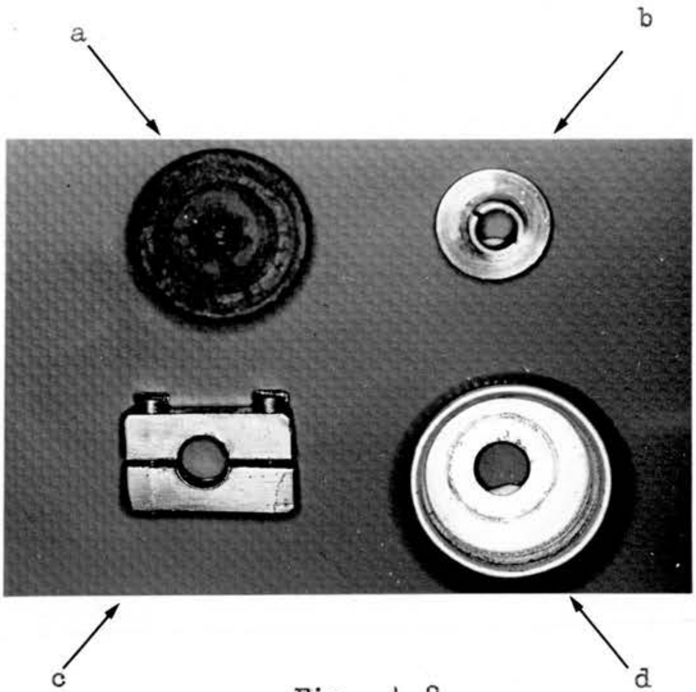


Fig. 4.8

the medium in the bijou, thus ensuring that the apex was constantly bathed in the culture medium during preparation of the root canal with instruments (Fig. 4.8a).

In use, the brass collet was placed in the modified bijou cap and the clamp, with the screws slackened off, placed over the external surface of the collet (Fig. 4.9). The prepared tooth was then inserted into the brass collet and the clamp tightened up to hold the tooth rigidly in position. The rubber disc was replaced in position inside the cap of the bijou, by means of sterile tweezers, pushing it as far up the root as possible. The complete assembly was then returned to the bijou and screwed into position. It is pointed out that the entire assembly, without the tooth, was packaged and pre-sterilised before use.

Preparation of the Tooth:

A tooth was removed from the stock solution, drained and dried. The root portion was prepared with parallel sides by means of the modified diamond shoulder instrument (Fig. 4.10) which was inserted into the 3 jaw chuck of a metal turner's lathe. Modification was carried out by cutting off the head of this instrument so that a hollow tube with a diamond cutting end resulted. This modification enabled the root portion to be prepared with much longer parallel sides than would have been possible if the unmodified instrument had been used in the dental handpiece. The root portion was thus prepared as far as the amelo-cemental junction so that as much root surface as possible would lie within the bijou itself (Fig. 4.11). Following preparation of the external root surface, the root canal

Fig. 4.9

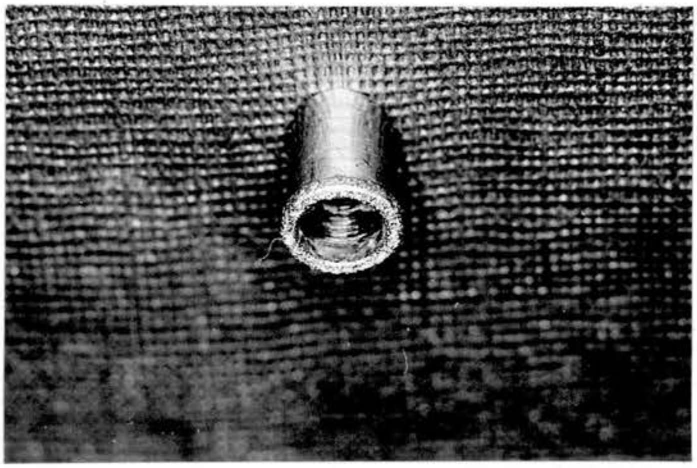


Fig. 4.10

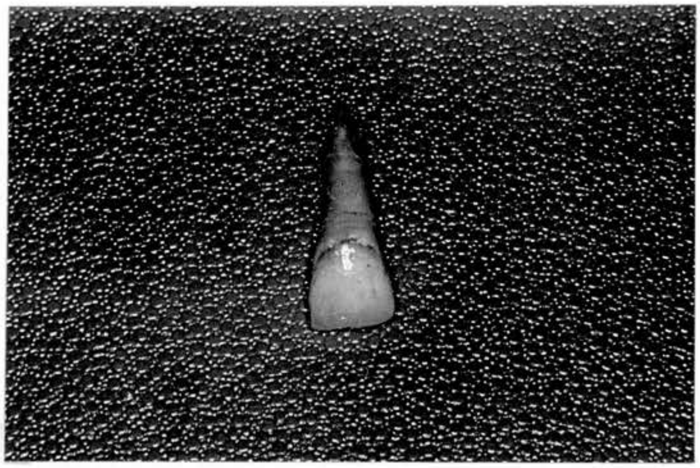


Fig. 4.11

was opened up in the conventional manner by cutting a triangular opening, for access to the root canal, in the lingual fossa. The tooth length was recorded and the pulp remnants carefully removed by means of a barbed broach with a marker placed at tooth length minus 1 mm. At no time during the entire investigation was the apical foramen passed by an instrument except that finally a No. 1 reamer was passed up the root canal until its tip was just visible at the external root apex when viewed with a watchmaker's lens. This was done to ensure that the apical foramen was patent otherwise a false negative result might have occurred because of a blocked apical foramen. It was considered that this procedure would in no way appreciably widen the apical constriction because the mean diameter of a sample group of 8 No. 1 reamers measured at 1 mm from the tip was found to be 0.195 mm (see Fig. 2.6, Chapter 2), whereas the mean diameter of what appeared to be the apical constriction of the group of 50 teeth used in the present investigation was found to be 0.251 mm. In 10 of these teeth the diameter of the apical constriction was found to be less than 0.195 mm and these had a mean diameter of 0.169 mm. Measurement of what appeared to be the apical constriction was obtained by mounting the tooth in such a position under the microscope objective that the root canal was as near vertical as possible and the microscope focused down the canal until the smallest diameter was obtained. By means of a 'Filar Head' on the eyepiece it was possible to read off the smallest diameter obtained. This is not proof that this reading was the smallest diameter of the root canal but it was the best that could be obtained. Therefore it appeared that using the No. 1 reamer in this way would cause little risk of opening up the apical constriction to any great extent but it did ensure that the foramen was patent thus reducing the risk of false results due to blockage of the apical constriction.

Also, to avoid false results, instrumentation was never carried to the apical end of the tooth in case a false result might be obtained by the infected instrument passing directly into the culture medium in the bijou. This is, of course, in keeping with clinical practice where instrumentation and permanent filling of the canal is carried only to the dentino-cemental junction (0.5 - 1.00 mm from the apical end of the tooth).

Having prepared the tooth it was returned to the stock solution for a further period of 24 hours so that contamination, which had occurred by handling, might be removed and, at the same time, to ensure that the pulp cavity was also sterilised. After 24 hours the tooth was removed from the stock solution, drained and placed in about 6 ml of sterile water for a further 24 hours to dilute the stock solution to such an extent that it was no longer bacteriostatic to the indicator organism.

<u>Method of using the Model Assembly:</u>

The tooth was removed from the sterile water and dried with sterile wipes and placed in the sterile assembly and the clamp tightened up. The rubber disc was placed in the bijou cap and pushed as far up the root as possible with sterile tweezers so that the maximum amount of root lay within the bijou bottle. The unmodified cap was removed from the bijou and the modified cap with the model assembly screwed into position.

The investigation was carried out under strict aseptic conditions. The root canal was dried with sterile paper points and instrumentation carried out, in every case to within 1 mm of the tooth length. To make certain that this length was consistently and accurately defined, a small disc of polyurethane was placed on the shaft of the instrument at tooth length less 1 mm and instrumentation carried out until the marker disc was level with the incisal edge of the tooth. All instrumentation was completed with the bijou inverted so that the root end was in intimate contact with the culture medium throughout the experiment.

In the experiment proper, each instrument that was used was dipped, on two occasions during instrumentation, in a suspension of the indicator organism containing 2×10^{8} organisms per ml. The reason for two inoculations of each instrument was that it was generally found that instrumentation to the predetermined length could be obtained with two applications of each instrument size. The instrument was dipped in the inoculum and used in the root canal to within a few mms of the true length. It was then withdrawn and wiped on a sterile cotton wool roll, the wiped instrument being again dipped in the inoculum and the canal instrumented to the true length of the tooth less 1 mm. This procedure was repeated until the final chosen size was reached. Therefore, when a root canal was reamed to a final size of No. 10, this root canal received a total of 20 inoculations with the indicator organism.

From the table (Fig. 4.3) it will be seen that the amount of inoculum received by each tooth during instrumentation varied in quantity depending on the final size of the instrument used. These quantities were found by weighing 'infected' instruments on the microbalance and the accumulated quantity ascertained (Figs. 4.12 and 4.13). Since the specific gravity of the inoculum of S. marcescens was found to be 0.997, any error between weight and volume would be quite insignificant. The mean volume carried to the root canal is recorded in Fig. 4.14. The volume carried to the canal is double that carried on the instruments since each instrument was dipped in the inoculum on two occasions during instrumentation (Fig. 4.4).

Instrumentation was carried out with both reamers and Hedstrom files, 40 teeth being reamed and 10 teeth filed. The actual final instrument size being recorded in Figs. 4.15 and 4.16.

Following instrumentation, the screw cap with the model assembly was removed and an unmodified cap replaced on the bijou bottle which was promptly sent for bacteriological examination. This examination was carried out as follows :- the contents of the bijou were thoroughly mixed and a viable count immediately performed on a small sample (6 drops, each of 0.025 ml on a well dried nutrient agar plate). The remainder was incubated overnight and the counts were repeated the following morning. With these procedures it was possible to assess the degree of contamination of the contents of the bijou which resulted from transfer of the organisms from the root canal through the apical foramen.

Instruments	Weight of Inoculum in Grammes carried on Instruments				
	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
Reamer No. 1	0.00011	0.00044	0.00013	0.00009	0.00005
No. 2	0.00016	0.00014	0.00006	0.00014	0.00013
No. 3	0.00012	0.00023	0.00028	0.00024	0.00015
No. 4	0.00036	0.00047	0.00022	0.00031	0.00029
No. 5	0.00031	0.00056	0.00056	0.00036	0.00051
No. 6	0.00055	0.00084	0.00074	0.00059	0.00067
No. 7	0.00138	0.00114	0.00091	0.00088	0.00096
No. 8	0.00136	0.00160	0.00121	0.00114	0.00110
No. 9	0.00124	0.00126	0.00141	0.00149	0.00122
No.10	0.00260	0.00218	0.00220	0.00203	0.00234
No.11	0.00241	0.00246	0.00249	0.00269	0.00206
No.12	0.00315	0.00272	0.00315	0.00359	0.00347
Total	0.01375	0.01404	0.01336	0.01355	0.01295

Fig. 4.12

Instruments	Weight of Inoculum in Grammes carried on Instruments				
	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
File No. 1	0.00004	0.00007	0.00015	0.00006	0.00011
No. 2	0.00028	0.00025	0.00037	0.00025	0.00018
No. 3	0.00036	0.00029	0.00018	0.00014	0.00009
No. 4	0.00047	0.00029	0.00066	0.00080	0.00079
No. 5	0.00051	0.00079	0.00065	0.00052	0.00039
No. 6	0.00104	0.00059	0.00054	0.00062	0.00060
No. 7	0.00073	0.00128	0.00105	0.00068	0.00089
No. 8	0.00118	0.00100	0.00106	0.00088	0.00093
No. 9	0.00159	0.00143	0.00146	0.00147	0.00163
No. 10	0.00186	0.00256	0.00176	0.00208	0.00180
No. 11	0.00289	0.00242	0.00249	0.00212	0.00242
No. 12	0.00228	0.00303	0.00270	0.00269	0.00265
Total	0.01323	0.01410	0.01307	0.01231	0.01248

Fig. 4.13

Instrument numbers	Volume carried on reamers ml	Volume carried on files ml
1 - 6	0.00196	0.00242
1 - 8	0.00430	0.00435
1 - 9	0.00563	0.00587
1 - 10	0.00790	0.00790
1 - 12	0.01353	0.01304

Fig. 4.14

Assessment of the results was made as follows:-

(i) heavy contamination of the bijou contents resulted in a confluent growth of organisms from immediate samples;

(ii) moderate contamination yielded countable numbers of colonies from immediate samples and the degree of contamination was indicated by the number of organisms that gave rise to individual colonies ("viable counts");

(iii) very slight contamination produced no growth from immediate samples, but growth of the test organism after overnight incubation of the contaminated culture fluid in the bijou and subsequent culture on nutrient agar;

(iv) no contamination was indicated by no growth from immediate samples or from the incubated medium.

The results from this series of experiments are set out in the tables in Figs. 4.15 and 4.16.

Results

Tooth	Length in mms	Final Reamer Size	Diameter of apical constriction mm	Growth 1 hr.after experiment	Growth 24 hrs. after experiment
/2	22	9	0.176	confluent	confluent
/1	23.5	9	0.267	no growth	confluent
1/	21.5	8	0.256	confluent	confluent
/2	22	8	0.204	countable	confluent
1/	20	6	0.299	confluent	confluent
2/	20	8	0.187	confluent	confluent
1/	24	10	0.184	no growth	no growth
2/	23	9	0.239	confluent	confluent
1/	25	9	0.280	confluent	confluent
1/	24.5	9	0.305	countable	confluent
/2	22	8	0.208	countable	confluent
1/	20	9	0.295	confluent	confluent
/1	22	9	0.220	countable	confluent
2/	23	9	0.264	confluent	confluent
1/	22	9	0.242	confluent	confluent
/1	21.5	9	0.208	countable	confluent
1/	20.5	9	0.329	confluent	confluent
1/	22	9	0.264	no growth	confluent
/1	21.5	6 *	0.323	no growth	no growth
1/	21	6 *	0.376	confluent	confluent
/1	21.5	6 *	0.235	confluent	confluent
1/	21	6 *	0.331	confluent	confluent
1/	26	6 *	0.269	countable	confluent
/1	28	6 *	0.377	confluent	confluent
1/	25	6 *	0.183	countable	confluent

Fig. 4.15

Tooth	Length in mms	Final Reamer Size	Diameter of apical constriction mm	Growth 1 hr. after experiment	Growth 24 hrs. after experiment
2/	21.5	6 *	0.325	countable	confluent
/2	26	6 *	0.200	countable	confluent
2/	20	6 *	0.233	countable	confluent
1/	25	6	0.274	countable	confluent
/1	27	9	0.194	countable	confluent
/2	26.5	6	0.307	countable	confluent
2/	26.5	6	0.397	countable	confluent
1/	24	9	0.248	confluent	confluent
2/	25	6	0.316	confluent	confluent
/2	22	6	0.328	confluent	confluent
/2	22	6	0.211	confluent	confluent
2/	22.5	6	0.185	confluent	confluent
2/	24	6	0.144	countable	confluent
2/	26	6	0.261	confluent	confluent
/1	24	8	0.145	confluent	confluent
/2	25	8	0.298	no growth	no growth
1/	25	8	0.128	no growth	confluent
/1	24	8	0.306	confluent	confluent
/2	21.5	9	0.210	countable	confluent
/1	24	9	0.227	countable	confluent
/1	24	8	0.196	confluent	confluent
/1	23	8	0.201	confluent	confluent
2/	25	8	0.167	countable	confluent
/1	26	8	0.242	confluent	confluent
/1	23.5	8	0.316	countable	confluent

Fig. 4.16

* File

Discussion of Results

One of the questions that was posed at the beginning of this chapter was - did material from the root canal pass through the apical foramen during the course of mechanical instrumentation? From the results obtained in this particular part of the present investigation it would appear that there is no doubt that material does pass through the foramen whenever this particular facet of endodontic treatment is being carried out. From Figs. 4.15 and 4.16 it will be observed that on only three occasions did a definite 'no growth' occur after overnight incubation. The reason for this is difficult to find. One possible explanation might be that the diameter of the apical constriction was small in these cases. However, when the diameter of the apical constriction was related to these 'no growth' cases it will be seen from Figs. 4.15 and 4.16 that the diameters were 0.184 mm, 0.298 mm and 0.323 mm. Therefore, whether the diameter was small or large, it was apparently in no way connected to the obstruction of the passage of the indicator organism through the apex into the bijou bottle.

Again a possible explanation might be the relationship of the amount of inoculum carried to the tooth and the degree of contamination. It will be observed from Figs. 4.15 and 4.16 that in one case of 'no growth' the volume was 0.0048 ml. (No. 6 file), in another it was 0.00860 ml. (No. 8 reamer) and in yet another it was 0.01580 ml. (No. 10 reamer). So the actual volume of inoculum carried to the root canal did not seem to have any bearing on a negative result. Likewise, the actual instrument used did not appear to be the causative factor. 'No growth' occurred with 2 reamers and with 1

Hedstrom file. There appears, therefore, to be no rational explanation why 'no growth' was recorded in these cases.

The other question posed at the beginning of this chapter was - was there a quantitative relationship between the amount of material passing through the apex of the tooth and the type of instrument being used in the mechanical preparation of the root canal? A comparison between No. 6 root canal reamers and No. 6 Hedstrom files, when being used in the preparation of the canal, is shown in Fig. 4.17. It would appear from this table that both the reamer and the file are capable of expelling material from the root canal through the apical foramen during the course of mechanical instrumentation within the canal, there being little or no difference in quantity when these two instruments are compared. When the No. 6 reamer was used there was gross contamination in 6 cases and moderate contamination in 4 cases. With use of the No. 6 Hedstrom file there was gross contamination in 4 cases and moderate contamination in 5 instances. There was, however, one case when no material was expelled through the apex and this occurred when using the No. 6 Hedstrom file. The results obtained for the various instruments used in this experiment are shown in Fig. 4.18. This gives the viable counts 1 hour after instrumentation. It was necessary, however, to carry out subcultures on blood agar plates in those cases where 'no growth' occurred at the one hour count. This was carried out and the final results for contamination (25 heavy, 19 moderate and 3 slight) are shown in Fig. 4.19. It is clear that since contamination occurred in 47 out of 50 cases, it is possible therefore to state that material from the root canal will be expelled through

Instrument Number	Contamination		
	Slight	Moderate	Heavy
Reamer No. 6	0	4	6
File No. 6	0	5	4

Fig. 4.17 Relationship between reamers and files in regard to contamination.

Instrumentation	Direct enumeration		
	No growth	Countable	Confluent
Filed to No. 6	1	5	4
Reamed to No. 6	0	4	6
Reamed to No. 8	2	4	7
Reamed to No. 9	2	6	8
Reamed to No. 10	1	0	0

Fig. 4.18 Viable count results obtained from samples within 1 hour of instrumentation procedures and subjected to the Miles and Misra technique promptly thereafter.

Instrumentation	Contamination		
	Slight	Moderate	Heavy
10 teeth Filed to No. 6	0	5	4
10 teeth Reamed to No. 6	0	4	6
13 teeth Reamed to No. 8	1	4	7
16 teeth Reamed to No. 9	2	6	8
1 tooth Reamed to No. 10	0	0	0

Fig. 4.19 Contamination revealed following 48 hours' incubation of subcultures on blood agar plates.

the apical foramen during mechanical instrumentation within the root canal.

The possibility of the final size of instrument used in the preparation of the canal being related to the amount of material being expelled through the apex was considered. It will be seen from Fig. 4.20, which shows the relationship between instrument size and gross infection, that 70% of the smaller sized instruments (No. 6 reamers and files), 54% of No. 8 reamers and 50% of No. 9 reamers caused gross infection. It is apparent that instrument size does not really bear any relationship to the expulsion of material through the apical foramen during mechanical instrumentation within the root canal.

In the same context, it was decided to investigate the volume of inoculum carried to the root canal during instrumentation to see if this had any bearing on the degree of contamination of the contents of the bijou bottle. This is, of course, related to instrument size since each instrument was dipped in the inoculum on two occasions during the course of preparation of the canal. Thus the greater the size of the instrument the greater the volume of inoculum carried to the canal. Fig. 4.21 shows that in fact the degree of contamination bore no relationship to the amount of inoculum carried to the root canal.

It was thought that there might be some definite relationship between the diameter of the apical constriction and the degree of contamination of the bijou contents. It will be seen from Fig. 4.22 that the diameter of the constriction has no relationship to the degree of contamination caused by the indicator organism.

Instrument Number	Confluent Growth (Gross Contamination)	Number Investigated
6	14	20
8	7	13
9	8	16
10	0	1

Fig. 4.20 Relationship of heavy contamination to instrument size.

Volume of inoculum carried to root canal, in mms	Contamination		
	Heavy	Moderate	Slight
0.00392 (20)	10	9	0
0.00860 (13)	7	4	1
0.01126 (16)	8	6	2

Fig. 4.21 Relationship of volume of inoculum carried to root canal and degree of contamination.

Diameter of apical foramen in mms	Heavy Contamination	Moderate Contamination	Slight Contamination
0.100 - 0.150	1	1	1
0.151 - 0.200	4	4	0
0.201 - 0.250	7	7	0
0.251 - 0.300	6	2	2
0.301 - 0.350	5	4	0
0.351 - 0.400	2	1	0

Fig. 4.22 Relationship of diameter of apical constriction to contamination of culture medium.

During the course of this investigation it was found, when the preparation of the canal was completed, that certain of the teeth used had their apical constriction blocked. This was observed by attempting to pass a very fine stainless steel wire (diameter 0.08 mm) through the apical foramen from the outside. In some cases the foramen was patent, while in others it was blocked. Blockage was always overcome by manipulation of the fine wire and passage through the entire canal length obtained. A record was kept of those foramina that were blocked as well as those that remained patent. It will be seen from Fig. 4.23 that whether the foramen was open or blocked there was an almost equal chance of contamination being either moderate or heavy. It can only be assumed that contamination occurred before the constriction became blocked by dentine debris released during preparation of the canal, or that during the course of instrumentation within the canal the dentine debris, infected by the indicator organism, had been pushed up the canal by the instrument and thereafter expelled through the apex into the bijou contents. When the foramen was patient the chance of moderate contamination was very much reduced since 10 of the cases of open apex were heavily contaminated while only 4 were moderately contaminated.

Another phenomenon which was observed during mechanical instrumentation was that in some cases the root canal of the tooth being prepared became flooded with some of the contents of the bijou bottle. This occurred at various times during preparation - sometimes in the middle and in others towards the end - but with no

State of apical foramen	Heavy contamination	Moderate contamination	Slight contamination
Blocked (32)	15	15	2
Open (15)	10	4	1

Fig. 4.23 Relationship of the state of apical foramen to contamination of culture medium.

definite pattern as to the actual time of flooding. The only possible reason for this flooding would appear to be that the flutes of the instrument became blocked with dentine debris and during the course of removal of the instrument from the canal it acted as a piston and created negative pressure within the apical portion of the canal, thus causing some of the contents of the bijou to be withdrawn into the root canal itself. That this reasoning appears to be logical is the fact that once flooding had occurred and instrumentation continued with the next sequential size, care being taken to guard against forcible withdrawal of the instrument, flooding did not occur on any other occasion while this tooth was being instrumented. It was thought that flooding might bear some relationship to the degree of contamination and it will be seen from Fig. 4.24 that this is in fact not true since those canals that were dry gave contamination in 93% of the cases while the flooded canals accounted for 94% contamination. It would appear therefore that whether the canal was dry or flooded with bijou contents, this bore no relationship to the contamination of the bijou contents with the indicator organism. It does not even bear a relationship to heavy contamination since 50% of the dry canals were heavily infected and 53% of the flooded canals were likewise contaminated.

State of canal during investigation	Heavy contamination	Moderate contamination	Slight contamination
(17) Flooded	9	7	1
(30) Dry	16	12	2

Fig. 4.24 Relationship of state of root canal during investigation.

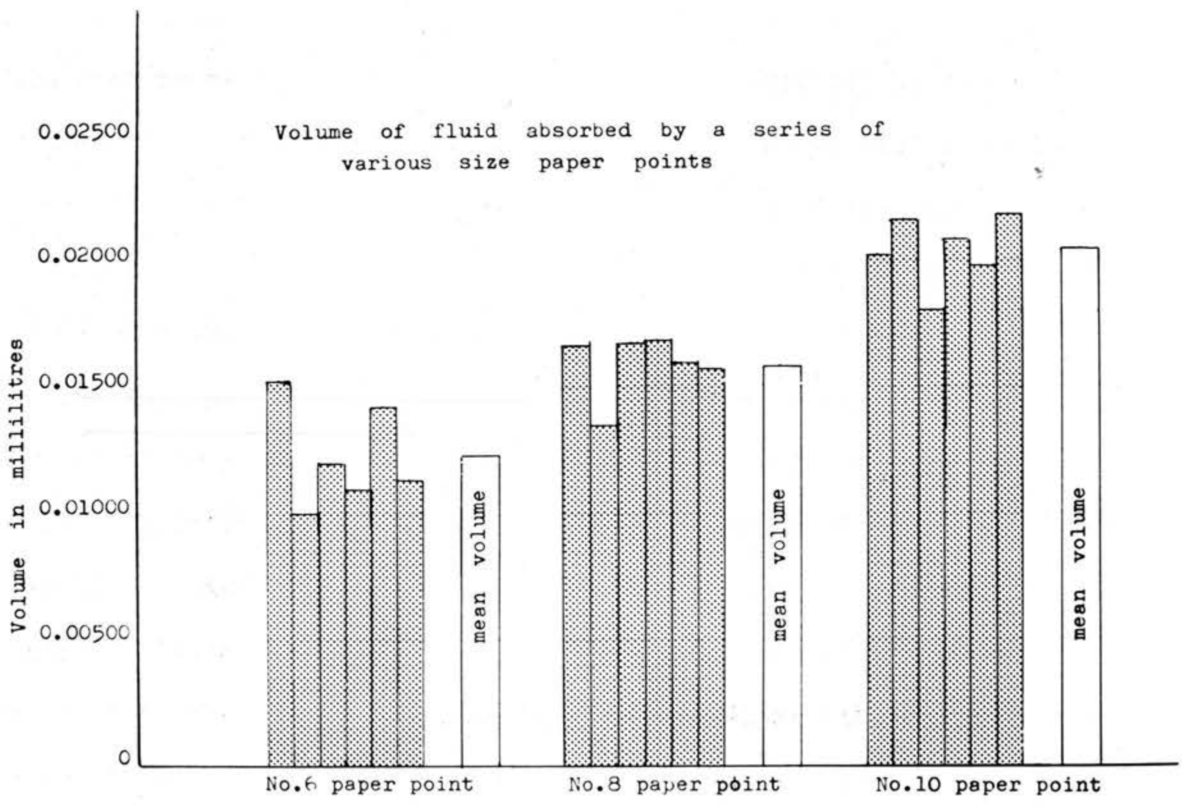
Controls

In this part of the investigation 10 teeth were used as controls, as far as possible carrying through the same procedure and under similar conditions as pertained when instrumenting the root canal with instruments infected with the indicator organism.

Teeth were reamed to No. 8 reamer size, care being taken to see that the apical foramen was patent by passing a No. 1 reamer right to the apex (Page 104). When this was completed the tooth was replaced in the glycerine/peroxide solution for 48 hours to re-sterilise it before using it under control conditions. Just prior to the control investigation the tooth was removed from the stock solution, all traces of this solution being diluted by immersing it in sterile distilled water for 24 hours to ensure that the stock solution was no longer bacteriostatic to the indicator organism.

The tooth was then dried in a sterile napkin and the root canal dried by means of sterile paper points. The control tooth was then mounted in the modified cap of a bijou bottle containing nutrient broth.

Prior experiments had shown that the volume of inoculum absorbed by paper points to be approximately the same as the volume carried to the root canal on the instruments (Figs. 4.25 and 4.26). Therefore a matched paper point was saturated with an inoculum of S. marcescens, care being taken to see that no excess inoculum was carried to the root canal. The inoculated paper point was inserted into the root canal for a distance equal to the distance that instrumentation had stopped, that is, tooth length minus 1 mm.



Volume of fluid absorbed by a series of
various size paper points
Volume in millilitres
0.02500
0.02000
0.01500
0.01000
0.00500
0
mean volume
mean volume
mean volume
No.6 paper point
No.8 paper point
No.10 paper point

Fig. 4.25

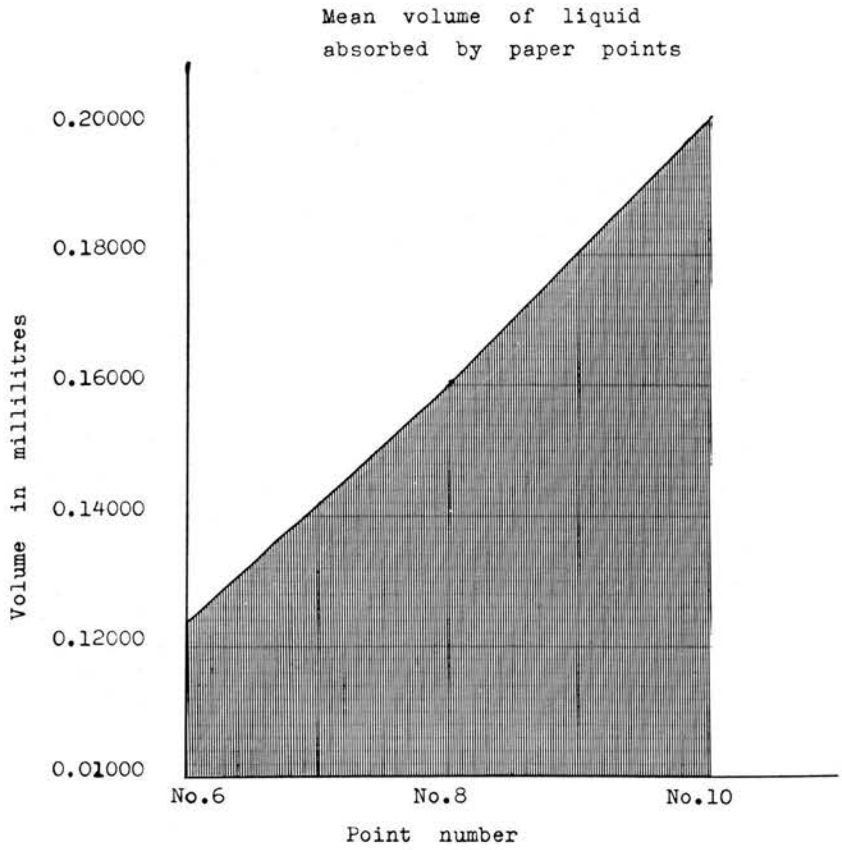

Mean volume of liquid
absorbed by paper points
Volume in millilitres
0.20000
0.18000
0.16000
0.14000
0.12000
0.01000
No.6
No.8
No.10
Point number

Fig. 4.26

So that control conditions would be similar to the instrumented tooth, the period of time spent carrying out instrumentation itself was recorded and the inoculated point left in the root canal for a similar length of time. In most cases this generally occupied about the same number of minutes as the instrument size. So a tooth reamed to No. 10 took approximately 10 minutes to carry out mechanical instrumentation and a No. 8 took approximately 8 minutes.

Again, in order that conditions would be duplicated for the control teeth, the bijou bottle was inverted during the time that the inoculated paper point remained in the root canal. In other words, every effort was made to carry the control tooth through exactly the same routine as the test tooth.

The results of the control cases are set out in Fig. 4.27. These show that in only one control case was there contamination and this was only moderate in character.

Again, as in the assessment of the medium in the bijou bottle in those cases where there was 'no growth' following instrumentation, the control cases were subjected to subculturing on blood agar plates for 48 hours following incubation on the agar plate. After 48 hours incubation of the blood agar plate the 9 negative plates still gave a negative result thus showing that in these nine cases no indicator organisms had got through the apical foramen into the medium in the bijou bottle.

Teeth used in control experiments

Tooth No. 1	No growth
Tooth No. 2	No growth
Tooth No. 3	No growth
Tooth No. 4	No growth
Tooth No. 5	No growth
Tooth No. 6	No growth
Tooth No. 7	Countable growth (Moderate contamination)
Tooth No. 8	No growth
Tooth No. 9	No growth
Tooth No.10	No growth

Fig. 4.27 Viable counts within 1 hour of control being completed.

CHAPTER 5

Measurement of Diameters of Gutta Percha and Silver Points at various distances along their Long Axis

Introduction

In the year 1887 Tomes stated that once the pulp tissue of a human permanent tooth is removed, the root canal may be filled without enlargement. This theory is, of course, no longer acceptable among endodontists. In root canal therapy there are three factors which require meticulous care and attention to detail if a successful end result is to be obtained. They are :-

1. Cleansing and 'sterilisation' of the root canal;
2. Mechanical preparation of the canal;
3. Accurate seating of the root filling point in the canal thereby ensuring hermetic sealing of the apical foramen.

It has already been shown that, as far as mechanical preparation is concerned, in order to obtain as good a seal as possible the canal should be prepared perfectly circular in diameter and with a uniform taper from the coronal aspect of the tooth to the apex (Coolidge (1958)). This is to conform to the size and shape of the root filling points currently available. It has also been demonstrated that the only method of obtaining this ideal circular canal is by means of the root canal reamer - the root canal file always tending to prepare the canal in an ovoid shape.

Human permanent teeth vary in length from 20.6 mm to 26.8 mm (Green (1955) and Ingle (1965)) and the question poses itself - is it necessary or essential that the pulp cavity of a pulpless tooth should be completely filled for its entire length, or is it sufficient to fill accurately the apical third of the root canal, ensuring that an efficient and hermetic seal exists at the apical foramen? Kells in 1918 stated that the prime necessity is to fill the canal to the apex. It has also been stated by Ireland (1966) that complete obliteration of the central space in a pulpless tooth should be aimed at, supporting the view of such workers as Bender et al (1964), Bulleid (1928), Coolidge (1958), Grossman (1950), Kuttler (1958), McGehee (1951), Rickert & Dixon (1931) and Sommer (1966). On the other hand, Blaney (1927), Curson (1966), Grove (1929), Hatton et al (1928), Moffitt (1913) and Seltzer et al (1964) all state that underfilling is preferable to overfilling, none of these workers specifying exactly what they mean by underfilling. Do they mean filling to the dentino-cemental junction or do they mean filling to an even lower level than this? In this respect it is pointed out that Grossman et al (1964) demonstrated that poorly filled root canals accounted for by far the largest percentage of failures in a series of 432 root filled teeth which they evaluated for success.

From the opinions stated in the available literature it would appear that the general concensus of opinion is that the level of root filling should be the dentino-cemental junction (Crane (1926), Berger (1926), Hartzell (1930), Ingle (1965), Kuttler (1955 & 1958), McGehee (1951), Rickert & Dixon (1931) and Sommer (1966). In this investigation the normal termination of root filling (the dentino-cemental junction) has been accepted as the level at which a root filling should end. A further reason for accepting this terminal point is that Grove has demonstrated that the area from the dentino-cemental junction to the true apex of the tooth is normally filled with periodontal membrane and he states that the space previously occupied by pulp tissue only, should be filled. As well as this it has been demonstrated that there exists in the apical region an apical delta (Sommer (1966) and Green (1955)). This is an area which, because of its shape, is impossible to instrument and therefore, for similar reasons, impossible to seal adequately. One worker, Green (1964), appears to think that the level of filling is not important; he states that the tooth can be root filled to either the dentino-cemental junction or to the true apex of the tooth.

It is therefore accepted, on the evidence produced, that the correct level of filling should be the dentino-cemental junction (apical constriction) of the root canal and this point of termination of the root filling is used in this investigation.

Root fillings may be either in the form of solid material or in the form of a paste. Paste material is usually limited to root canals which do not allow proper instrumentation, for example, root canals of immature teeth where the apex is not fully developed (Friend (1967)). Only solid materials have been used in this investigation. The solid root filling materials commonly available in this country are metal - usually Silver - and Gutta Percha. Gutta percha is a soft flexible material obtained by evaporating a milky fluid obtained from trees of the Sapotaceae family, found mostly in the Malay Archipelago and in Brazil (Encyclopaedia Brittanica). The solid root filling points (silver and gutta percha) are circular in diameter and taper along their long axis. They are manufactured in various sizes and, as far as the root filling points from Produits Dentaire are concerned, range from the finest (No. 1) up to the largest (No. 12) in Conventional points and from No. 15 to No. 110 in Standardised points.

A series of Conventional and Standardised Gutta Percha points and Silver points were therefore measured to determine the various diameters along their long axis and to correlate these diameters to the technical data supplied by the manufacturer and to see what relationship these measurements bore to the measurements obtained for the reamers used in this investigation. The root filling points investigated were those manufactured by Produits Dentaire since this company's instruments were chosen for measurement and also since the company state that their points were matched to their root canal instruments.

Measurements were made at various distances along the long axis of the point. Since it has been accepted that the level of filling should be the dentino-cemental junction, it was decided that particular attention should be paid to the terminal 1 mm to 6 mm of these points.

When this investigation was commenced, both Conventional and Standardised points were available and it was felt that it would be of value to compare and contrast these two types of solid root filling material. However, during the course of the investigation Produits Dentaire withdrew the Conventional type of point, all points being now labelled as Standardised but still numbered with the old Conventional number, together with the Standardised number.

Method

Method of measuring root filling points.

Because of the inherent softness of gutta percha it is impossible to utilize an engineer's micrometer to obtain the necessary measurements. Also, due to the fact that these points are tapered along their long axis, it would be difficult, if not impossible, to obtain accurate readings. Therefore it was decided to use the measuring microscope in exactly the same way as was used to obtain measurements for the various root canal instruments.

Commencing with the Conventional gutta percha points, the base of each point investigated was pressed into a small piece of plasticine, placed on a glass microscope slide (Fig. 5.1). So that as little focusing as possible of the microscope would be required and so that readings would be as uniform as could be expected, the long axis of each point was placed parallel to and as near the surface of the glass slide as possible. The slide was then placed on the mechanical stage of a Watson microscope using an objective lens of 'X10'. A Filar head (Breck & Sons, London) was fitted to the microscope, giving a further 10 times magnification (Fig. 5.2). This total magnification ensured that accurate readings to within 0.001 mm could be easily made. Measurements were made along the long axis of the point at distances 1 mm, 3 mm, 6 mm from the tip and so on until the final distance - 15 mm from the tip of the point. The first point was chosen for measurement (1 mm) because this point corresponded to the initial measurement point on the root canal instruments.

The tip of the point was orientated to correspond to the base

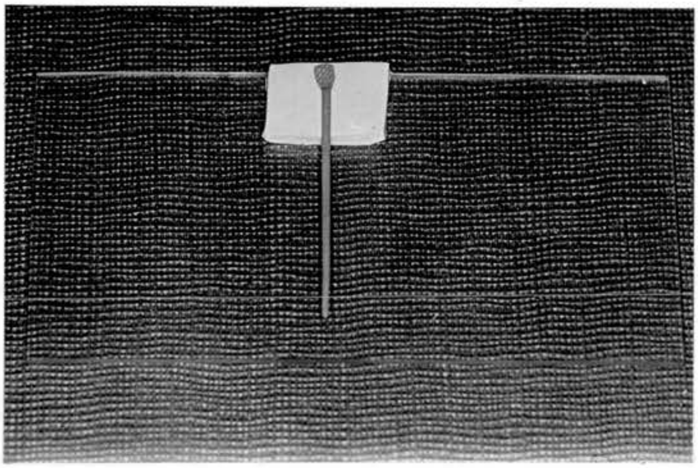


Fig. 5.1

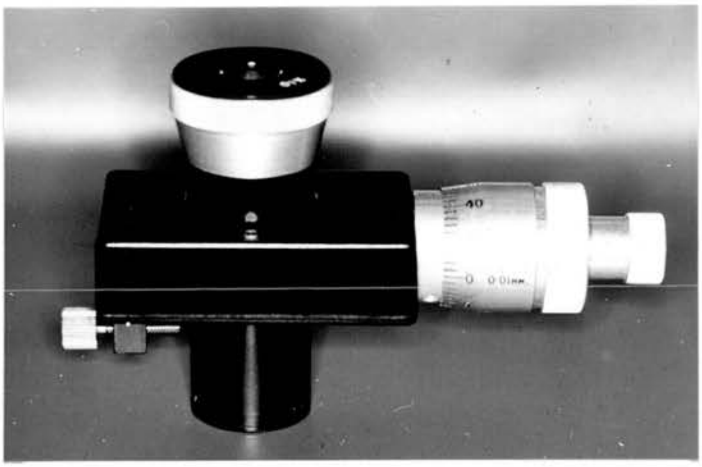


Fig. 5.2

line on the vernier scale of the Filar head and by moving the stage of the microscope exactly 1 mm, as read off on the microscope vernier scale, the reading of the diameter of the point was made. The stage was then moved 2 mm more thus giving the 3 mm position on the long axis of the root canal point under review and so on until the 15 mm diameter was recorded.

Similar measurements were made for Standardised gutta percha points and for Conventional and Standardised silver points.

Results

The measurement obtained for Conventional gutta percha points at the various positions along their long axis are set out in Figs. 5.3 to 5.14.

Similar measurements were made for Standardised gutta percha points and are tabulated in Figs. 5.15 to 5.26.

Conventional and Standardised silver points were investigated in a similar manner and the measurements obtained set out in Figs. 5.27 to 5.32.

Conventional Gutta Percha Points - No. 1

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.171	0.200	0.250	0.298	0.342	0.343
0.204	0.224	0.261	0.296	0.351	0.374
0.182	0.217	0.274	0.276	0.330	0.333
0.192	0.226	0.271	0.309	0.329	0.323
0.193	0.209	0.237	0.255	0.265	0.270
0.182	0.208	0.246	0.265	0.289	0.314
0.191	0.224	0.285	0.318	0.316	0.332
0.166	0.185	0.223	0.258	0.284	0.295
0.174	0.202	0.251	0.288	0.308	0.331
0.200	0.221	0.285	0.315	0.332	0.338
0.196	0.228	0.280	0.331	0.331	0.328
0.200	0.227	0.285	0.300	0.323	0.316
0.187	0.195	0.235	0.297	0.356	0.365
0.212	0.225	0.262	0.298	0.313	0.315
0.153	0.178	0.225	0.276	0.302	0.311
0.243	0.276	0.312	0.300	0.305	0.309
0.170	0.199	0.238	0.267	0.285	0.304
0.167	0.192	0.248	0.284	0.311	0.328
0.165	0.191	0.244	0.291	0.310	0.325
0.197	0.223	0.279	0.326	0.385	0.381
0.200	0.216	0.253	0.291	0.318	0.337
0.165	0.190	0.228	0.329	0.359	0.376
0.204	0.226	0.263	0.298	0.313	0.321
0.185	0.207	0.244	0.283	0.312	0.319
0.199	0.220	0.273	0.314	0.325	0.329
0.209	0.218	0.267	0.307	0.320	0.320
0.221	0.243	0.282	0.322	0.347	0.350
0.244	0.272	0.316	0.367	0.382	0.406
0.184	0.206	0.243	0.275	0.306	0.318
0.201	0.223	0.270	0.308	0.318	0.319
0.223	0.238	0.283	0.335	0.351	0.354
0.163	0.182	0.244	0.278	0.302	0.323

Fig. 5.3

Conventional Gutta Percha Points - No. 2

1 mm	3mm	6 mm	9 mm	12 mm	15 mm
0.262	0.302	0.353	0.405	0.434	0.446
0.267	0.303	0.378	0.406	0.440	0.416
0.235	0.250	0.288	0.345	0.402	0.416
0.291	0.301	0.362	0.421	0.463	0.454
0.274	0.316	0.385	0.448	0.487	0.508
0.314	0.349	0.376	0.419	0.454	0.482
0.334	0.359	0.385	0.382	0.423	0.441
0.186	0.217	0.259	0.324	0.392	0.426
0.257	0.283	0.335	0.440	0.485	0.496
0.216	0.261	0.326	0.394	0.435	0.444
0.225	0.248	0.276	0.337	0.383	0.386
0.211	0.240	0.282	0.344	0.416	0.442
0.255	0.273	0.322	0.373	0.406	0.429
0.235	0.273	0.352	0.402	0.407	0.409
0.248	0.267	0.309	0.344	0.366	0.373
0.236	0.268	0.312	0.356	0.412	0.423
0.264	0.280	0.322	0.381	0.410	0.417
0.274	0.315	0.386	0.436	0.463	0.446
0.225	0.243	0.290	0.330	0.356	0.367
0.264	0.290	0.342	0.374	0.383	0.377
0.205	0.249	0.303	0.368	0.407	0.442
0.288	0.327	0.379	0.413	0.413	0.406
0.240	0.268	0.309	0.360	0.408	0.415
0.296	0.337	0.387	0.448	0.477	0.484
0.235	0.273	0.347	0.405	0.410	0.414
0.270	0.287	0.335	0.375	0.416	0.429
0.227	0.272	0.348	0.411	0.421	0.441
0.222	0.257	0.332	0.380	0.448	0.469
0.216	0.250	0.347	0.416	0.458	0.479
0.211	0.246	0.292	0.368	0.404	0.425
0.267	0.296	0.330	0.376	0.410	0.423
0.223	0.285	0.306	0.365	0.378	0.406

Fig. 5.4

Conventional Gutta Percha Points - No. 3

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.393	0.422	0.475	0.484	0.498	0.510
0.302	0.317	0.345	0.374	0.427	0.455
0.369	0.389	0.395	0.406	0.441	0.441
0.294	0.330	0.354	0.418	0.470	0.485
0.257	0.275	0.330	0.390	0.427	0.446
0.272	0.312	0.365	0.426	0.457	0.504
0.273	0.292	0.352	0.403	0.408	0.417
0.332	0.356	0.403	0.436	0.501	0.500
0.362	0.373	0.387	0.411	0.445	0.442
0.297	0.334	0.356	0.423	0.500	0.527
0.242	0.254	0.313	0.360	0.402	0.426
0.255	0.277	0.322	0.376	0.434	0.444
0.281	0.363	0.393	0.489	0.513	0.518
0.246	0.290	0.354	0.438	0.503	0.501
0.250	0.274	0.315	0.363	0.372	0.400
0.374	0.388	0.436	0.495	0.510	0.524
0.241	0.272	0.338	0.410	0.461	0.474
0.222	0.262	0.318	0.361	0.412	0.443
0.278	0.284	0.316	0.366	0.406	0.440
0.261	0.293	0.322	0.373	0.392	0.407
0.353	0.402	0.448	0.486	0.524	0.526
0.346	0.355	0.393	0.447	0.465	0.485
0.421	0.444	0.455	0.517	0.524	0.529
0.307	0.322	0.355	0.382	0.412	0.415
0.340	0.359	0.418	0.490	0.508	0.514
0.266	0.290	0.337	0.375	0.451	0.463
0.253	0.291	0.312	0.357	0.380	0.406
0.224	0.279	0.364	0.453	0.462	0.490
0.300	0.325	0.386	0.470	0.478	0.490
0.196	0.228	0.293	0.348	0.395	0.441
0,291	0.306	0.355	0.415	0.459	0.466

Fig. 5.5

Conventional Gutta Percha Points - No. 4

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.237	0.284	0.322	0.392	0.448	0.508
0.300	0.325	0.383	0.417	0.452	0.508
0.336	0.355	0.419	0.446	0.440	0.459
0.315	0.360	0.406	0.435	0.467	0.500
0.303	0.341	0.379	0.401	0.412	0.450
0.335	0.367	0.416	0.454	0.508	0.537
0.267	0.311	0.357	0.392	0.446	0.495
0.335	0.371	0.408	0.446	0.483	0.524
0.312	0.351	0.410	0.449	0.490	0.537
0.282	0.325	0.376	0.436	0.470	0.533
0.298	0.337	0.395	0.437	0.478	0.497
0.276	0.320	0.365	0.396	0.437	0.498
0.312	0.357	0.400	0.443	0.450	0.481
0.299	0.347	0.405	0.450	0.469	0.522
0.295	0.335	0.396	0.460	0.492	0.535
0.263	0.309	0.383	0.440	0.477	0.530
0.285	0.320	0.368	0.406	0.448	0.499
0.281	0.300	0.379	0.453	0.514	0.550
0.283	0.312	0.381	0.417	0.479	0.544
0.272	0.310	0.367	0.405	0.444	0.505
0.273	0.304	0.368	0.419	0.464	0.516
0.273	0.314	0.415	0.468	0.516	0.534
0.262	0.308	0.353	0.414	0.466	0.547
0.310	0.340	0.375	0.430	0.460	0.502
0.298	0.330	0.384	0.431	0.481	0.526
0.360	0.431	0.423	0.452	0.464	0.491
0.270	0.312	0.365	0.414	0.458	0.476
0.289	0.337	0.368	0.435	0.476	0.523
0.335	0.368	0.407	0.445	0.476	0.512
0.312	0.348	0.397	0.434	0.471	0.524
0.268	0.304	0.358	0.415	0.450	0.507
0.300	0.365	0.413	0.456	0.480	0.522
0.298	0.325	0.386	0.405	0.448	0.500

Fig. 5.6

Conventional Gutta Percha Points - No. 5

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.339	0.369	0.452	0.548	0.567	0.582
0.461	0.498	0.553	0.598	0.620	0.631
0.402	0.477	0.576	0.582	0.592	0.579
0.346	0.379	0.463	0.532	0.593	0.608
0.332	0.397	0.482	0.548	0.600	0.600
0.317	0.406	0.492	0.550	0.548	0.597
0.361	0.434	0.484	0.546	0.572	0.589
0.324	0.376	0.439	0.542	0.578	0.592
0.467	0.502	0.567	0.610	0.625	0.657
0.462	0.501	0.566	0.592	0.612	0.606
0.375	0.446	0.480	0.582	0.596	0.618
0.400	0.467	0.545	0.601	0.629	0.627
0.399	0.451	0.545	0.578	0.624	0.629
0.497	0.552	0.609	0.651	0.663	0.664
0.366	0.406	0.472	0.563	0.583	0.598
0.384	0.426	0.505	0.547	0.573	0.587
0.357	0.448	0.517	0.576	0.608	0.613
0.378	0.418	0.518	0.558	0.600	0.637
0.350	0.382	0.483	0.538	0.581	0.598
0.404	0.461	0.493	0.546	0.579	0.624
0.398	0.438	0.486	0.566	0.586	0.618
0.423	0.480	0.517	0.539	0.568	0.570
0.373	0.422	0.487	0.542	0.571	0.593
0.341	0.398	0.472	0.518	0.546	0.554
0.381	0.472	0.518	0.572	0.597	0.610
0.404	0.455	0.523	0.598	0.626	0.626
0.364	0.401	0.462	0.515	0.572	0.604
0.439	0.475	0.559	0.586	0.605	0.612
0.379	0.429	0.528	0.586	0.609	0.634
0.388	0.435	0.489	0.537	0.570	0.603
0.417	0.475	0.520	0.565	0.599	0.632
0.344	0.393	0.461	0.529	0.570	0.612

Fig. 5.7

Conventional Gutta Percha Points - No. 6

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.429	0.462	0.528	0.600	0.726	0.742
0.462	0.528	0.594	0.762	0.759	0.775
0.462	0.528	0.600	0.742	0.775	0.775
0.478	0.544	0.594	0.676	0.742	0.742
0.469	0.503	0.576	0.653	0.723	0.744
0.419	0.439	0.537	0.648	0.717	0.760
0.476	0.547	0.638	0.717	0.749	0.774
0.434	0.517	0.620	0.686	0.724	0.735
0.418	0.457	0.534	0.611	0.688	0.744
0.446	0.507	0.601	0.676	0.697	0.712
0.407	0.476	0.559	0.678	0.726	0.740
0.404	0.441	0.522	0.629	0.685	0.711
0.430	0.496	0.587	0.706	0.757	0.777
0.342	0.421	0.551	0.642	0.701	0.743
0.441	0.514	0.603	0.677	0.725	0.743
0.369	0.424	0.514	0.613	0.704	0.722
0.411	0.480	0.563	0.656	0.709	0.719
0.421	0.492	0.604	0.711	0.763	0.766
0.426	0.503	0.602	0.685	0.728	0.774
0.396	0.457	0.545	0.642	0.719	0.742
0.470	0.509	0.602	0.700	0.743	0.766
0.501	0.565	0.646	0.718	0.742	0.804
0.452	0.464	0.539	0.594	0.648	0.689
0.435	0.493	0.551	0.624	0.706	0.732
0.415	0.492	0.575	0.659	0.720	0.754
0.554	0.602	0.676	0.709	0.744	0.758
0.382	0.439	0.537	0.642	0.699	0.712
0.429	0.502	0.595	0.692	0.725	0.746
0.421	0.462	0.577	0.639	0.696	0.720
0.400	0.467	0.564	0.678	0.708	0.732
0.348	0.427	0.521	0.618	0.684	0.729
0.412	0.494	0.570	0.467	0.693	0.737
0.396	0.465	0.539	0.644	0.729	0.755

Fig. 5.8

Conventional Gutta Percha Points - No. 7

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.573	0.644	0.778	0.852	0.867	0.850
0.605	0.659	0.723	0.769	0.797	0.827
0.541	0.630	0.763	0.825	0.865	0.867
0.506	0.582	0.706	0.759	0.812	0.851
0.556	0.613	0.685	0.857	0.826	0.844
0.610	0.644	0.734	0.802	0.827	0.854
0.538	0.607	0.717	0.803	0.826	0.854
0.592	0.692	0.773	0.826	0.942	0.937
0.566	0.621	0.723	0.811	0.832	0.868
0.546	0.607	0.708	0.790	0.817	0.834
0.578	0.651	0.732	0.805	0.850	0.877
0.555	0.618	0.720	0.794	0.844	0.850
0.503	0.591	0.703	0.757	0.802	0.825
0.567	0.643	0.717	0.780	0.794	0.812
0.537	0.614	0.696	0.772	0.801	0.811
0.505	0.564	0.653	0.726	0.763	0.800
0.503	0.601	0.720	0.804	0.819	0.823
0.581	0.641	0.728	0.806	0.822	0.820
0.544	0.603	0.707	0.772	0.815	0.841
0.593	0.642	0.716	0.785	0.826	0.834
0.547	0.594	0.713	0.764	0.808	0.808
0.570	0.617	0.705	0.803	0.829	0.856
0.568	0.636	0.739	0.801	0.838	0.863
0.556	0.653	0.740	0.843	0.855	0.854
0.625	0.654	0.760	0.813	0.842	0.858
0.580	0.622	0.694	0.771	0.802	0.814
0.581	0.628	0.698	0.770	0.811	0.837
0.548	0.636	0.698	0.800	0.829	0.833
0.549	0.600	0.683	0.753	0.816	0.846
0.538	0.617	0.721	0.802	0.836	0.854
0.530	0.610	0.709	0.804	0.833	0.848

Fig. 5.9

Conventional Gutta Percha Points - No. 8

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.618	0.664	0.760	0.847	0.919	0.967
0.626	0.678	0.766	0.838	0.908	0.940
0.659	0.702	0.795	0.876	0.938	0.975
0.709	0.780	0.826	0.912	0.978	1.008
0.692	0.715	0.801	0.855	0.923	0.962
0.608	0.662	0.752	0.839	0.907	0.952
0.643	0.696	0.796	0.901	0.938	0.959
0.632	0.673	0.749	0.840	0.925	0.954
0.639	0.677	0.752	0.847	0.913	0.961
0.668	0.710	0.788	0.883	0.939	0.968
0.678	0.745	0.795	0.876	0.934	0.977
0.647	0.703	0.785	0.857	0.945	0.971
0.648	0.700	0.761	0.858	0.927	0.970
0.611	0.669	0.750	0.847	0.901	0.947
0.603	0.657	0.708	0.789	0.851	0.953
0.587	0.657	0.722	0.815	0.892	0.955
0.747	0.787	0.826	0.876	0.932	0.977
0.712	0.757	0.826	0.919	0.959	0.982
0.650	0.693	0.775	0.864	0.920	0.966
0.707	0.752	0.831	0.899	0.949	0.977
0.700	0.770	0.843	0.922	0.957	0.984
0.745	0.782	0.870	0.928	0.965	0.982
0.692	0.733	0.821	0.883	0.944	0.966
0.625	0.663	0.748	0.827	0.916	0.964
0.642	0.703	0.780	0.861	0.924	0.967
0.669	0.699	0.765	0.827	0.903	0.965
0.586	0.638	0.745	0.826	0.924	0.945
0.737	0.801	0.848	0.910	0.936	0.954
0.651	0.716	0.767	0.846	0.900	0.942
0.613	0.674	0.759	0.842	0.907	0.972
0.678	0.749	0.817	0.883	0.946	0.991
0.634	0.712	0.773	0.837	0.895	0.950

Fig. 5.10

Conventional Gutta Percha Points - No. 9

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.627	0.706	0.807	0.936	1.010	1.038
0.673	0.732	0.866	0.966	0.998	1.028
0.684	0.743	0.925	0.957	1.006	1.016
0.566	0.640	0.767	0.865	0.959	0.991
0.483	0.577	0.688	0.833	0.974	0.982
0.578	0.640	0.720	0.789	0.884	0.971
0.706	0.772	0.844	0.951	1.018	1.031
0.586	0.646	0.770	0.865	0.976	0.990
0.576	0.658	0.745	0.865	0.976	0.995
0.595	0.669	0.758	0.849	0.936	0.995
0.547	0.600	0.684	0.778	0.881	0.951
0.652	0.734	0.798	0.874	0.934	0.963
0.603	0.667	0.756	0.847	0.952	0.987
0.583	0.652	0.740	0.821	0.919	0.957
0.577	0.648	0.763	0.830	0.945	0.996
0.662	0.716	0.778	0.885	0.917	0.941
0.624	0.678	0.819	0.972	1.017	1.024
0.459	0.556	0.644	0.741	0.823	0.911
0.539	0.608	0.718	0.816	0.923	0.973
0.644	0.709	0.807	0.900	0.974	0.986
0.511	0.597	0.702	0.804	0.913	0.956
0.579	0.645	0.733	0.841	0.949	0.971
0.546	0.589	0.669	0.743	0.875	0.968
0.533	0.679	0.839	0.927	0.962	1.016
0.621	0.682	0.773	0.865	0.973	0.987
0.699	0.754	0.842	0.952	0.974	0.983
0.619	0.684	0.776	0.842	0.977	1.015
0.586	0.675	0.778	0.889	0.948	0.976
0.672	0.732	0.850	0.964	1.035	1.022
0.603	0.687	0.811	0.922	0.957	0.978
0.632	0.700	0.774	0.870	0.952	0.983
0.600	0.667	0.743	0.850	0.926	0.953

Fig. 5.11

Conventional Gutta Percha Points - No. 10

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.690	0.795	0.920	1.042	1.108	1.152
0.910	0.980	1.074	1.103	1.107	1.108
0.690	0.844	0.938	1.095	1.110	1.152
0.914	0.957	1.076	1.102	1.111	1.132
0.726	0.810	0.922	1.024	1.111	1.161
0.664	0.756	0.915	1.027	1.133	1.172
0.663	0.794	0.902	1.058	1.129	1.171
0.928	0.997	1.076	1.124	1.125	1.144
0.653	0.726	0.911	1.074	1.155	1.173
0.860	0.950	1.032	1.091	1.110	1.147
0.861	0.771	0.922	1.027	1.084	1.136
0.934	0.980	1.109	1.156	1.160	1.161
0.591	0.700	0.864	0.990	1.082	1.146
0.692	0.807	0.976	1.084	1.113	1.169
0.842	0.965	1.060	1.161	1.196	1.208
0.962	1.021	1.086	1.145	1.182	1.202
0.714	0.806	0.909	1.037	1.098	1.157
0.623	0.735	0.842	0.991	1.126	1.197
0.665	0.797	0.925	1.066	1.175	1.208
0.993	1.024	1.108	1.151	1.155	1.172
0.612	0.768	0.909	1.088	1.127	1.194
0.606	0.720	0.863	1.009	1.129	1.181
0.943	1.022	1.116	1.152	1.165	1.179
0.716	0.827	1.026	1.045	1.140	1.169
0.861	0.957	1.072	1.141	1.145	1.160
0.572	0.673	0.812	0.971	1.110	1.143
0.694	0.765	0.874	0.880	1.170	1.205
0.950	1.084	1.095	1.127	1.145	1.155
0.742	0.816	1.012	1.012	1.135	1.173
0.625	0.713	0.828	0.968	1.057	1.102
0.544	0.658	0.826	0.955	1.092	1.141
0.636	0.732	0.838	0.987	1.125	1.158

Fig. 5.12

Conventional Gutta Percha Points - No. 11

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.980	1.018	1.071	1.129	1.177	1.215
1.056	1.113	1.198	1.234	1.253	1.256
0.969	1.053	1.179	1.219	1.240	1.251
1.046	1.077	1.110	1.173	1.195	1.198
0.973	1.019	1.072	1.135	1.162	1.197
0.941	0.960	1.040	1.089	1.146	1.211
0.988	1.017	1.070	1.090	1.132	1.163
0.920	1.057	1.076	1.182	1.250	x
0.678	0.815	0.916	1.013	1.106	1.231
0.755	0.844	1.033	1.198	x	x
0.928	0.987	1.092	1.155	1.200	1.224
0.834	0.965	1.086	1.149	1.236	x
1.094	1.116	1.182	1.203	1.214	1.233
1.023	1.050	1.129	1.207	x	x
1.000	1.015	1.062	1.123	1.161	1.214
0.917	0.980	1.082	1.173	1.218	1.232
1.006	1.035	1.083	1.137	1.194	1.222
1.141	1.176	1.194	1.221	1.247	x
0.913	0.954	1.130	1.235	x	x
0.942	0.990	1.004	1.069	1.112	1.159
1.028	1.055	1.111	1.209	1.234	x
1.073	1.097	1.151	1.184	1.217	1.246
0.714	0.732	0.879	0.998	1.101	1.032
0.600	0.707	0.843	0.974	1.119	1.140
0.609	0.746	0.877	1.001	1.095	1.140
0.601	0.700	0.807	0.932	1.061	1.108
0.622	0.685	0.801	0.982	1.131	1.178
0.924	0.986	1.078	1.126	1.197	1.234
0.664	0.776	0.881	1.014	1.059	1.126
0.685	0.779	0.937	1.040	1.157	1.202

Fig. 5.13

Conventional Gutta Percha Points - No. 12

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
1.155	1.238	x	x	x	x
1.168	1.213	x	x	x	x
0.991	1.082	1.175	x	x	x
0.826	0.968	1.156	x	x	x
0.621	0.855	0.930	1.216	x	x
0.923	1.042	1.144	x	x	x
1.075	1.147	1.228	x	x	x
1.037	1.138	1.240	x	x	x
1.145	1.217	x	x	x	x
0.960	1.057	1.171	1.235	x	x
0.817	0.931	1.023	1.131	1.214	x
0.877	1.140	1.204	1.242	x	x
0.964	1.160	1.248	x	x	x
1.049	1.201	x	x	x	x
1.080	1.185	x	x	x	x
1.031	1.122	1.134	x	x	x
0.891	1.001	1.114	x	x	x
1.199	x	x	x	x	x
1.252	x	x	x	x	x
0.831	0.953	1.114	1.229	x	x
1.045	1.188	x	x	x	x
0.833	0.964	1.140	x	x	x
0.694	0.790	0.955	1.083	1.223	x
0.923	0.998	1.082	1.160	1.225	x
1.124	1.216	x	x	x	x
0.976	1.085	1.168	x	x	x
1.058	1.150	1.226	x	x	x
1.072	1.160	1.228	x	x	x
0.995	1.072	1.184	x	x	x
1.035	1.117	1.204	x	x	x
1.013	1.080	1.150	1.247	x	x

Fig. 5.14

Standardised Gutta Percha Points - No. 15

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.242	0.265	0.367	0.384	0.395	0.428
0.269	0.270	0.363	0.374	0.388	0.407
0.244	0.260	0.359	0.368	0.392	0.413
0.210	0.237	0.282	0.325	0.340	0.369
0.212	0.243	0.299	0.335	0.340	0.358
0.257	0.267	0.326	0.412	0.423	0.430
0.228	0.251	0.301	0.342	0.356	0.369
0.260	0.284	0.318	0.312	0.317	0.316
0.255	0.273	0.319	0.341	0.355	0.367
0.211	0.249	0.287	0.325	0.332	0.348
0.244	0.268	0.315	0.347	0.365	0.391
0.213	0.240	0.309	0.350	0.378	0.393
0.250	0.287	0.306	0.349	0.364	0.375
0.211	0.248	0.317	0.362	0.387	0.409
0.236	0.267	0.316	0.353	0.362	0.379
0.226	0.260	0.304	0.326	0.349	0.402
0.247	0.264	0.303	0.345	0.360	0.368

Fig. 5.15

Standardised Gutta Percha Points - No. 20

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.384	0.412	0.453	0.490	0.502	0.510
0.375	0.402	0.451	0.483	0.514	0.527
0.358	0.382	0.445	0.475	0.492	0.520
0.335	0.384	0.443	0.472	0.513	0.525
0.327	0.371	0.440	0.485	0.514	0.514
0.316	0.350	0.397	0.445	0.473	0.502
0.333	0.365	0.433	0.475	0.513	0.520
0.342	0.377	0.423	0.473	0.493	0.511
0.342	0.379	0.428	0.452	0.468	0.510
0.301	0.352	0.403	0.460	0.497	0.511
0.332	0.360	0.426	0.452	0.484	0.524
0.353	0.401	0.450	0.480	0.504	0.511
0.322	0.367	0.411	0.463	0.502	0.511
0.338	0.373	0.419	0.467	0.496	0.501
0.365	0.393	0.441	0.474	0.516	0.522
0.380	0.398	0.436	0.468	0.486	0.517
0.309	0.355	0.403	0.460	0.483	0.518

Fig. 5.16

Standardised Gutta Percha Points - No. 25

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.408	0.426	0.426	0.404	0.404	0.422
0.440	0.459	0.476	0.442	0.424	0.439
0.320	0.343	0.381	0.436	0.470	0.493
0.416	0.428	0.437	0.427	0.426	0.460
0.314	0.351	0.405	0.444	0.462	0.482
0.414	0.425	0.418	0.387	0.403	0.425
0.327	0.370	0.411	0.447	0.455	0.451
0.371	0.384	0.431	0.459	0.475	0.460
0.358	0.373	0.395	0.407	0.423	0.440
0.312	0.340	0.416	0.467	0.467	0.474
0.347	0.364	0.407	0.454	0.441	0.468
0.250	0.276	0.333	0.393	0.434	0.477
0.380	0.410	0.431	0.444	0.443	0.452
0.426	0.425	0.430	0.419	0.408	0.441
0.407	0.430	0.451	0.444	0.428	0.412
0.341	0.381	0.426	0.445	0.434	0.430
0.325	0.374	0.406	0.450	0.477	0.517
0.397	0.419	0.432	0.420	0.409	0.414
0.393	0.414	0.433	0.424	0.415	0.426

Fig. 5.17

Standardised Gutta Percha Points - No. 30

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.402	0.467	0.523	0.576	0.615	0.618
0.252	0.290	0.371	0.453	0.495	0.586
0.328	0.377	0.453	0.495	0.498	0.496
0.400	0.443	0.474	0.509	0.514	0.512
0.362	0.399	0.467	0.483	0.471	0.472
0.312	0.353	0.443	0.501	0.513	0.535
0.363	0.404	0.499	0.540	0.527	0.515
0.282	0.335	0.394	0.460	0.507	0.519
0.365	0.405	0.473	0.522	0.549	0.531
0.380	0.441	0.501	0.538	0.551	0.540
0.339	0.366	0.444	0.486	0.500	0.515
0.337	0.401	0.457	0.528	0.546	0.539
0.352	0.389	0.479	0.530	0.551	0.550
0.302	0.342	0.429	0.518	0.568	0.556
0.356	0.393	0.462	0.499	0.513	0.512

Fig. 5.18

Standardised Gutta Percha Points - No. 40

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.362	0.383	0.417	0.475	0.531	0.601
0.440	0.447	0.471	0.514	0.557	0.576
0.458	0.520	0.580	0.620	0.645	0.643
0.422	0.475	0.512	0.571	0.607	0.621
0.426	0.430	0.451	0.509	0.548	0.586
0.459	0.472	0.492	0.531	0.613	0.643
0.418	0.473	0.538	0.580	0.612	0.637
0.395	0.398	0.512	0.537	0.584	0.632
0.401	0.434	0.515	0.599	0.645	0.659
0.459	0.457	0.474	0.525	0.560	0.606
0.463	0.469	0.561	0.608	0.608	0.617
0.463	0.471	0.482	0.541	0.559	0.579
0.423	0.465	0.518	0.589	0.643	0.688
0.465	0.461	0.478	0.527	0.555	0.572
0.410	0.433	0.465	0.538	0.596	0.650
0.438	0.450	0.472	0.516	0.564	0.598
0.401	0.422	0.441	0.504	0.537	0.605
0.409	0.404	0.451	0.522	0.589	0.651
0.422	0.471	0.507	0.531	0.613	0.620

Fig. 5.19

Standardised Gutta Percha Points - No. 50

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.452	0.532	0.613	0.714	0.742	0.788
0.418	0.500	0.563	0.646	0.715	0.735
0.453	0.506	0.602	0.689	0.705	0.754
0.396	0.482	0.533	0.655	0.750	0.756
0.474	0.594	0.667	0.719	0.753	0.769
0.452	0.512	0.646	0.705	0.752	0.766
0.438	0.475	0.523	0.664	0.699	0.740
0.476	0.537	0.651	0.752	0.751	0.781
0.440	0.510	0.612	0.698	0.762	0.760
0.385	0.443	0.556	0.639	0.668	0.728
0.477	0.542	0.643	0.724	0.773	0.798
0.509	0.536	0.611	0.657	0.698	0.718
0.489	0.548	0.620	0.668	0.714	0.738
0.482	0.523	0.607	0.678	0.712	0.726
0.510	0.576	0.624	0.677	0.733	0.737
0.486	0.528	0.593	0.631	0.665	0.729
0.474	0.524	0.584	0.656	0.681	0.718

Fig. 5.20

Standardised Gutta Percha Points - No. 60

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.605	0.727	0.758	0.815	0.865	0.879
0.626	0.731	0.742	0.794	0.840	0.851
0.566	0.625	0.738	0.785	0.831	0.830
0.579	0.647	0.738	0.808	0.844	0.856
0.578	0.643	0.743	0.788	0.825	0.837
0.643	0.705	0.740	0.817	0.855	0.868
0.600	0.661	0.777	0.833	0.856	0.863
0.564	0.637	0.719	0.793	0.812	0.838
0.641	0.663	0.713	0.782	0.827	0.843
0.538	0.595	0.670	0.752	0.789	0.810
0.617	0.665	0.761	0.816	0.831	0.842
0.604	0.656	0.710	0.787	0.823	0.827
0.613	0.673	0.746	0.792	0.822	0.853
0.582	0.626	0.715	0.811	0.838	0.852
0.507	0.614	0.692	0.751	0.794	0.845
0.594	0.666	0.745	0.811	0.835	0.863
0.580	0.636	0.746	0.805	0.840	0.835
0.574	0.632	0.724	0.787	0.832	0.846
0.547	0.636	0.742	0.814	0.831	0.842

Fig. 5.21

Standardised Gutta Percha Points - No. 70

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.729	0.730	0.766	0.840	0.897	0.955
0.804	0.815	0.871	0.909	0.938	0.951
0.758	0.761	0.837	0.891	0.941	0.964
0.762	0.794	0.861	0.912	0.948	0.969
0.737	0.768	0.825	0.879	0.928	0.951
0.756	0.796	0.850	0.927	0.979	0.994
0.793	0.791	0.839	0.903	0.931	0.952
0.707	0.734	0.792	0.876	0.954	0.984
0.791	0.817	0.862	0.918	0.950	0.975
0.831	0.864	0.906	0.932	0.957	0.969
0.804	0.840	0.881	0.925	0.942	0.968
0.702	0.728	0.822	0.887	0.934	0.962
0.814	0.834	0.873	0.881	0.953	0.965
0.736	0.768	0.808	0.880	0.937	0.969
0.802	0.842	0.900	0.932	0.950	0.976
0.760	0.781	0.818	0.886	0.941	0.968
0.700	0.737	0.794	0.861	0.913	0.950
0.761	0.784	0.847	0.896	0.940	0.969

Fig. 5.22

Standardised Gutta Percha Points - No. 80

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.800	0.889	0.992	1.026	1.017	0.997
0.785	0.883	0.988	1.027	1.049	1.037
0.791	0.855	0.926	0.950	0.962	0.970
0.794	0.856	0.947	0.980	0.986	0.992
0.769	0.850	0.940	0.988	1.007	1.042
0.778	0.890	0.974	1.001	1.021	1.008
0.816	0.892	0.973	0.993	1.018	1.037
0.828	0.879	0.975	1.010	1.027	1.021
0.798	0.872	0.969	1.025	1.034	1.039
0.796	0.879	0.966	0.990	0.992	1.034
0.781	0.860	0.937	0.998	1.028	1.026
0.846	0.912	0.986	1.012	0.998	0.993
0.860	0.909	0.966	1.004	1.010	1.010
0.773	0.901	0.988	1.036	1.025	1.059
0.822	0.903	0.963	0.981	0.950	0.957
0.798	0.881	0.941	0.998	0.991	0.997
0.786	0.870	0.938	0.993	1.009	1.013
0.752	0.837	0.970	1.012	1.019	1.026

Fig. 5.23

Standardised Gutta Percha Points - No. 90

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.950	0.974	1.032	1.049	1.088	1.107
0.942	0.984	1.064	1.073	1.102	1.104
0.922	0.964	1.028	1.079	1.128	1.140
0.970	1.008	1.040	1.103	1.126	1.151
1.037	1.086	1.107	1.135	1.121	1.132
0.934	0.959	1.009	1.063	1.117	1.149
1.012	1.035	1.086	1.131	1.159	1.187
1.062	1.092	1.182	1.190	1.174	1.117
0.927	0.974	1.017	1.066	1.105	1.140
1.030	1.045	1.107	1.133	1.140	1.163
0.950	0.983	1.054	1.112	1.141	1.155
1.007	1.018	1.036	1.054	1.054	1.076
1.023	1.063	1.104	1.125	1.153	1.176
1.038	1.054	1.091	1.097	1.100	1.111
0.976	1.012	1.084	1.149	1.171	1.181
1.010	1.059	1.098	1.140	1.172	1.202
1.055	1.105	1.088	1.081	1.095	1.117
1.017	1.050	1.079	1.087	1.103	1.093

Fig. 5.24

Standardised Gutta Percha Points - No. 100

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.947	1.000	1.013	1.119	1.191	1.213
1.028	1.091	1.192	1.252	x	x
0.986	1.097	1.162	1.200	1.221	1.243
0.941	1.043	1.140	1.220	x	x
0.959	1.007	1.151	1.197	1.226	x
0.988	1.058	1.178	1.221	1.254	x
1.155	1.223	x	x	x	x
1.017	1.093	1.165	1.172	1.209	1.229
0.941	1.043	1.161	1.229	x	x
1.177	1.256	x	x	x	x
0.855	0.966	1.083	1.169	1.193	1.235
1.115	1.169	1.237	x	x	x
1.037	1.093	1.178	1.227	x	x
1.102	1.163	1.223	x	x	x
1.047	1.112	1.184	1.243	x	x
1.034	1.088	1.196	1.239	x	x
1.018	1.049	1.183	1.233	x	x
0.957	1.054	1.174	1.240	x	x
1.220	1.235	x	x	x	x
0.987	1.134	1.214	x	x	x
1.140	1.147	1.247	x	x	x

Fig. 5.25

Standardised Gutta Percha Points - No. 110

1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
0.991	1.099	1.200	1.256	x	x
1.069	1.188	1.241	x	x	x
1.171	1.226	x	x	x	x
1.176	1.254	x	x	x	x
1.154	1.242	x	x	x	x
0.988	1.119	1.235	x	x	x
1.069	1.175	1.252	x	x	x
1.130	1.241	x	x	x	x
1.141	1.211	1.247	x	x	x
0.985	1.009	1.226	x	x	x
1.107	1.184	1.249	x	x	x
1.033	1.234	x	x	x	x
1.149	1.249	x	x	x	x
1.122	1.195	1.253	x	x	x
1.116	1.223	1.252	x	x	x
1.029	1.132	1.249	x	x	x
1.077	1.236	x	x	x	x
1.135	1.235	x	x	x	x
1.122	1.204	1.256	x	x	x

Fig. 5.26

Conventional Silver Points

No.	1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
1	0.183	0.226	0.285	0.334	0.399	0.444
	0.178	0.226	0.287	0.335	0.403	0.457
	0.179	0.228	0.284	0.344	0.413	0.450
	0.174	0.223	0.287	0.335	0.401	0.448
	0.181	0.219	0.280	0.331	0.397	0.437
2	0.266	0.310	0.362	0.410	0.482	0.502
	0.224	0.264	0.316	0.362	0.416	0.500
	0.251	0.287	0.342	0.398	0.464	0.516
	0.256	0.303	0.365	0.427	0.497	0.542
	0.261	0.304	0.364	0.411	0.467	0.536
3	0.305	0.341	0.402	0.456	0.528	0.558
	0.292	0.339	0.400	0.454	0.521	0.550
	0.290	0.330	0.387	0.437	0.500	0.561
	0.305	0.343	0.403	0.463	0.536	0.558
	0.275	0.315	0.371	0.423	0.473	0.556
4	0.342	0.380	0.431	0.488	0.535	0.592
	0.339	0.379	0.428	0.491	0.540	0.604
	0.346	0.390	0.444	0.496	0.541	0.589
	0.340	0.392	0.427	0.485	0.539	0.578
	0.328	0.386	0.430	0.493	0.542	0.607

Fig. 5.27

Conventional Silver Points

No.	1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
5	0.418	0.455	0.515	0.569	0.629	0.687
	0.423	0.460	0.521	0.570	0.641	0.703
	0.416	0.454	0.506	0.564	0.630	0.689
	0.415	0.461	0.518	0.566	0.631	0.696
	0.422	0.472	0.529	0.587	0.648	0.705
6	0.510	0.555	0.605	0.667	0.721	0.778
	0.539	0.576	0.627	0.688	0.732	0.803
	0.546	0.579	0.628	0.695	0.750	0.805
	0.537	0.571	0.627	0.678	0.732	0.800
	0.551	0.594	0.648	0.716	0.770	0.798
7	0.610	0.679	0.751	0.816	0.867	0.905
	0.611	0.685	0.760	0.792	0.870	0.914
	0.607	0.675	0.757	0.822	0.877	0.901
	0.595	0.664	0.729	0.797	0.855	0.910
	0.566	0.652	0.729	0.799	0.859	0.900
8	0.586	0.762	0.846	0.913	0.952	1.014
	0.651	0.791	0.858	0.913	0.952	1.013
	0.659	0.794	0.849	0.905	0.944	1.012
	0.677	0.750	0.833	0.904	0.964	1.010
	0.737	0.770	0.822	0.881	0.930	1.012

Fig. 5.28

Conventional Silver Points

No.	1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
9	0.804	0.869	0.907	0.950	1.006	1.104
	0.802	0.861	0.894	0.949	0.998	1.096
	0.806	0.861	0.904	0.951	1.001	1.102
	0.822	0.854	0.910	0.962	1.002	1.107
	0.807	0.852	0.897	0.950	1.001	1.100
10	0.942	0.968	1.024	1.111	1.126	1.213
	0.960	0.988	1.033	1.110	1.142	1.214
	0.927	0.958	1.012	1.073	1.121	1.217
	0.956	0.996	1.040	1.105	1.149	1.213
	0.962	0.981	1.047	1.101	1.147	1.217
11	1.031	1.077	1.128	1.172	1.216	x
	1.002	1.068	1.124	1.161	1.216	x
	1.010	1.064	1.119	1.154	1.204	x
	1.019	1.073	1.122	1.175	1.223	x
	1.015	1.050	1.101	1.144	1.195	x
12	1.124	1.164	1.221	x	x	x
	1.140	1.175	1.234	x	x	x
	1.108	1.140	1.197	x	x	x
	1.103	1.138	1.190	x	x	x
	1.113	1.150	1.202	x	x	x

Fig. 5.29

Standardised Silver Points

No.	1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
15	0.173	0.207	0.272	0.330	0.389	0.447
	0.197	0.236	0.299	0.351	0.413	0.453
	0.180	0.221	0.289	0.341	0.408	0.451
	0.193	0.231	0.289	0.349	0.405	0.458
	0.194	0.236	0.299	0.352	0.420	0.440
20	0.238	0.276	0.348	0.399	0.459	0.501
	0.231	0.274	0.332	0.380	0.443	0.499
	0.245	0.299	0.352	0.393	0.454	0.499
	0.234	0.278	0.334	0.387	0.449	0.520
	0.234	0.279	0.327	0.389	0.447	0.501
25	0.277	0.320	0.378	0.431	0.494	0.548
	0.269	0.312	0.370	0.412	0.484	0.549
	0.288	0.327	0.389	0.438	0.497	0.558
	0.297	0.342	0.389	0.452	0.509	0.564
	0.273	0.309	0.367	0.426	0.492	0.559
30	0.329	0.375	0.438	0.481	0.564	0.606
	0.353	0.390	0.456	0.501	0.566	0.609
	0.345	0.384	0.446	0.501	0.555	0.611
	0.353	0.389	0.447	0.498	0.562	0.603
	0.328	0.371	0.436	0.485	0.552	0.607

Fig. 5.30

Standardised Silver Points

No.	1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
40	0.422	0.466	0,517	0.570	0.629	0.688
	0.417	0.453	0.519	0.565	0.632	0.684
	0.414	0.451	0.507	0.562	0.629	0.683
	0.411	0.450	0.500	0.570	0.619	0.688
	0.405	0.451	0.505	0.560	0.617	0.686
50	0.516	0.564	0.615	0.668	0.734	0.788
	0.531	0.570	0.632	0.685	0.744	0.785
	0.529	0.572	0.613	0.679	0.744	0.797
	0.503	0.540	0.608	0.661	0.718	0.782
	0.523	0.574	0.634	0.685	0.744	0.792
60	0.602	0.663	0.750	0.809	0.871	0.903
	0.596	0.660	0.742	0.805	0.855	0.905
	0.594	0.661	0.743	0.802	0.852	0.904
	0.608	0.682	0.763	0.835	0.879	0.910
	0.595	0.663	0.740	0.801	0.863	0.900
70	0.689	0.767	0.836	0.905	0.954	0.991
	0.700	0.762	0.835	0.903	0.953	1.008
	0.713	0.779	0.853	0.920	0.967	1.011
	0.701	0.776	0.845	0.917	0.956	1.008
	0.700	0.769	0.843	0.914	0.965	1.012

Fig. 5.31

Standardised Silver Points

No.	1 mm	3 mm	6 mm	9 mm	12 mm	15 mm
80	0.775	0.861	0.933	1.004	1.059	1.114
	0.779	0.878	0.966	1.033	1.082	1.113
	0.789	0.878	0.965	1.032	1.089	1.106
	0.775	0.868	0.954	1.026	1.085	1.116
	0.785	0.870	0.960	1.021	1.085	1.116
90	0.893	0.993	1.073	1.140	1.189	1.223
	0.872	0.993	1.071	1.135	1.196	1.215
	0.841	0.974	1.059	1.125	1.187	1.212
	0.866	0.983	1.063	1.137	1.193	1.219
	0.876	0.987	1.069	1.135	1.197	1.216
100	0.888	1.069	1.134	1.207	x	x
	0.937	1.053	1.129	1.200	x	x
	0.979	1.045	1.133	1.199	x	x
	0.941	1.052	1.131	1.203	x	x
	0.950	1.044	1.143	1.202	x	x
110	1.096	1.138	1.199	1.255	x	x
	1.121	1.159	1.220	x	x	x
	1.102	1.150	1.206	1.253	x	x
	1.122	1.178	1.222	x	x	x
	1.099	1.141	1.208	1.251	x	x

Fig. 5.32

Discussion of Results

The plea made by Grove (1929) and Ingle (1955) for standardisation of root canal instruments and root filling points has been accepted by most of the dental manufacturing companies. Instruments and points are now produced which are said to conform to universal specifications. The days are long since past when it was necessary to pick through a box of assorted points in order to select one which nearly corresponded to the diameter and taper of the prepared root canal. The size number of the root filling point now corresponds to the size number on the instrument, and it is stated by the manufacturer that the root filling point is 'matched' in diameter and taper to the root canal instrument.

When considering the diameter of the root canal instrument it is known that, because the initial process of manufacture is carried out by machines, a reasonably close tolerance limit of ± 0.005 mm is possible (Gehrig (1965) and Maillefer (1966)). However, the final twisting of the prepared metal shank into reamer form is less critical since the molecular configuration of the steel along the entire length of the shaft can never be uniform and therefore absolutely uniform twisting can never be attained, some positions along the length of the shaft having a greater or smaller diameter than others. For this reason the tolerance limits are stated to be ± 0.025 mm. It is therefore apparent that it is not possible to obtain root canal instruments that are identical in diameter one to the other, an allowance must always be made for manufacturing tolerance limits.

Bearing in mind the manufacturer's statement of tolerances, root filling points should conform to a mean diameter of the root canal instruments. Unfortunately, when it comes to considering whether or not gutta percha points conform to the mean diameter of the ihstruments, a further difficulty arises and must be taken into account. Gutta percha points are manufactured by rolling a 'string' of gutta percha, of given diameter, into a given size root filling point. This operation is carried out manually and even though it is carried out by women of great experience, it is understandable that no great accuracy in diameter can be obtained. The tolerance limits in the case of gutta percha points is stated to be ± 0.05 mm (Gehrig (1965)).

When considering silver points on the other hand, these are entirely machine made and, as one would expect, the manufacturing tolerance limits are correspondingly more precise, namely, ± 0.001 mm. Provided the cutting edge of the tool which forms the taper on the silver wire as it is fed into the machine is kept under constant surveillance, no great inaccuracies in obtaining uniform diameters can occur.

In order that it can be ascertained whether or not the diameter of the root filling points correspond to the diameter stated by the manufacturer, it is necessary to add to the stated diameter the tolerance limits within which these points are manufactured. For example, the stated diameter of a No. 40 gutta percha point at 1 mm from the tip is 0.40 mm; the manufacturing tolerance is ± 0.05 mm, which must be added and substracted from 0.40 mm. Therefore, all No. 40 gutta percha points which fall within 0.35 mm and 0.45 mm, at

1 mm from the tip, will compare favourably with the diameter stated by the manufacturer.

The number of Conventional and Standardised gutta percha points investigated whose diameter corresponds to the manufacturer's stated diameter is set out in Figs. 5.33 and 5.34 respectively. Similarly, the number of Conventional and Standardised Silver points investigated whose diameter corresponds to the stated diameter is set out in Figs. 5.35 and 5.36.

While it is stated by the manufacturer that root filling points are manufactured to conform to the diameter of the root canal instruments, this is not the complete picture. A further factor, must of necessity, be taken into account. Consideration must be given to the well known engineering fact that it is impossible to drill a hole whose diameter corresponds exactly to the diameter of the drill being used. It is pointed out that in the case of a root canal reamer this instrument can be said to correspond to a metal drill and should not be confused with an engineer's reamer which is an entirely different instrument and is used in an entirely different manner. In every case where the drilling process is carried out, the diameter of the drilled hole will be greater than the diameter of the drill to a greater or lesser extent, depending on the manner in which the cutting edge of the drill is ground. It has been stated (Austin (1963)) that incorrect grinding of the drill point results in the cutting flutes being longer on one side than the other and results in an oversize and non-circular hole.

Since, as has already been pointed out, a root canal reamer can

Conventional Gutta Percha Points

Point Number	1 mm from tip	3 mm from tip	6 mm from tip	Total Points measured
1	24	30	30	32
2	16	23	24	32
3	20	23	25	31
4	33	31	32	33
5	23	24	26	32
6	8	16	20	33
7	17	29	27	31
8	17	20	21	32
9	0	0	2	32
10	9	6	4	32
11	10	10	15	30
12	6	10	16	31

Fig. 5.33 Number of Conventional Gutta Percha points whose diameter conforms to the manufacturer's data.

Standardised Gutta Percha Points

Point Number	1 mm from tip	3 mm from tip	6 mm from tip	Total Points measured
15	0	4	8	18
20	0	0	0	17
25	2	3	6	19
30	7	7	6	15
40	13	17	13	19
50	12	13	14	17
60	17	17	16	19
70	7	10	11	18
80	18	14	6	18
90	6	11	7	18
100	11	19	3	21
110	11	6	11	19

Fig. 5.34 Number of Standardised Gutta Percha points whose diameter conforms to the manufacturer's data.

Conventional Silver Points

Point Number	1 mm from tip	3 mm from tip	6 mm from tip	Total Points measured
1	0	0	0	5
2	0	0	0	5
3	0	0	0	5
4	0	0	0	5
5	0	0	1	5
6	0	0	0	5
7	0	0	0	5
8	0	0	0	5
9	0	0	1	5
10	0	0	0	5
11	0	0	0	5
12	0	0	0	5

Fig. 5.35 Number of Conventional Silver points whose diameter conforms to the manufacturer's data.

Standardised Silver Points

Point Number	1 mm from tip	3 mm from tip	6 mm from tip	Total Points measured
15	0	0	0	5
20	0	0	0	5
25	0	0	0	5
30	0	0	0	5
40	0	0	1	5
50	0	0	1	5
60	0	0	0	5
70	3	0	0	5
80	0	0	0	5
90	0	0	0	5
100	0	1	0	5
110	0	0	2	5

Fig. 5.36 Number of Standardised Silver points whose diameter conforms to the manufacturer's data.

never be twisted into a uniform spiral, this will inevitably result in the reamer having one cutting edge longer than the other and, as such, will ream (drill) a root canal to a diameter which is larger than the reamer diameter itself. As far as the degree of non-circularity is concerned, it is felt that this is of little import since the dimensions are microscopic and will, in any case, be counterbalanced by the flexibility and flow of the gutta percha, when using this material as the canal obturator.

That the diameter of the reamed canal is greater than the diameter of the instrument used, at a given point along its long axis, was proved by a small survey of 12 teeth that were reamed to a specific instrument size. These teeth were reamed to within 1 mm of the true apex of the tooth and sectioned at 3 mm from the apex, all measurements and sectioning being carried out as precisely as possible under a watchmaker's lens. The position of the reamed root canal at 3 mm from the apex corresponds to the position on the root canal reamer 2 mm from the tip, since the canal was reamed to within 1 mm from the apex. Measurements of root canal diameter and reamer diameter at these two positions were carried out under the measuring microscope and the results tabulated in Fig. 5.37. This small survey shows an increase (2% - 10%) in the diameter of the root canal over the reamer diameter. This agrees favourably with Haga (1967) who found the increase in diameter to be between 3.8% and 12.8%.

Therefore, to be assured that a good hermetic seal will be obtained, a root filling point must be used whose diameter is greater than the instrument diameter. It was necessary to ascertain the number of root filling points out of the total investigated whose

Experiment	Tooth reamed 1 mm short of apex with reamer number	Diameter of reamer at 2 mms from tip - in millimetres	Diameter of root canal 3 mms from apex - in millimetres
1	8	0.739	0.756
2	8	0.739	0.776
3	8	0.739	0.817
4	8	0.739	0.783
5	10	0.922	0.986
6	10	0.922	0.947
7	10	0.922	0.983
8	10	0.922	0.972
9	12	1.140	1.187
10	12	1.140	1.179
11	12	1.140	1.187
12	12	1.140	1.184

Fig. 5.37

diameter was greater than the diameter stipulated by the manufacturer, even allowing for the tolerance limits given in the technical data. Also, since it has been accepted that the correct level of filling the root canal is the dentino-cemental junction, particular attention was paid to the apical portion of the root filling point, that is, the terminal 6 mm, 3 mm and 1 mm region. It will be seen from the table (Fig. 5.38) of measurements for Conventional gutta percha points that out of a total of 381 points investigated, the number that were larger than the stated diameter at 1 mm was 141, at 3 mm 151 and at 6 mm 146. Expressed as a percentage, this means that only 37% of the points measured at 1 mm, 40% at 3 mm and 38% at 6 mm were larger than the diameter stipulated by the manufacturer (Fig. 5.39).

On the other hand, out of a total of 218 Standardised gutta percha points measured (Fig. 5.40), 72% at 1 mm, 83% at 3 mm and 86% at 6 mm were larger in diameter than the diameter laid down by the manufacturer (Fig. 5.41). A histogram showing the percentage difference between Standardised and Conventional gutta percha points is shown in Fig. 5.42.

As was stated on page 35; if it is found that the diameter of the root filling point is larger than the diameter of the instrument used in the preparation of the canal, this would lead to ensuring that a good hermetic seal would be obtained. From the information recorded, a greater percentage of Standardised gutta percha points were larger in diameter than Conventional gutta percha points; it can be stated therefore that there is more certainty of obtaining a good hermetic seal by utilising Standardised gutta percha points than

Conventional Gutta Percha Points

Point Number	1 mm from tip	3 mm from tip	6 mm from tip	Total points measured
1	32	26	17	32
2	31	29	24	32
3	24	17	13	31
4	11	11	7	33
5	10	15	15	32
6	2	4	4	33
7	3	7	20	31
8	6	9	9	32
9	0	0	1	32
10	8	11	13	32
11	8	9	9	30
12	6	13	14	31

Fig. 5.38 Number of Conventional Gutta Percha points whose diameter is greater than that stipulated by the manufacturer.

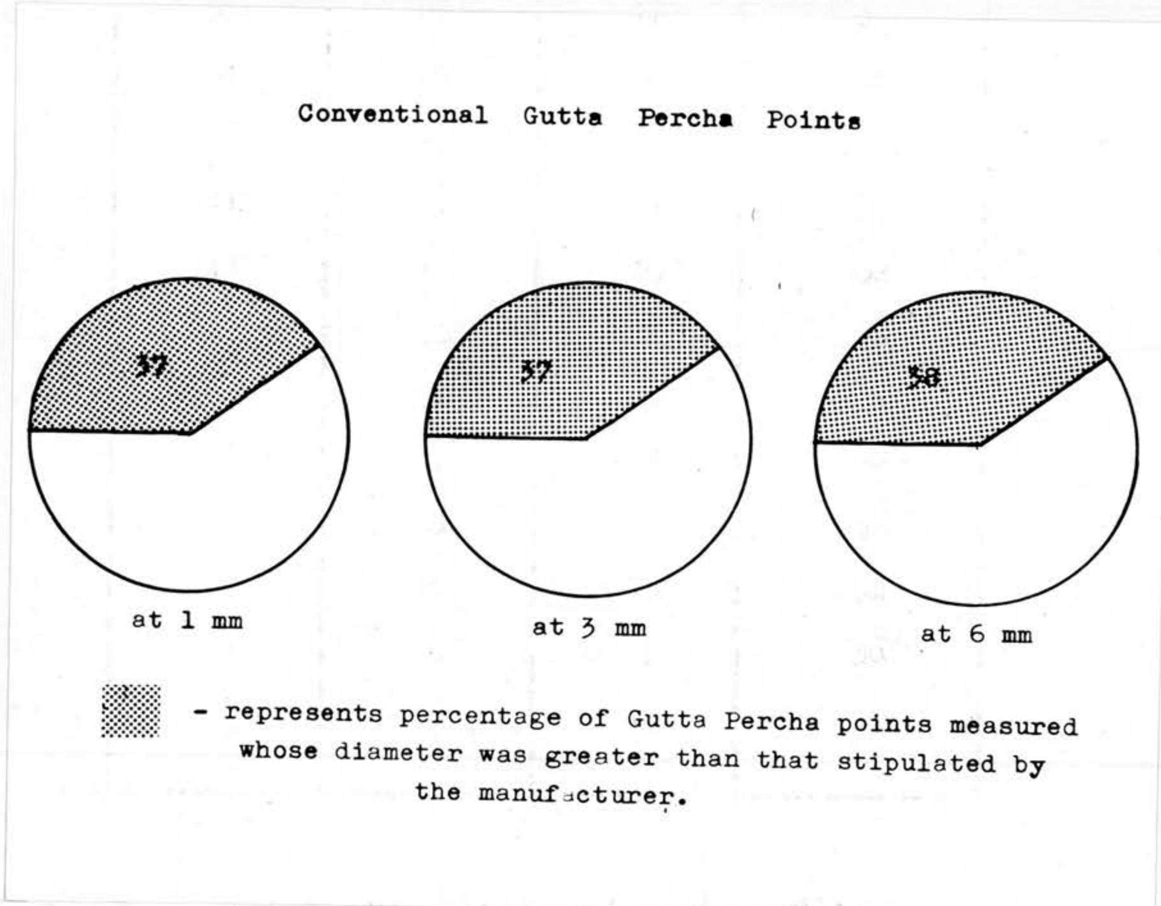

Conventional Gutta Percha Points
37
37
38
at 1 mm
at 3 mm
at 6 mm
- represents percentage of Gutta Percha points measured whose diameter was greater than that stipulated by the manufacturer.

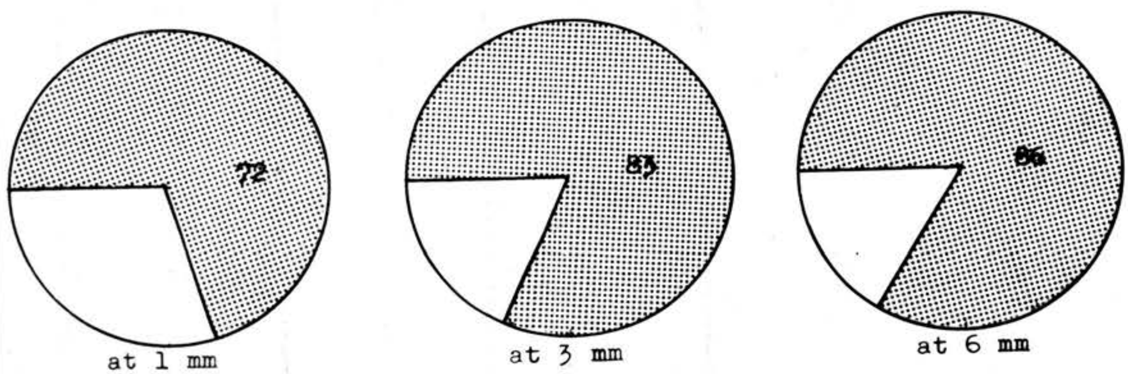
Fig. 5.39

Standardised Gutta Percha Points

Point Number	1 mm from tip	3 mm from tip	6 mm from tip	Total Points measured
15	18	18	18	18
20	17	17	17	17
25	18	18	18	19
30	13	12	13	15
40	17	12	7	19
50	2	3	9	17
60	7	10	17	19
70	17	14	15	18
80	5	17	18	18
90	18	18	18	18
100	12	16	19	21
110	11	15	18	19

Fig. 5.40 Number of Standardised Gutta Percha points whose diameter is greater than that stipulated by the manufacturer.

Standardised Gutta Percha Points



- represents percentage of Gutta Percha points measured whose diameter was greater than that stipulated by the manufacturer.

Fig. 5.41

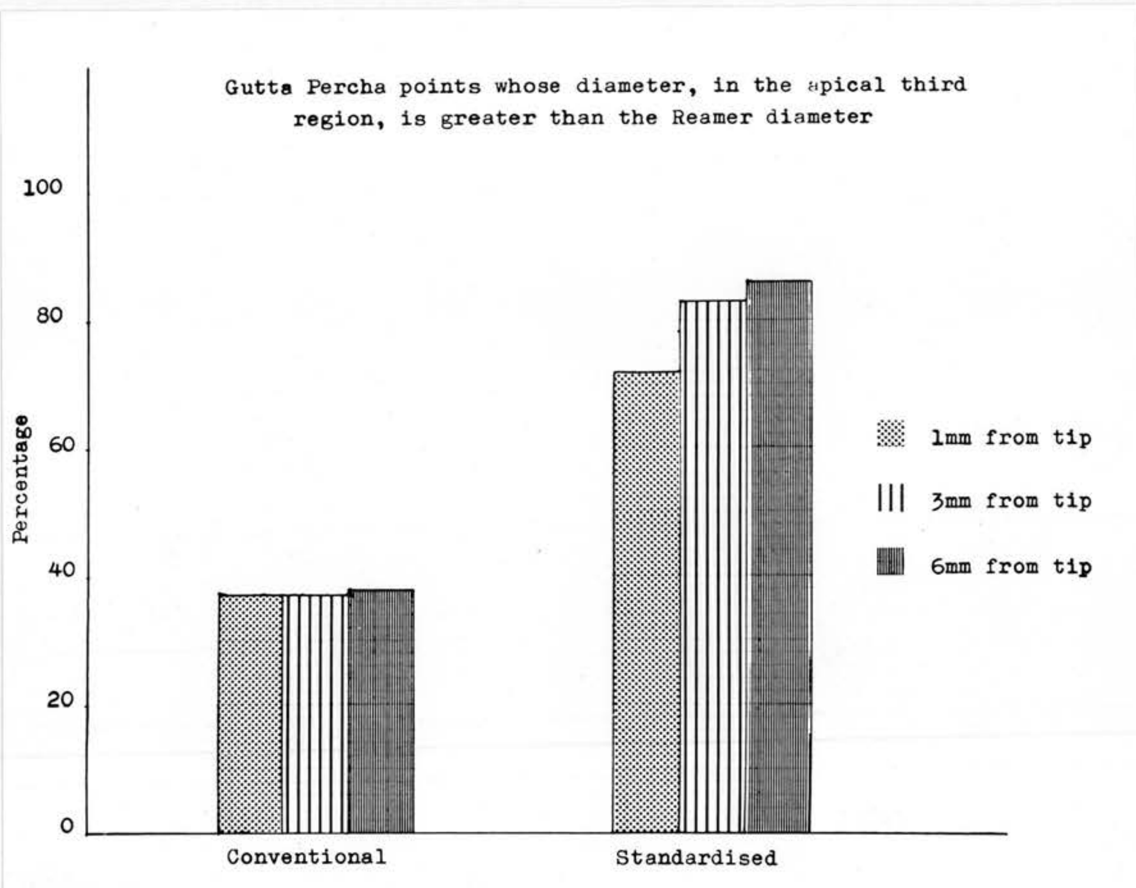

Gutta Percha points whose diameter, in the apical third region, is greater than the Reamer diameter
100
80
60
40
20
0
Percentage
1mm from tip
3mm from tip
6mm from tip
Conventional
Standardised

Fig. 5.42

would be possible when Conventional gutta percha points are used to obturate the root canal of a permanent tooth.

While this is only one facet of the picture there still remains the question of the point diameter relative to the preparing instrument. The results of the readings obtained for Conventional and Standardised gutta percha points relative to the instrument diameters are set out in Fig. 5.43 for distances 1 mm from the tip, in Fig. 5.44 for distances of 3 mm from tip and in Fig. 5.45 for 6 mm from tip. From Fig. 5.43 it will be observed that at 1 mm from the tip, all Standardised gutta percha points are greater in diameter than the mean diameter of the reamer, except No. 7, whereas the measurements for Conventional gutta percha points show that only sizes Nos. 1, 2, 3 and 12 were larger in diameter than the reamer diameter.

When the measurements were taken at 3 mm from the tip, it will be seen that again only one size (No. 6) in Standardised gutta percha points was smaller than the reamer diameter (Fig. 5.44). In the case of Conventional gutta percha points at 3 mm from the tip, Fig. 5.44 shows that only 3 sizes were larger than the reamer, namely, Nos. 1, 2 and 3.

At 6 mm from the tip, Fig. 5.45 shows that measurement for Nos. 5 and 6 were smaller than the reamer in Standardised gutta percha points while only two sizes for Conventional gutta percha points were larger in diameter, that is, sizes Nos. 2 and 7.

Therefore, since it has been stated that a good hermetic seal is obtained by using gutta percha points with a diameter larger than the reamer, this seal will be obtained with more certainty when

Number	Mean diameter of Conventional Gutta Percha points at 1 mm from tip	Mean diameter of Reamer - 1 mm from tip	Mean diameter of Standardised Gutta Percha points at 1 mm from tip	Number
1	0.192	0.163	0.235	15
2	0.249	0.202	0.342	20
3	0.293	0.269	0.365	25
4	0.295	0.306	0.342	30
5	0.386	0.417	0.428	40
6	0.429	0.448	0.459	50
7	0.578	0.602	0.587	60
8	0.658	0.667	0.763	70
9	0.599	0.795	0.798	80
10	0.752	0.862	0.992	90
11	0.887	0.903	1.031	100
12	0.989	0.966	1.093	110

Fig. 5.43

Number	Mean diameter of Conventional Gutta Percha points at 3 mm from tip	Mean diameter of Reamer - 3 mm from tip	Mean diameter of Standardised Gutta Percha points at 3 mm from tip	Number
1	0.215	0.209	0.260	15
2	0.281	0.244	0.378	20
3	0.321	0.312	0.389	25
4	0.334	0.361	0.387	30
5	0.440	0.449	0.449	40
6	0.488	0.538	0.522	50
7	0.624	0.636	0.655	60
8	0.710	0.712	0.788	70
9	0.670	0.849	0.879	80
10	0.842	0.934	1.025	90
11	0.950	1.060	1.101	100
12	1.085	1.092	1.192	110

Fig. 5.44

Number	Mean diameter of Conventional Gutta Percha points at 6 mm from tip	Mean diameter of Reamer - 6 mm from tip	Mean diameter of Standardised Gutta Percha points at 6 mm from tip	Number
1	0.261	0.271	0.315	15
2	0.333	0.300	0.429	20
3	0.365	0.398	0.418	25
4	0.386	0.432	0.458	30
5	0.508	0.528	0.491	40
6	0.575	0.622	0.603	50
7	0.718	0.706	0.733	60
8	0.784	0.831	0.842	70
9	0.771	0.928	0.963	80
10	0.964	1.025	1.072	90
11	1.040	1.140	1.176	100
12	1.146	1.195	1.242	110

Fig. 5.45

Standardised points are used in preference to Conventional points.

When silver points are considered it was felt that no great discrepancy should be revealed between Conventional and Standardised silver points for the simple reason that both types are manufactured by machine and therefore no great difference should occur in diameter unless the manufacturer had gone to some trouble to ensure that Standardised points were manufactured to closer tolerance limits than Conventional points.

From the histogram in Fig. 5.46 it will be observed that both Standardised and Conventional silver points follow roughly the same pattern in that approximately the same number of both types of points are greater in diameter than the reamer diameter. The actual numbers of both types at the various positions are set out in the tables in Figs. 5.47 and 5.48. From this it can be deduced that, if anything, the advantage lies with the Conventional silver point in obtaining a good hermetic seal. In fairness, however, it should be reiterated that Conventional silver points are no longer available or, at least all Produits Dentaire silver points on the market today are said to be Standardised silver points (Gehrig (1965)) and are labelled with both the old number (Conventional) and the new number (Standardised).

In order that an overall picture of the fit of the various points used in the obturation of the root canal might be obtained, graphs were drawn comparing the mean diameter of the root canal reamer with the mean diameter of the points used. These graphs compare the diameters at various points along their long axis. It will be

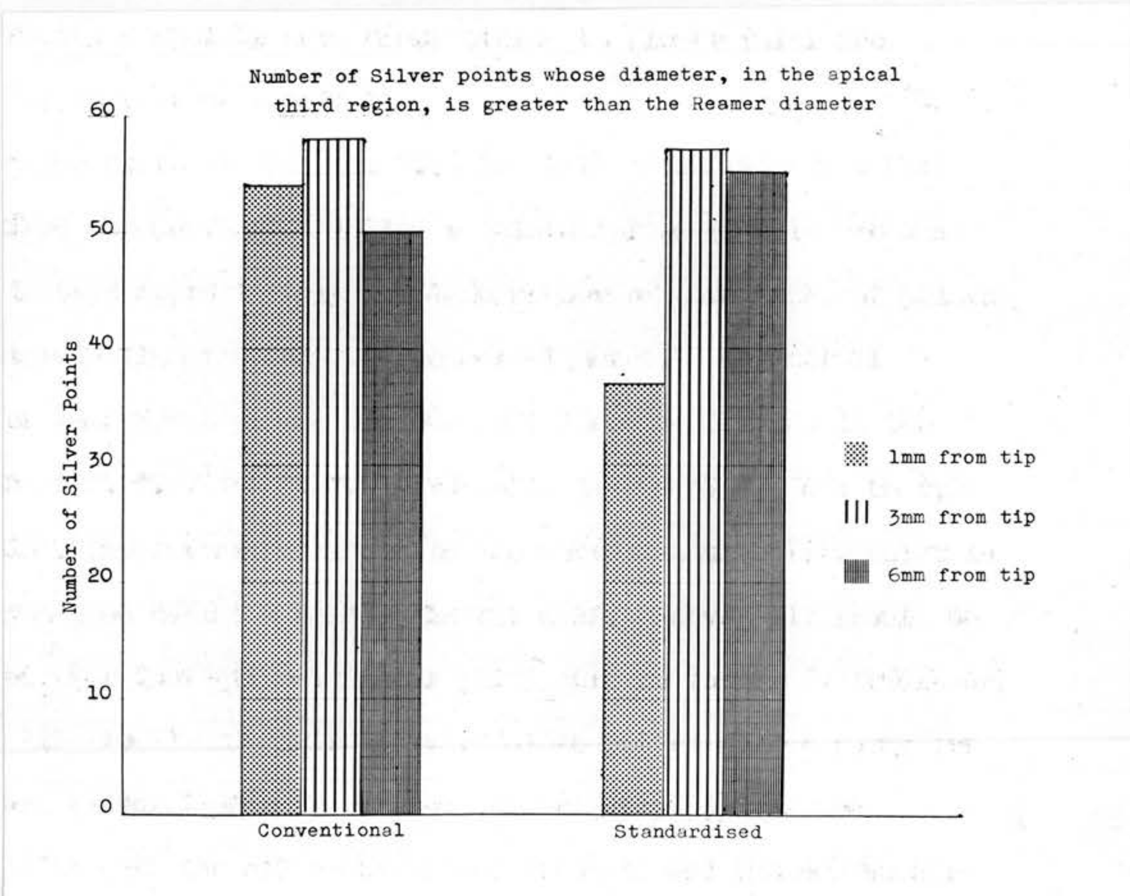

Number of Silver points whose diameter, in the apical third region, is greater than the Reamer diameter
60
50
40
30
20
10
0
Number of Silver Points
Conventional
Standardised
1mm from tip
3mm from tip
6mm from tip

Fig. 5.46

Standardised Silver Points

Point Number	1 mm from tip	3 mm from tip	6 mm from tip	Total Points measured
15	5	5	5	5
20	5	5	5	5
25	5	5	5	5
30	5	5	5	5
40	5	5	2	5
50	5	4	5	5
60	2	5	5	5
70	2	5	5	5
80	0	5	5	5
90	0	5	5	5
100	0	5	5	5
110	3	3	3	5

Fig. 5.47 Number of Standardised Silver points whose diameter is greater than that stipulated by the manufacturer.

Conventional Silver Points

Point Number	1 mm from tip	3 mm from tip	6 mm from tip	Total points measured
1	5	5	5	5
2	5	5	5	5
3	5	5	5	5
4	5	5	5	5
5	5	5	4	5
6	5	5	4	5
7	3	5	5	5
8	1	5	5	5
9	5	5	1	5
10	5	5	5	5
11	5	5	4	5
12	5	3	2	5

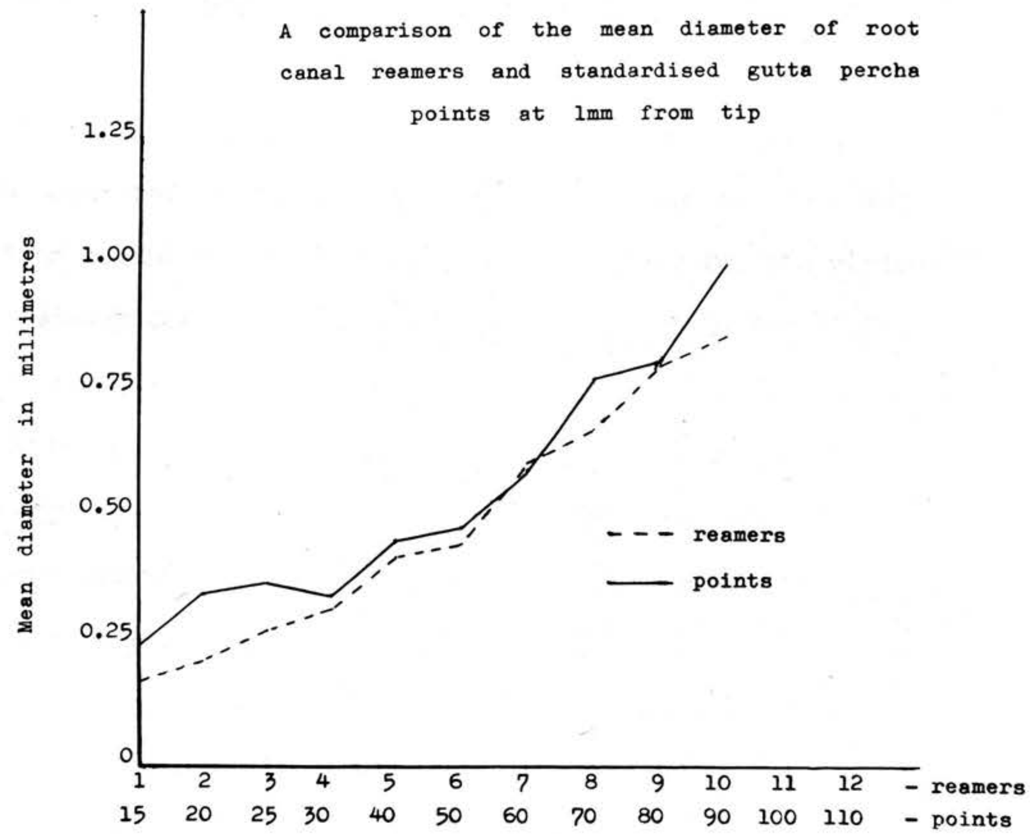
Fig. 5.48 Number of Conventional Silver points whose diameter is greater than that stipulated by the manufacturer.

observed from Fig. 5.49 that in the region 1 mm from the tip, standardised gutta percha were all larger in diameter than the reamer with the exception of size 60. In the region 3 mm (Fig. 5.50) from the tip only size 50 was smaller in diameter than the reamer, while at the 6 mm mark (Fig. 5.51) only size 40 was smaller than the reamer diameter. These three graphs indicate that standardised gutta percha points form a very suitable medium for obturation purposes in the root canal of a permanent tooth.

When the graph for silver points is examined it will be seen that there is a closer relationship between the mean diameters of the point and the reamer. This is to be expected purely on the grounds of manufacturing processes. At the 1 mm mark (Fig. 5.52), size 40 was the only size smaller than the reamer, at 3 mm from the tip (Fig. 5.53) it was size 100, while at 6 mm (Fig. 5.54) it was sizes 25 and 40.

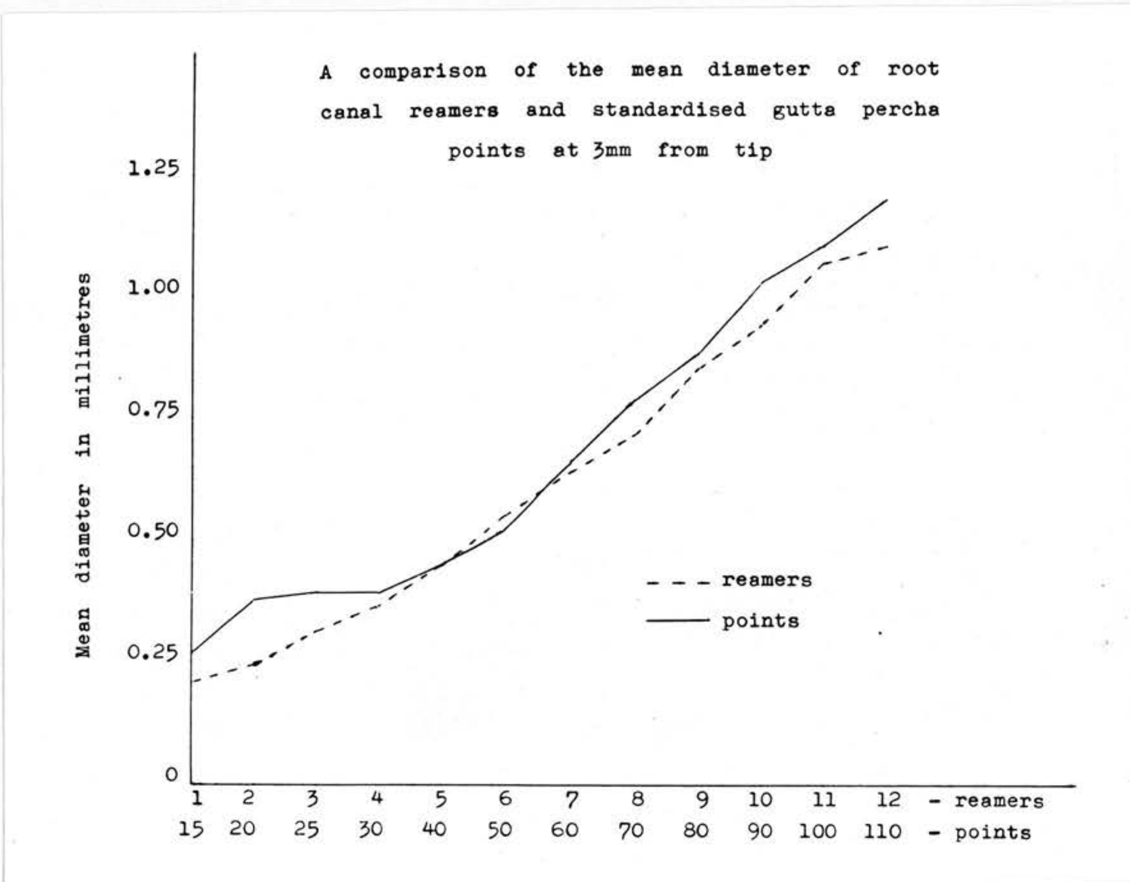
From these graphs it can be seen that there is more uniformity between the mean diameters of the reamer and the silver point than between the reamer and the gutta percha point. This is in direct contrast to the findings of Allen (1968). It is therefore considered that there will be less trial and error in the selection of the required point to fill the prepared canal in the case of the silver point. Since there is a wider divergence in the mean diameters of the gutta percha points, more time would be required to select a suitable point to fill the prepared root canal

To sum up the findings of this particular chapter - it has been shown that when it comes to obturating the root canal of a permanent tooth, there is more certainty of obtaining the desired



A comparison of the mean diameter of root canal reamers and standardised gutta percha points at 1mm from tip
Mean diameter in millimetres
1.25
1.00
0.75
0.50
0.25
0
reamers
points
1 2 3 4 5 6 7 8 9 10 11 12 - reamers
15 20 25 30 40 50 60 70 80 90 100 110 - points

Fig. 5.49



A comparison of the mean diameter of root canal reamers and standardised gutta percha points at 3mm from tip
Mean diameter in millimetres
1.25
1.00
0.75
0.50
0.25
0
- - - reamers
—— points
1 2 3 4 5 6 7 8 9 10 11 12 - reamers
15 20 25 30 40 50 60 70 80 90 100 110 - points

Fig. 5.50

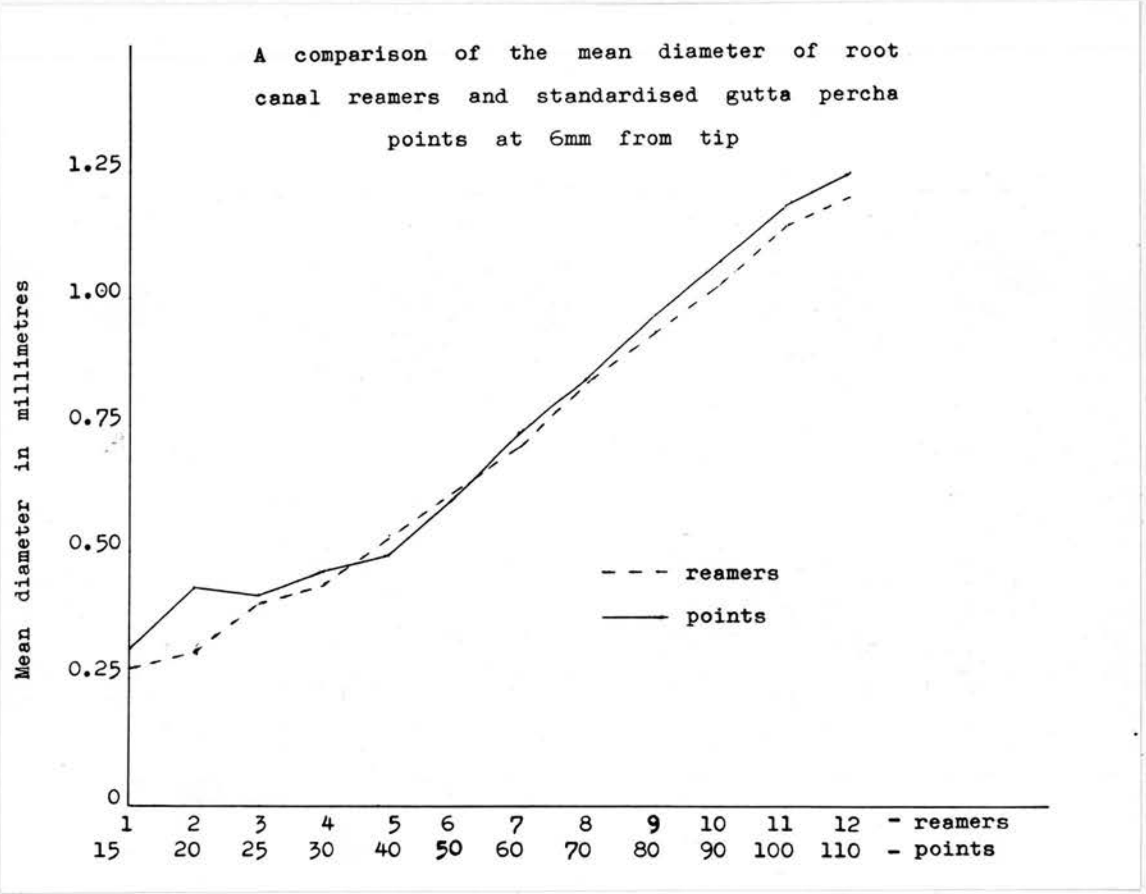

A comparison of the mean diameter of root canal reamers and standardised gutta percha points at 6mm from tip
Mean diameter in millimetres
1.25
1.00
0.75
0.50
0.25
0
reamers
points
1 2 3 4 5 6 7 8 9 10 11 12 - reamers
15 20 25 30 40 50 60 70 80 90 100 110 - points

Fig. 5.51

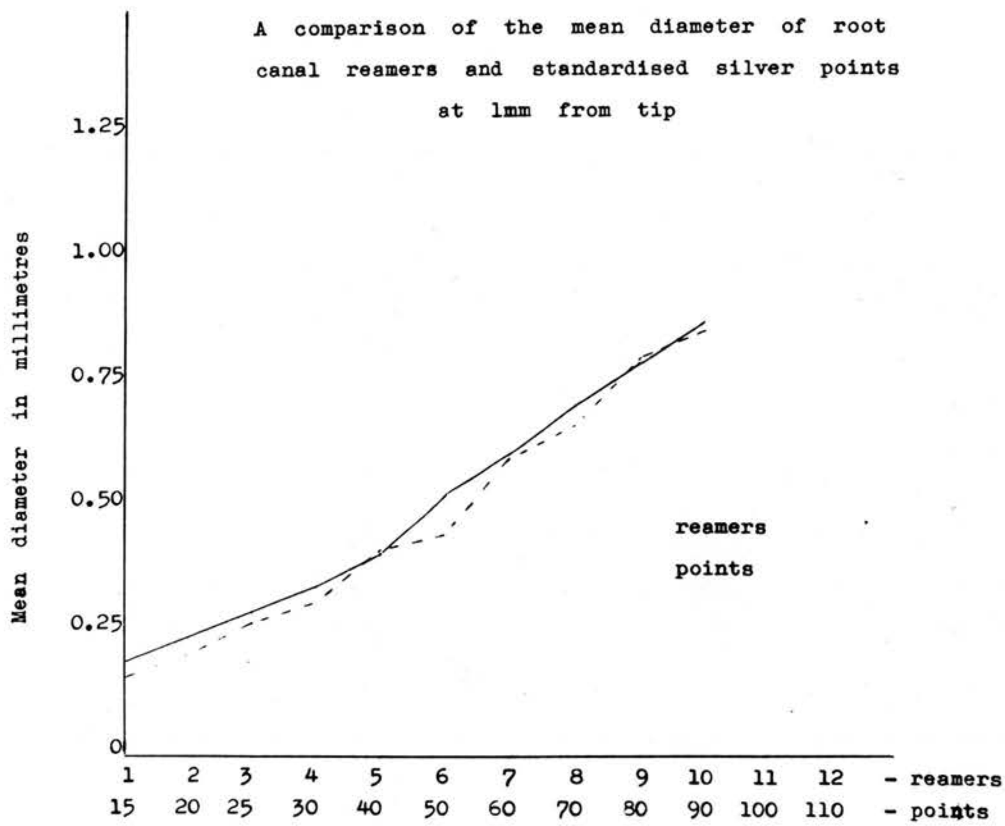

A comparison of the mean diameter of root
canal reamers and standardised silver points
at 1mm from tip
Mean diameter in millimetres
1.25
1.00
0.75
0.50
0.25
0
reamers
points
1 2 3 4 5 6 7 8 9 10 11 12 - reamers
15 20 25 30 40 50 60 70 80 90 100 110 - points

Fig. 5.52

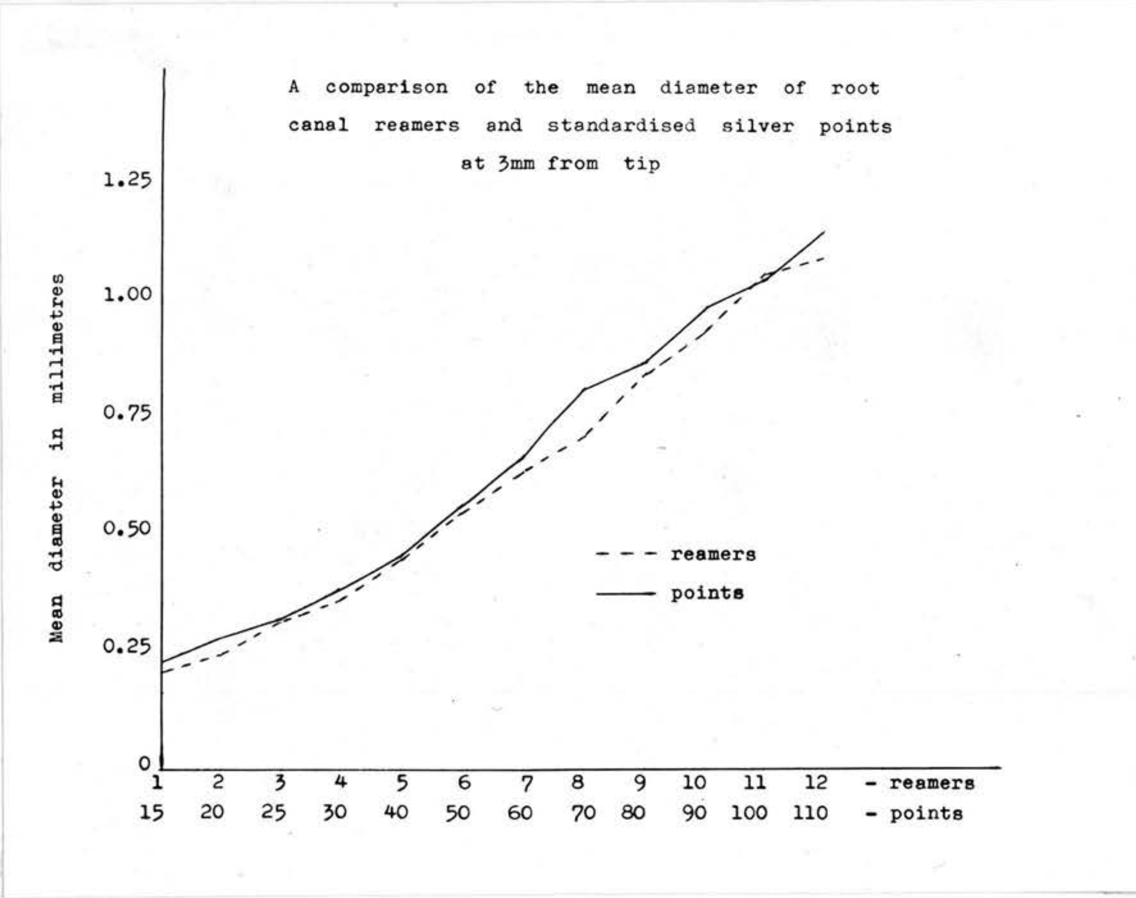

A comparison of the mean diameter of root canal reamers and standardised silver points at 3mm from tip
Mean diameter in millimetres
1.25
1.00
0.75
0.50
0.25
0
reamers
points
1 2 3 4 5 6 7 8 9 10 11 12 - reamers
15 20 25 30 40 50 60 70 80 90 100 110 - points

Fig. 5.53

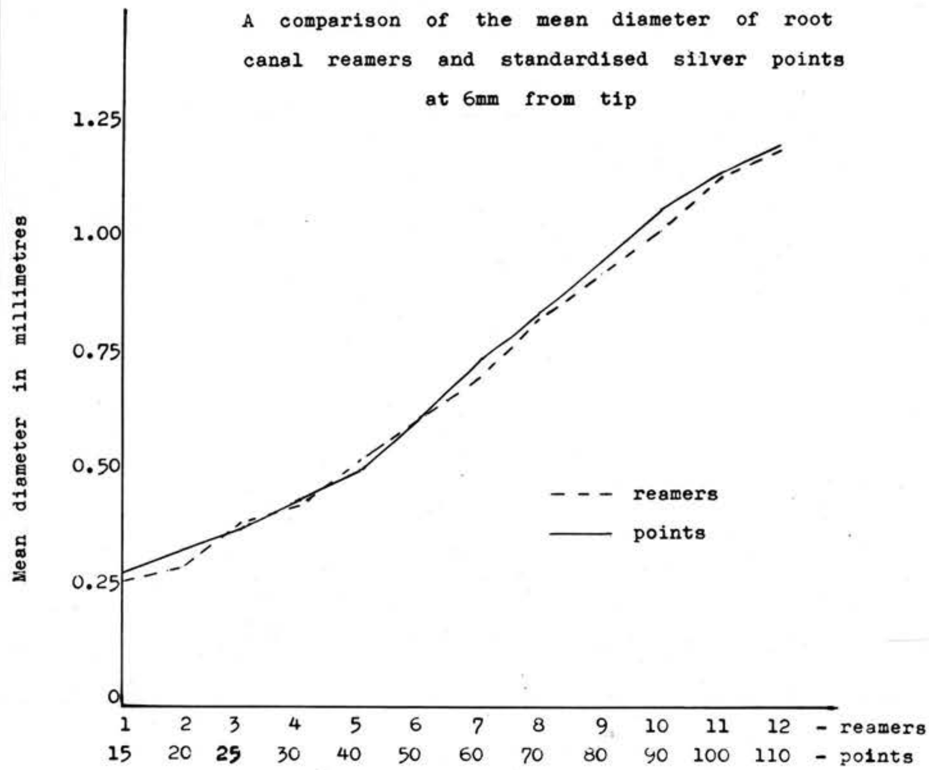

A comparison of the mean diameter of root canal reamers and standardised silver points at 6mm from tip
Mean diameter in millimetres
1.25
1.00
0.75
0.50
0.25
0
- - - reamers
—— points
1 2 3 4 5 6 7 8 9 10 11 12 - reamers
15 20 25 30 40 50 60 70 80 90 100 110 - points

Fig. 5.54

hermetic seal in the apical region if silver points are used. On the other hand, it is not always desirable that silver should be used, this being especially so in the case of a tooth which will eventually require a post crown restoration. It is, however, possible to obtain a good seal with gutta percha points since by and large they provide over the complete range of sizes an increase in mean diameter over the root canal reamers. One would still have to resort to a certain amount of trial and error in certain sizes. This fact alone can be frustrating, in some ways, in a technique which requires a good deal of application and accuracy. Illustration of the irregular increase in diameter for the various sizes of Conventional gutta percha points is shown in Fig. 5.55. The graphs in Figs. 5.56, 5.57 and 5.58 relate to Standardised gutta percha points and Conventional and Standardised silver points respectively, the latter two being more linear than those for gutta percha points, showing that the increase in diameter, size by size, is more uniform.

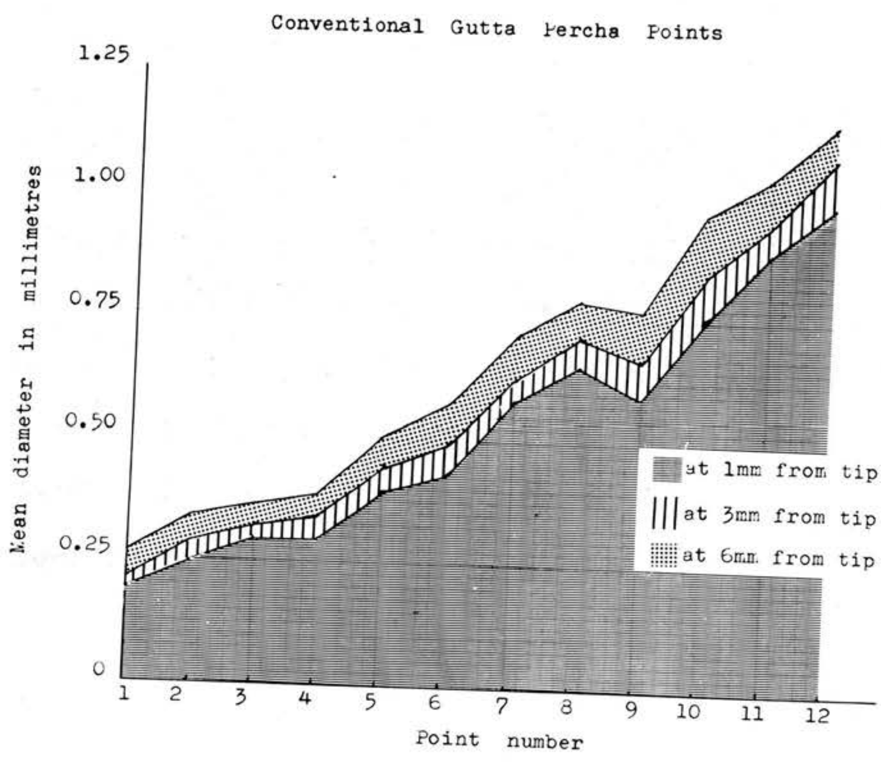
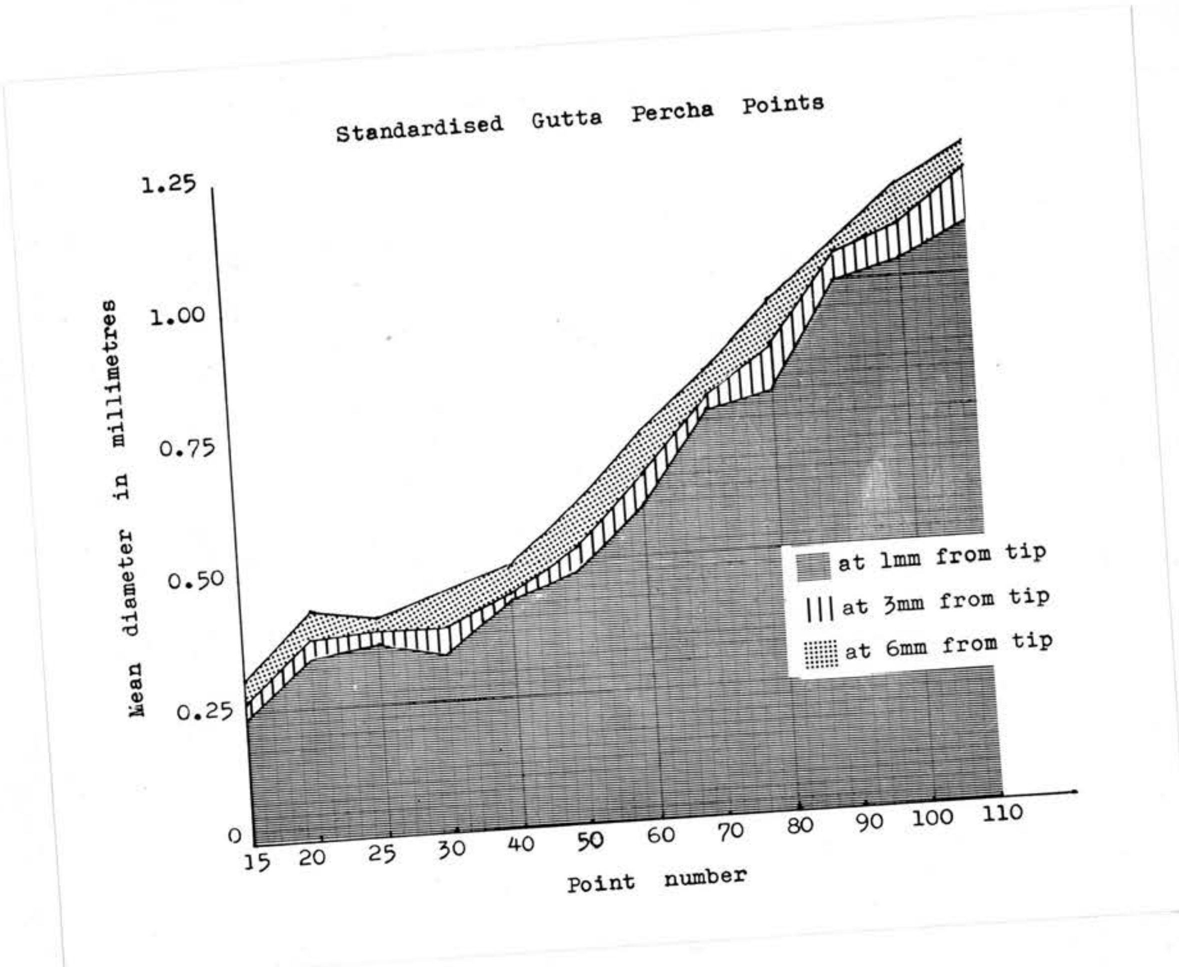

Conventional Gutta Percha Points
Mean diameter in millimetres
1.25
1.00
0.75
0.50
0.25
0
1
2
3
4
5
6
7
8
9
10
11
12
Point number
at 1mm from tip
at 3mm from tip
at 6mm from tip

Fig. 5.55



Standardised Gutta Percha Points
Mean diameter in millimetres
1.25
1.00
0.75
0.50
0.25
0
15
20
25
30
40
50
60
70
80
90
100
110
Point number
at 1mm from tip
at 3mm from tip
at 6mm from tip

Fig. 5.56

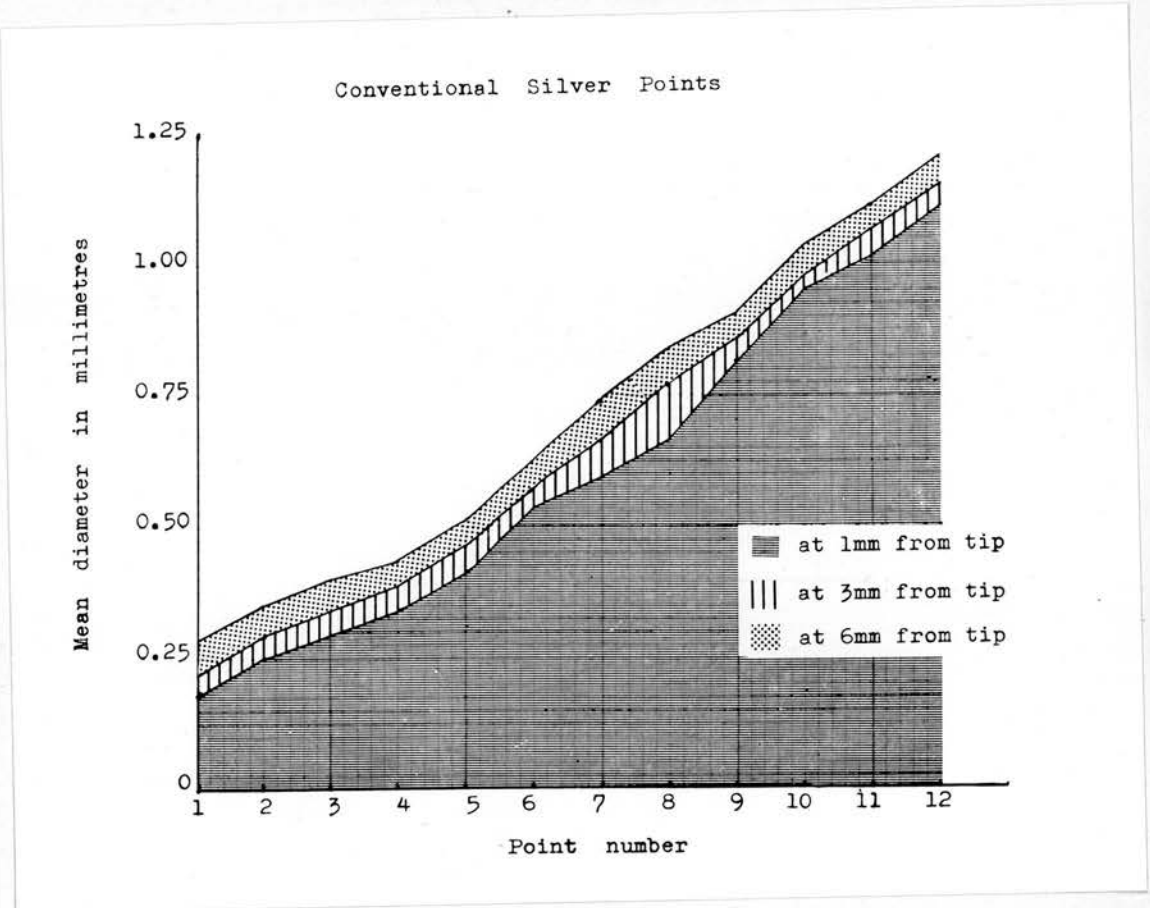
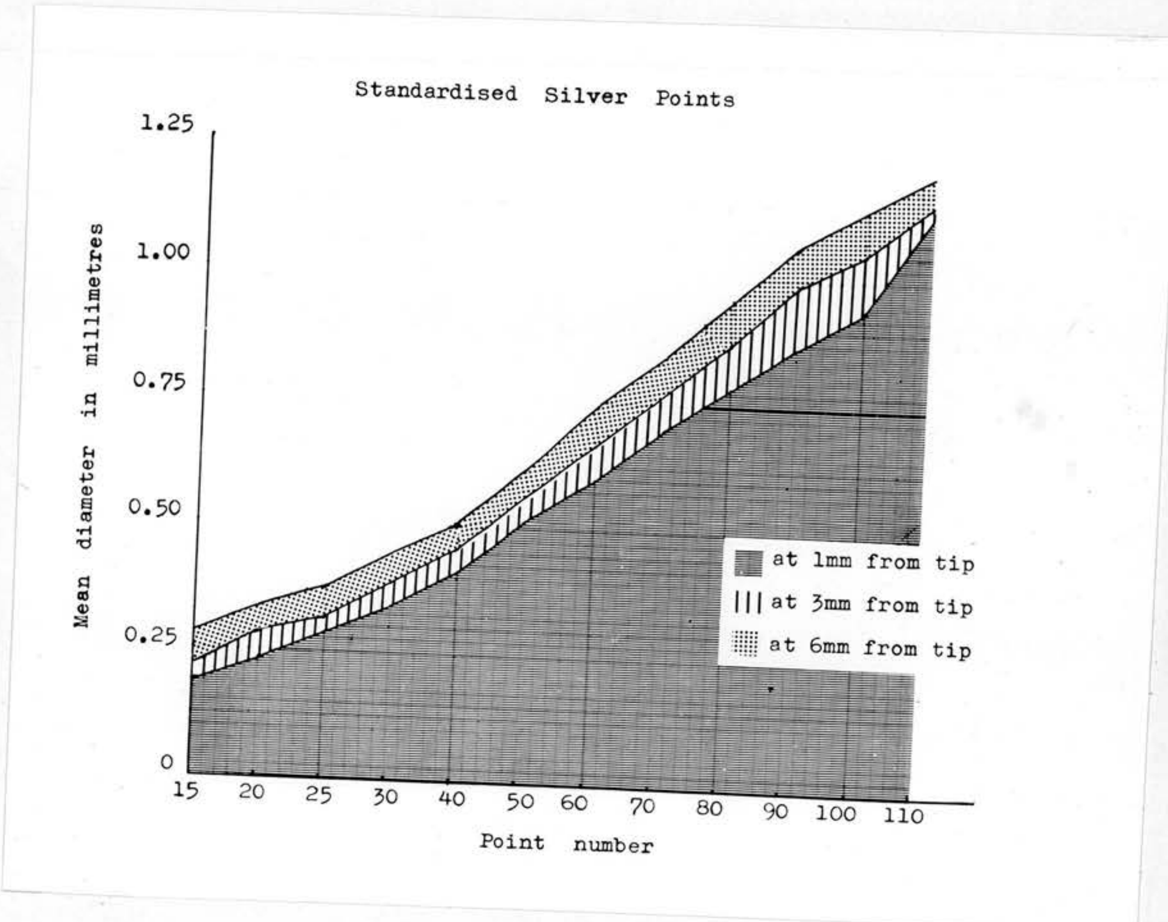

Conventional Silver Points
1.25
1.00
0.75
0.50
0.25
0
Mean diameter in millimetres
1
2
3
4
5
6
7
8
9
10
11
12
Point number
at 1mm from tip
at 3mm from tip
at 6mm from tip

Fig. 5.57



Standardised Silver Points
Mean diameter in millimetres
1.25
1.00
0.75
0.50
0.25
0
15
20
25
30
40
50
60
70
80
90
100
110
Point number
at 1mm from tip
at 3mm from tip
at 6mm from tip

Fig. 5.58

CHAPTER 6

Survey of Root Canal Fillings

Introduction

It has been demonstrated that it is essential that the root canal should be prepared in such a manner that the walls are presented smooth, round and tapering so that the root filling point could be placed accurately, both in relation to length and diameter, as these criteria are of the utmost importance in obtaining the desired apical seal. It has, however, been stated on Page 8 that clinical experience has shown that it was not always as simple a matter achieving complete obturation of the root canal of a pulpless tooth as endodontic textbooks inferred, even when using the so called matched points.

In the author's long clinical exposure to endodontics, both in relation to teaching and to clinical practice, it has always been the desire that students should comprehend the necessity of accurate mechanical instrumentation and assessment of true tooth length in order that root canal therapy can be carried through to a successful conclusion. These factors are the basic fundamentals on which sound and successful root canal therapy is built and failure to carry out any one of these steps accurately will inevitably lead to unsuccessful endodontic control.

In the preceeding chapters the necessity of mechanical instrumentation of the root canal of a permanent tooth by means of a root canal reamer, up to and as far as the apical constriction, has been demonstrated. It was also stated that to be certain of a well sealed canal, a standardised root filling point should be chosen which matched the final instrument size. It was further stated that a review of the literature had made it clear that it was essential, when placing the root filling point in position in the root canal, that it should be coated with root canal sealer as well as placing sealer in the canal itself. This is to ensure that small irregularities, existing between the point and the side wall of the canal, would be obliterated. Reference was made to the possibility of introducing air bubbles into this sealer during placement in the canal thus producing a poorly sealed root canal (Page 83).

To assess how effective the various criteria for root canal therapy, enumerated in this investigation, were being carried out by the students in the Conservation Department of the Edinburgh School it was decided that a survey of root treatments, completed during a three year period, should be undertaken. Authors such as Ingle (1965), Ingle & Zeldow (1958), Seltzer et al (1964), Grossman (1951) and Grahnen et al (1961) agree that incomplete obliteration of the central space of a pulpless tooth is one of the most probable causes of root canal therapy failure. In this respect it is argued that it is of the utmost importance that the apical one third should be adequately sealed by means of the root filling point. This concept is in agreement with statements by Strindberg (1956), Marshall & Massler (1961), Dow & Ingle (1955), Crawford & Larson (1956) and Going et al (1960). Therefore one of the features of this study that required special assessment was the degree of obturation of the central space.

It is pointed out that this survey is <u>not</u> to assess the success of root canal therapy as such but rather investigate how effective the various stages in the technique of root canal therapy are completed by the students in the Edinburgh School. To assess the success of root canal therapy requires a period of observation of 2 years at least, as was demonstrated by the Washington Study (1955). In a review of the Washington Study Ingle (1965) states that it is essential that a good recall is obtained, if the survey is to be considered valid. In this respect he stated that a 5% recall would invalidate the results of the study. A good percentage recall is difficult to attain for various reasons. Masterton (1965) states that it is difficult to clinically follow-up patients with root treatments and that he, even with an excellent record system, was able to clinically follow-up only 30% of the patients he treated.

To assess what percentage recall might be possible in this survey, 50 patient's records chosen at random, who had root treatments carried out in the Edinburgh Dental Hospital during a 3 year period prior to 1968, were examined and it was found that the number of patients from this 50, who were still receiving treatment in the Conservation Department, was so small that the probable recall rate would be hopeless. The results obtained in this way for endodontic success would be so low as to be valueless. It was reluctantly considered that a radiographic study should be undertaken rather than attempting to assess the success rate for endodontic therapy.

From the radiographic records of root treatments carried out in the Edinburgh Conservation Department, patients were chosen for whom pre-treatment and post-treatment X-rays were available.

Fig. 6.1

Fig. 6.3

Fig. 6.4

From the pre-treatment X-ray it was possible to state the degree of pathology that was present in each case, while from the post-treatment X-ray the following assessments were made.

1. <u>The degree of obturation of the central space</u> examples of which are shown in Fig. 6.1, where space exists in the middle and coronal portions of the root. It is felt that space in these two areas is of no significance provided a good apical seal exists. In Fig. 6.2 there is space evident in the apical third region and this constitutes a poor apical seal and is therefore undesirable. Figs. 6.3 and 6.4 are extreme examples of incomplete root fillings. In both these latter examples it is apparent that no attempt has been made to select the correct size root filling point and it is even dubious that mechanical instrumentation itself has been carried out.

2. <u>the distance between the root filling point and the apex of the tooth</u>. Fig. 6.5 shows a root filling point which has been placed at the apex of the tooth while Fig. 6.6 shows a root canal that has been sealed at the apical constriction.

Fig. 6.5

Fig. 6.6

Fig. 6.7

3. <u>whether or not the root filling was beyond the apex of the tooth (over-filling)</u> an example of which is seen in Fig. 6.7. In this case it would appear that the apical constriction has been passed during mechanical instrumentation. This, together with poor assessment of true tooth length, results in placing the point well beyond the apex of the tooth into the periapical region.

4. <u>whether or not the apical constriction was adequately sealed.</u> Fig. 6.8 shows a tooth which has been adequately sealed at the apical constriction while in Fig. 6.9 an example is given of a poor seal of the apical constriction. If a root filling is to be successful there is no doubt that the apical constriction must be adequately sealed.

5. <u>whether or not an apicectomy had been carried out</u>. It is pointed out that this heading in no way affects the criteria being examined except in the case of the apical seal. It is the author's impression that areas of rarefaction at the apex of a tooth should be treated conservatively and it was thought that this would be of interest in ascertaining how this feeling would stand up to critical examination.

Fig. 6.8

Fig. 6.9

In Chapter 3 it was pointed out that Ingle (1965), Kuttler (1958), Sommer, Ostrander & Crowley (1966), Strindberg (1956), Bender, Seltzer & Turkenhoff (1964) and Grossman (1943) all agree that the central space of a pulpless tooth must be completely filled and that anything short of total obliteration is not to be tolerated. The most recent paper (Haga 1968) states that one of the main objectives of root canal preparation is total obliteration of the central space. So that in a complete root filling, as opposed to a sectional one, the whole of the central space should be sealed off and there should be no evidence of space anywhere along the long axis of the root. This particular facet of root canal therapy was one of the main points of interest in the present survey of root filling X-rays. The method of assessment and how this was achieved will be elaborated later in this chapter.

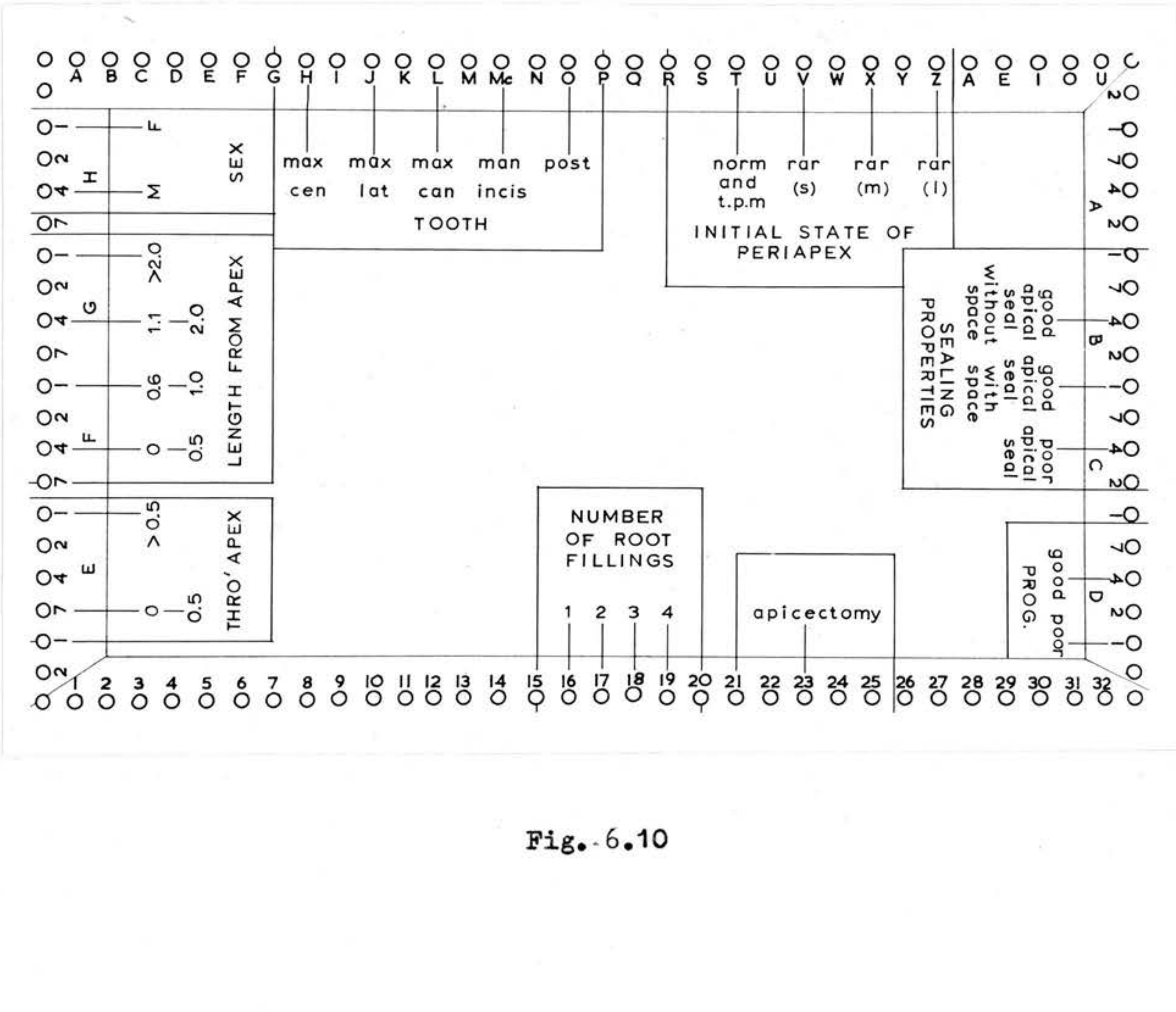
The second point that required close scrutiny was the distance between the root filling point and the true apex of the tooth being treated. When deciding the ideal point of termination of the root filling point it should be remembered that it is virtually universal endodontic practice to root fill to the apical constriction (Crane(1926), Hartzell (1930), Ingle (1965), Kuttler (1958), McGehee (1951) and Sommer, Ostrander & Crowley (1966)), the argument being that this region is easily sealed by virtue of a mechanically prepared round configuration and therefore when this region is hermetically sealed nothing from the root canal can penetrate the periapex. Whenever part of the apical region of a root canal is left unfilled, tissue fluids tend to stagnate in the void and, as a result of stagnation, protein breakdown products percolate through the apex into the periapical region with a consequent severe irritation (Rickert & Dixon (1931)). Therefore the point of termination of the root filling is important and each X-ray was measured to ascertain the distance remaining between the root filling point and the true apex of the tooth.

The third measurement undertaken was, whether or not the root filling point passed beyond the apex of the tooth (over-filling). It was considered that this was of some importance in determining whether or not the student undertook accurate assessment of true tooth length before carrying out the final stage of filling the canal. A root filling point which passes beyond the apex of the tooth will undoubtedly cause periapical irritation - either by the point itself acting as a foreign body or by the normal physiological movement of the tooth during mastication. It has been recognised that over-filling mitigates against success in root canal therapy (Ingle (1965) and Sommer, Ostrander & Crowley (1966)).

It has already been stated that it is essential that the root canal space be sealed in such a way that nothing from the root canal can percolate through the apex into the periapical space and it is stated that the only method of insuring this, is that the apical constriction must be hermetically sealed. Ingle (1965), Grossman (1951), Seltzer et al (1964) and Grahnen (1961) bear out this concept in their articles. Therefore it is felt that too much emphasis cannot be placed on this particular facet of root canal therapy. If the apical constriction is not adequately sealed then the root filling is doomed to failure; so it was considered of the utmost importance that the fourth essential should be included in all the X-rays surveyed.

It has been stated that the final facet (apicectomy) included in this survey was not from the point of student participation in root canal therapy but rather to assess how frequently apicectomies were carried out in the Conservation Department of the Edinburgh School.

Method



A B C D E F G H I J K L M Mc N O P Q R S T U V W X Y Z A E I O U
SEX
F
M
H
max cen
max lat
max can
man incis
post
TOOTH
norm and t.p.m
rar (s)
rar (m)
rar (l)
INITIAL STATE OF PERIAPEX
LENGTH FROM APEX
G
F
>2.0
1.1
2.0
0.6
1.0
0
0.5
THRO' APEX
E
>0.5
0
0.5
SEALING PROPERTIES
good apical seal without space
good apical seal with space
poor apical seal
A
B
C
NUMBER OF ROOT FILLINGS
1 2 3 4
apicectomy
PROG.
good poor
D
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32

Fig. 6.10

The radiographic points of interest, referred to in the introduction, that were to be examined in this study, were apparently simple to assess provided a good radiograph was present. However there were occasions, even when a good X-ray was available, that the image of the involved tooth was not 100% clearly defined. This was due, in most cases, to superimposition on the lesion and/or the root filling by some extraneous anatomical feature. It has been demonstrated by Bender & Seltzer (1961) and Sommer, Ostrander & Crowley (1966) that this phenomenon is particularly likely to occur in the maxilla where cancellous bone overlies the periapical lesion thus casting suspicion on the true clinical picture. They demonstrated that X-ray detection of some lesions is not readily appreciated under these conditions and it is not until such time as expansion of the lesion causes erosion of the innermost layer of the cortex that a true picture is obtained. In this study, any root fillings or apical lesions that were not readily placed in their particular category (Fig. 6.10) were discarded.

In the initial attempt at assessing whether or not a space remains around a root filled canal, as demonstrated by an area of radiolucency in an otherwise radio-opaque region, it was thought that a high degree of magnification would be essential. Moffitt (1932) has stated that to be certain that a root canal was filled in such a way that it prevented an ingress of pathogenic organisms it would be necessary to view the X-ray under a magnification of 1,200 but it has not been possible to confirm whether or not he considered the possibility of interpretation of such a magnified image. It was therefore considered that a smaller magnification of the X-ray would suffice. As it turned out this was in fact the case. The initial attempt of obtaining, what was considered an optimum magnification, was carried out by projecting the X-ray on to a screen by means of a photographic projector. By this procedure the magnification could be varied to some extent by the simple process of adjusting the screen distance from the projector. This method proved useless since it was found impossible to read the projected X-ray image because of the silver grain size of the emulsion on the X-ray negative. It is recognised that fast photographic films have greater silver grain size than the slower ones and since dental X-ray films are relatively photographically fast, the silver grain size is correspondingly large. Not only was the projected image impossible to read with any degree of accuracy, it was in fact impossible to state categorically where one tissue ended and another began. This method was rejected.

A further extension of this method was then considered in which the X-ray film would be viewed under a stereomicroscope. It was thought that since the degree of magnification was considerably smaller than the projection method some assessment of the X-ray film would be possible. Unfortunately even here the same features were found - the silver grain size was far too large to enable the film to be interpreted properly. In this method, as in the previous method, a distinct merging of radio-lucencies and radio-opacities occurred with no clearly defined dividing line. This method was also abandoned.

Eventually the author used the following simple method of assessment. Illumination of the X-ray film by means of a good light source was obtained and the film inspected by means of a watchmakers lens with a magnification of $3\frac{1}{2}$ times. This gave a picture with relatively small silver grain shadows, one where it was clearly possible to differentiate between radiolucent and radio-opaque sections of the film. By this means it was possible to observe portions of the root canal where inadequate obturation had occurred, as demonstrated by distinct radiolucent areas.

It was therefore possible to interpret each radiograph and assess whether or not a space was present within the root canal, a space which occurred between the root filling point and the side wall of the canal itself and which was not filled with root canal sealer. Spaces which were present would substantiate the statement that it is difficult to introduce root canal sealer into a root canal without some air bubbles being formed (Page 83). In this study 158 teeth (20% of the total number) showed radiographic evidence of air voids within the canal of an otherwise well sealed apical constriction. The statement on Page 83, that the inclusion of air bubbles in the root canal sealer is a hazard that is ever present, can therefore be considered to be correct.

Using the same criteria, it was possible to state with some accuracy whether a good apical seal or a poor apical seal was present. It is, however, recognised that an X-ray picture presents a two dimensional body and as such may lead to doubts being cast on the veracity of the results obtained. This philosophy of course applied to the interpretation of all X-rays, but in defense of this concept of assessment of a two dimensional picture of a three dimentional body where root canal fillings are concerned, it is pointed out that Ingle (1965), Kuttler (1955) and Sommer, Ostrander & Crowley (1966) state that there is general agreement that in most teeth the apical constriction is round in configuration. Since a circular root filling point is placed in a space of similar configuration, whenever there is no evidence of space in a mesio-distal direction, it is reasonable to assume that no space will be present in a labio-lingual diameter. It is therefore felt that assessment of X-rays of root filled teeth using this method is remarkably accurate and is, in fact, the only means known to the author whereby a true picture of the various facets of endodontics can be obtained.

Densitometer Tests

So that a permanent record of this personal method of assessing the radiographs used in this study might be obtained, it was decided that a densitometer trace of radiographic examples of what were considered 'air bubbles' within the filled root canal would be most useful. As a result of permission being obtained from Professor N. Feather, Department of Natural Philosophy, Edinburgh University for access to a Double Beam Recording Densitometer Mark IIIB by Joyce Loebl & Co. Ltd., various radiographs were surveyed and a permanent record obtained for each. After many trials with 'slit effect' and 'slit height' a setting was obtained for this instrument which gave optimum results. In all traces recorded the 'slit' was set at 0.3 mm and the 'height' at 3 mm.

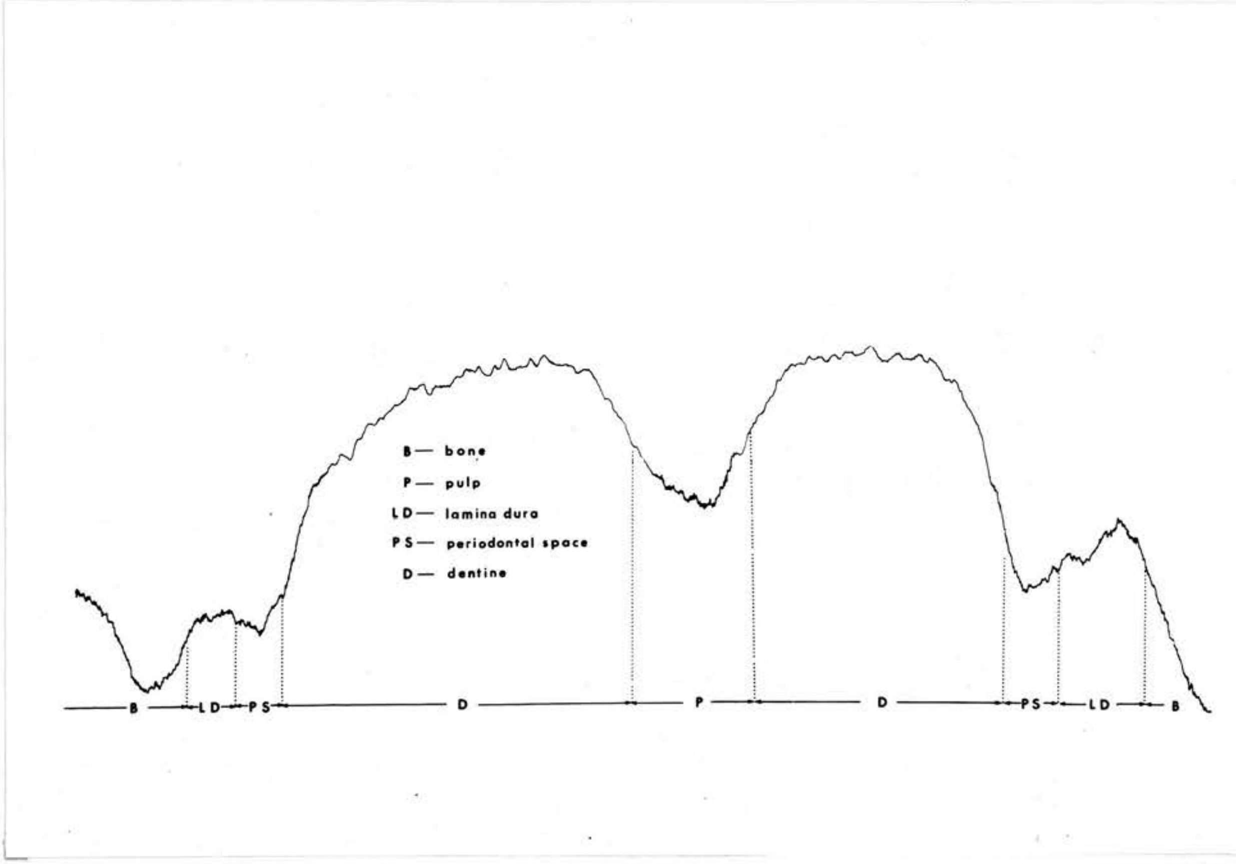


Fig. 6.11

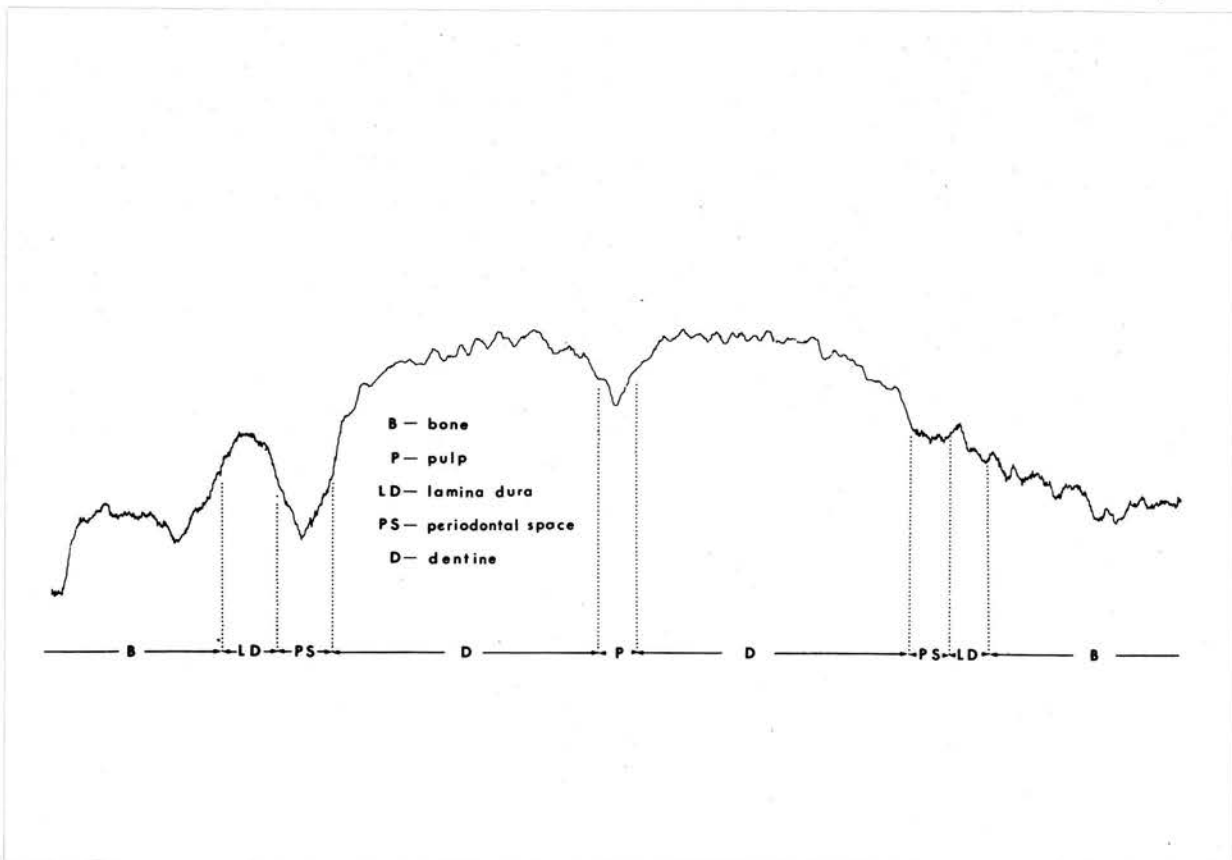


Fig. 6.12

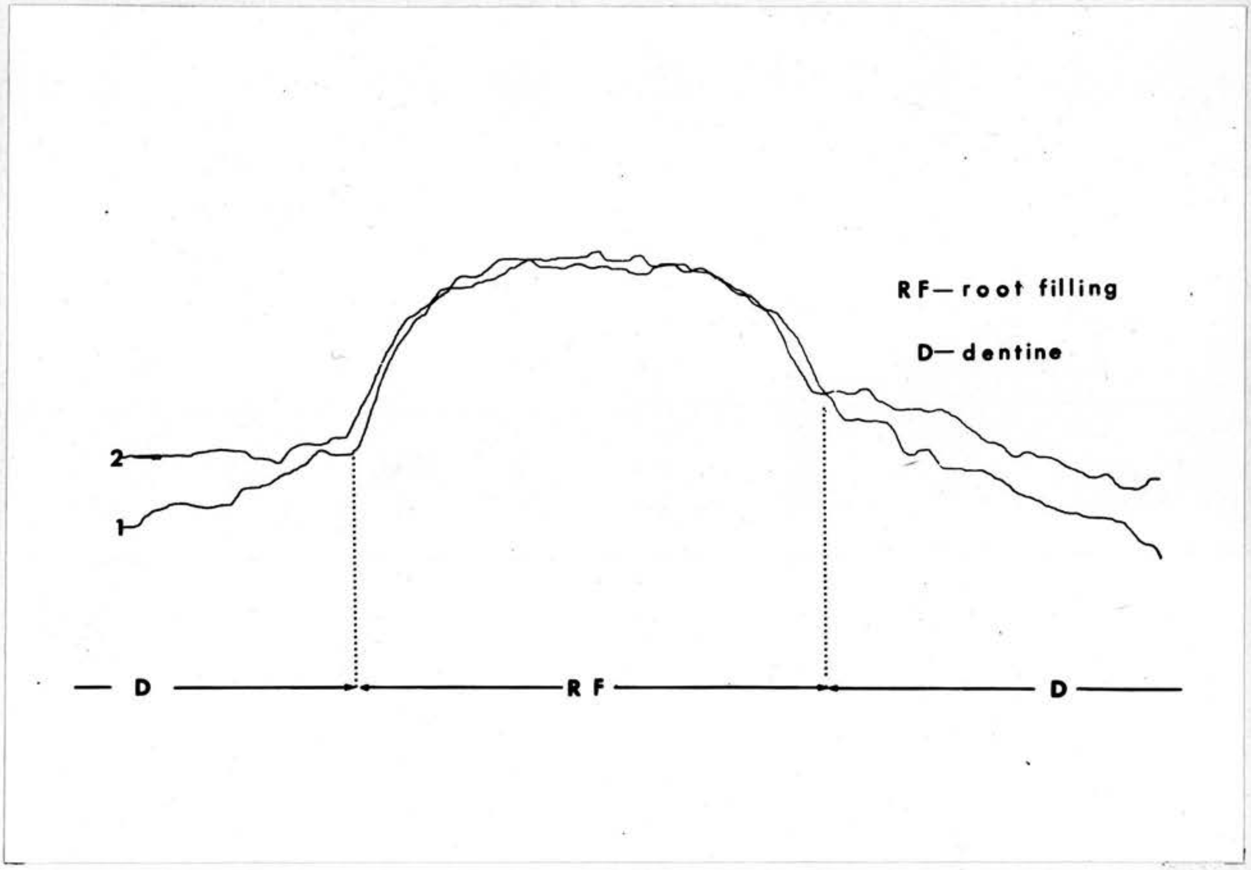


Fig. 6.13

It was thought that it would be of advantage, for the purposes of orientation, to initially survey radiographs of normal healthy teeth. As a result an intraoral radiograph of mandibular incisors from a young patient together with a comparable radiograph of an old patient were surveyed and traces recorded (Fig. 6.11 and Fig. 6.12). In these examples and in all others undertaken, the trace commenced in bone just outside the distal lamina dura, progressed across the root and terminated in bone outside the mesial lamina dura. The various structures surveyed by the densitometer are clearly defined in these two diagrams. Comparison of the two traces clearly defines the decrease in the width of the root canal with age.

Following normal healthy tooth traces, a well filled root canal was surveyed (Fig. 6.13). In this diagram the two traces show that the root filling is an area of greater density than dentine therefore the record obtained by the densitometer trace shows an upward trend whenever the instrument is traversing the root filling itself. These two traces represent two areas close together which were surveyed by progressing the 'slit height' about 1 mm from the proceeding trace. Since the root of a tooth is a tapering body, the area surveyed nearer the apex of the tooth will be slightly narrower and hence less dense than the area surveyed nearer the crown of the tooth. This is clearly illustrated in the diagram.

Whenever the root filling itself is surveyed longitudinally, the trace obtained should be a reasonably straight line provided the root filling is of uniform density. There should however be

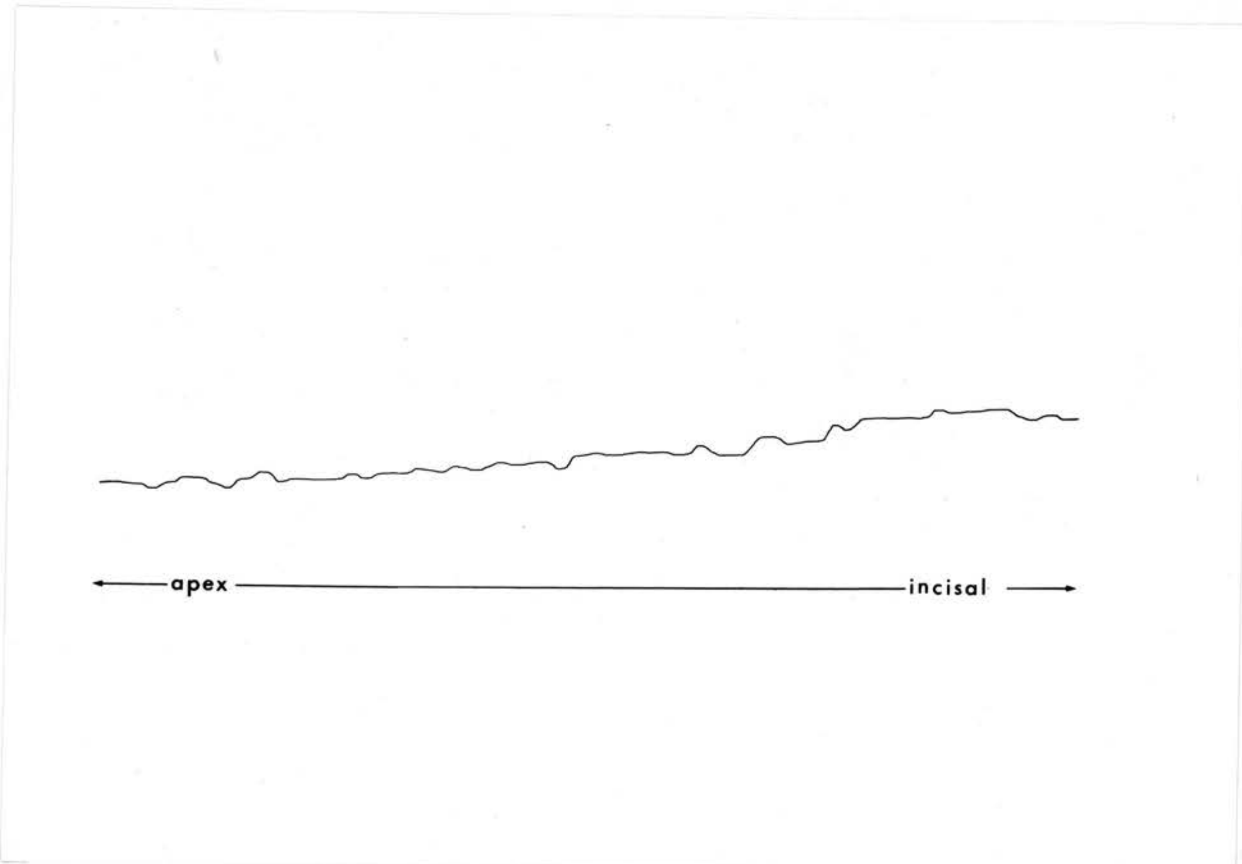


Fig. 6.14

a slight increase in total density as the trace progresses towards the coronal portion of the root filling, due to the increasing diameter of the root filling and Fig. 6.14 shows this to be the case. The density of the filling material is not completely uniform, represented by the slightly wavy line but this is to be expected since gutta percha points are hand rolled and therefore can never be of uniform density.

Finally, several photographs of what were considered to be 'air bubbles' within the root canal sealer were surveyed and an example is shown in Fig. 6.15. The method of recording this is best illustrated from traces obtained from a well filled root canal. The distal wall of the root canal was lined up parallel to the slit on the densitometer so that the various traces taken from this root filled tooth would have a common base line. This can be seen in Fig. 6.16 where four traces were recorded for a radiograph of a well filled root canal. The base line is clearly demonstrated on the left of the diagram where all four traces are reasonably well approximated. The increasing width of the root and the increase in density, as the densitometer is moved towards the crown of the tooth, can be clearly seen from the traces on the right of the diagram. Having obtained trace one, the densitometer was progressed about 1 mm and the second trace effected and so on until all four were recorded.

Having obtained traces for a well filled root canal, radiographs showing 'air bubbles' within the root canal sealer were then surveyed. One example for the trace obtained for this type of radiograph is shown in Fig. 6.15. This record was

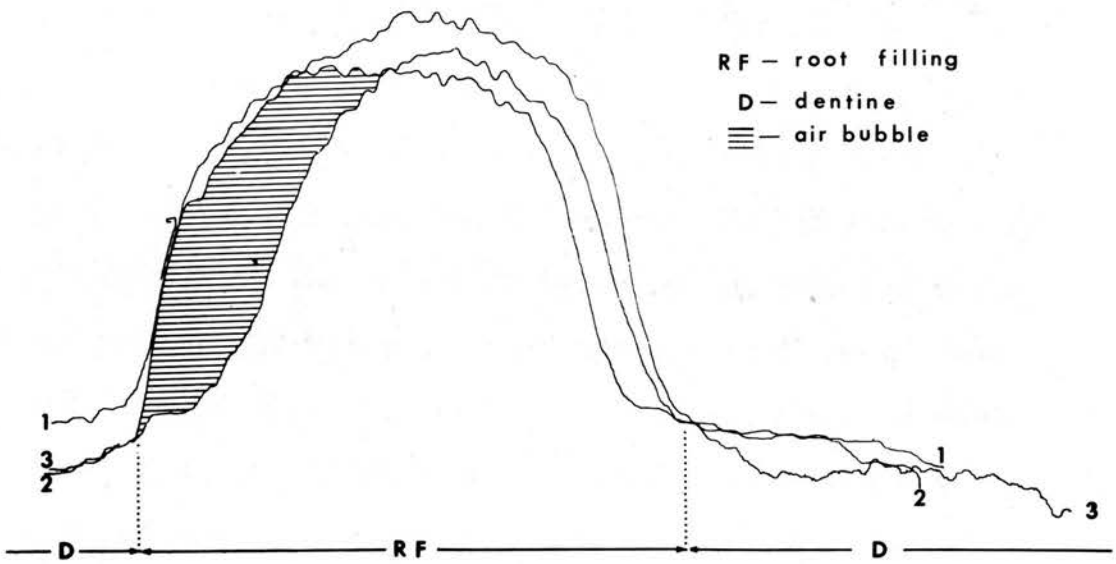


Fig. 6.15

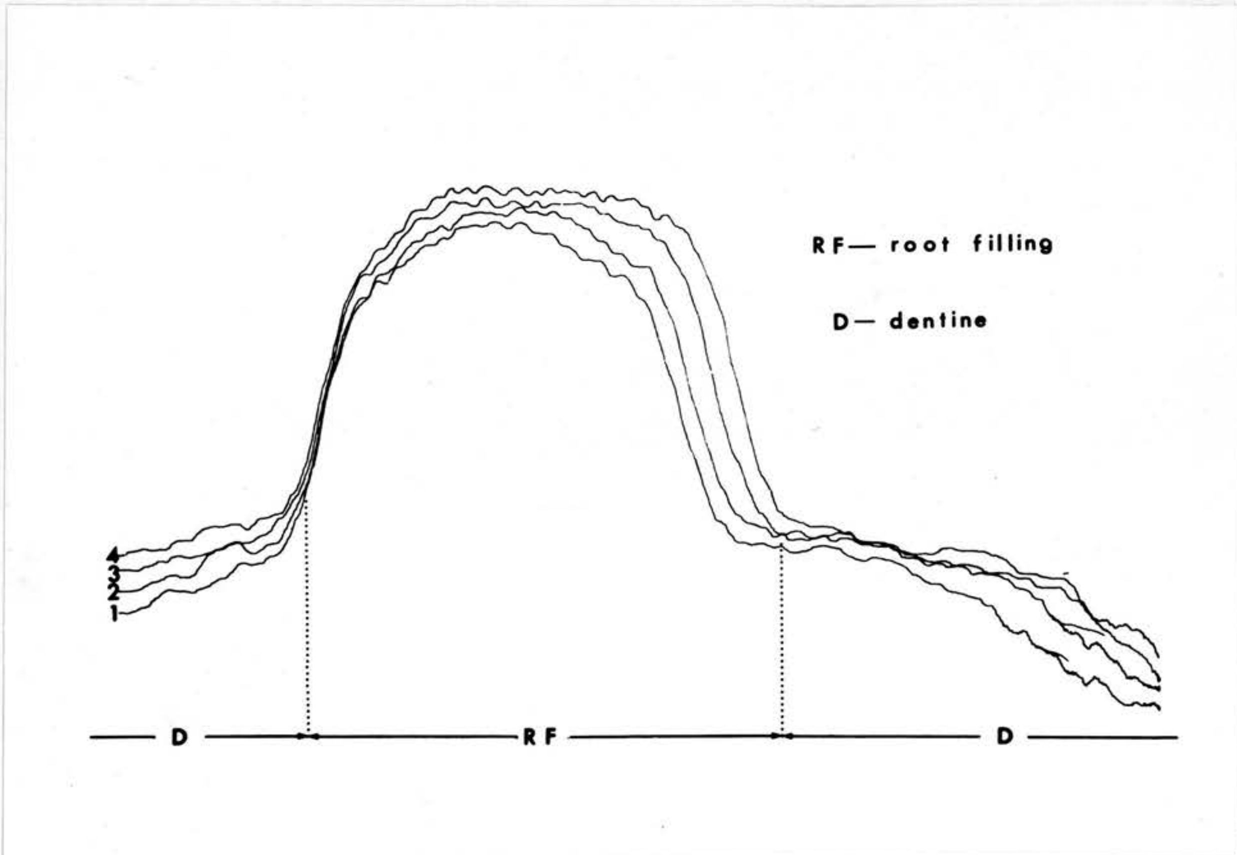


Fig. 6.16

obtained as follows:- a trace 0.3 mm wide was obtained for the area immediately coronal to the air bubble (trace 1) followed by a trace immediately apical to the bubble (trace 2). A trace midway between these two traces would be through the air bubble itself and should be recorded as a line superimposed on the other two on the left of the diagram (base line), as explained above. On the right of the diagram trace 3 should be midway between tracesl and 2. That this is correct is demonstrated by the position of trace 3 on the right of the diagram which is in its correct position but on the left trace 3 is not superimposed on traces 1 and 2; instead it takes a course to the right of the base line as indicated in the diagram, the shaded area being an area less dense than the other two traces, corresponding to a space within an otherwise well filled canal. Therefore what was visually assessed as a 'space' or 'air bubble' is shown on the densitometer as an area of decreased density in an otherwise dense region and can reasonably be assumed to be an area incompletely obliterated or an 'air bubble.'

Tooth involved	Percentage	Males	Females	Total
Maxillary centrals	41	167	157	324
Maxillary laterals	36	129	158	287
Maxillary canines	8	31	30	61
Mandibular incisors	6	25	27	52
Single rooted posteriors	9	33	35	68

Fig. 6.17

Tooth	Washington Study	Present Study
Maxillary centrals	37%	41%
Maxillary laterals	26%	36%
Maxillary canines	8%	8%
Mandibular incisors	10%	7%

Fig. 6.18

In this survey pre-treatment and post-treatment X-rays were collected for patients who had had root canal therapy carried out on single rooted teeth in the Conservation Department of the Edinburgh Dental School over a three year period. In all 792 double X-rays were examined and assessed and the various points being investigated were recorded on punch cards as shown in Fig. 6.10. The various single rooted teeth investigated were made up of the teeth shown in Fig. 6.17. All those X-rays that could not be accurately interpreted were discarded. It was found that the distribution of teeth in this sample corresponded remarkably closely to the relative teeth used in the Washington Study (1955) as is shown in Fig. 6.18. It is pointed out, however, that in the total number under investigation in the Washington Study all teeth were included, whereas in the present study, for ease of interpretation, single rooted only were examined. Nevertheless there is a strong correlation between equivalent percentages. Included in the total root fillings examined in the present investigation were several cases of multiple root fillings; 63 patients who had had root fillings on two teeth completed at the same time and 13 patients who had had three root fillings completed concurrently.

With the punch cards used in this investigation (Fig. 6.10) it is possible to extract a variety of information regarding root treatments carried out in the Edinburgh Dental Hospital. Among the many points recorded on the punch card, the importance of the distribution of the teeth treated, the pathological state of the periapex, the relative position of the root filling point in relation to the apex, the degree of obturation of the central space and the adequacy of the apical seal can all be easily extracted. It is also possible to obtain a variation of these points in relation to each other, and from all the collected information it will be possible to state with some assurance the degree of accuracy obtained by the Edinburgh students when carrying out the various facets of this particular branch of restorative dentistry.

The total number of radiographs for the teeth examined in this study was made up of approximately equal numbers of male (385) and female (407). It will be seen that the only divergence for individual teeth treated occurs in the case of the maxillary lateral; 129 males having had root treatment on this tooth while 158 females were involved in root canal treatment on the maxillary lateral incisor, a difference of 10%. It was thought that this might be due to a desire on the part of the female to retain natural teeth as long as possible but this is not borne out by the remainder of the figures. These show an almost equal distribution between the sexes.

The periapical condition on the pre-treatment X-ray was recorded. This was sub-divided into four groups as set out below :-

1. normal and thickened periodontal space were considered under one heading since it is frequently difficult to state precisely, from a single intra-oral radiograph, whether or not the periodontal space around an individual tooth is thickened.
2. rarefaction - (a) small - less than 4 mm in any diameter
   (b) medium - between 4 mm and 8 mm in any diameter

State of periapex	Total	Percentage
Normal and thickened periodontal space	207	26
Rarefaction (small)	125	16
Rarefaction (medium)	84	11
Rarefaction (large)	376	47
Total teeth	792	100

Fig. 6.19

Tooth	Normal and thickened periodontal space	Rarefaction
Maxillary centrals	24%	76%
Maxillary laterals	20%	80%
Maxillary canines	36%	64%
Mandibular incisors	8%	92%
Single rooted posteriors	69%	31%

Fig. 6.20

size of area	present study	Sommer's study
small	16%	9%
medium	11%	38%
large	47%	45%

Fig. 6.21

(c) large - greater than 8 mm in
any diameter

The results obtained from 792 radiographs examined are set out in Fig. 6.19 and for individual teeth in Fig. 6.20.

The sub-division of areas of rarefaction into small, medium and large is after Sommer (1966) and appeared to be a simple method of placing these areas into clear cut divisions. In this study no account is taken of the actual diagnosis of the pathology of the area, whether it was a granuloma or chronic abscess or cyst. It has in fact been shown by Sommer (1966) that diagnosis of apical areas of rarefaction is virtually impossible from the radiograph alone, reliance must be placed on the histological picture for accurate diagnosis. A comparison of the radiographic results of the present study of areas of rarefaction and those obtained by Sommer, Ostrander & Crowley (1966) is shown in Fig. 6.21. It will be seen that the percentages obtained for small and medium areas of rarefaction vary widely from those obtained by Sommer, while the percentage of large areas of rarefaction present at the apex of pulpless teeth show no real divergence in both investigations. Personal interpretation of these smaller areas may account for this divergence.

An important facet of root canal therapy under consideration in this study was the distance between the terminal point of the root filling and the apex of the tooth. This was considered of great importance for, in the success of a root filling, if a space exists in the apical area of the canal it has been shown that tissue fluid will collect in this void and stagnate with consequent liberation of protein breakdown products. These

Tooth	Through apex in mm		Distance from apex in mm			
	0 - 0.5	0.5	0 - 0.5	0.6 - 1	1.0 - 2	2.0
Maxillary centrals (324)	21	13	216	62	12	0
Maxillary laterals (287)	27	12	162	61	21	4
Maxillary canines (61)	2	1	40	15	2	1
Mandibular incisors(52)	3	3	32	11	2	1
Single rooted posteriors(68)	5	2	41	13	5	2
Grand totals	58	31	491	162	42	8
Percentage	11%		88%			1%

Fig. 6.22

Tooth with poor apical seal	Through apex in mm.		Distance from apex in mm.			
	0 - 0.5	0.5	0 - 0.5	0.6 - 1	1.1 - 2	2
Maxillary centrals (28)	1	2	18	6	1	
Maxillary laterals (20)		1	10	3	3	3
Maxillary canines (3)			2			1
Mandibular incisors (1)						1
Single rooted posteriors (3)			1	1		1
Totals (55)	1	3	31	10	4	6

Fig. 6.23

irritants will percolate through the apical foramen into the periapical tissues with a consequent continual irritation of this region (Rickert & Dixon (1931)) and Sommer, Ostrander & Crowley (1966)).

The relationship between the terminal point of the root filling and the apex of the various teeth examined in this study is set out in Fig. 6.22. It will be observed from the last column of this table that 1% of the root treatments carried out in the Edinburgh School had a space of 2 mm or more between the terminal point of the root filling and the apex of the tooth. Added to this 1% is 11% which showed evidence that the root filling point was through the apex of the tooth. On the other hand, it is considered that teeth with a root filling which is placed less than 2 mm from the apex can be said to be adequately root filled and in this study this accounted for 88% of all teeth examined. It is stressed however that not all teeth with correctly placed root fillings, in relation to length, did have a good apical seal. Those teeth with a poor apical seal must therefore be considered when assessing the total number of 'incorrectly root filled teeth.' The teeth in this study which exhibited a space in the apical constriction area were designated as having a poor apical seal and out of the 695 teeth with correct root filling length, 45 were placed in this category (Fig. 6.23), the remaining 10 seen in this study were to be found in teeth considered failures for other reasons (over-filling etc). Therefore a total of 650 teeth (82%) can be shown to be placed in the category of 'correctly filled teeth.'

A comparison of the figures obtained from the Washington Study and those from the present study are set out below. It is pointed out that the Washington Study figures were for success rate as found on a 2 year recall, while in the present investigation, a probable success rate was determined by an X-ray study alone. While some of the cases in the present study exhibited features on the radiographic survey which could be expected to lead to failure, they might on the other hand have been considered successful if examined on a 2 year recall basis. This is particularly so in the teeth where the root canal was only slightly over-filled. Therefore the percentage failure rate could, in fact, be less than that shown in this study.

Washington Study	Failures	Successful
1,229	104 (8.46%)	1,125 (91.54%)

Present Study	Failures	Successful
792	142 (18%)	650 (82%)

In the Washington Study it was found that 61 (59%) of the 104 failures was due to incomplete obliteration of the central space; in the present study it was found that 55 (38.9%) of the 142 failures was due to incomplete obliteration of the central space. In the Washington Study 4% of the failures was due to over-filling of the canal but in the present study this failure rate was 11% It is apparent from these results that in Edinburgh, students would appear to be paying insufficient attention to diagnostic X-rays and their use in assessment of true tooth length prior to final root filling of the prepared canal, nevertheless the results they obtained for root canal obliteration compare favourably with the Washington Study.

Out of a total of 55 teeth which were shown to have a poor apical seal, it was found that 10 of these teeth were involved in the multiple root filling cases, that is, those patients who had had more than one root filling completed at the same time, the remaining 45 teeth with poor apical seals representing 5.7% of the 792 root fillings examined. The 10 teeth concerned with multiple root fillings represents 18.1% of the total number (55) of root fillings with poor apical seals seen in this study. From these percentages it would appear that there is three times less likelihood of carrying out some of the procedures involved in root canal therapy correctly whenever multiple root fillings are attempted. It is argued that this is almost bound to be the case since, as has already been pointed out, root canal therapy is a meticulous and painstaking operation and demands concentration and accuracy, all of which are bound to be affected if more than one root filling is attempted at a time.

Was there a variance in risk in obtaining a poor root filling for the various teeth examined in this study? To find the risk involved, the figures for over-filled and grossly under-filled root canals must be added as represented by columns 1, 2 and 6 in Fig. 6.22. Correctly filled root canals are obtained from the addition of columns 3, 4 and 5 of the same table.

Tooth	Overfilled	Underfilled	% failure
Maxillary centrals (324)	34 (10.5%)	0	10.5
Maxillary laterals (287)	39 (13.6%)	4 (1.4%)	15
Maxillary canines (61)	3 (4.9%)	1 (1.6%)	6.5
Mandibular incisors (52)	6 (11.5%)	1 (1.9%)	13.4
Single rooted posteriors(68)	7 (10.3%)	2 (2.9%)	13.2

Fig. 6.24

The probable percentage failure rate set out in Fig. 6.24 shows that the maxillary canine has a much smaller possible failure rate than the other teeth examined. The reason for this is not completely clear but a possible reason is that this may be due to the fact that this tooth is often the longest tooth requiring endodontic treatment, Sommer (1966) stating that the maxillary canine is often found to be longer than the longest endodontic instrument. If this is the case, then the liability of over-filling will be less than in the case of a tooth of normal length. It will be seen that the percentage of under-filled teeth is reasonably similar for all teeth, with the exception of the maxillary central incisor.

Why should no maxillary central incisor be seen in this study whose root canal was grossly under-filled? When considering this question it is seen from the number of under-filled and over-filled root canals that the maxillary central and lateral incisors are particularly liable to over-filling. It is thought that this may be due to the ease of access of these teeth and also due, in some measure, to their morphology. The maxillar central incisor is in most cases straight rooted and conical and, paradoxically, it is this particular configuration that causes difficulty in root canal instrumentation. Because the root is straight and basically round, instrumentation is simple but at the same time the operator is particularly prone to pierce the apical constriction because of the easy access. This should not happen, for as Sommer (1966) points out there is a definite apical constriction in this root canal. If the central shows over-filling, due attention has not been paid to the tactile appreciation of this constriction in the first instance and later in the treatment sequence, failure to accurately assess true tooth length from the diagnostic radiographs. Ingle (1965) points out that it is frequently the straight conical canals that have the apex perforated with instruments, followed by gross over-filling. The statements by these two workers is certainly borne out in this study, where the maxillary central and lateral incisor had been over-filled on a large number of occasions.

It is demonstrated by this study that by far the greatest possible cause of failure of root canal therapy is imperfect instrumentation and lack of attention to detail in diagnostic assessment of tooth length. It is again stressed that these points must be meticulously performed if a successful result is to be obtained. It is the operative errors of improper use of endodontic instruments and filling materials, together with the lack of standardisation of endodontic equipment, assessed in this thesis, that are responsible for the majority of root treatment failures and it is these very points that the previous chapters have shown to be difficult to carry out accurately.

In Chapter 2 it was demonstrated that accurate preparation of the root canal, up to and as far as the apical constriction, was essential if the desired apical seal was to be obtained and it was pointed out that the root filling point should not be placed beyond this constriction. It was also demonstrated experimentally in Chapter 3 that the ideal shaped canal was prepared by means of the root canal reamer, thus presenting a tapered canal with a round cross-section ready to receive the round tapered root filling

Tooth involved	Males	Females	Total
Maxillary centrals	4	6	10
Maxillary laterals	3	0	3
Maxillary canines	0	0	0
Mandibular incisors	0	1	1
Single rooted posteriors	0	1	1
Grand totals	7	8	15

Fig. 6.25

point. In Chapter 5 it was shown that certainty of hermetic sealing of the apical constriction was only possible whenever root filling points were chosen whose diameter was slightly greater than the diameter of the prepared root canal and it was found that standardised gutta percha and silver points were a suitable medium for obliteration of the central space of a pulpless tooth. The results of a study of 792 radiographs of root filled teeth demonstrated that it is lack of attention to these very details that is responsible for failures in this branch of restorative dentistry. Poor preparation and instrumentation cannot be condoned since failure in these steps has been shown to be mainly responsible for inadequate obliteration of the canal space.

The final point of interest in the present study was the frequency of apicectomies performed during the course of endodontic treatment in the Edinburgh Conservation Department. In this study it was found that 15 apicectomies were carried out (Fig. 6.25) involving 10 maxillary centrals, 3 maxillary laterals, 1 mandibular incisor and 1 single rooted posterior tooth. Thus only 2% of root treated teeth in the Edinburgh School have surgery carried out in conjunction with root fillings. This hears out the author's clinical impression. This was expected, since the general concept of endodontic therapy among the teachers of conservation in this School is one of conservatism when approaching root canal therapy. It is thought that of the areas of rarefaction present at the apex of pulpless teeth, by far the largest percentage are granulomatous in nature (Sommer, Ostrander & Crowley (1966)) and this being the case it is judicious to treat this condition in a conservative manner. Should resolution of the area of rarefaction not occur, as seen on follow-up X-rays, then justification for surgery is indicated.

CHAPTER 7

Conclusions

General conclusions and their significance in the technique of mechanical preparation of the root canal of a human permanent tooth

As a result of the present investigation, it is possible to make definite conclusions regarding the manner in which the stages of mechanical preparation and filling the root canal of a human permanent tooth should be performed.

In Chapter 2 it was demonstrated that a certain degree of discrepancy occurred between the measured diameter of the various root canal instruments and the diameter stated by the manufacturer. It was also shown that the most important region of the root canal was the apical third region, corresponding to the terminal 6 mms of the instrument. In this region it was shown that the root canal reamer was slightly more accurate than the Hedstrom file and would therefore appear, from the manufacturing point of view, to be the instrument of choice for the mechanical preparation of the canal. It was again demonstrated from the results obtained in Chapter 3 that the root canal reamer is the instrument of choice for preparing the canal. This was demonstrated by reason of the fact that the root canal reamer tended to prepare a circular root canal, whereas the Hedstrom file always tended to prepare the root canal oval in shape whether the canal was circular or ovoid in circumference before mechanical preparation commenced. A circular root canal, especially in the apical third, is essential if a hermetic seal is to be obtained in this region. Hermetic sealing will not necessarily be assured in an ovoid canal if reliance has to be placed on the sealing properties of the cementing medium used to cement the root canal point into the canal because of the possibility of introducing air bubbles into the cement, either during the mixing process or during introduction of the cement into the canal. That this is a real hazard was shown by the number of X-rays that revealed evidence of air bubbles in the canal after the final point had been inserted (Page 150 of Chapter 6).

Therefore, on the count of accuracy of preparation of the canal and on the count of sealing properties of the root filling point, the root canal reamer is a more successful instrument than the Hedstrom file. It is suggested that use of the Hedstrom file should be limited to smoothing irregularities in the canal wall in the coronal third of the tooth - irregularities caused during the course of the initial opening for access to the root canal.

Final sealing of a canal prepared by means of root canal reamers will be adequately obtained using matched gutta percha points, that is, matched to instrument size. It was shown in Chapter 5 that in almost all cases the diameter of the matched point was greater than the diameter of the equivalent instrument. It was also pointed out that this fact alone was desirable whenever using gutta percha as the obturating medium since this material has a certain amount of flexibility and compressibility and can be placed in position under some pressure, thus ensuring that the point adequately seals the prepared root canal. It was demonstrated that the difference in diameter between the prepared canal and the gutta percha point was small, enough, it is suggested, to allow compensation for accurate fit by compression of the gutta percha. Unfortunately in the case of the very narrow canal gutta percha is too flexible to allow the point to be placed under force and so resort would have to be made to silver points.

In the instances where silver points can be used (narrow canals, posterior teeth) the difference in diameter tended to be smaller and more uniform over the long axis than the gutta percha points and therefore, it is suggested, silver points would be more accurate in obturating properties. Unfortunately silver points cannot be used as the obliterating material in all cases of root canal therapy (for instance, where a post crown restoration is contemplated), nevertheless gutta percha points have been shown to provide adequate sealing properties when used as the obliterating agent in root canal therapy.

In Chapter 4 it was pointed out that it was generally implied in the literature (Black (1917), Brady (1920), Curson (1966), Grayson (1909), Ingle (1965), Kürer (1966) and Sommer (1966)) that material from the canal was expelled through the apical foramen during the course of mechanical instrumentation within the root canal. It was also stated that this investigator could find no evidence that this statement had been demonstrated experimentally even though every endodontist has this aim constantly before him during the operation of preparation of the root canal. In the introduction to Chapter 4 two questions were posed :-

1. Did material from the root canal pass through the apical foramen during the act of preparation of the canal?
2. Was there a quantitative relationship between the amount of material expelled and the type of instrument used?

It has been demonstrated that the intuitive assumption that debris from the root canal was expelled through the apical foramen during mechanical instrumentation was in fact true. It was shown that in virtually all teeth investigated expulsion of material through the apex did occur whether the root canal was prepared by means of the root canal reamer or the Hedstrom file. As far as the assumption that one instrument might be more traumatic than the other, it was demonstrated in this Chapter that this was not true, each instrument expelling as much material as the other. Therefore on this count alone the root canal reamer was not necessarily the instrument of choice. However, on the other counts already discussed, it was shown to be the instrument of choice and therefore, in the final analysis, is to be desired instead of the Hedstrom file in the mechanical preparation of a root canal of a permanent tooth.

In Chapter 6, a study of radiographs of root fillings carried out by students of the Edinburgh Dental School showed that the results obtained for the assessment of true tooth length were not as good as was hoped and that the introduction of root canal sealer into the prepared root canal must be carried out more precisely to avoid the inclusion of air bubbles. It can be stated, that whenever root treatment is required on a permanent human tooth, mechanical preparation of the root canal should be carried out by means of root canal reamers and, whenever possible, the root canal should ideally be filled by means of silver points. Since this is not always clinically possible, gutta percha points do provide an adequate hermetic seal to the apical constriction of a permanent tooth in those cases where they must be used in place of silver points.

APPENDIX

Published Paper

A Preliminary Report on the Correlation between Apical Infection and Instrumentation in Endodontics.

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A Preliminary Report on the Correlation between Apical Infection and Instrumentation in Endodontics

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ONE of the principles that is frequently reiterated in endodontic textbooks and research literature is the avoidance of expelling material from the root canal through the apical foramen into the periapical tissues. This is thought to be of particular importance if sepsis is present in the root canal and it is generally implied that instrumentation should not be attempted until the canal has been "sterilised"; for example see Black, (1917) Brady, (1920) Curson, (1966) Ingle, (1965) McGehee, (1951) Marshall, (1909) Moffitt, (1913) and Sommer, (1966).

The aims of the present work were (i) to design a model assembly for *in-vitro* studies; (ii) to prove that material may indeed pass through the apical foramen of a permanent incisor tooth during mechanical instrumentation of the canal; and (iii) to determine whether there is a quantitative relationship with the type of instrumentation employed.

Methods and Results

Sterile extracted permanent incisors were individually fixed in the cap of a bijou bottle with the apical region of each tooth bathed in a culture medium so that, when an instrument was infected with a known organism and was used in the preparation of the root canal, it could be shown beyond reasonable doubt whether or not the infecting organism passed beyond the apical foramen into the culture medium.

Results of preliminary experiments indicated that the organism *Serratia marcescens* was preferable to a streptococcus or a coliform bacillus as an indicator organism. *S. marcescens* is a small pleomorphic bacillus which is easily grown on simple media. It is virtually non-pathogenic and it is readily destroyed. It is not commonly found in large numbers as a contaminant of the materials that were to be examined and its distinctive pigmentation distinguishes its colonies from the common flora of the mouth or contaminants of extracted teeth. It is readily counted by the method of Miles and Misra (1938) and it did not produce clumps or chains under the conditions of the present experiment.

The organism was grown at 37°C overnight in Oxoid nutrient broth and the stationary phase culture was then held at room temperature and used within three days. Viable counts were performed by the method of Miles and Misra (1938) on the contents of the test bijoux. Drops of known volume (0.025 ml.) were received on well-dried nutrient agar plates and, after further drying, these were incubated overnight at 37°C. Colonies were then enumerated and, after a further period at room temperature, any contaminants were detected by their lack of typical pigmentation. Contaminants were not commonly encountered.

It was first necessary to ensure that the tooth was sterile and that it was held rigidly during mechanical instrumentation. The method evolved was as follows : A collet of brass was turned in the lathe (Fig. 1) so that its internal diameter was similar to the internal diameter of a diamond shoulder instrument produced by

Fig. 1. *Brass Collet*

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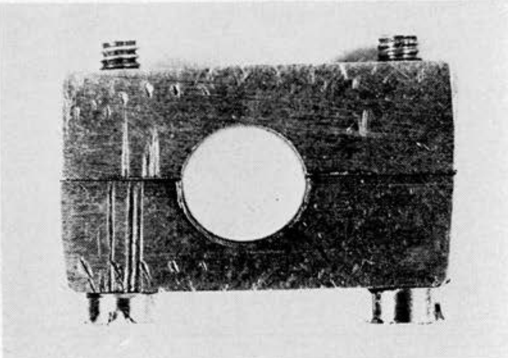

Fig. 2. *Brass clamp.*

one of the dental manufacturing companies for the preparation of jacket crowns. The chosen instrument had an internal diameter of 5 mm. The brass collet was turned in very thin section and the vertical portion was sawn through diametrically so that the prepared root could be rigidly secured by means of the brass clamp (Fig. 2). The metal cap of a bijou bottle was accurately drilled to take the brass collet as a sliding fit (Fig. 3). The rubber disc in the bijou cap was also prepared to accommodate the apical portion of the root of the tooth. In use, the brass collet was placed in the bijou cap, the brass clamp was placed over the collet (Fig. 4), and the rubber disc was replaced. The complete assembly was sterilised in the autoclave.

Fig. 3
Bijou cap and rubber disc.

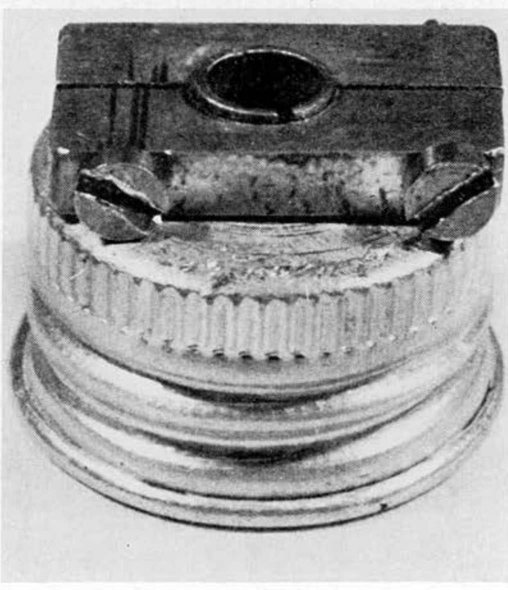

Fig. 4. *Bijou cap with collet and clamp in position.*

The preparation of the extracted tooth was as follows : Maxillary incisor teeth were placed in 10% formalin immediately after extraction and kept in this solution for about 7 days. Thereafter, they were stored in a stock solution of 50% glycerine and 50% hydrogen peroxide (10 vols.) until required.

An opening for access to the root canal was made, in the conventional manner, in the lingual fossa and the tooth was returned to the stock solution. After 24 hours the tooth length was recorded and the pulp remnants were removed with a barbed broach; at no time was the apical foramen passed with the broach. Finally, a No. 1 reamer was passed up the root canal until it was just visible at the root apex when viewed with a watchmaker's lens, thus ensuring that the apical foramen was patent. The mean diameter of a sample group of 8 No. 1 reamers at 1mm. from the tip was 0.195 mm. whereas the mean diameter of the apical construction of the root canals of the 28 teeth used in this preliminary study was 0.244 mm. The diameters of the constriction of the root canal of only 4 of these teeth were less than 0.195 mm. and these were 0.176, 0.183, 0.184 and 0.187 mm. Therefore by using the reamer in this way there was thus little risk of enlarging the diameter of the apical constriction in the teeth used, but the procedure ensured that the apex was patent and reduced the risk of producing false negative results.

The external portion of the root was machined with a modified diamond shoulder instrument (Fig. 5) which was inserted into the 3-jaw chuck of a metal turner's lathe and the sides of a portion of the root were made parallel for presentation to the brass collet. The root portion was thus prepared as far as the amelo-cemental junction so that as much of the root apex as possible would lie within the bijou bottle. The prepared tooth (Fig 6) was then returned to the stock solution for a further period of 24 hours to ensure sterility. It was then drained free of excess solution and transferred to a sterile container in which it was completely covered with about 6 ml. of sterile distilled water for at least 24 hours. This ensured that the stock solution was adequately diluted before proceeding with the experiment. Prior experiments with the test organism confirmed that the gylcerine/hydrogen peroxide solution was bacteriostatic in dilutions up to 1 in 640 but not at 1 in 1280. Control experiments with teeth treated as described above, showed that no contaminating organisms survived.

For a typical experiment, the tooth was placed in the sterile assembly (Fig. 4) and the rubber disc was pushed with sterile tweezers as far up the root portion of the tooth as was possible. A maximum area of the apical portion of the root was thus in contact with the fluid medium in the bijou. The clamp was screwed up tightly to hold the tooth rigidly in position.

Under sterile conditions the cap with its fittings was screwed firmly on to a bijou containing nutrient broth (Fig. 7). The root canal was dried with sterile paper points and in every case instrumentation was carried out to within 1 mm. of the apex of the tooth. To make certain that this limit was consistently and accurately defined, a small rubber disc marker was placed on the shank of the instrument at tooth length minus 1 mm. and instrumentation was carried out until the marker was level with the incisal edge of the

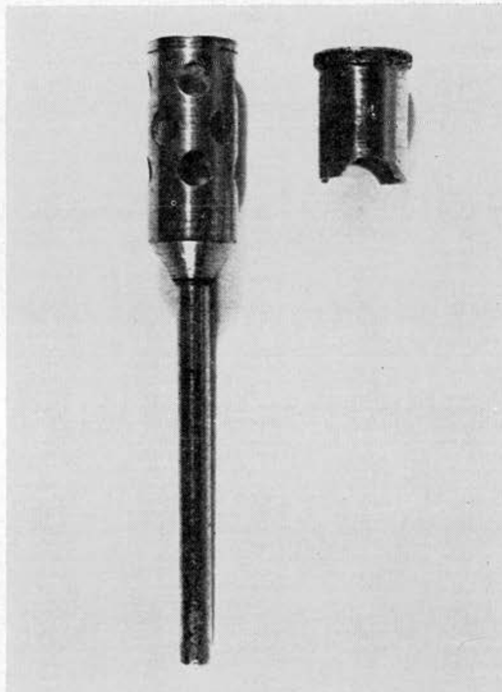

Fig. 5. *Diamond shoulder instrument, unmodified and modified.*

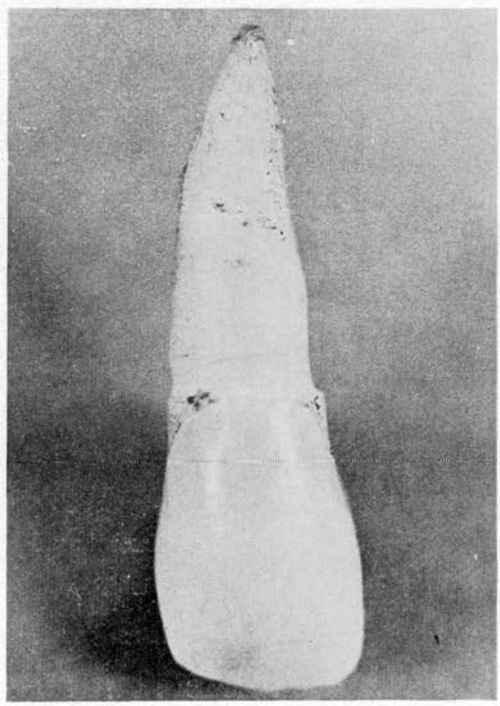

Fig. 6. *The prepared tooth.*

Fig. 7. *Prepared tooth held in clamp on bijou cap.*

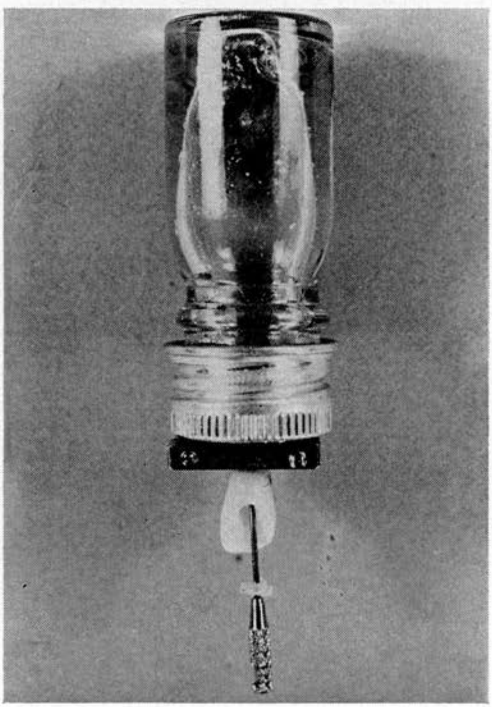

Fig. 8. *Bijou bottle inserted during instrumentation.*

tooth. The root canal was instrumented with the bijou bottle inverted so that culture medium was in intimate contact with the root end during the experiment (Fig. 8).

In control experiments, 2 teeth were instrumented with sterile reamers in sequential sizes up to No. 9. In each case the medium remained sterile after incubation. The stock solution had rendered the tooth apices sterile and no contamination had occurred during sterile instrumentation. In the experiment proper, the same procedure was adopted except that each instrument was dipped in a culture of the indicator organism twice. Generally it was found that instrumentation to the predetermined length could be obtained in 2 steps with each instrument size. The instrument was dipped in the indicator organism and used to within a few millimeters of the root length. It was then withdrawn from the root canal and debris was removed by wiping on a sterile cotton wool roll. The instrument was recharged with the indicator organism and the root canal was prepared to the predetermined length, i.e., the total length less 1 mm. The procedure was repeated with the instrument of the next size.

Altogether, 18 root canals were reamed and 10 root canals were filed. When the file was used, all canals were filed to No. 6 but when the reamer was used 1 root canal was reamed to No. 6, 4 to No. 8, 12 to No. 9 and 1 to No. 10. As an example, a tooth reamed to a No. 10 reamer received 16 innoculations because instrumentation commenced at No. 3 and each reamer was dipped in the indicator organism on two occasions. In this instance, the accumulated dose of culture suspension carried on the instruments was found to be 0.027 ml. In the case of teeth instrumented to No. 9, the total quantity of culture fluid was 0.02 ml, and instrumentation to No. 6 carried a cumulative inoculum of about 0.01 ml.

Following instrumentation, the screw cap with the attachment was removed and an unmodified sterile screw cap was replaced on the bijou bottle which was promptly sent for bacteriological examination. The contents of the bijou bottle were mixed thoroughly and a viable count was immediately performed on a small sample (6×0.025 ml.). The remainder was incubated overnight and counts were repeated on the following morning. By these procedures it was possible to assess the degree of contamination of the contents of the bijou resulting from transfer of organisms through the apical foramen. Heavy contamination resulted in a confluent growth of organisms from the immediate samples, and moderate contamination yielded countable numbers of colonies. Slight contamination produced no growth of colonies from drops obtained from the immediate samples, but profuse growth resulted after overnight incubation of the contaminated culture fluid. No contamination was indicated by no growth from the immediate samples or from the incubated medium. Results of control experiments indicated that a normal culture of *S. marcescens* contained 1×10^8 viable organisms per ml. and that adequate numbers of organisms were transferred during the test procedures to ensure that the above quantitation was likely to be achieved in practice. Using a culture containing 2×10^8 organisms per ml, 0.02 ml. ($= 4 \times 10^6$ organisms) would be transferred to the root canal. If a thousandth part of the infected material were dislodged, 4×10^3 organisms would be liberated. This would be deposited in about 3 – 4 ml. of fluid so that 1 ml. would contain 1×10^3 organisms. A drop (0.025 ml.) of this could contain about 20 organisms which would be readily countable.

Results

The results obtained in his preliminary study are summarized in the Table :—

Instrumentatoin		Direct Samples Yielded: No Growth	Countable	Confluent
Reamed	(18)	3	6	9
Filed	(10	1	5	4

The relationship of the type of endodontic instrumentation to the in-vitro expulsion of infective material from 28 experimental teeth.

When 18 teeth were instrumented with root canal reamers the indicator organism passed through the apical foramen of 15. When 10 teeth were instrumented with root canal files, material from the root canal passed beyond the apical foramen in 9 cases. It therefore seems that the instrumentation in a root canal, whether by reamers or files, is almost certain to push material from the root canal through the apical foramen into the periapical space.

It should be pointed out that 9 (50%) of the immediate samples from the 18 teeth that were reamed gave confluent growths and 4 of the 10 teeth that were filed (40%) produced immediate samples that yielded confluent growths. With due appreciation that the attention to detail in these experiments restricted their numbers, the results would not appear to support the intuitive assumption that the use of a root canal file is much less likely to push material through the apical foramen than is the case when a root canal reamer is used. The number of observations is too small to permit a more dogmatic conclusion and the further development of this model may allow more accurate quantitation.

Summary

A model assembly is described for the *in-vitro* study of problems associated with endodontic instrumentation. In a preliminary survey of the effects of endodontic instrumentation, the expulsion of infective material from the root canal was demonstrated in 24 (86%) of 28 teeth tested. There was no significant difference if reamers or files were used. The results support the principle that the root canal should be rendered as "sterile" as possible before attempting endodontic instrumentation.

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