1.0 INTRODUCTION

Root canal preparation has been considered the most important phase in endodontic therapy. The objectives of root canal preparation can be defined as cleaning and shaping. Shaping is easily accomplished in straight canals; however, as the canal curvature increases, it will become increasingly difficult. Molar root canals generally exhibit some amount of curvatures along their path. In these curved canals, canal preparations were routinely performed with stainless steel files using step-back or step-down techniques before rotary instrumentation technique became popular. Problems such as limited access, blocked canals, time constraint, operator fatigue, separated instrument and canal aberration were often encountered. Irregularities in shape and the presence of calcifications also present problems during canal preparation (Johnson, 1986).

The ideal preparation of the root canal is a funnel-shaped form with the smallest diameter at the apex and the widest diameter at the orifice (Schilder, 1974). Hand preparation techniques can be time consuming and, especially in narrow and curved canals, aberrations such as ledging, zipping and danger zones and transportation can occur because larger instruments tend to straighten the canal (Esposito & Cunningham, 1995; Glosson *et al.*, 1995).

Reports have shown that nickel-titanium (NiTi) instruments are two to three times more flexible than conventional stainless steel files and are more resistant to torsional failure (Walia *et al.*, 1988). One of the recent NiTi instruments that is gaining popularity is the ProTaper® (Dentsply Mailefer, Ballaigues, Switzerland).

Manufacturers generally claim their instruments to have superior characteristics for their design and application.

This study has been designed to compare several parameters of canal preparation between hand instrumentation and ProTaper® rotary instruments by superimposing the pre- and post-operative digital radiographs to measure the change in canal curvature and occurrence of procedural errors. Recently many investigations have been done on the performance of ProTaper® instruments (Bergman *et al.,* 2003; Peters *et al.,*2003; Iqbal *et al.,* 2004; Schafer & Vlassis, 2004; Calberson *et al.,* 2004; Guelzow *et al.,* 2005; Paque *et al.,* 2005) but records on canal aberrations such as ledge, apical zip, elbow and over-instrumentation are relatively few. Step-down technique was chosen for hand instrumentation while rotary instrumentation was performed with crown-down technique since both the technique is very similar to each other. K-Flexofiles were chosen as controls since it is well known that out of all hand instruments used in rotary motion, these instruments displayed the greatest cutting efficiency (Tepel *et al.,* 1995; Schafer & Florek, 2003) and most ideal shape (Al Omari *et al.,* 1992; Schafer *et al.,* 1995).

Conventional and digital radiographic analyses have been used in various studies to analyze several parameters in canal preparation such as apical transportation, loss of working length and procedural errors (Iqbal *et al*., 2004; Nagy *et al*., 1997; Esposito & Cunningham, 1995). Digital radiographs have several advantages over conventional radiograph especially in research works. Optimizing digital radiographs and visible light images is relatively easy using currently available software (Levin, 2001). In the double radiographic superimposition method, radiographs taken before and after root canal preparation provide good means for two-dimensional study of the longitudinal shape of the root canal.

The purpose of this study is therefore to compare the performance of ProTaper® rotary instruments with a routinely used canal preparation method with K-Flexofiles. This study would act as a baseline for comparative studies using other rotary instruments and also for further investigations on ProTaper® instruments.

2.0 OBJECTIVES OF STUDY

The objective of this investigation is to compare the performance of two root canal preparation techniques, ProTaper® rotary instruments versus stainless steel hand K-Flexofiles, in preparing the curved root canals in the mesial roots of mandibular first molars. The comparison in canal preparation is done based on:

- Changes in the angle of canal curvature pre- and post-preparation using ProTaper® rotary files and stainless steel hand K-Flexofiles (measurements done using AutoCAD software).

- Occurrences of apical transportation by superimposition of the pre- and post-operative digital radiographs (superimposition done using Adobe Photoshop software).

- The frequency of separation of ProTaper® rotary files when used with torque-controlled motors at recommended range of torque according to manufacturer's instructions.

- The frequency of separation of stainless steel hand K-Flexofiles

- Incidence of procedural errors (ledges, over instrumentation, lateral perforation, zips & elbows) by ProTaper® and stainless steel K-Flexofiles.

3.0 LITERATURE REVIEW

Cleaning and shaping of root canal space is a primary objective of root canal therapy. This has been traditionally accomplished with hand files, reamers and broaches. Schilder (1974) has stated that the objective of making the final root canal preparation is to conform to the general shape and direction of the original canal. The most neglected phase of endodontic treatment and the greatest problem lie in attempting to maintain the canal curvatures in the apical regions especially for the posterior teeth. The mandibular first molar seems to be the most frequently in need of endodontic treatment. Usually, this tooth exhibits various curvatures in its roots and the root canals systems (Burns & Herbranson, 1998).

3.1 MANDIBULAR FIRST PERMANENT MOLAR

3.1.1 ANATOMICAL FEATURES

Mandibular first molar usually has two roots, a mesial root containing two distinct canals and a distal root with one oval root canal. Apart from the two-rooted mandibular molar, an accessory distolingual root may be encountered (Barker, 1973). The mesial roots are usually curved, with the greatest curvature in the mesiobuccal canal. The orifices are usually well separated at the floor of the pulp chamber and situated in the buccal and lingual aspects under the cusp tips (Burns & Herbranson, 1998). The canals of the distal root are often larger than of the mesial root. Occasionally the orifice is wide from buccal to lingual surface (Burns & Herbranson, 1998).

3.1.2 CANAL SHAPE AND CONFIGURATION

Mesial root canals

A study performed by Weine (1995) on about 9000 samples from patients treated in his private practice has shown that the mesial root canals may join and exit at a single apical foramen in 15% of cases (Weine Type II) or they may each have their own apical foramina (Weine Type III) in approximately 85% of cases (Weine, 1983 & Weine, 1995).

In Vertucci's (1984) root canal classification study performed on 100 samples, 59% had two canals at the apex, 40% had one canal at apex and 1% had 3 canals at apex. Out of the 40 samples that had one canal at apex, 28 samples had 2 canals at the orifice that later joined to exit in a single foramen. The results were in agreement with a study by Pineda & Kuttler (1972) who found 57% of the mesial canals with two foramens and of remainder 43% with a single foramen 30.2% started as two separate canals at the orifice.

The dimension of the mesial canals varies considerably. In a study by Karekas & Tronstad (1977) on root canal diameters of mesial canals, at a point of 1mm from the apex, values between 0.15 and 2.2 mm were recorded and they have observed canal diameters up to 5mm at a level of 5mm from apex. The most common diameter for narrow mesial canals of mandibular molars is size #15 (Tan & Messer, 2002). The average wide diameter in the apical 1-2mm of the mesial canals is 0.3-0.4mm (Zuckerman *et al.*, 2003). Hence, one has to wonder whether the common recommendation of master apical file size of #25 or #30 for routine use in hand instrumentation techniques in the mesial canals of mandibular molars is sufficient to remove all infected debris near the apical terminus (Tan & Messer, 2002).

3.1.3 STUDIES OF THE VARIATIONS IN CANAL ANATOMY

In the past, many studies were done on the variations in the canal anatomy of the mandibular first molars. As early as 1925, Hess examined the internal morphological structure of mandibular molars and reported that 10% of the specimens had two root canals, 85% had three canals and 5% had four canals with no distinction being made between first and second molars for these prevalence values.

Later, studies by Skidmore and Bjorndal (1971) and Green (1973) focused on the orifices in the pulp chamber and termination at the apical foramen. Skidmore and Bjorndal found that 59.5% of the mesial and 38.5% of the distal canals remained separate along the entire length of the root, the remainder joining to form a common canal and foramen at apical third. Green (1973) found that in mesial roots of mandibular molars, 87% had double canal orifices in the pulp chamber with 38% having two apical foramina. They reported that 60% of the mesial roots had two canals at the apex and 40% had one.

More recent researchers like Goel *et al.* (1991) and Wasti *et al.* (2001) have also studied the root canal configuration of mandibular first permanent molars. However, the percentage of multiple canals in the mesial root shows a great deal of variations. Goel *et al*. (1991) reported 78.3% of the mesial roots had two canals while Wasti *et al.* (2001) found that 97% of the mesial roots had two canals.

The presence of two separate, fine and curved canals in the mesial root of mandibular molar facilitates the use of such roots for comparative study of canal preparation using two different instruments (e.g. Glosson *et al*., 1995; Gilles & Del Rio, 1990; Nagy *et al.*, 1997; Leseberg & Montgomery, 1991; Davis *et al.*, 2002; Ponti *et al.*, 2002; Tan & Messer, 2002; Garala *et al.*,2003; Bergman *et al.*,2003; Hulsmann *et al.*,2003; Iqbal *et al.*, 2004; Paque *et al.*, 2005).

Based on the reports in the literature, it can be concluded that human mandibular first permanent molar has an average length of 21mm, has two roots in majority of the cases and has two separate mesial canals (60%) (Bjorndal & Skidmore, 1983; Vertucci, 1984; Ingle *et al.*, 1994). General configurations of mandibular first molars are summarized in Tables **3.1** to **3.5.**

Table 3.1 Average length of mandibular first permanent molar

Length of Tooth	Mesial (From cusp to root tip)	Distal (From cusp to root tip)
Average Length	20.9mm	20.9mm
Maximum Length	22.7mm	22.6mm
Minimum Length	19.1mm	19.2mm
Range	3.6mm	3.4mm

* (Bjorndal & Skidmore, 1983; Ingle *et al.*, 1994)

Table 3.2 Variability of canals in the roots of mandibular first permanent molar

No Of Canals	Percentage
Two Canals	6.7%
Three Canals	64.4%
Four Canals	28.9%

*(Bjorndal & Skidmore, 1983; Ingle *et al.*, 1994)

Table 3.3 Root canal configuration of mandibular first permanent molar

Roots	One canal at apex			Two canals at apex				Three canals at apex
	Type I 1-canal	Type II 2-1 canals	Type III 1-2-1 canals	Type IV 2-canals	Type V 1-2 canals	Type VI 2-1-2 canals	Type VII 1-2-1-2 canals	Type VIII 3-canals
Mesial Root	12%	28%	0%	43%	8%	10%	0%	1%
Distal Root	70%	15%	0%	5%	8%	2%	0%	0%

* (Bjorndal & Skidmore, 1983; Ingle *et al.*, 1994)

Table 3.4 Root canal anatomy of mandibular first permanent molar

Roots	Number of canals by Weine's classification		
	Type I (one canal one foramen) (1)	Type II (Two canals one foramen) (2-1)	Type III (Two canals two foramen) (2-2)
Mesial root	0.0%	40.5%	59.5%
Distal root	71.1%	17.7%	11.1%

*(Vertucci, 1984)

3.1.4 VARIATIONS AND METHODS TO ASSESS CANAL CURVATURE

Few studies have actually measured the degree of curvature in root canals. Schneider (1971) was one of the first to describe a method of determining canal curvatures from clinical view radiographs. He did not investigate curvatures seen from the proximal view. Later, this method was modified by Bone & Moule (1986) to describe secondary curvature in the apical region. Yet, these researches have not investigated the degree of root curvature in the proximal direction.

On the other hand, Cunningham & Senia (1992) have studied root canal curvatures both in clinical and in proximal directions. The degree and root canal configuration of canal curvature was studied in the mesial roots of 100 randomly selected mandibular first and second molars. They found that all of them demonstrated curvatures in both views. No correlation in degree of curvature was found to exist between the clinical and proximal views. Secondary curvature, in a direction opposite to that of the principle curve was seen more frequently in the proximal view. In the proximal view the canals exhibited greater mean curvature than in the clinical view 38% of the time. They also concluded that clinical view curvatures of the mesiobuccal and the mesiolingual canals in the same tooth were similar and directionally correlated.

Backman *et al.* (1992) did a radiographic comparison of two root canal instrumentation techniques by using 50 root canals from extracted maxillary and mandibular molars. Only buccal canals of maxillary molars and mesial canals of mandibular molars were used. They used drawings and projected radiographic images of the files to calculate the change in angle and radius of curvatures after instrumentation in both clinical and proximal views. Radiographs were projected onto drawing paper secured to the countertop, resulting in an enlargement of approximately 7x. The clinical and proximal angles were determined from drawings made from the images manually. They calculated the radius measurement for single canal from the tip of the instrument at the apical foramen to where the canal deviated from the coronal axis. Two radius measurements were determined for double or S-type curvatures, first from where the first curve began to the point at which the second curvature occurred. The second measurement was made from the tip of the instrument at the apical foramen to where the second curvature began. These two measurements were used to classify the intensity of the canal curvatures used in their study.

More recently, Kartal & Cimilli (1997) performed a study to determine the frequency, degree of curvature, and the configuration of mesiobuccal and mesiolingual root canals of first molars. 697 freshly extracted mandibular first molars were used in this study. After introducing size #08 to #15 K reamers into the mesial root canals, the teeth were radiographed in buccolingual or clinical (CV) and mesiodistal or proximal (PV) directions. All samples showed curvatures at varying degrees in both views. Vertucci type II canals were detected in 40.7% of samples, while type IV was detected at 53.7%, and Vertucci Type VI in 5.6% of the samples respectively. As for the curvatures, mesiobuccal canal was one that showed the largest primary curvatures and no correlation was found between CV and PV primary curvature value for either the mesiobuccal or the mesiolingual canals. As to secondary curvatures, they encountered more secondary curvatures in PV than in CV, and the mesiolingual canal showed the highest degree of secondary curvature in the PV. They also observed 24 tertiary curvatures, which had not been previously discussed in literature; 7 of which were in the CV of mesiolingual canals and 17 in the PV of mesiobuccal canals.

From the studies above, we can derive the conclusion that mesial roots of mandibular molars exhibit canals with primary curvatures toward distal and can be measured from clinical view radiographs. They also have secondary and sometimes tertiary curvatures that can be observed from both clinical and proximal view radiographs.

Table 3.5 Root curvature of mandibular first permanent molar

Direction Of Curvature	Mesial Root	Distal Root
Straight	16%	74%
Distal	84%	21%
Mesial	0%	5%
Buccal	0%	0%
Lingual	0%	0%

- (Bjorndal & Skidmore, 1983; Ingle *et al.*, 1994).

3.2 CANAL PREPARATION

Schilder (1974) introduced the concept of “cleaning and shaping”, which is the foundation of endodontic therapy. In fact, most obturation problems are really the result of improper cleaning and shaping. The two concepts, cleaning and shaping are inseparable. Cleaning and shaping outcomes are significantly improved when the coronal two-third of a canal is first scouted and then pre-enlarged (Ruddle, 2001).

3.2.1 CORONAL FLARING

Pre-enlargement of the coronal portion of the canal can be accomplished with a variety of hand and rotary instruments. There are a number of benefits in pre-enlarging the coronal two third. Firstly, pre-enlargement give the clinician better tactile control when directing small files into the delicate apical third of the canal. Early coronal enlargement increases volume of irrigant inside the canal that enhances cleaning by accelerating dissolution of pulp tissue towards the apical and lateral aspect of the canal. It also dramatically promotes the removal of dentin mud. Enlarged two third of canal also decreases post-treatment problems because the bulk of the pulp tissue and bacteria and their endotoxins (when present) have been removed. Passing files through debris-laden and infected canal has the potential to push more irritants into the periapical area, thereby causing more post-operative exacerbations (Fairbourn *et al.*, 1987). Electronic apex locators are more reliable when used in pre-enlarged canals because instruments are more likely to contact dentin as they approach the apical foramen (Kovacevic & Tamarut, 1998).

Once the appropriate working length (WL) has been established, maintaining consistency of that measurement throughout the course of endodontic treatment is crucial to the clinician's ability to instrument and obturate to the desired apical location. Should the working length change over the course of treatment, the depth of canal treatment becomes unpredictable. This is particularly true in the instrumentation of curved canals. Davis *et al.* (2002) studied the effect of early coronal flaring on working length change by using rotary NiTi and stainless steel files. They used 30 curved canals from extracted maxillary and mandibular molars. Coronal flaring was accomplished by using Gates-Glidden drills for the stainless steel group and NiTi rotary files for the NiTi group. Their results indicated that working length decreased for all canals as a result of canal preparation, which decrease was greater in the stainless steel group.

The single most important factor influencing the success of root canal treatment is the apical extent of the root filling, which probably implies both the apical extent of canal preparation as well as filling (Gulabivala *et al.*, 2005). The probability of success is reduced if the root filling is extruded beyond the radiographic apex, regardless of the presence or absence of pre-existing periapical disease (Gulabivala *et al*., 2005). If the radiographic apex of the teeth were used as the measure for working length determination, over instrumentation and transportation of the foramen would likely occur in majority of teeth (Haapasalo *et al*., 2005).

Most endodontic researchers conclude that the quality of the apical preparation determines the effectiveness of the apical seal (Allison *et al.,* 1979). This anatomic region harbors more lateral canals, more accessory canals, more curvature, and certainly more potential for irreversible damage, than coronal two-thirds of the canal system. Depending on the apical configuration, canal morphology and curvature, variation in apical preparation will result. Most desirable is the apical stop, then an apical seat, as opposed to an open apex (Walton, 1992).

The desirable final size of the apical preparation remains controversial. Two main concepts have been proposed. The first concept aims at complete circumferential removal of dentine. The traditional rule has been, to prepare at least three sizes beyond the first file that binds at working length (Hulsmann *et al.,* 2005). Histological studies could demonstrate that 15-30% of the root canal walls remained untouched by instruments following manual preparation even when the recommended instrument sizes were used (Walton, 1976; Bolanos & Jensen, 1980).

The second concept aims to keep the apical diameter as small as practical (Schilder, 1974). This concept for apical preparation includes scouting of the apical third, establishing apical patency with a size #10 instrument passively inserted 1mm through the foramen, gauging and tuning the apical third and finally finishing the apical third to at least a size #20. Corresponding to this technique GT instruments (Dentsply Tulsa Dental, Tulsa, OK, USA) in their original sequence included four instruments for apical finishing, all with size #20 tips but different tapers. Similarly, ProTaper® Finishing instruments have apical diameters ranging from 0.20mm to

0.30mm (Hulsmann *et al*., 2005). The influence of final apical preparation size has been examined in two long-term studies on treatment outcome. Whereas Strindberg (1956) reported on a poorer prognosis for larger apical preparation, Kerekes & Tronstad (1979) found similar results for apical preparation to ISO sizes 20-40 versus sizes 45-100. Card and his group demonstrated in vivo a significantly increased reduction of intracanal bacteria after apical enlargement to larger sizes with NiTi instruments (Card *et al*., 2002).

Coronal pre-enlargement of a canal may be accomplished in either a step-back or crown-down manner. A step-back technique is the sequential use of instruments starting with the smaller sizes and progressing towards the larger sizes, regardless of type of instrument used (Coffae & Brilliant., 1975; Goodman *et al.*, 1985). A crown-down technique is the serial use of instruments, starting with the larger sizes and progressing towards the smaller sizes (Marshall & Pappin, 1980).

3.2.2 STEP-DOWN TECHNIQUE

In the step down technique sequential enlargement of the root canal from the pulp chamber to the apex is advocated using instruments with a filing action (Buchanan, 1991; Goerig *et al.,* 1982). Early preparation of the coronal straight section of canal is achieved with increasing sizes of Hedstrom files followed by Gates-Glidden burs; copious irrigation is essential. The working length is then established and the apical part of the preparation starts with a pre-curved, lubricated fine file (#08, #10 or #15) used with an apical- coronal filing motion. Increasing sizes of files are used until the apical preparation has been enlarged to a minimum of size

#25. The preparation is stepped back with progressively larger files to join the already enlarged coronal part.

Major goals of initial coronal enlargement are reduction of periapically extruded necrotic debris, improved straight-line access, improved irrigation penetration and minimization of root canal straightening. Since after the step-down there is less constraint to the files and better control of the file tip, it has been expected that apical zipping is less likely to occur. Over the years several variants of the technique have been proposed, such as the crown-down technique, as well as hybrid techniques combining an initial step-down with a subsequent step-back (modified double flare) (Hulsmann *et al.,* 2005).

Although step-back and step-down techniques may be regarded as the traditional manual preparation techniques there are surprisingly few comparative studies on the two techniques (Hulsmann *et al*., 2005). There is no definite proof that classical step-down techniques are superior to step-back techniques. Only the balanced force technique, which is a step-down technique as well, has been shown to result in less straightening than step-back or standardized techniques (Hulsmann *et al.,* 2005; Calhoun & Montgomery, 1988; Backman *et al.,* 1992; Sabala *et al.,* 1988).

There is no doubt that the preparation of curved canals present one of the greatest challenges in endodontic treatment and fraught with potential difficulties. A variety of techniques have been proposed for preparing these canals. They include pre-curving stainless steel files, anti-curvature filing body shaping and balanced force technique (Druttman, 2001).

3.2.3 STAINLESS STEEL INSTRUMENTS

Traditionally, hand files were manufactured by twisting square or triangular shaft of metal about their long axis, converting the vertical edges into inclined cutting blades. For almost a century, instruments for the manual preparation of the root canal system have been manufactured in a similar way: there are the three main types, namely the reamer and the K-file. The common features of all three are that they have a total cutting length of 16mm and an increase in diameter by 0.02 mm per millimeter, that is, a *taper* of 2%. In addition the cutting edges are mostly positioned at equal intervals so that all endodontic instruments of this type are designed to be similar to a screw. The cutting edges meet the canal wall at different angles (reamer with an angle of approximately 20°, K-files with 40°, and H-files with 60°). However, recently computer assisted machining has enabled manufacturers to modify existing file geometries (Ruddle, 2002).

K-Flexofiles®

Out of all hand instruments tested in a rotary motion, K-Flexofiles® displayed the greatest cutting efficiency (Tepel *et al*., 1995; Schafer & Florek, 2003) and most ideal and tapered canal shape (Al-Omari *et al*., 1992; Schafer *et al*., 1995). K-Flexofiles are actually K-files with additional flexibility due to smaller metallic core and a change of cross-sectional geometry from square into triangular. Additionally, decreasing the helical angle and increasing the distance between the cutting blades have improved instruments efficiency. By making the inter-blade grooves or flutes deeper, there is more space to accommodate dentinal shavings (Ruddle, 2002). The increased flexibility together with non-cutting tip allows the instrument to be used in curved canals with reduced risk of ledging and transportation. K-type files are considerably more effective than K-reamers, although because of the significantly higher risk of screwing themselves into the canal, they must not be turned in the canal more than half a circle (180°) (Clauder & Baumann, 2004).

K-Flexofiles® are produced in various diameters but the taper is the same. As the file size increases, the flexibility is reduced and this means that a curved canal will tend to be straightened during preparation. The deviation from the original canal shape results in over-cutting on the outer wall in the apical region (zipping, ledging) and along the inner wall more coronally (stripping), particularly at the start of the curve (danger zone). A further disadvantage of 0.02 taper hand instruments is their tendency to create narrow canal shapes minimizing access of irrigants and creating potential to allow debris to be pushed apically (Saunders, 2005). As a general rule, all K-files must be pre-curved before placing them in a canal. The degree of the pre-curving depends on the radiographic appearance of the root curves. A pre-curved file makes its way more easily through the obstacles it might encounter. The file must be pre-curved in a gentle and gradual way at its 2-3mm end; it must not be bent (Rebeiz, 2006).

3.2.4 CROWN DOWN TECHNIQUE

Crown down may be defined as a process of using a series of files from the coronal part of a canal towards the apical part while decreasing the instrument size or instrument taper. The next smaller file will perform its cutting action deeper in the canal, leaving the engaging surface of each instrument minimal and, therefore, decreasing the torque load of each instrument. Repeating the use of such a series of files will also result in either gaining deeper access into the canal or enlarging the canal further by each sequence.

Crown down minimizes coronal interference, eases instrument penetration, increases apical tactile awareness, reduces canal curvature, minimizes change in the working length during apical instrumentation, allows irrigation penetration to preparation depth, removes bacteria before approaching the apical canal third, reduces the contact area of each instrument, and reduces instrument tip contact and the incidence of procedural errors (Walsch, 2004).

The technical problems associated with adequate biomechanical instrumentation and obturation of small curved root canals, are well known. A number of studies suggested that root canal debridement, achieved with standard techniques and instrument sizes, were frequently inadequate (Southard *et al., 1987*).

Some teeth have simple straight roots but the majorities have some degree of curvature, especially in the apical third. The internal diameter of the canal may also vary from fine to large depending on the particular tooth and the amount of reparative dentin that has been laid down. The mesial roots of mandibular molars, for example, have fine curved canals that can be very challenging to instrument. The canal may be roughly circular in cross section along its length, or only the apical part may be round while the remainder is oval or irregular in cross section. When an instrument is used with a complete rotating action in a canal with apical curvature a gouged cavity may be created. If reaming is continued iatrogenic root perforation is likely (Vessay, 1969; Saunders & Saunders, 1997).

3.2.5 INFLUENCE OF NiTi INSTRUMENTS DESIGN ON ROOT CANAL PREPARATION

Recent advancement in technologies has permitted the manufacture of endodontic files from Nitinol, a nickel-titanium alloy with very low module of elasticity. The flexibility of endodontic files is an important characteristic, as the more flexible files tend to negotiate curved canals better and reduce the tendency of straightening, zipping, ledging or perforation of curved canals (Weine, 1989; Mullaney, 1979). Because of the metallic properties of NiTi, it became possible to engineer instruments with tapers greater than 2%, which is the norm for stainless steel instruments (Bergmans *et al.,* 2001). Various NiTi files systems have been invented to assist in the preparation of curved root canals e.g. ProTaper® system, LightSpeed® system, K3® rotary NiTi file system, FlexMaster® system, Profile® system and Hero 642® instruments system.

Ideally, root canal preparation should follow the exact outline of the horizontal dimensions of the root canal at every level of the canal. In this ideal condition, especially for long-oval root and flattened root canals they can be cleaned and shaped properly with minimal mishaps of weakening, stripping, or perforating the canal walls. Circumferential preparation or instrumentation may have to be considered for those cases to minimize incomplete cleaning of the root canal system. Most of the NiTi rotary instruments are used in a continuous reaming action that makes the canal relatively circular in shape. Indiscriminate use of the NiTi rotary instruments alone for root canal cleaning and shaping may lead to incomplete cleaning of the root canal system and lead to failure of the endodontic therapy (Jou *et al.,* 2004).

NiTi rotary instruments can be divided into two main categories based on their designs: active and passive instruments (Walsch, 2004). Active instruments have active cutting blades similar to the K-Flexofile, whereas passive instruments have a radial land between cutting edge and flute. The radial land touches the canal wall on its entire surface, guiding the instrument stable and balanced within the canal. In general, active instruments cut more effectively and more aggressively, and have a tendency to straighten the canal curvature (Walsch, 2004). In addition, the more positive the rake angles of the blade produces more aggressive the cutting action of the instrument. Passive instruments perform a scraping or burnishing rather than real cutting action, remove dentin slower, and therefore have less of a tendency for canal straightening (Walsch, 2004).

3.2.6 PROGRESSIVELY TAPERED INSTRUMENTS (PROTAPER®)

The ProTaper® system is designed for both hand use and rotary use. Progressively Tapered (PROTAPER®) NiTi rotary files (Dentsply Tulsa Dental) represent a revolutionary progress in root canal preparation procedures (West, 2001). The ProTaper® files were specifically designed to provide superior flexibility, unmatched efficiency and greater safety. This enables clinicians to create uniformly tapered shapes in anatomically difficult or significantly curved canals more consistently (Ruddle, 2002). ProTaper® instruments have a convex triangular cross-sectional form, very similar to that of FlexMaster®, and also are relatively strong. ProTaper® instruments are unique among all NiTi rotary instruments in that they have different tapers along a single instrument (multi-tapered instruments) (fig **3.1**).

The ProTaper® System Geometries

The set contains just six simple-to-use files and the series comprises of three shaping and three finishing instruments.

a) Shaper X- also referred as SX has an overall length of 19mm, providing access in restrictive areas. It is also regarded as substitute for the Gates – Glidden drills (coronal flaring).

b) Shaping file No 1 and No 2- also referred as S1 and S2 has increasingly larger tapers over length of their cutting blades allowing each instrument to engage, cut and prepare specific area of canals. S1 has been designed to prepare coronal one-third of a canal while S2 enlarges and prepares middle-third of a canal as they do progressively enlarge apical one-third.

c) Finishing files No 1, 2 and 3- also referred as F1, F2 and F3 corresponding to the ISO classification of standard files size #20, #25 and #30. These instruments have been designed to finish the apical one-third optimally while progressively blending and expanding the shape in to middle-third of canal.

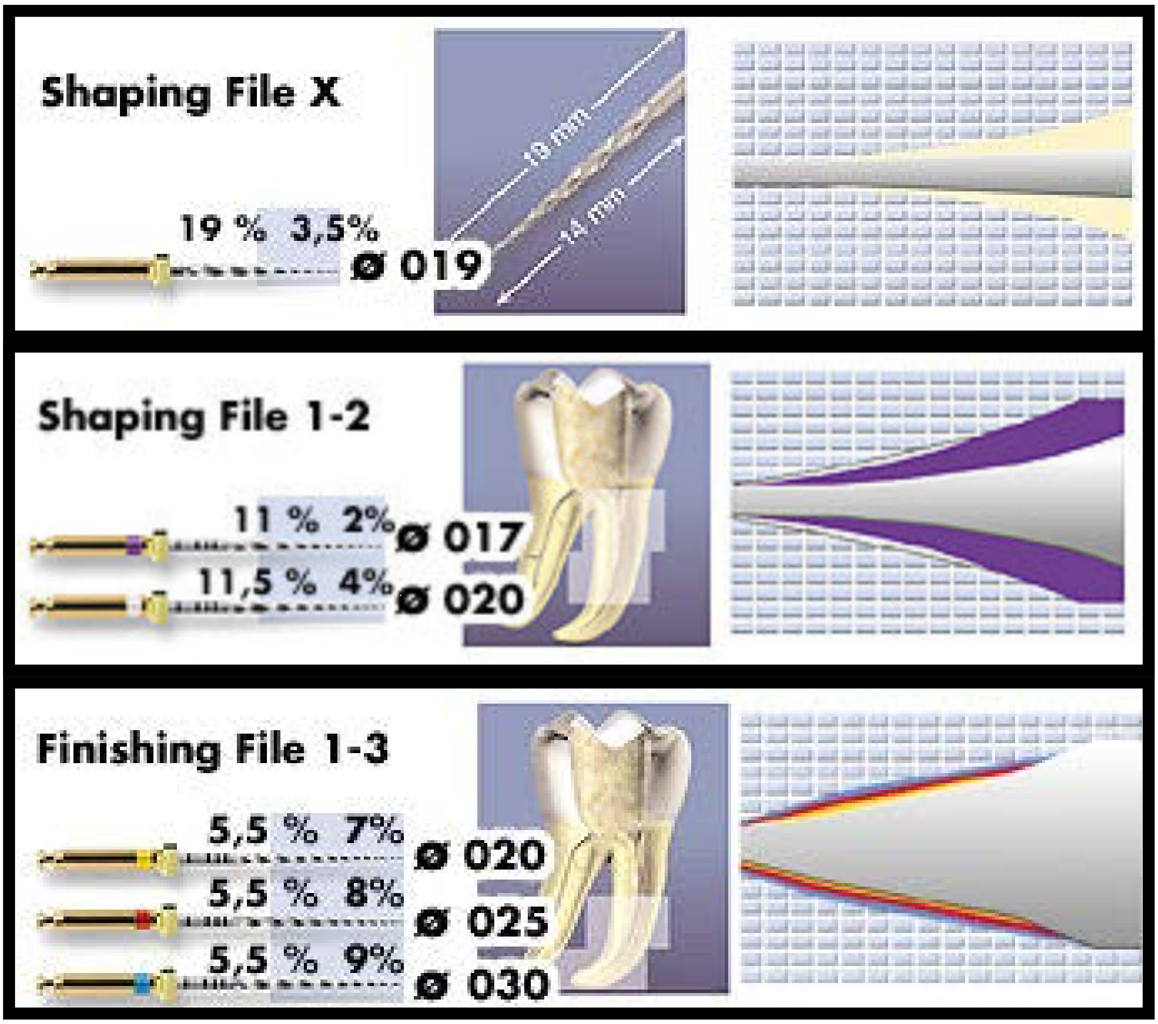


Figure 3.1 Various taper of ProTaper® rotary instruments and specific area of preparation of each file.

ProTaper® features and benefits

Multiple tapers of each instrument are designed to cut at a specific zone (fig **3.1**). Convex triangular cross-section reduces the contact between the blade of the file and dentin, serves to enhance the cutting action and improve safety by decreasing torsional load. Modified active tip follows the canal better and enhance its ability to find its way through soft tissue and loose debris without damaging the canal walls. Variable pitch and helical angle-minimizes screw-in effect during rotation and effectively allows its blades to auger debris out of canals. Short handles improve access into posterior regions of the mouth, especially when there is a narrow occlusal space (Dentsply Asia ProTaper® guidelines for use, 2004 & Ruddle, 2002).

In recent years, numerous studies have been conducted after NiTi rotary instrument became popular in clinical use. Various NiTi systems have been experimented but researches about ProTaper® instruments are significantly less as it was introduced into the market in the year 2001 (Clauder & Baumann, 2004). The manufacturer claims it to be the ideal instrument for cleaning and shaping small and curved root canals especially in posterior teeth. They strongly recommend the crown-down technique with rotary ProTaper® files(Dentsply Asia ProTaper® guidelines for use, 2004).

Originally, NiTi ProTaper® instruments were developed to facilitate instrumentation of difficult, constricted and severely curved canals. These instruments were designed "to cover the whole range of treatment with only a few files, which incorporate superior flexibility, unmatched efficiency and improved safety" (Ruddle, 2002). The number of files with a progressive taper (ProTaper®) was decreased to a set of six instruments: three shaping files for the crown-down procedure and three finishing files for apical shaping and creating a smooth transition from the middle one third of the canal providing the preparation deep shape. The three shaping files are characterized by increasing tapers over the whole length of their cutting blades, allowing for a controlled cutting performance in special sections of the instrumented root canal. The finishing files are available in different diameters, #20, #25, #30 and a fixed taper over 3 mm to finish apical preparation (Clauder & Baumann, 2004).

The ProTaper® files generate lower torque values than do rotary instruments with a U-file design (radial land). Furthermore, higher forces that are generated in some cases of constricted canals were insufficient to fracture ProTaper® instruments (Peters *et al.,* 2003a; Spanaki-Voreadi *et al*., 2006). Constricted canals are a major problem because of the correlation of high torque values (Peters *et al.,* 2003a; Spanaki-Voreadi *et al*., 2006). Using a ProTaper® file seems to minimize fracture risk of the instrument. Apical instrumentation with K-files is extremely important in these cases. After carefully preparing access cavity to working length, initial negotiations must be done with a #10 or #15 K-file up to about two thirds of the estimated working length. In addition, discarding the instruments that have been used on calcified or constricted canals after or during use helps to minimize the fracture risk (Berruti *et al.,* 2004; Spanaki-Voreadi *et al*., 2006). Mathematical models have confirmed that in case of similar apical loads, ProTaper® instruments work longer in super elastic phase than do instruments with U-file design, allowing for high performance and less risk (Peters *et al.,* 2003a; Peters *et al*., 2003b; Zelada *et al.*, 2002). Recent studies have shown that the ProTaper® system perfectly shapes curved and constricted canals (Peters *et al.*, 2003a; Peters *et al*., 2003b; Zelada *et al.*, 2002).

Comparing the ProTaper® NiTi system with other systems, one can notice that other file systems focus on one taper within a file and tend to combine a series of files to achieve the necessary effect. In contrast, ProTaper® system has varying tapers within one file ranging from 2% to 19%, which makes it possible to shape specific sections of a root canal with one file. Other new design features are the modified guiding tips and the varying tip diameters. The modified guiding tip allows one to follow the canal better and the variable tip diameters allows the files specific cutting action in defined areas of the canal, without stressing the instruments in the other sections (Clauder & Baumann, 2004).

After the ProTaper® system was introduced, the possibility of more or less severe canal transportation produced by active cutting action was discussed. The latest evidence shows that "canal can be prepared with the ProTaper® system without major procedural errors" (Peters *et al*., 2003a). Micro–computed tomographic evaluation of prepared canal shapes showed that the ProTaper® system tends to transport canals slightly more than file systems with a passive cutting action. Therefore, it is important to immediately remove the instrument out of the root canal once working length is achieved. Prolonged rotation of the instrument with an active cutting blade can lead to unnecessary misshapes in canal anatomy (Peters *et al*., 2003a). Achieving proper coronal shaping and straight-line access can minimize this tendency. Straight-line access helps to minimize transportation during the shaping procedure (Peters *et al.,* 2003).

ProTaper® instruments provide a continuous tapered preparation of the root canal, without significant transportations from the original position. The ProTaper® files engage specific sections of the root canal system, as the instrument geometry and design allows. This can be demonstrated very easily, inspecting the instruments for debris remnants immediately after use (Clauder & Baumann, 2004).

In cases of severe curvatures, rotational speed of the instruments could be reduced to about 150 rotations per minute as high speed could cause instruments separation (Martin *et al.*, 2003; Zelada *et al*., 2002). In cases of pronounced and acute curvatures (Pruett *et al*., 1997) with a small radius, the use of ProTaper® files in a hand file manner is helpful, especially because there are new useful handles available. The files can be used safely in watch winding motion. Cutting efficiency can be improved in a turning motion (Clauder & Baumann, 2004).

ProTaper® instruments also can be helpful in retreatment cases; the finishing files are especially useful in the careful removal of gutta-percha. For reshaping the canal anatomy after establishing patency, the instruments can be used in the same sequence, if pretreatment did not result in far greater apical diameters (Clauder & Baumann, 2004).

Rotary files can prepare canals to a constant taper of 0.06 mm per mm (Ruddle, 2002) with a uniformly round space (Glosson *et al.*, 1995). Gutta-percha cones are now produced to match the taper of canals prepared with .04 or .06 rotary instruments. Larger taper gutta-percha can be used with warm vertical compaction techniques or with cold lateral compaction techniques (Wilson & Baumgartner, 2003). With NiTi rotary preparation of the root canal and the use of a sealer, these cones may provide three-dimensional obturation of the root canal over its whole length without the requirements of accessory cones or time spent on lateral condensation (Gordon *et al.*, 2005).

3.2.7 INSTRUMENTATION WITH PROTAPER® FILES

The ProTaper® system is a preparation system that can be used in complex and standard cases, allowing a clean, efficient, and predictable preparation of the root canal. The successful application demands certain preconditions (Clauder & Baumann, 2004).

Torque-controlled electric motors

To minimize the risk of separation, it is recommended that inexperienced users take advantage of torque-controlled endodontic motors (Yared *et al.*, 2001). Even experienced operators can reduce risk of separation by working with the recommended range of torque.

In 2003, Yared and his colleagues studied the influence of torque controlled motors and the operator's proficiency on ProTaper® failures. The purpose of the study was to evaluate the influence of 2 electric torque control motors and operator experience with a ProTaper® on the incidence of deformation and separation of instruments. ProTaper® rotary instruments were used at 300rpm. In the first part of the study, electric high torque control (group 1) and low torque control (group 2) motors were compared. In the second part of the study 3 operators with varying experience (group 3, 4 and 5) were also compared. Twenty sets of ProTaper® instruments and 100 canals of extracted human molars were used in each group. From their results they concluded that pre-clinical training in the use of the ProTaper® technique at 300 rpm is crucial to prevent instrument separation and reduce the incidence of instruments deformation. Inexperienced operators should make use of the low torque motors as the motor will reverse the rotation of the instrument when the instrument is subjected to stress levels equal to the preset torque value. Consequently, instrument separation will be prevented. The use of an electric high torque motor is safe with the experienced operator (Yared *et al.,* 2003).

3.3 METHODS OF STUDY

3.3.1 RADIOGRAPHY

Conventional radiographs

Conventional dental radiographs have been used frequently to record longitudinal images of canal shape (Chenail & Teplitsky, 1985; Lim & Webber, 1985; Tang & Stock, 1989). The low resolution and grainy, indistinct images produced on these films are not ideal, particularly when the images are enlarged or transferred to photographic prints (Tang & Stock, 1989); the clarity of the critical apical portion of the canals is often lost. In order to overcome this problem, a method to enhance images with a progressive decreases in exposure time over the affected regions need to be used. The use of microradiographs results in clear high resolution images, which accurately reflect the real size and shape of the canals because the roots contact the film and also because the source-object distance is large, with the result that X-ray beam passing through the roots is parallel. The use of radiopaque contrast media within the canals can also improve the clarity of the resultant images, but this does not overcome the inherent shortcomings of the conventional dental films (Thompson *et al.,* 1995). Other major problems with conventional radiography are inaccurate length estimations of small endodontic files, inability to manipulate image after acquisition to produce a clearer diagnostic image and the inability to store electronically (Friedlander *et al*., 2002).

In order to improve the images of canals, Ahmad & Pitt ford (1989) used a process of macro radiography to take pre- and post instrumentation radiographs. They used an industrial micro focal unit to produce images on fine grain, non-screen (a film for getting very fine detail, used without a cassette and requiring long exposure time. Some countries have banned the use of it) medical x-ray film. The radiographic images of each canal were subjected to a subtraction technique in order to produce a composite image with the area removed by instrumentation appearing dark compared with the original canal shape. The subtraction prints appeared to be of high quality and allowed accurate quantitative assessment of the dentine removed during preparation (Thompson *et al*., 1995).

Digital radiographs

A recent development is direct digital radiography (Mentes & Gencoglu, 2002). The three methods of producing digital images are CCD sensors, phosphor plates and scanning of conventional films. All three systems are available in periapical and panoramic views. It provides an image that can be enhanced for contrast and density on the monitor for better viewing (Borg & Grondahl, 1996; Leddy *et al.*, 1994). Direct digital radiography and phosphor plates have many other advantages over silver halide film, such as speed, reduced radiation, environmental waste reduction, elimination of darkroom costs, possibility of e-mail image transfer, and enhanced practice image (Levin, 2001).

Recently, numerous studies have been done to compare the accuracy and reliability towards the use of digital radiographs in endodontics. Radan & Price (2002) performed a study to compare the effects of geometric and digital unsharpness in dental radiograph using an endodontic file model. Endodontic files of sizes #06, #08, #10, and #15 were placed in an extracted lower incisor in 3 different positions at

2-mm increments. Radiographs were taken with a GE 100 x-ray unit at different magnifications and different resolutions. Ten observers viewed the digitized images and identified the position of the end of the files and end of the roots, as well as assessed image quality. They concluded that a digital resolution of 300 dpi is adequate to produce good image quality (Radan & Price, 2002).

Friedlander and group (2002) compared phosphor-plate digital images with conventional radiographs for perceived clarity of fine endodontic files and periapical lesions. They used 20 extracted mandibular premolars with size #06 K-files to evaluate the clarity of the images. Four evaluators ranked the perceived clarity of fine endodontic files and periapical lesions and rated that clarity was significantly less with phosphor-plate digital images than with conventional radiographs.

Mentes & Gencoglu (2002) compared the accuracy of a digital radiographic imaging system with conventional radiography for the purpose of estimating endodontic file length in curved canals of mandibular molars. They used 60 extracted molars with root curvatures ranging from 5° to 52°. The results showed that although both conventional and digital radiograph method of analysis overestimated the true canal length, the direct digital radiography accuracy improved as the canal severity increased. They concluded that the accuracy is comparable to that of conventional radiograph (Mentes & Gencoglu, 2002). More recently, Woolhiser *et al.* (2005) compared the accuracy of D- and F-speed intraoral radiographs and digital and enhanced digital radiographic images for endodontic file length determination. They used size #15 K-files cemented in 51 canals of 34 human cadaver teeth. The distance measured on each image was compared with the actual measurement. They concluded that all 4 image types were similar in accuracy of file measurement. The image quality of enhanced digital images was subjectively superior to others. Iqbal and his group (2003) who compared apical transportation of four NiTi instrumentation techniques have regarded digital images as a useful tool to study radiographs and to work with. They have stated that the digitized radiographs of root canals taken before and after root canal preparation can be analyzed with the help of CAD/CAM software with precision and accuracy (Iqbal *et al*., 2003).

Radiopaque medium

In order to delineate the canal walls more clearly, radiopaque medium may need to be introduced into each canal. In the past, researchers have used various radiopaque mediums and various methods of introducing them into the canal. For example, Ahmad and Pitt Ford (1989) used a mixture of glycerin and pure tungsten powder and syringing it into the occlusal opening while applying apical suction using a vacuum pump to draw in the contrast medium. Thompson *et al.* (1995) also used the same method but different radiopaque medium that was thick slurry of lead oxide powder mixed with omnipaque liquid.

In a comparative study of four instrumentation techniques, Luiten *et al.* (1995) used mercury as a contrast medium by injecting it into the pulp chamber until it was visibly expressed from the apex. Jardine and Gulabivala (2000) also employed this method in their studies of rotary NiTi canal preparation. Even though the use of mercury permits easy removal of radiopaque medium from the canal, it requires careful handling due to its high toxicity.

In contrast, Nagy and his group (1997a, b) used a different method of filling the root canals with radiopaque medium. They filled the root canals with a radiopaque mixture of Lipiodol Ultra-Fluid and Micropaque HD Oral by centrifuging at 1200 **g** for 30 s. Many of these methods needed expensive and complicated setup to implement. In this study, BaSO4 powder was used as the radiopaque medium by applying it onto the canal walls.

3.3.2 MEASUREMENT OF CURVATURES

Root canal curvature can be measured in two ways, namely, by angle measurement and radius measurement. Angle measurement in degrees is the most common method used in the literature. Schneider (1971) first published a reproducible method to determine the degree of curvature. He used radiographs on which a line was scribed parallel to the long axis of the canal. A second line was drawn from the apical foramen to intersect with the first at the point where the canal began to leave the long axis of the tooth. The acute angle thus formed was measured by the means of a protractor (Schneider, 1971).

This method was later modified by Southard *et al.* (1987), Cunningham & Senia (1992) and other researchers who used the smallest file to bind instead of empty canal. Point **a** was marked at the middle of the file at the level of the canal orifice. A line was drawn with a straight edge aligned parallel to the file image from point **a** to a point where the instrument deviated from the straight edge, point **b.** A third point **c** was made at the apical foramen and a line was drawn from this point to point **b.** The angle formed by the intersection of the two lines was measured as canal curvature (Cunningham & Senia, 1992) (fig **3.2**).

The first curve encountered in a canal was the primary curve. A secondary curve was the one that deviated in a direction opposite to the primary curve. When more than one curve was present in the canal, the primary curve was measured as previously described to its most apical extent (point **c)** prior to the deviation away from the central axis of the tooth. The secondary curvature was then measured from point **c** to the apical foramen **d** (Cunningham & Senia, 1992) (fig **3.3**).

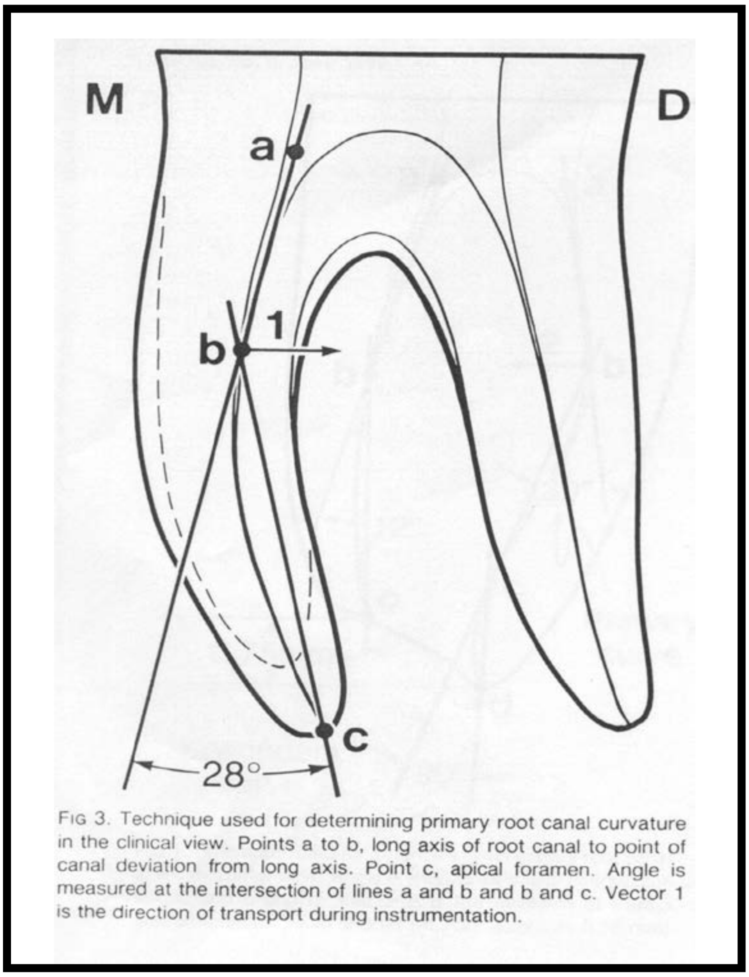


Figure 3.2 Technique used for determining primary root curvature in the clinical view (Cunningham & Senia, 1992).

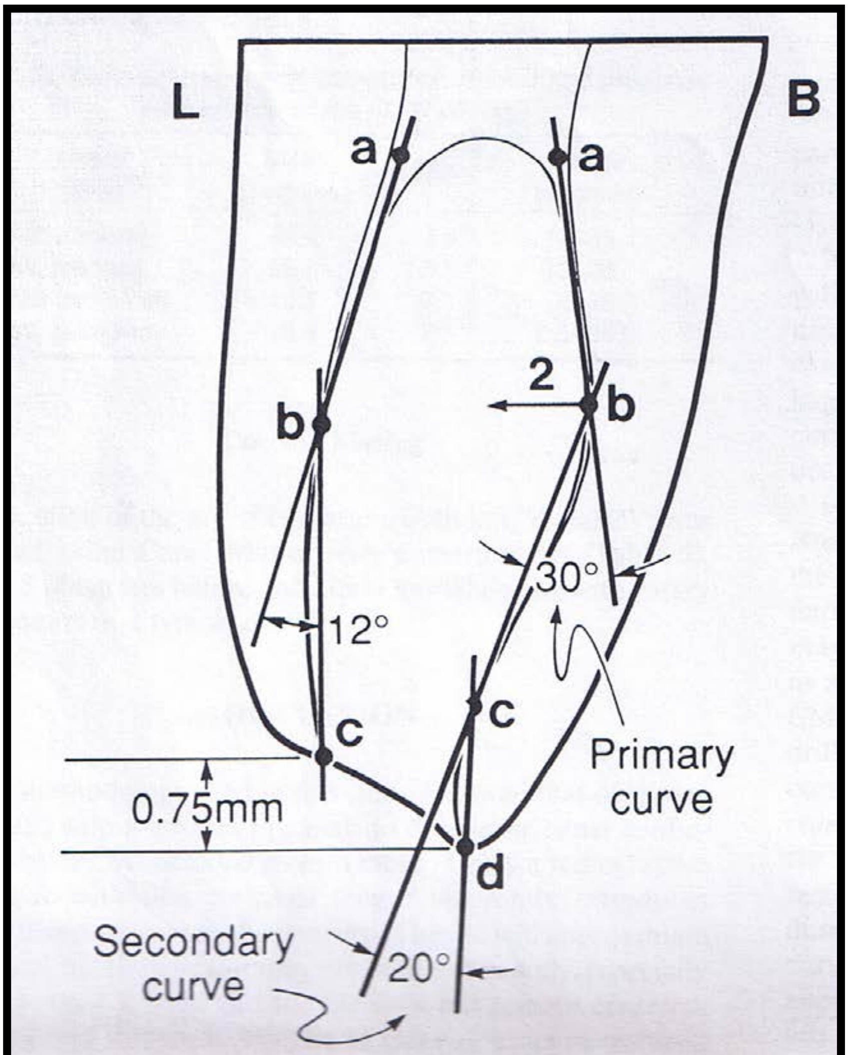


FIG 4. Technique used for determining secondary root canal curvature in the proximal view. Angle is measured at the intersection of lines b and c and c and d. Vector 2 is the direction of transport during instrumentation. Note shorter ML root (average, 0.75 mm).

Figure 3.3 Technique used for determining secondary root curvature in the proximal view (Cunningham & Senia, 1992).

Luiten *et al.* (1995) has criticized Schneider's method of measuring the canal curvature that it tends to underestimate the extent of curvature. It provides an acceptable estimate of gradual root curvatures, but it does not take into consideration canals with acute deviations near the apex. They introduced a different method to measure canal curvatures. Curvature was determined by drawing a line through the midpoint of a line drawn across the canal orifice and the midpoint of the line drawn across the canal 2mm apical to the orifice. The apical intersecting line was drawn parallel to the apical 1mm of the canal and the resulting angle was measured as canal curvature (Luiten *et al.,* 1995) (fig **3.4**).

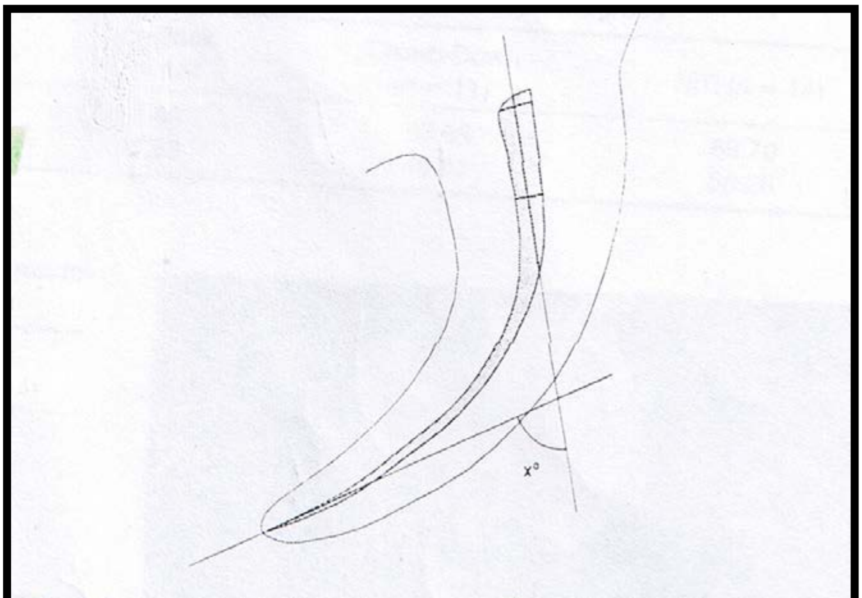


FIG 3. Determination of canal curvature. The midpoint of lines drawn across the canal orifice and 2 mm apical to the orifice intersected a line drawn parallel to the apical 1 mm of the canal. The resulting angle defined the curvature of the canal.

Figure 3.4 Technique used by Luiten *et al.* for determining root curvature in the clinical view (Luiten *et al.,* 1995).

In order to further improve on the curvature measurements, Backman *et al.* (1992) used radius measurements together with angle measurement to classify canal curvatures of their samples. The radius measurement for single curvatures was measured from the tip of the instrument at the apical foramen to where the canal deviated from the coronal axis (refer to Figure **3.5).** Two radii were determined for double or S-type curvatures, first from where the first curve began to the point at which the second curvature occurred. The second measurement was made from the tip of the instrument at the apical foramen to where the second curvature began.

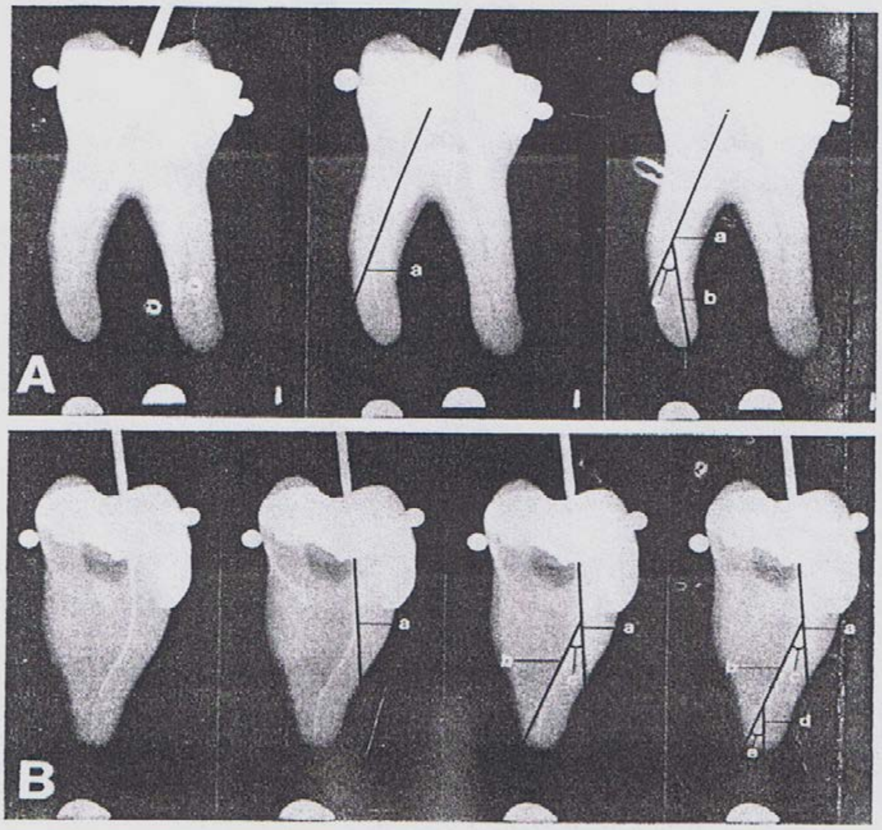


FIG 1. Method of canal curvature measurement. *A*, Method for single curvature. *a* and *b* lines drawn on image of instrument; *c*, angle of canal curvature formed by intersection of lines *a* and *b*. *B*, Method for double curvature. *a*, *b*, and *d* lines drawn on image of instrument; *c*, angle of coronal canal curvature; *e*, angle of apical canal curvature.

Figure 3.5 Technique used by Backman *et al.* for determining canal curvature and radius measurement (Backman *et al.*, 1992).

It was postulated that in addition to canal curvature, the length of the canal segment over which a given curvature occurred might be an important factor affecting the ability of an instrument to negotiate the curvature. In order to test this, a value termed the "radius quotient" was calculated for each canal. This value was obtained by dividing a given angle by its "radius" measurement. Thus, the larger the value of the radius quotient, the greater the presumed “severity” of the curvature (Backman *et al.*, 1992).

Pruett *et al.* (1997), too, has criticized the method used by Schneider to measure canal curvatures. According to them, the shape of any root canal is more accurately described using two parameters; angle of curvature ($\propto$) and radius (r) of curvature. To determine these parameters, similar to the method described by Luiten *et al.* (1995), a straight line is drawn along the long axis of the coronal portion of the canal (Fig **3.6**). A second line is drawn along the long axis of the apical portion of the canal. There is a point on each of these lines at which the canal deviates to begin (point a) or end (point b) the canal curvature. The curved portion of the canal is represented by a circle with tangent at points a and b the angle of curvature is the number of degrees on the arc of the circle between point a and b. the angle of curvature can also be defined by the angle formed ($\propto$1 and $\propto$2) by perpendicular lines drawn from the points of deviation (a and b) that intersect at the center of the circle. The length of these lines is the radius of the circle and defines the radius of the canal curvature. The radius of curvatures (r1 and r2) is the length of the radius of the circle measured in millimeters. The radius of the curvature represents how abruptly or severely a specific angle of curvature occurs as the canal deviates from a straight line. The smaller the radius of the curvature, the more abrupt will be the canal deviation. The parameters of angle of curvature and radius of curvature are independent of each other. Canals can have the same angle of curvature while having different radii of curvature, resulting in more abrupt curves (Pruett *et al.*, 1997).

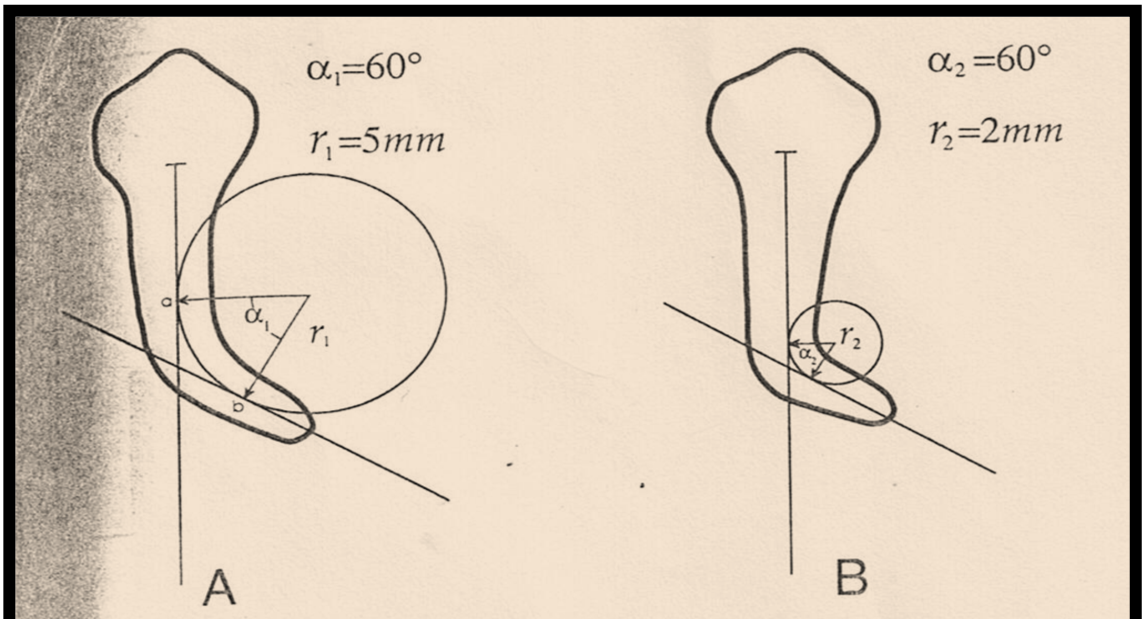


FIG 2. Radius of curvature and angle of curvature. New method of describing canal geometry using two parameters. Radius of curvature (r) and angle of curvature (α) are determined on the same teeth as in Fig. 1. These teeth accurately depict the guide tubes used in this study that had a 60-degree angle ($\alpha_1 = \alpha_2$). Angle of curvature (α) is determined by the angle formed by the lines that intersect at the circle's center. These two lines are perpendicular to the lines drawn along the long axes of the coronal and apical portions of the root canal space. Points *a* and *b* are the points wherein the canal deviates from the straight lines and either begin or end the curved portion of the root canal space. Angle (α) is taken to be the angle formed by the arc in degrees between points *a* and *b*. The *arc* lies on a circle whose size is specified by it's radius, and the circle's radius is taken to be the radius of curvature of the canal in that local area. The circle's radius is the radius (r_1 and r_2) of the curved portion of the root canal space and defines how abruptly the canal curves. The canal geometry of these two teeth differs only in the rádius of curvature (r_1 and r_2), whereas the angle of curvature (α_1 and α_2) equals 60 degrees. *A* represents a sweeping canal curvature having a 5-mm radius of curvature (r_1). *B* represents an abrupt canal curvature having a 2-mm radius of curvature (r_2). Clinically, the radius of curvature and angle of curvature of any root canal space could be measured using this technique with the aid of a circle gauge.

Figure 3.6 Technique used by Pruett *et al.* for determining canal curvature and radius measurement (Pruett *et al.,* 1997).

3.3.3 SOFTWARES

Curvature analysis

In the past, various techniques and gadgets has been used to measure and analyze canal curvatures. One of the earliest by Schneider (1971) was to use a protractor on the magnified radiographic image by using a special view box. Later developments were to use slide projection to enlarge radiographic images and tracing them on a tracing paper secured on the screen (Southard *et al.,* 1987; Cunningham &Senia, 1992; Backman *et al.,* 1992). Then, the angle of curvature was measured manually using cephalometric protractors and the radius using a drafting template (Thompson *et al.*, 1995).

More recent advancement is to use computer software to measure curvature angle and radius of the curve. As early as 1990, Gambill *et al.* has used JAVA (Jandel Video Analysis Software/ Jandel Scientific) imaging software package to measure canal curvatures. Radiographs were placed on a dissecting microscope and magnified 70x. Images were captured and digitized using a video camera and connected to the computer system and analyzed using Schneider's method (Gambill *et al.*, 1990). Apart from this, Glosson *et al.* (1995); Luiten *et al.* (1995); Schafer & Florek (2003) and Schafer & Vlassis (2004) have used imaging software (Image J, National Institutes of Health, Bethesda, MD, USA) to calculate the angle of curvature following Schneider's method. Meanwhile, Iqbal *et al.* (2003 and 2004) have used AutoCAD 2000 software to calculate the angle and radius of curvature in their studies. They have also adapted Schneider's method in calculating the angle. In 2005, Guelzow *et al.* have used a new dental radiography software SIDEXIS 5.5/5.5x:

(Sirona Dental Systems, Benshiem, Germany) in their research. They analyzed both the alteration of working length and straightening of the curved root canals using this software.

Superimposition

Superimposition of radiographs provides a clear picture of the changes to the canal outline after instrumentation. It can be used to measure the extent of apical transportation (Luiten *et al.,* 1995; Iqbal *et al.,* 2003 and 2004) and the degree of straightening (Hulsmann *et al.,* 2003). There are several methods described in the literature to superimpose the pre- and post- instrumentation radiographs. Luiten *et al.* (1995) have used a double-exposure method to superimpose the pre- and post-operative canal shape. Mercury was injected into the unprepared tooth and radiographed in buccolingual plane. The mercury was removed and the tooth was then instrumented. Following the canal preparation, the tooth was re-infused with mercury, placed back in the positioning device, and re-radiographed, exposing the original film again. The amount of apical transportation was determined by comparing the image of the original canal with the superimposed, instrumented canal (Luiten *et al.*, 1995).

The preoperative and post-operative radiographic images of the canal can also be superimposed by using a photographic enlarger to project 10x-magnified images onto a sheet of A4 graph paper with 1mm square grid. The outline of the root and the preoperative root canal were traced onto the paper using pens with 0.05 tips. The post-operative image was then superimposed onto the traced image of the root allowing the post-operative image to be traced (Jardine & Gulabivala, 2000). Hulsmann *et al.* (2003) and Jodway & Hulsmann (2006) have also used the same method in their research but they used an X-ray viewer instead of a photographic enlarger.

Gilles & del Rio (1990) have used another technique to superimpose radiographs to evaluate transportation. Preoperative and post-operative radiographs were taken in the same film-holding device. The post-operative radiographs were photographed to produce enlarged 4x5 inches positives. The preoperative radiographs were enlarged into 4x5 inches negatives and superimposed. The position of the final instrument was noted in relation to the diagnostic instrument. Exact superimposition of the final instrument over the diagnostic instrument in the radiographs was considered as no transportation. The direction of deviation or transportation of the final instrument from the diagnostic instrument was evaluated in the mesial and clinical planes and measurements were taken with a dial caliper at 1 and 4 mm from the apex. At the same time, the distance between the apical exit of the root canal and the apical terminus of the preparation was measured (Gilles & del Rio, 1990).

Superimposition of radiographs can also be done with the aid of the computer software programs namely the Adobe Photoshop (Adobe Systems Inc., San Jose, CA, USA) software program with precision and accuracy. This software program has been used in the literature to perform various tasks. Iqbal *et al.* (2003 and 2004), for instance, have used Adobe Photoshop to posterize the edges of the final instrumentation radiograph and for superimposition of preoperative and post-operative radiographs for evaluation of transportation.

Adobe Photoshop software has also been used to superimpose photographs of preoperative and post-operative canal cross-sections to compare the remaining wall thickness (Garala *et al*., 2003) and the centering ability of rotary file systems (Ponti *et al*., 2002). This program has also been used to assess shaping ability and canal aberrations in simulated canals. Calberson *et al.* (2004) have used the software to superimpose digital images taken with a digital camera connected to a computer. The canal shape contours on the image were precisely determined by making colour mode adjustment to facilitate visualization and further analysis (Calberson *et al*., 2004). Sonntag *et al*. (2003) have also used the same method. Among the parameters evaluated were the amount of transportation and aberrations of the prepared canal. Assessments were made under 32x magnification using Adobe Photoshop software for the presence and position of various types of canal aberrations such as apical zip, elbow and ledge (Sonntag *et al*., 2003).

In the present study, Adobe Photoshop would be used to sharpen the images, to give different color to the preoperative and post-operative images and for the superimposition. Assessment of apical transportation was done by measuring the horizontal distance between the tips of the files under 100x magnification.

3.4 EVALUATION OF THE QUALITY OF THE CANAL PREPARATION AND INSTRUMENTS

3.4.1 IATROGENIC DAMAGE CAUSED BY ROOT CANAL PREPARATION

Displacement and enlargement of the apical foramen may occur as a result of incorrect determination of working length, straightening of curved root canals, over-extension and over-preparation. As a consequence, irritation of the periradicular tissues by extruded irrigants or filling materials may occur because of the loss of an apical stop. Overzealous shaping of the canal to accommodate large pluggers or spreaders leads to the weakening of tooth structure or even fracture of an apical tip (Fava, 1991).

Ledge

Ledges in canals can result from a failure to make access cavities that allow direct access to the apical part of the canals, or from using straight or too-large instruments in curved canals, which cut ledge at curve. Ledge formation should be suspected when the root canal instrument no longer can be inserted into the canal to full working length. There may be a loss of tactile sensation with the tip of the instrument passing through the lumen (Frank, 1994).

Ledging also occur as a result of preparation with inflexible instruments with a sharp cutting tip particularly when used in rotational motion. The ledge will be found on the outside of the curvature as a platform, which would be difficult to bypass as it is frequently associated with blockage of the apical part of the canal. The occurrence of ledges was related to the degree of curvature and design of instruments (Bergenholtz *et al*., 1979; Greene & Krell, 1990; Kapalas & Lambrianidis, 2000).

Eleftheriadis & Lambrianidis (2005) performed a study to assess the occurrence iatrogenic errors in endodontic cases treated by students in undergraduate dental clinic. They used the immediate post-operative radiographs of 388 root treated teeth. All teeth were prepared using step-back technique with stainless steel instruments (K-files and Gates- Glidden drills). The results indicated that 24.8% of all root canals had ledges. Anterior teeth and premolars were ledged less frequently than molars. This probably occurred due to the prevalence of narrow and curved root canals in molars. In molars, a ledge was present in 38.9% of the root canals. Canal curvature was found to be the most significant factor affecting the incidence of ledging (Eleftheriadis & Lambrianidis, 2005).

Elbow

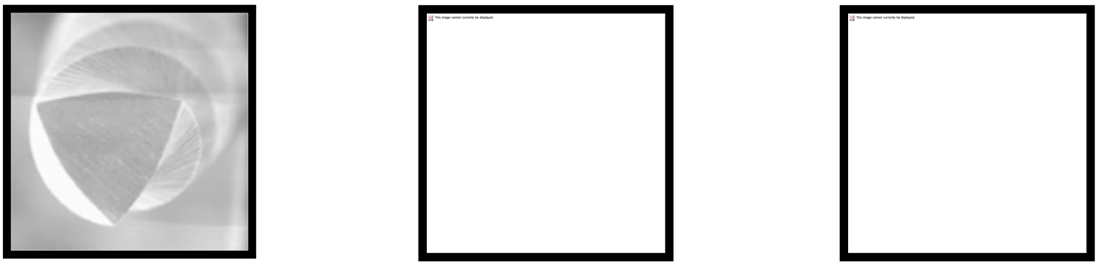
An elbow can be defined as a constriction in a post instrumented canal where the canal width apical to this point was greater than the canal width coronal to this point. Early preparation of the apical section using files in rotating motion tend to result in over preparation of the outer curve with transportation of the apical preparation to form an elliptically shaped defect. Coronal to this apical defect, the canal had its narrowest part, which gives an hourglass shape that will be difficult to obturate three dimensionally (Frank, 1994). The irregular conicity and insufficient taper and flow associated with elbow may jeopardize cleaning and filling the apical part of the root canal (Hulsmann *et al.,* 2005).

Zipping or Apical transportation

Over preparation of the outer wall of the apical curvature of the canal with inflexible instruments will cause zipping (Frank, 1994). This forms a tear-shaped foramen, which makes a successful apical seal more difficult (Weine *et al*., 1975). The main axis of the root canal is transported, so that it deviates from its original axis. Therefore, the terms straightening, deviation, transportation are also used to describe this type of irregular defect (Hulsmann *et al*., 2005).

In NiTi instruments like ProFile, the cutting edges are of the U-file design and the cutting edges are supported by radial lands, which are believed to keep the instruments centered in the root canal, leading to minimal transportation and zipping. In contrast, the ProTaper® instruments are designed with more positive rake angles, but the convex triangular cross-section is claimed to reduce the contact area between the file and the dentine (refer Figures **3.7**). Nevertheless, this feature also predisposes the canal to a greater transportation because of which the manufacturer cautions against taking these instruments to length more than one time and for more than one second (Iqbal *et al*., 2004).

K-Flexofiles® also display active cutting blades. In previous studies, it was shown that stainless-steel files removed excessive material from the outer wall at the end of the curve and from the inner wall at the beginning of the curvature in a curved canal and caused apical transportations (Al-Omari *et al*., 1992; Backman *et al*., 1992).



Figures 3.7 ProTaper® SEM of cross-section showing convex triangular design, modified guiding tip and active cutting surface of shaping files

Perforation

Excessive over preparation with non-safe-ended instruments may lead to perforation of apical region. “Stripping is a lateral perforation caused by over instrumentation through a thin wall in the root and it is most likely to happen on the inside, or concave, side of curved canal, such as the distal wall of the mesial roots in mandibular first molars (Frank, 1994).

Anatomically, the inner or furcal wall of the mesial roots of maxillary and mandibular molars often exhibits a concavity with a thin dentinal wall. During the instrumentation process, removal of tooth structure from this can result in perforation or strip. To prevent stripping, some authors proposed a technique where the canal is intentionally filed toward the outer wall or line angle of the tooth (Abou-Rass *et al*., 1980; Johnson, 1986).

In a study by Kessler and co-workers (1983), various methods of instrumentation were evaluated for their effects on the inner or furcal wall. They found that neither of the techniques was significantly different from the traditional step-back technique in their risk to the furcal area. When evaluating the sections of the prepared teeth, the authors noted that the greatest numbers of thin sections were found at 4 to 6 mm apical to the canal orifice. Based on this observation, special care should be exercised when flaring a curved canal at or pass this level (Kessler *et al*., 1983; Johnson, 1986).

In both the step-down and the crown-down technique, coronal flaring is done prior to apical preparation. The increased coronal taper in the ProTaper® system also increases the risk of lateral perforations. In a study on the influence of NiTi shaft design, Bergmans *et al.* (2003) have compared the center displacement of ProTaper® with K3 instruments at the middle-coronal level and stated that ProTaper® instruments removed more dentin towards the furcation. Even though no perforation was noted, the higher values for the ProTaper® group may have resulted from the absence of radial lands area (refer figures **3.7**) in combination with the large coronal diameter of the ProTaper® shaft (Bergmans *et al.,* 2003).

3.4.2 INSTRUMENT SEPARATION

This type of procedural mishap is a result of material failure. Usually the instrument is advanced into the canal until it binds, and further twisting or bending it then leads to breakage, leaving a segment of it in the canal. Other common causes to this mishap are the use of stressed (or deformed) instruments, placing exaggerated bends on instruments to negotiate curved canals, and forcing down a canal before it has been opened sufficiently. NiTi instruments also have a tendency to fracture if used with excessive force (Frank, 1994). Usually the fracture occurs at the apical area, thus impeding adequate cleaning, shaping, and obturation. These instruments may break without warning or any indication of previous, permanent, visible deformation or defect (Ruddle, 2001).

Fatigue failure

After a certain number of cycles of continuous rotation in a curved root canal, microscopically detectable flaws begin to form on the surface. It is the result of linking up of micro-cracks, which generally run normal or perpendicular to the long axis of the instrument, developing into distinct crack lines on the skin of the material. Improving the surface hardness or smoothness will generally improve the resistance of a material to fatigue crack initiation (Suresh, 1998; Cheung, 2009). Once initiated, the fatigue crack(s) propagates incrementally during each turn and centripedally, this direction being normal to the maximum tension, until the remaining bulk of material is unable to withstand the same load and fails catastrophically. The fatigue-crack growth rates in NiTi are significantly faster than other metal alloys of similar strength (Dauskardt *et al.*, 1989; Cheung, 2002), which observation corroborates the general impression that NiTi rotary instruments fails without much forewarning sign during clinical use. Such failure is manifested as a "clean" fracture of the instrument with little plastic deformation on either side of the separation. This type of fracture is commonly referred to as "fatigue failure" and occurs usually at some distance, viz. 3-4 mm, from the instrument tip (Sattapan, 1997; Cheung, 2002).

The manufacturer states that one of the benefits of progressively tapered instruments system is that each instrument engages a smaller zone of dentine, thus reducing torsional loads and the chance for instruments breakage (Ruddle, 2002). Although stresses developed over ProTaper® instruments may be less intense and more uniformly-distributed mathematically (Berutti *et al*., 2003), as they have been reported to fail more frequently and without warning (Ankrum *et al*., 2004). A study by Peng *et al.* (2005) explains some of the reasons. They evaluated the defects in ProTaper® shaping instrument S1 after a defined schedule of clinical use. 122 ProTaper® S1 discarded instruments were collected and examined under scanning electron microscope and evaluated. Multiple use of ProTaper® S1 seemed to result in micro crack formation and wear of the cutting edges. There was a low prevalence of plastic deformation and most ProTaper® S1 instruments failed without discernible sign of unwinding of the flutes (Peng *et al.,* 2005).

The high incidence of instrument fractures with the ProTaper® system may be related to the convex triangular cross-sectional design, which results in a larger core of the instruments and increased rigidity (Guelzow *et al*., 2005). Instrument fractures are also dependant on the frequency of use (Hulsmann *et al*., 2005). In some of the recent studies where a new set of ProTaper® instruments were used for each canal, fracture rate was reported to be significantly low (Calberson *et al*., 2004; Paque *et al.*, 2005; Guelzow *et al*., 2005).

However, a recent research (Spanaki-Voreadi *et al*., 2006) done on the failure mechanism of ProTaper® reported that the failure mechanism is not associated with any cumulative damage (i.e. fatigue mechanism), the concept of using NiTi files in a limited number of root canals to avoid failure is unrealistic. According to the results of their study, a single overloading that causes dimple rupture during chemo-mechanical preparation of root canals causes the fracture of ProTaper® instruments. Such overloading can be induced by an abrupt change in canal curvature, clogging of the cutting instruments and other factors that cause stress development during the instrumentation (Spanaki-Voreadi *et al*., 2006). A report by Yared *et al.* (2003) stated that the experience of the operator has some influence on the instruments failures. They found that the least experienced operator separated more files than the well-trained ones; more fractures were found with ProTaper® S1 instrument.

A research by Blum *et al.* (2003) can be used to explain the fracture mechanism of ProTaper® files. According to them, there are several factors to be considered when using rotary ProTaper® files in the apical one-third of a canal:

1. The more apical working portion of a file is of smaller diameter relative to its more coronal larger diameters.
2. When an instrument is engaged towards its apical extent, greater torsional forces exists because of the distance between the torque generator (handle) and the resulting working torque at the apical extent of the file.
3. Instruments that work in the apical one-third are more predisposed to breakage because this region of the canal commonly exhibits a smaller diameter, greater curvature and division.
4. When using rotary instruments at a constant rpm, the time lag between a potential failure torque and a broken instrument is too short for the practitioner to avoid the problem.

Considering these factors, they suggest that apical progression using finishing files must be very deliberate and slow to facilitate its cutting action. Indeed the penetration induces a cutting action at the apical part that is not the safest or most efficient part of an instrument. To encourage safety, the ProTaper® finishing files require no vertical penetrating forces and slow penetration speed (Blum *et al.*, 2003). According to them, mechanized preparations are not possible for all root canals and certain canals are best prepared by using manual, mechanical, or a combination of both. If ProTaper® instruments meet resistance to apical movement, it should be immediately withdrawn and a manual instrumentation technique used.

When analyzing the quality of root canal preparation created by instruments and techniques several parameters are of special interest, particularly their cleaning ability, their shaping ability as well as safety issues. A list of potential criteria for assessment of the quality of root canal instruments or preparation techniques are presented in tables **3.6** and **3.7**

Table 3.6 Summary of possible criteria for assessment of Canal preparation shape

Preparation shape			
No	*Longitudinal*	*In cross sections*	*Three- dimensional*
1	Straightening/ deviation	Diameter	Straightening and transportation
2	Displacement and enlargement of the apical foramen	Circumferential/cross sectional shape	Changes in volume
3	Zips and elbows	Over /under preparation	Canal axis movement
4	Taper and conicity	Fins and recesses	-
5	Flow	Increase in canal area	-
6	Over/Under extension	Danger of perforation into the furcation	-
7	-	Canal axis movement	-

***** (Hulsmann *et al.*, 2005)

Table 3.7 Summary of possible criteria for assessment of safety issues

Safety issues	
1	Instruments fractures
2	Ledges
3	Perforation
4	Excessive dentin removal / Zip / Elbows
5	Apical blockage
6	Loss of working length
7	Extruded debris and irrigant
8	Temperature increase

***** (Hulsmann *et al.*, 2005)

3.4.3 COMPARISON OF CANAL PREPARATION WITH STAINLESS STEEL FILES AND NITI FILES.

Esposito & Cunningham (1995), in a comparison of canal preparation with NiTi versus stainless steel files, found that the incidence of deviation from the original canal path during instrumentation with stainless steel files increased with file size. The differences between NiTi group and stainless steel group became statistically significant with instruments larger than size #30. This study found that NiTi files were more effective in maintaining the original canal path on curved roots when the apical preparation was beyond size #30.

Gambil *et al.* (1996) used computed tomography to evaluate root canals prepared by NiTi hand and stainless steel hand instruments. He found that NiTi instruments used in reaming technique caused significantly less canal transportations, removed less volume of dentin, required less instrument time and produced more centered and rounded canal preparation than K–flex stainless steel files.

3.4.4 COMPARISON OF CANAL PREPARATIONS WITH PROTAPER® AND OTHER NITI FILES.

Bergman and his group (2003) conducted a study comparing progressively tapered (ProTaper®) versus constant tapered (K3) shaft design in curved canals of extracted mandibular molars. They came to a conclusion that ProTaper® was less influenced by the midroot curvature, thereby providing a good centered apical preparation. However, ProTaper® instruments tended to transport towards the furcation in the coronal region.

Iqbal *et al.* (2004) used a radiographic technique to compare apical transportation and loss of working length between 06 tapered Profile series 29 and ProTaper® rotary instruments in vitro. They used mesiobuccal canals of 40 extracted mandibular molars. Teeth were stratified in such a manner that the average curvature of root canals in each of the groups was as close to each other as possible. The results indicated that both ProTaper® and Profile instruments are comparable to each other with regard to their ability to enlarge root canal with minimal transportation and loss of working length.

Paque and colleagues (2005) compared various parameters of root canal preparation using RaCe® and ProTaper® rotary instruments. They used 50 extracted mandibular molars, with mesial root curvatures between 20° and 40°, which were embedded in a muffle system. The parameters evaluated were straightening of the curvature, post-operative root canal cross-sections, safety issues, and working time. Cleanliness of the root canal walls was investigated under SEM using 5-score indices for debris and smear layer. They found that both systems respected original root curvatures well and were safe to use. Cleanliness was not satisfactory in both systems (Paque *et al.,* 2005).

Similarly, Guelzow *et al.* (2005) performed a study to compare various parameters of root canal preparation in a total of 147 extracted mandibular molars. Six rotary NiTi instrumentation systems including ProTaper® were compared with a manual preparation technique. They found that all the NiTi systems maintained the curvature, were associated with few instrument breakages and were more rapid than a standardized manual technique. ProTaper® instruments created more regular (round) canal diameters (Guelzow *et al*., 2005).

Many other comparative studies have been performed on various NiTi instruments for their shaping ability. Some selected studies are summarized in Table **3.8** (on next page); those involving ProTaper® system are summarized in Table **3.9.**

Table 3.8 Investigations Comparing Various NiTi Instruments

Author	**Instruments tested**	**Teeth \Canals**	**Parameters**	**Technique**	**Results**	**Preparation And technique**
Gilles & del Rio (1990)	• Canal master • K-type file	40 mesial canals of mandibular molar	• Transportation at 1mm • At 4mm from apex • Roundness of prep	• Radiograph super imposition • Cross section	CM transported less and rounder preparation but high tendency of breakage	Circumferential filling technique -Step-back technique
Leseberg & Montgomery	• CM • Flex –R • Flex -K	36 canals from Mandibular molar	• Canal curvature • Canal shape • Direction & • Extend of Transportation • Amount of dentin removed	• Radiograph • Cross section • Photograph	-No significant differences in canal curvature -Round canal with FR &CM	CM instrumentation technique -Balanced force -Roane technique -Step-back
Esposito & Cunningham (1995)	• NiTi hand • NiTi rotary • K-flex	Mixed 45 canals	• Original canal path	• Radiograph	NiTi better	
Gambil *et al.* (1996)	• -NiTi • Hand -K-flex	40 Single rooted	• Transportation • Curvature	• CT scan	Transportation	-Quarter turn pull -Reaming motion
Nagy *et al.* (1997)	• Canal master • K-type file	420 Mesial canals of mandibular molar	• Transportation at 1mm & 4mm from apex • Roundness of prep.	• Radiograph • Super imposition • Cross section	-CM transported less and rounder preparation but high tendency of breakage	-Circumferential filing technique - Step-back technique

Table 3.8, continued

Author	**Instruments tested**	**Teeth \Canals**	**Parameters**	**Technique**	**Results**	**Preparation And technique**
Rhodes *et al. (*2000)	• NiTi flex hand • Profile 04	All 3 canals of mand molar	• Area of dentin removed • Transportation &centering	MCT scan	No significant differences	-Balanced force -Crown down
Davis *et al.* (2002)	• Hand -K-flex +GG drill • GT profile rotary	30 canals from mesial canals of mandibular and mesial canals of max. Molar	• Working length change	Radiograph	Loss of working length more with SS flex	-Hand -K-flex +GG drill -GT profile rotary
Ponti *et al.* (2002)	• NiTi rotary profile.06 series 29 • Profile GT series	10 mesial root canals of mand. 1st & 2nd molars	• Centering ability	Digital photographs of sectioned tooth at 3 levels	No significant differences	-Crown down Technique
Tan & Messer (2002)	• K file • Lightspeed®	30 mesial canals of mandibular molar	• Cross section • Canal cleanliness • Canal trans. • Canal shape	Light microscope	-Step back more transportation -Lightspeed rounder canals	-Step back -Lightspeed manufacturers ins. Step back technique with coronal flaring

Table 3.8, continued

Author	Instruments tested	Teeth \Canals	Parameters	Technique	Results	Preparation And technique
Weiger *et al* (2003)	• Flex master rotary • NiTi hand file • Light speed rotary	136 canals from mixed molars	• Loss of working length • Fractured ins. • Time spent	• Cross section photographed	-LS loss of w.length, -2 LS ins. Fractured -Least time for F.Master but more transportation	Crown down (FM) Step back (LS) Balanced force (H-Files)
Garala *et al.* (2003)	• Profile & • Hero 642	54 mesial canals of mandibular molar	• Minimum wall thickness	• Digital imaging • Radiograph	Both comparable to each other in maintaining canal wall thickness	-Crown down technique
Schafer & Florek (2003)	• K3 NiTi rotary • SS hand files	96 stimulated curved canals	• Canal transportation • Fracture • Time taken	• CCD camera	K3 file-- 11 separated -Less working time Ss file –more zip & ledges	-K3-crown down technique -Ss file-reaming motion till w.length
Schafer & Schiligemann (2003)	• K3 NiTi rotary • SS hand files	60 root canals from Mand. &max molars	• Straightening of canals • Debris and smear layer • Separation	• Radiograph • SEM	Ss file-better removal of debris K3 –fracture, maintained curvature better	-K3-crown down technique -Ss file-reaming motion till w.length
Bergman *et al.* (2003)	• ProTaper® • K3	10 mesial canals of mandibular molars	• Dentin removal • Centering ability • Shaping	• XMCT-Scanner	ProTaper® more centered prep. but transport toward furcation	-Crown down Technique

Table 3.9 Investigations Comparing Various NiTi Instruments with ProTaper files

Author	**Instruments tested**	**Teeth \Canals**	**Parameters**	**Technique**	**Results**	**Preparation And technique**
Calberson *et al.* (2004)	• ProTaper®	40 stimulated canals	• Flaring of canal • Transportation • Instrument evaluation	• Digital camera	-Transp at inner curve esp. at very curved canal -F3 care should be taken to avoid deformation	-Crown down
Schafer &Vlassis (2004)	• RaCe • ProTaper®	48 severely curved canals from maxillary and mandibular molars	• Straightening • Debris & smear layer • Fracture	• Radiograph • SEM	RaCe better in cleaning and maintaining curvature	- Crown down tech.
Paque *et al.* (2005)	• RaCe • ProTaper®	50 mesial roots of mand molars	• Straightening of canal • Post-operative cross section • Safety issues • Working time	• Radio graph • Cross section • SEM investigation	-Both maintain curvature well - ProTaper® more dentin removal in coronal part - ProTaper® less working time & Etc	- Crown down tech.
Guelzow *et al.* (2005)	• Flex M • System GT • HERO 642 • K3 • ProTaper® • RaCe • Manual	147 mesiobuccal root of mand molar	• Straightening of canal • Post-operative cross section • Safety issues • Working time • Procedural errors	• Light microscope • Radiograph • Photograph	-NiTi maintained canal curvature better - ProTaper® more regular canal diameter	- Crown down tech.

Table 3.9, continued. Investigations Comparing Various NiTi Instruments with ProTaper® files

Author	Instruments tested	Teeth \Canals	Parameters	Technique	Results	Preparation And technique
Hulsmann *et al.* (2003)	• Flex master • Hero 642	50 canals from mandibular molars	• Debris and smear layer • Curvature • Working time • Cleaning ability.	• SEM analysis • Cross-sections • X-rays	Both system respected curvature well	- Manufacturers instruction (crown down)
Peters *et al.* (2003)	• ProTaper®	Maxillary molars all canals	• Volume • Thickness • Surface area • Canal transportation	• Micro CT	Canals in maxillary molars can be prepared without major errors	-Crown down Technique
Zhao & Wang (2004)	• ProTaper® hand • SS hand	40 stimulated canals	• Time • Fracture &deformation • Shaping ability • Canal shape after prep • Apical extrusion of debris • Apical extrusion of irrigation	• Scanned photographs	ProTaper® better in time, fracture & deformation, shaping ability & volume of apical extrusion of debris & irrigation	-Crown down -Step back
Iqbal *et al.* (2004)	• 06 taper Profile • ProTaper®	40 mesial canals of mandibular molars	• Apical transportation • Loss of working length	• Digital radiograph	Comparable to each other	Manufacturers instruction (crown down)

4.0 MATERIALS AND METHODS

4.1 MATERIALS

The instruments used in this study are listed below: -

a. K-files #10 & #15 (Dentsply Maillefer, Ballaigues, Switzerland)

b. K-Flexofiles sizes #20 to #30 (Dentsply Maillefer, Ballaigues, Switzerland)

c. K-Flexofiles #35 to #80 (Dentsply Maillefer, Ballaigues, Switzerland)

d. Gates-Glidden drills, sizes #2, #3 & #4 (Dentsply Maillefer, Ballaigues, Switzerland)

e. K-File Nitiflex #30 (Dentsply Maillefer, Ballaigues, Switzerland)

f. ProTaper® rotary instruments set (Tulsa Dental, Dentsply Maillefer, Ballaigues, Switzerland)

g. ProTaper®-for-hand use instrument, size F3 (Tulsa Dental, Dentsply Maillefer, Ballaigues, Switzerland)

h. Lentulo Spiral size #30 (Dentsply Maillefer, Ballaigues, Switzerland)

4.1.1 INSTRUMENTS FOR K-FLEXOFILES GROUP

Three sets of hand instruments were required to prepare a canal using the step-down technique- a new set of files was used for every 10 canals. In the event of any deformity, the file was replaced with a new one. Nitiflex #30 was used during the X-ray as they are more flexible and tend to follow the canal curvatures when positioned inside the canal.

The instruments used for the hand instrumentation group are listed in the table **4.1** below.

Table 4.1 Instruments used in canal preparation of K-Flexofiles group

Technique	Instruments
Canal negotiation	K-file #10 & #15
Coronal preparation/ Flaring	Gates Glidden #2, #3 & #4
Working length	Predetermined
Apical preparation	K-Flexofiles #20, #25 & #30
Enlargement into tapering form (stepping back)	K-Flexofiles #35 to #60 (file size increased at every 1.0mm)
X-ray	K-File Nitiflex #30

4.1.2 INSTRUMENTS FOR PROTAPER® GROUP

Only one set of instrument was needed for canal preparation with ProTaper® instruments after glide path was established using K-file size #10 and #15. However, a ProTaper® hand files size F3 was used for recapitulation of the canal after mechanized preparation and for post-operative radiograph taking. This was done to avoid additional stress to the F3 rotary instruments used in the study. A new set of instruments was used for every 10 canals. A separated instrument would be replaced with a new one.

The armamentarium is listed in table **4.2** below. Illustrations of some of the instruments used are shown in figures **4.1.**

Table 4.2 Instruments used in the ProTaper® group

Technique	Instruments
Canal negotiation	K-file #10 & #15
Coronal preparation	SX
Working length	Predetermined
Apical preparation	S1 & S2
Enlargement into tapering form	F1, F2 & F3
X-ray	F3 hand ProTaper®

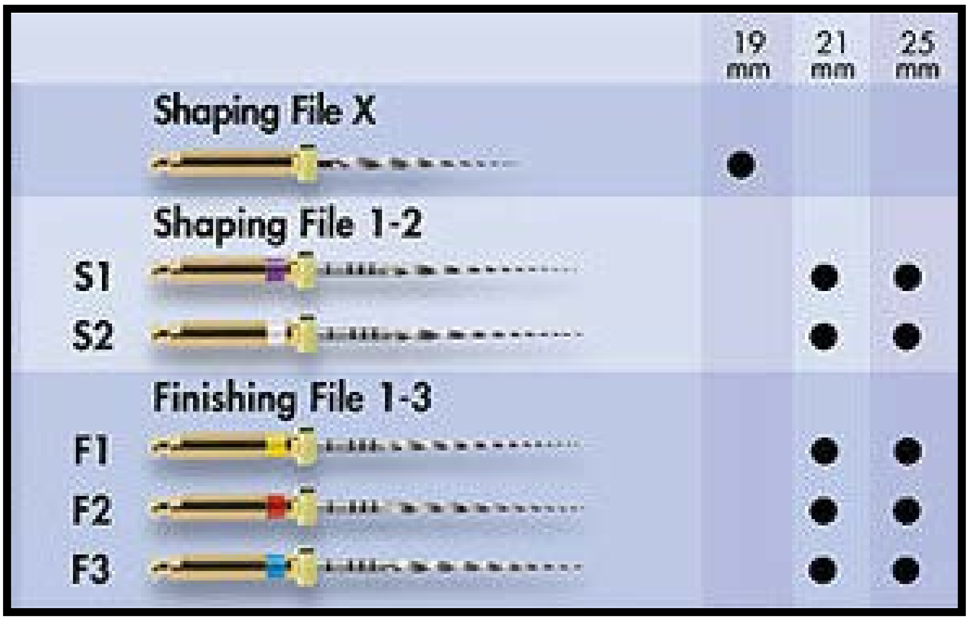


Fig 4.1. (a) ProTaper® rotary files SX, S1, S2, F1, F2 and F3

Fig 4.1. (b) ProTaper® for hand use F3 (#30) for post-operative x-ray

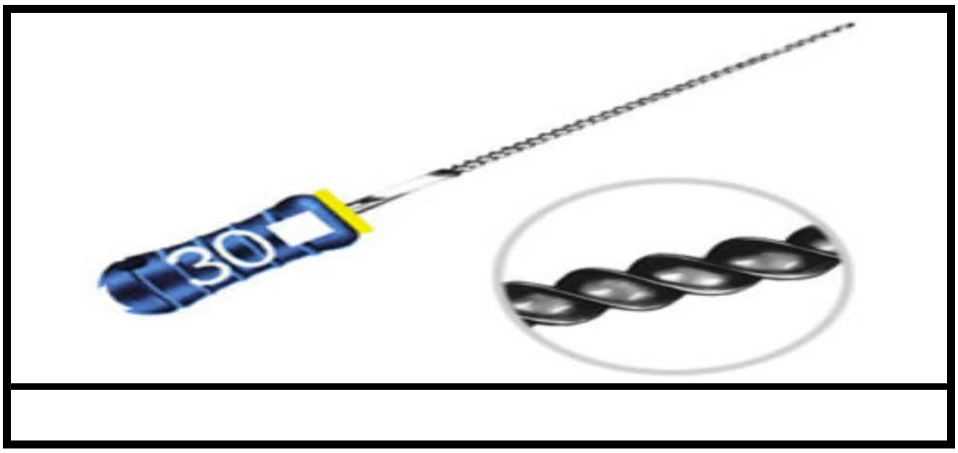


Fig 4.1. (c) A K-Flexofile size #30 as a comparison

Fig 4.1. (d) Tecnika torque controlled motor and handpiece

Figures 4.1 Instruments used for the study

4.2 METHODS

4.2.1 SPECIMEN SELECTION

41 mandibular first molars were selected for this study. These teeth were used within six months after the extraction. Only the mesial canals were used for this study, as they are more curved, rounder and have smaller diameter than the distal canals. Samples with fully formed apices and of similar degree of mesial root curvature (10° to 30° by Schneider's classification) on visual inspection were selected, while severely curved roots were discarded. Samples that show internal deformities and sclerotic canal appearance in the radiograph were also discarded

Selected samples were soaked with sodium hypochlorite [Clorox (Malaysia) Sdn Bhd] 5.25% for five minutes to disinfect and to dissolve soft tissues from the root surfaces. Ultrasonic scaler (Piezon S, EMS SA, Swiss) was used to remove calculus from the tooth surfaces. These specimens were stored in distilled water and kept in room temperature (28°C).

4.2.2 SPECIMEN PREPARATION

Caries were removed using round diamond burs (Shofu, Japan). Access cavities were prepared using a diamond cylindrical bur (Shofu) and tungsten carbide long tapered bur with non-end-cutting tip (Endo Z, Dentsply Mailefer). Distal roots were removed with carborandum disc (Shofu) at the bifurcation to avoid superimposition of the radiograph i.e. image of the distal root with the mesial one. The distal canal orifice was then sealed with a clear acrylic (Vertex-dental, B.V-Zeist, Netherlands).

Glide path was established with size #10 K-file (Colorinox, Dentsply Maillefer) for the two mesial canals. The file was inserted until its tip was just visible at the apical foramen. This was to ensure canals patency. Canals with diameter of the apical foramen larger than size #10 K-file were also excluded. If a size #15 K-file inserted in the canal could easily pass the apical foramen, then the canal diameter is assumed to be too large hence not suitable for the study. Calcified, blocked canals and complex canal systems (e.g. 2-1-2) were also discarded. Working length for all specimens was standardized to 18 mm, which is 1mm shorter than root length. Teeth longer than 19 mm in length were trimmed at the occlusal surface to the standardized length, while shorter teeth were built up with composite material.

A round, clear coloured, soft modeling wax (Cavex, Haarlem, Netherlands) was placed at the mesial root tip to prevent intrusion of acrylic into the canal via the apical foramen. The teeth were then embedded with acrylic resin in a clear-colored plastic rectangle box (Unicorn, Heelee enterprise, Malaysia). Prior to that, the samples were stabilized with soft modeling wax. A self-curing clear acrylic (Vertex-dental, Netherlands) was mixed according to manufacturer's instructions and poured into the plastic box until it covered the enamel-cementum junction. K-file size #10 was inserted to ensure the canal patency. A total of 41 teeth were so mounted in separate plastic boxes. Samples were labeled accordingly from Sample 1 to Sample 41. The buccal and mesial surfaces of each tooth were marked B and M for radiographic taking.

4.2.3 RADIOGRAPHIC PLATFORM

Two standard Plexiglas jigs (Southard *et al.*, 1987; Iqbal *et al.*, 2003) were designed (Figures **4.3, 4.4, 4.5 & 4.6**) to take radiographs in two views. Plexiglas 1 (Figure **4.3 & 4.4**) was used to take proximal-view (mesio-distal) radiographs while Plexiglas 2 (Figure **4.5**) was used to take radiographs in the clinical view (buccolingual). The head of the X-ray tube (Elitys Trophy, West Sussex, UK)) was glued with double sticker tape between the openings in the Plexiglas so that it could be accurately repositioned at a later stage of the experimental procedure. One clear rectangle plastic box (which exactly fits the specimen box) was placed 20 cm away from the X-ray tube so that the principal X-ray beam passed through the center of the tooth. The sensor of a digital radiographic unit was secured to a Plexiglas wall located behind the plastic box. One segment of orthodontic wire, square in cross-section, was set in "L" shape and glued to the Plexiglas wall facing the digital sensor. The projected images of this wire on the digital radiograph were used as a guide for superimposing the pre-and post instrumentation radiographs.

The specimen in plastic box was later fitted into the slot replica of the plastic box glued on a radiographic platform (Figure **4.4**). This could exactly reproduce the position used to take radiograph before and after instrumentation. Three preoperative radiographs and four post-operative radiographs were taken in the following order (refer to flow chart in Figure **4.2**).

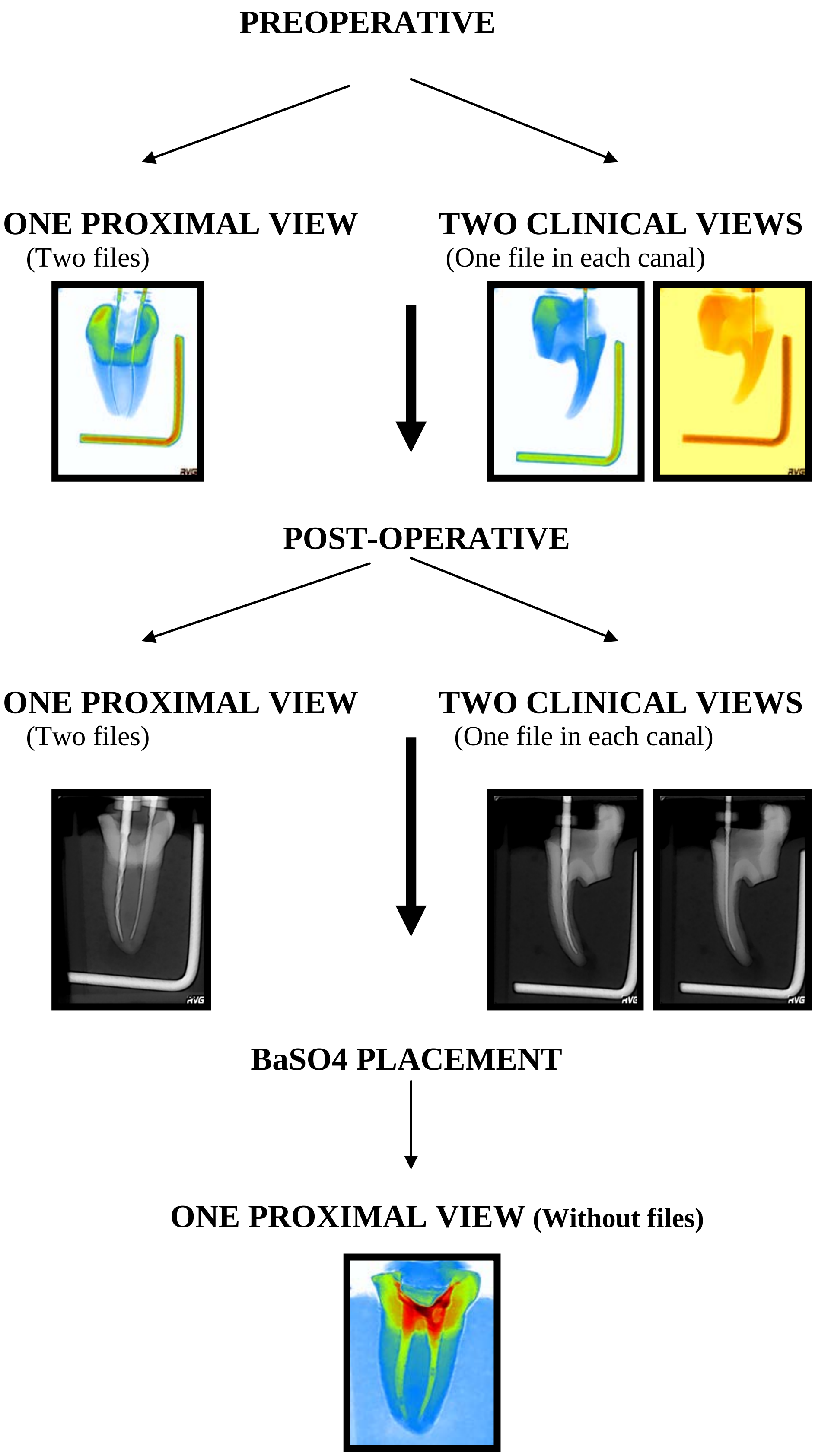


Figure 4.2 Flow chart showing order of radiographs taken in the study

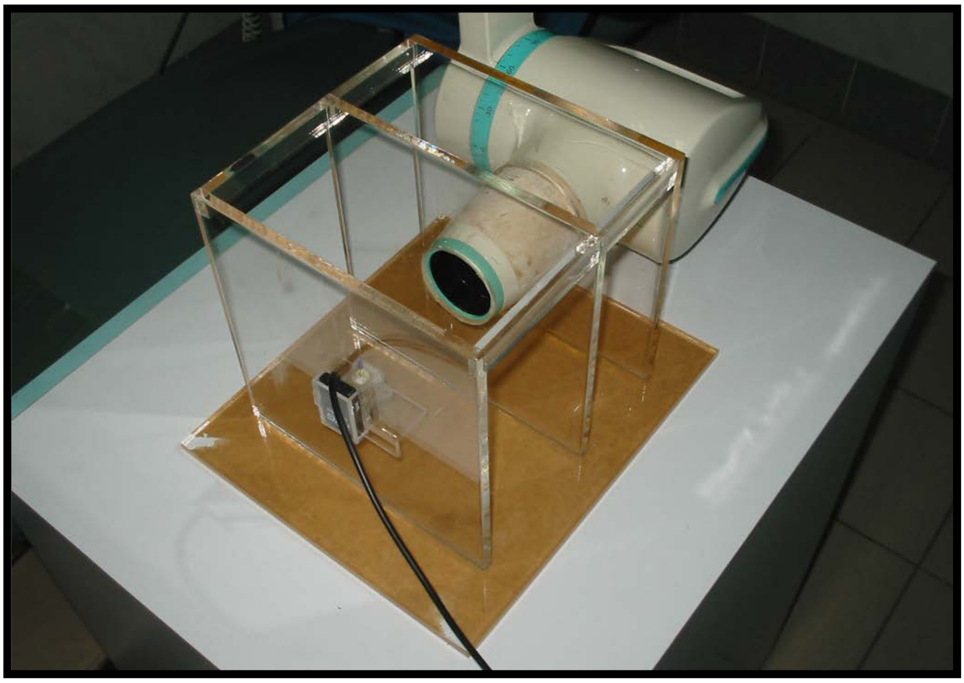


Figure 4.3 Radiographic platform P1with x-ray tube and digital sensor in position

Figure 4.4 Position of digital sensor and plastic box to place specimen in P1

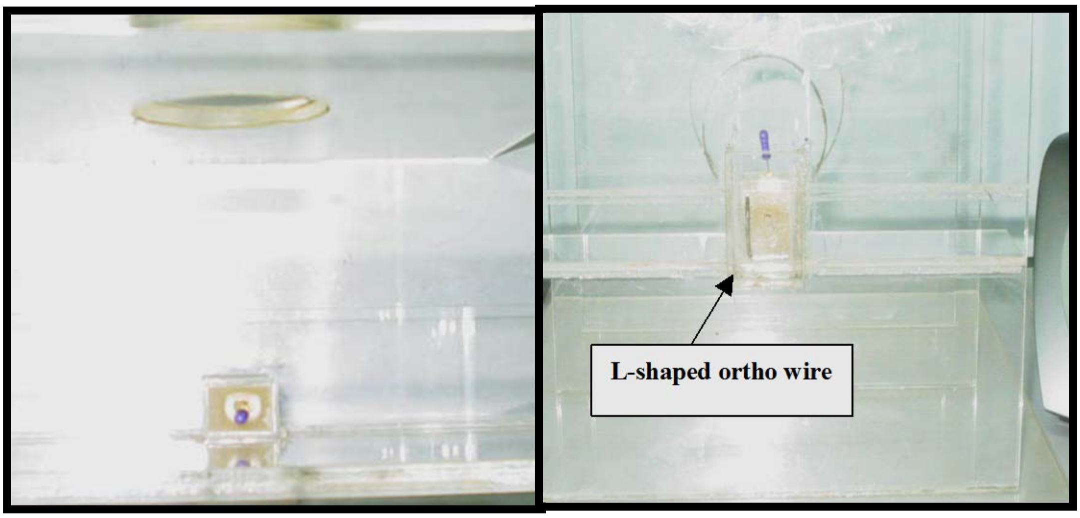


Figure 4.5 Clinical view position of specimen and L-shaped orthodontic wire in Plexiglas P2

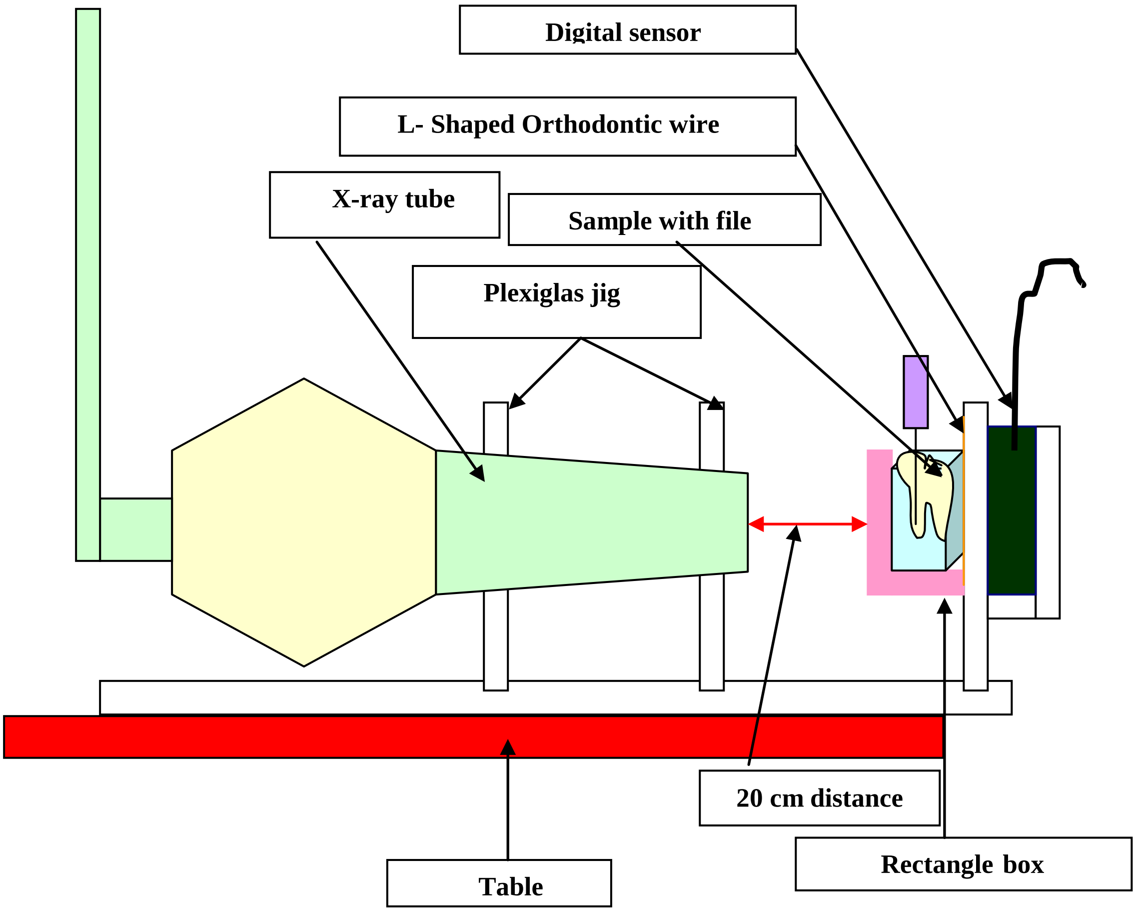


Figure 4.6 A schematic diagram showing the radiographic platform

4.2.4 PREOPERATIVE RADIOGRAPHS

The sample was placed in the interproximal Plexiglas jig (P1) and radiographs were taken mesially with two K-files size #10 in the mesial canals at the working length (18 mm) (Figure **4.8**). Two more radiographs in clinical view were taken using second Plexiglas jig (P2) (Figure **4.9**). Altogether, 3 preoperative radiographs were taken for each sample using interproximal view Plexiglas jig and buccal view Plexiglas jig and the images were stored in the Trophy Windows 2000 digital imaging system (Figures **4.8** & **4.9**).

4.2.5 ROOT CANAL PREPARATION

The samples were divided into 2 groups. 41 randomly selected canals were prepared using step-down technique using K-Flexofiles while the other 41 canals were prepared using crown-down technique using ProTaper®. A total number of 20 mesiobuccal and 21 mesiolingual canals were instrumented in the K-Flexofiles group and similar number of canals in the ProTaper® group (Figure **4.7**).

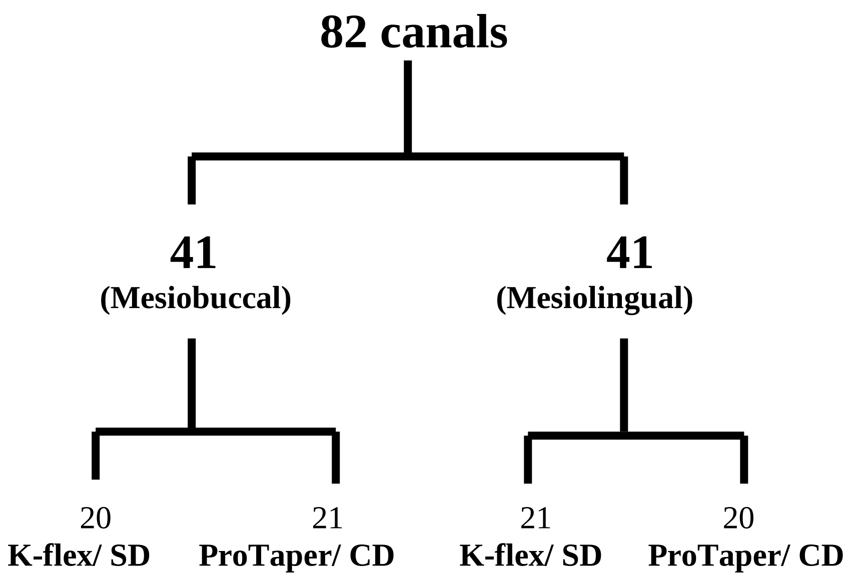


Figure 4.7 Flow chart showing the canal allocation into two groups

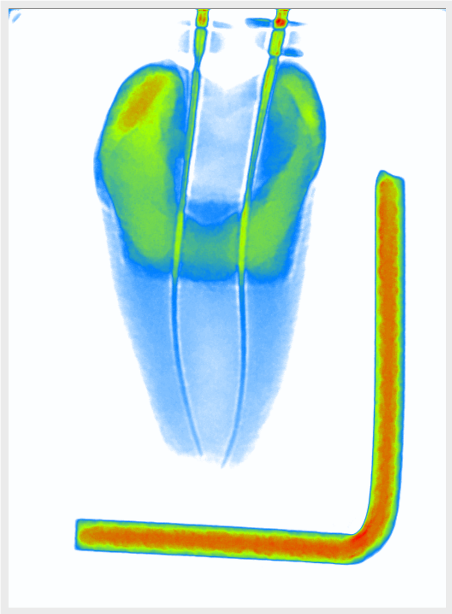
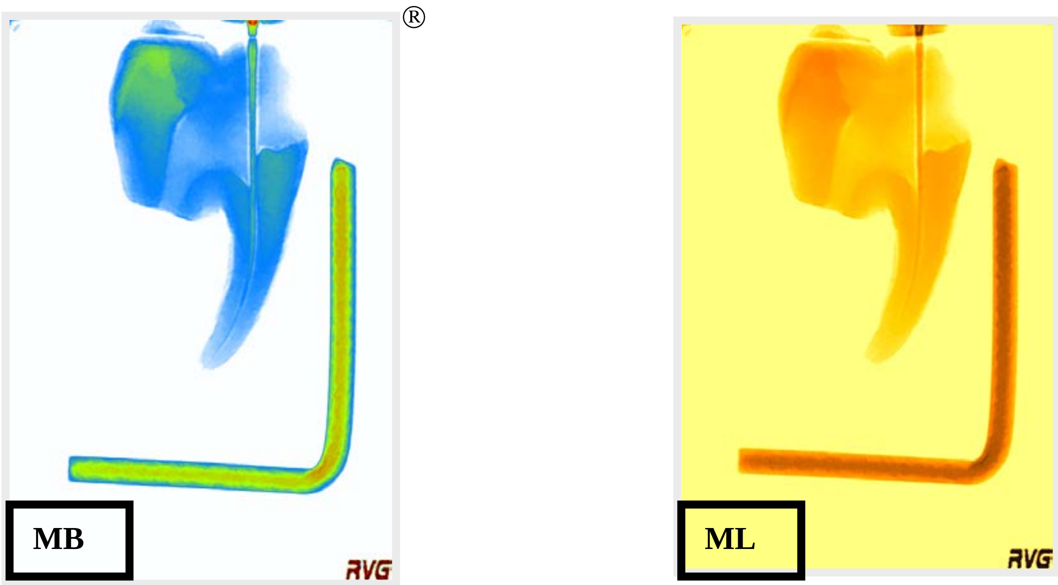


Figure 4.8 Initial digital radiograph at proximal view with two #10 K-files in the mesiobuccal and mesiolingual canal



Figures 4.9 Initial digital radiograph at clinical view with #10 K-files in the mesiobuccal and mesiolingual canal

Root canal preparation of the K-Flexofile group

Coronal preparation of the canal;

The coronal two-third of the canal length (12mm) was measured and the canal was prepared with Gates-Glidden no. 2 (#50), followed with no.3 (#70) and no. 4 (#90). The canal was irrigated with 2 ml of 5.25 % (Malaysian concentration) sodium hypochlorite (NaOCl) (Clorox, Rawang, Selangor, Malaysia).

Apical preparation of the canal;

A K-File, size #15 (Dentsply Maillefer) was inserted to the working length (18.0mm). Filing was carried out with in and out motion to remove canal irregularities in the unprepared apical part of the canal. Then the filing was done circumferentially until the file was seated loosely in the canal. The canal was then irrigated with 2 ml of NaOCl. Using successive K-Flexofiles, the apical area was enlarged to a size #30. This size was noted as Master Apical File (MAF). The patency was maintained with a K-File #10 approximately 1mm beyond the working length.

Stepping back;

A K-Flexofile one size larger than the MAF (size #35) was used to instrument the canal 1mm short of the working length. This was followed by a file two sizes larger than the MAF (size #40) and filing was done to 2mm short of the working length. Stepping back was done at every 1mm until file size #60. Recapitulation was performed by introducing the MAF to the working length after each larger file was used. The canal was irrigated with 2 ml of 5.25% NaOCl after using each file. Finally, the shaped canal was dried with size #30 (02 Taper) paper points (ISO Color Paper points, Dentsply Maillefer).

Canal preparation using ProTaper® system

Straight-Line Access

Access cavities were reshaped with diamond round or tapered burs so that a straight-line access to apical regions could be achieved. The axial walls were extended laterally and the internal walls were flared and smoothed to provide straight-line access into the orifice and the root canal system. Access objectives were confirmed when all the orifices can be visualized without moving the mouth mirror. The angle of the inserted instrument was good indicator: if straight-line access has been achieved, the instrument stood upright.

Coronal Flaring / Coronal One-third preparation

The pulp chamber was flooded with 5.25% of NaOCl for lubrication and to dissolve organic materials inside the canal. Based on the preoperative radiograph, a K-file size #10 was used on coronal two-third of canal. This scouter files were used to verify sufficient space for reproducible glide path for rotary instruments. No attempts were made to reach the terminus. 5-6 cutting cycles were achieved passively with this file and then the same action was followed with K-file size #15 where more restrictive dentin was removed and the glide path improved. The canal was reirrigated copiously with 5.25% NaOCl. The ProTaper® system begins when there is straight-line coronal access, reservoir of fresh irrigant and reproducible glide path in the upper two-third of the canal. A torque controlled motor (Tecnika motor) attached with a low-speed handpiece used at recommended torque and speed was used when using the ProTaper® system.

Shaping file S1 was selected and the glide path was followed and allowed to move just short of depth of hand files that preceded it. After the S1 was taken out, the canal was irrigated and recapitulated with a size #10 file to break up debris. The next rotary instrument was the auxiliary shaping Shaper X (SX). It was passively fed into the canal until it encountered light resistance, withdrawn 1-2 mm and used like a brush to expand the shape and improve radicular access.

Apical One-third preparation

A K-file size #10 was inserted until the working length followed by irrigation and K-file size #15 until a predictable glide path to the terminus was established. The pulp chamber was filled with NaOCl and ProTaper® S1 file was carried to the full working length or where resistance was met. Irrigation with 5.25% NaOCl was done followed by recapitulation with S1 to the working length. Then re-irrigation was done again. Depending on the degree of apical curvature, it required a few recapitulations to move the S1 to working length. The canal was irrigated with 5.25% NaOCl after every recapitulation. This was followed by ProTaper® S2 file. It was allowed to rotate until it reached the working length and then was withdrawn. The canal was re-irrigated with 2 ml of 5.25% NaOCl.

Final Apical preparation

ProTaper® F1 file (finishing file no 1) was introduced into canal and passively allowed to move to just short (approx. 0.5mm) of working length with the canal flooded with irrigant. ProTaper® F2 file was carried to working length and when it was within 1mm of recorded working length, it was immediately withdrawn.

Due to the cutting efficiency of the ProTaper® files, working length will progressively decrease in more curved canals as each rotary instrument creates a more direct path to the terminus. Monitoring the working length at this stage of treatment is important as the high cutting efficiency of these files may create over-preparation of canals (Ruddle, 2002). The canal was reirrigated with 2 ml of 5.25% NaOCl.

ProTaper® F3 file was carried passively to within about 2 mm of the recorded working length, which in actuality will closely approximate the physiological terminus of the canal, then immediately withdrawn. The canal was reirrigated with 2 ml of 5.25% NaOCl. This completed the instrumentation with the ProTaper® rotary system. Preparation was checked with stainless steel hand file of size #30. Finally, the shaped canal was dried with size #30 (ProTaper®) paper points (ISO Color Paper points, Dentsply Maillefer).

4.2.6 POST-OPERATIVE RADIOGRAPHS

To evaluate canal curvature

Post-operative radiographs were taken using Plexiglas jigs [Figures **4.10(a), 4.10(b) & 4.10(c)**] at the same view as preoperative radiograph. Nitiflex size #30 was placed in the K-Flexofiles group canals whereas ProTaper® hand F3 (#30) in ProTaper® group. The images obtained were saved in Trophy windows 2000 software system according to their sample numbers.

For procedural errors evaluation

Barium sulphate ($BaSO_4$) powder was mixed with water into a paste consistency and placed into the canal using a lentulo spiral size #30. This was to enhance the image of the prepared canal walls. Radiographs were taken using the Plexiglas jig for a proximal view only [Figure **4.10 (d)**]. This image gave a radiopaque appearance to prepared canal walls, which enabled the evaluation of prepared canal shape with regard to the formation of ledges, apical zip, elbows and over instrumentation. Two independent evaluators evaluated these images.

Fig 4.10.(a) Mesiobuccal canal with ProTaper® F3

Fig .10.(b) Mesiolingual canal with NiTi -flex #30

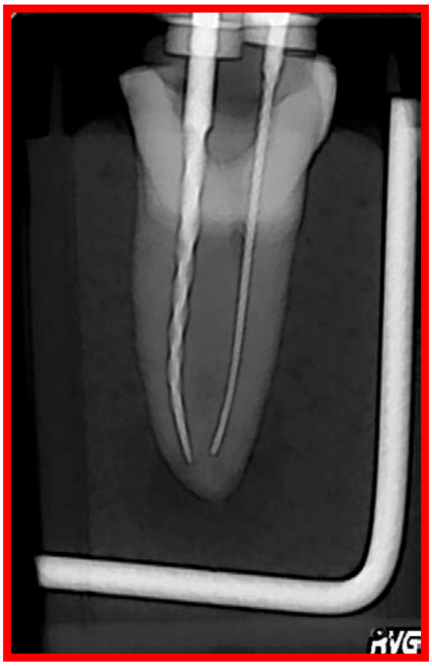


Fig 4.10.(c) Proximal view with both files at working length

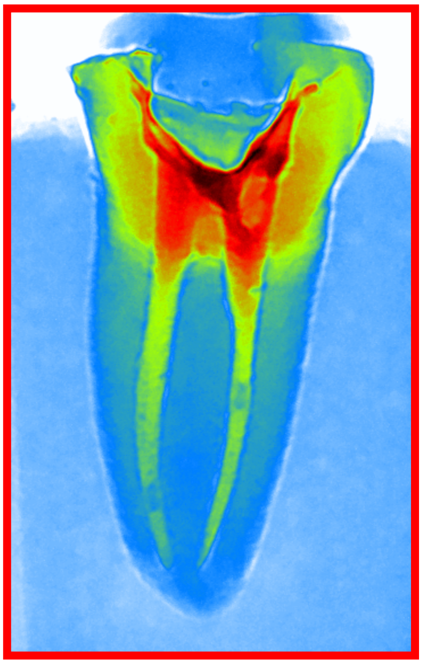


Fig 4.10.(d) Proximal view with $BaSO_4$

Figures 4.10 Post-operative radiographs

4.2.7 EVALUATION OF CANAL PREPARATION

Evaluation of the canal preparation with the two different instruments was based on three main criteria:

a. Maintenance of canal curvature and straightening of root canal system

b. Apical transportation

c. Canal shape after preparation / other procedural errors

a. Maintenance of canal curvature and straightening of root canal system

Maintenance of curvature was studied by measuring the changes in the angle of curvature before and after preparation. The canal curvatures were calculated in clinical view only by using the technique described by Schneider (1971) and also by Cunningham & Senia (1992). Point **a** was marked at the middle of the file image at the level of canal orifice (Figure **4.11**). A line was drawn with a straight edge aligned parallel to the file image from point **a** to a point where the instrument deviated from the straight edge, point **b.** A third point **c** was made at the apical foramen and a line was drawn from this point-to-point **b.** The angle form by the intersection of the two lines was measured as the canal curvature.

All the images (buccolingual view) before and after preparation were transferred into AutoCAD Release 14 Software for calculation of the curvatures. Images of different samples were stored separately. Calculations of curvatures were done twice using the software and the averages were taken as the canal curvature in order to minimize the impact of random error.

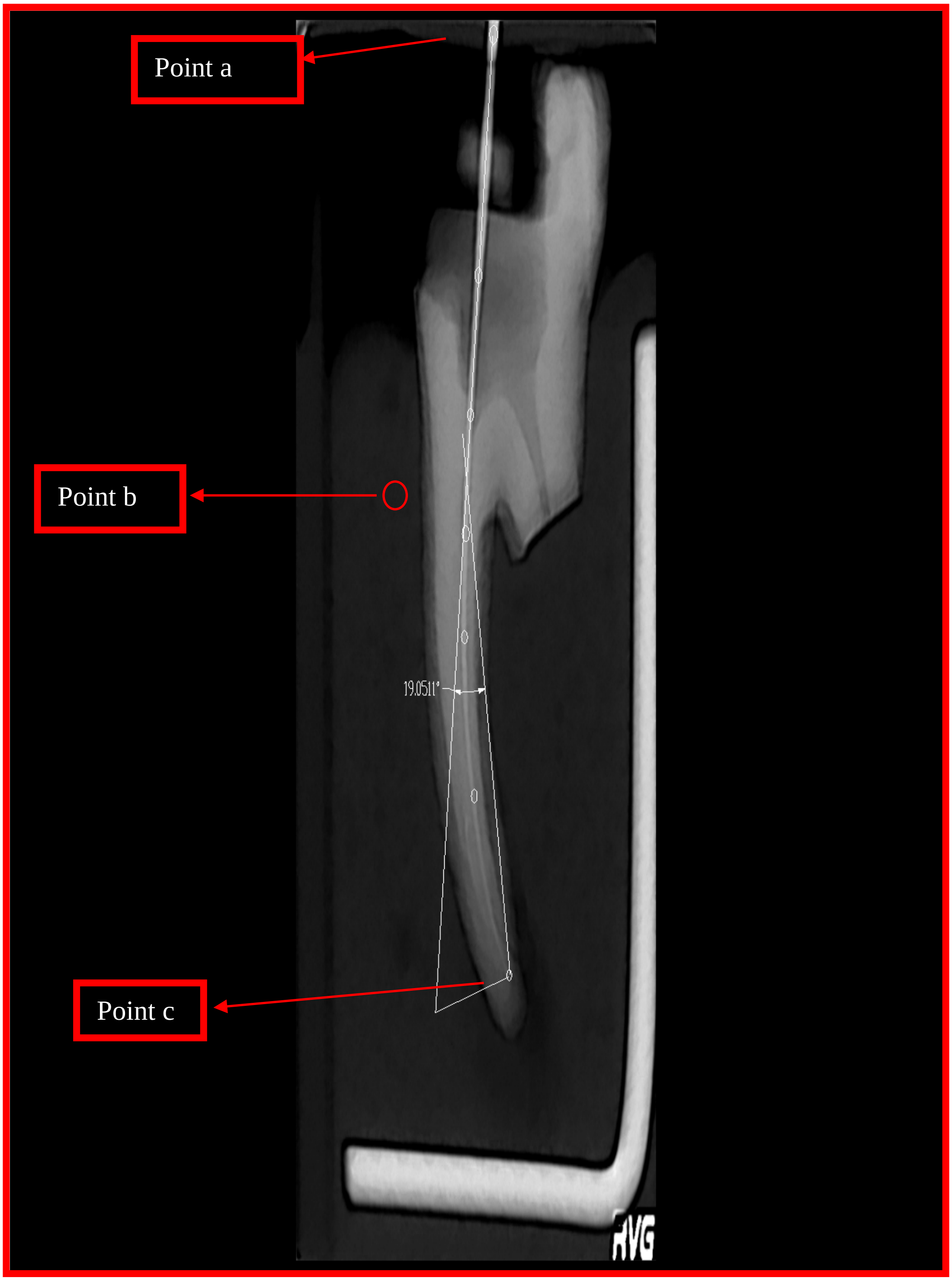


Figure 4.11 An AutoCAD drawing shows the method of calculating angle of curvature in a preoperative radiograph. Technique used for determining primary root canal curvature in the clinical view. Points **a** to **b**, long axis of root canal to point of canal deviation from long axis. Point **C** is the apical foramen. Angle is measured at the intersection of lines **a and b** and **b and c.** (adapted from Cunningham & Senia, 1992)

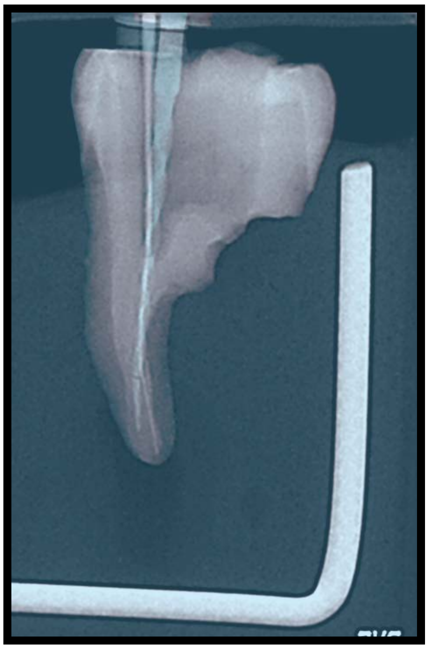
First, a few circles were drawn along the file image from the rubber stopper, the canal orifice, apical one-third and at the apical foramen (Figure **4.11**). A construction line was drawn from point **a** to the straight portion of the file. Point **b** was marked at the point where the line deviates from the long axis of the file. Then a line was drawn from point **c** that was the apical foramen to point **b** at the construction line. The angle created by the intersection of these lines was calculated as angle curvature. The same procedure was repeated for all specimens both on the preoperative and post-operative radiographs. Since the researcher drew the circles and the two lines with the aid of the computer software (AutoCAD), this can introduce systematic error while calculating the angle of curvature. In order to minimize this error, intra-examiner calibration was done and the researcher underwent self-training and repeated measurements until they are consistent. Furthermore, intra-examiner reliability test was performed on a random selection of specimens to ensure consistency of measurements. The intra-examiner reliability test correlation coefficient showed a very good relation of 0.98.

Independent samples t-test was used to examine the difference in mean curvature between the two groups at baseline (Curvatures Before). While to test if there is a difference in mean curvature before and after preparation for both groups, paired samples t-test was used. The difference in angle before and after preparation was termed as curvature reduction. General Linear Models Repeated Measures was used to test if there is a significant difference in mean curvature reduction between the two instrument types.

b. Apical transportation

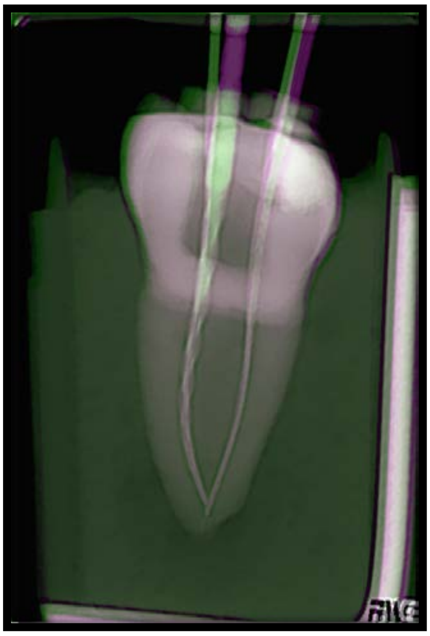
All the radiographs in clinical and proximal views were imported to the Adobe Photoshop (version 7.0) software for superimposition. The preoperative radiographs were colored red whereas post-operative radiographs were coloured blue or green prior to superimposition. The tip of the files was magnified to 100%. No transportation would be indicated if the tip of the files were seen as one. Transportation noted whenever two tips were seen separately (as Figures **4.12 & 4.13**).

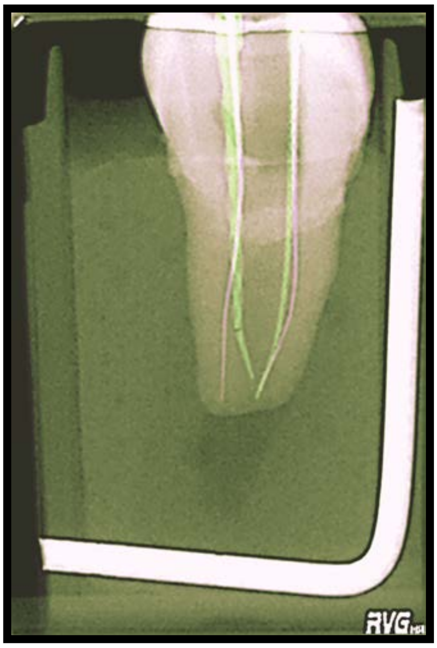
The intensity of the apical transportation was categorized as severe (**4.12a**) and slight transportation (**4.12b**) based on the horizontal distance between the two file tips. If the distance between two file tips was more than 1.0 mm but less than 3.0 mm it was considered slight transportation and more than 3.0 mm was severe transportation. These measurements were repeated twice and the average was taken as the intensity of the apical transportation. Intraexaminer reliability test was done to check the reliability of the readings using percentage agreement and the test showed 100% agreement. Statistical analysis of the apical transportation was performed using cross-tabulation with Fisher's exact test.



a. Severe transportation

b. Slight transportation



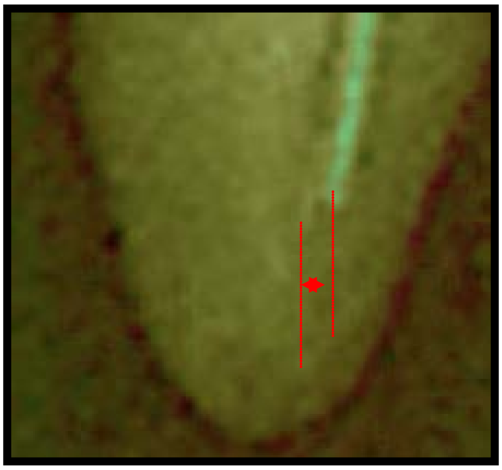


c. No transportation (proximal view)

d.Severe transportation (proximal view)

Figures 4.12 Superimposed radiographs showing severe and slight transportation of canal preparation

a. Severe transportation (horizontal distance more than 3.0mm) under 100%magnification



b. Slight transportation (horizontal distance between 1.0 mm-3.0 mm)

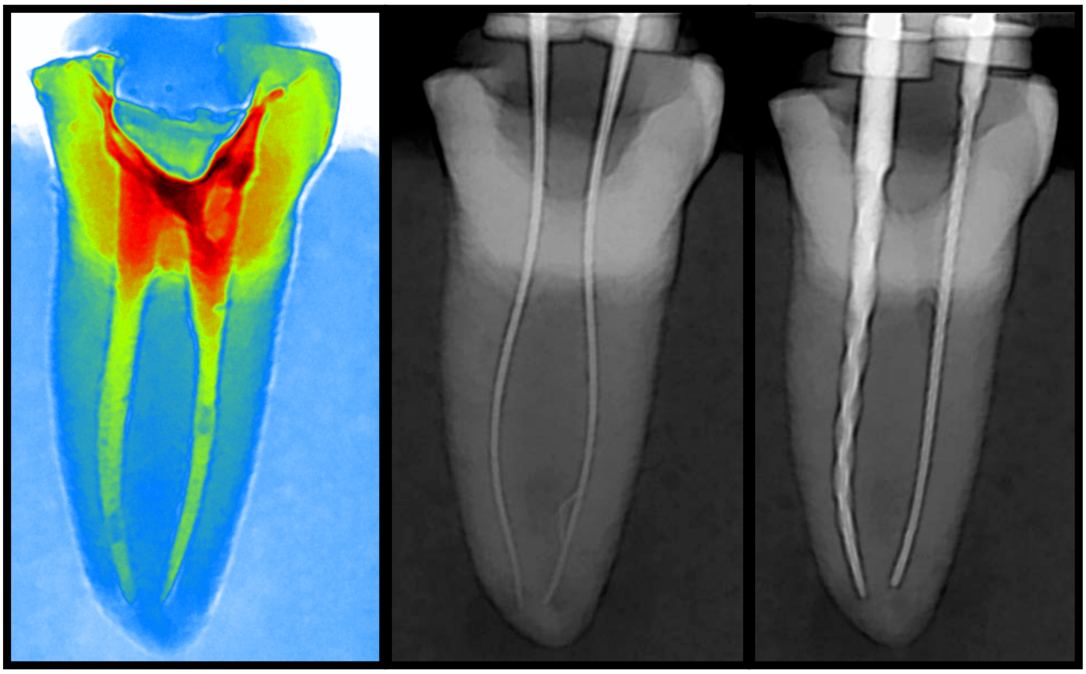
Figures 4.13 Super imposed radiographs showing severe and slight transportation of canal preparation under high magnification (100%)

c. Procedural errors

The evaluation on the procedural errors after instrumentation was based on the occurrence of ledges, apical zips, and elbows and over-instrumentations. Instrument separation was also recorded in this section. The evaluation was performed by two experienced endodontists.

All the three proximal-view radiographs were copied into Microsoft PowerPoint software according to the respective sample numbers, saved to CDs, and given to the endodontists for evaluation. An example of ledges, apical zips, elbows and over-instrumentations occurred in this samples were given to the evaluators as guidance and for standardization (Figures **4.14**, **4.15a**, **4.15b** & **4.15c**).

The researcher recorded the incidences of instrumental fractures (Figure **4.16**) and lateral perforations (Figure **4.17**) separately. All the data collected for the parameters were grouped according to different instrument groups and was analyzed using cross-tabulation with Fisher’s exact test.



Figures 4.14 Radiographs in proximal view for evaluation of canal shape after preparation

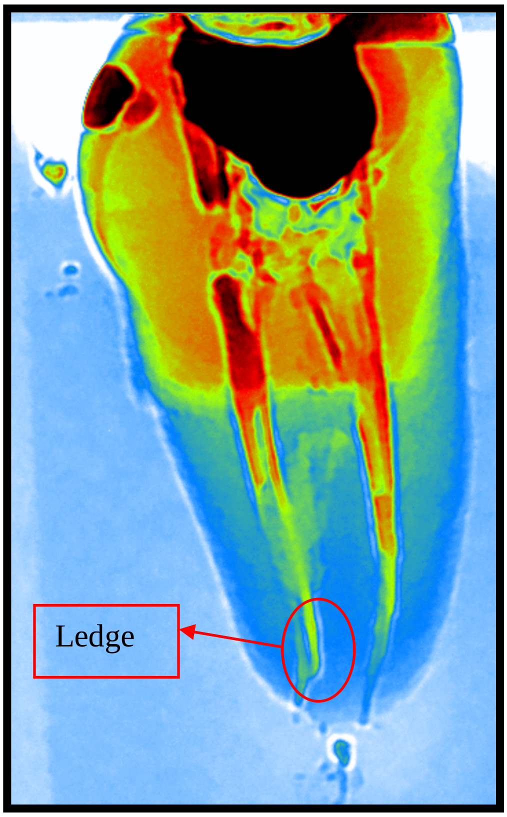


Fig.4.15. (a) Ledge

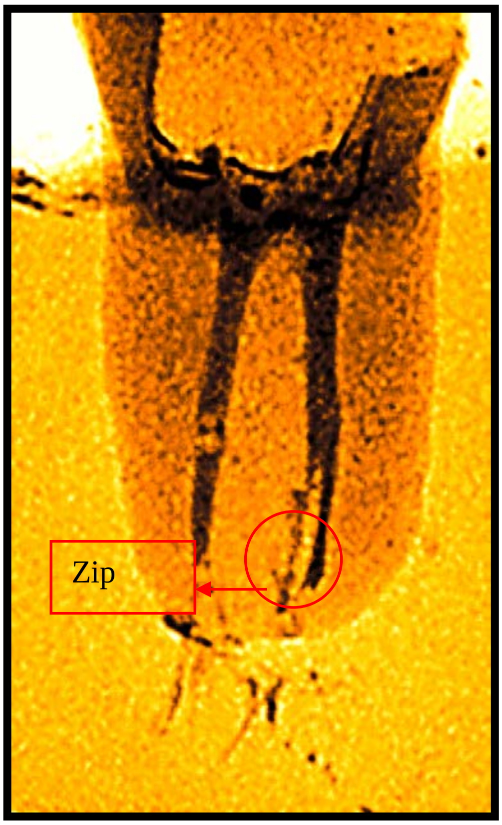


Fig. 4.15. (b) Apical zip

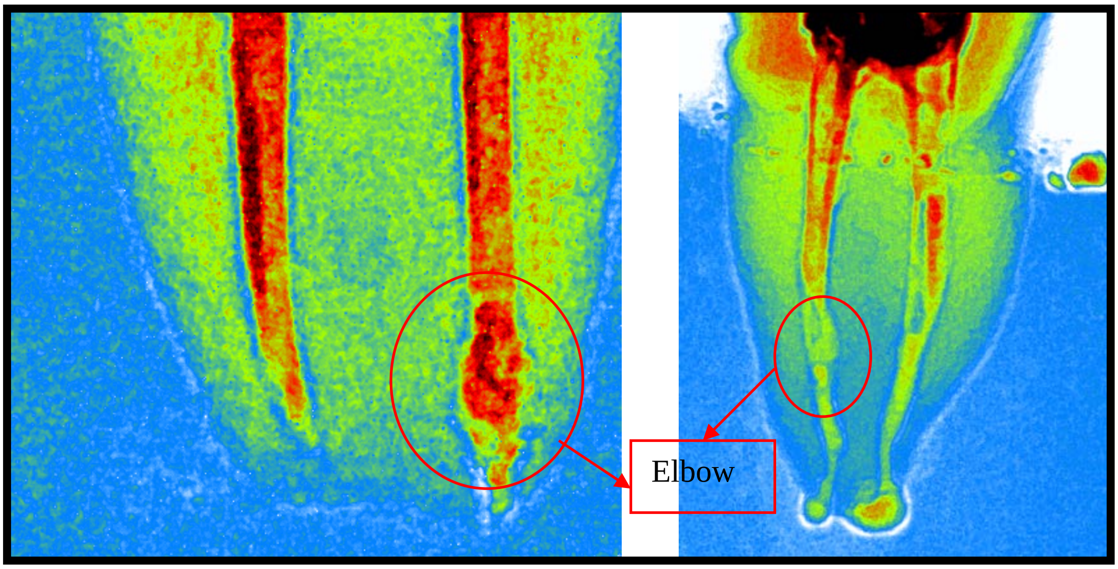


Fig. 4.15. (c) Elbows

Figures 4.15 Radiographs in proximal view with BaSO4 for evaluation of canal shape after preparation with examples of ledge, apical zip and elbows

Figures 4.16 Radiographs in proximal view showing fractured instruments

Figure 4.17 Radiograph superimposed showing lateral perforation

5.0 RESULTS

5.1 HOMOGENEITY OF SAMPLES

41 specimens were used in the study (82 canals ie: 41 mesiolingual and 41 mesiobuccal canals). A total of 82 preoperative radiographs were taken. All 82 preoperative radiographs were used to determine the homogeneity of the samples with regards of severity of canal curvature before treatment. In each group there were 41 canals. For the K-Flexofiles group, the mean curvature was 17.0 degrees while for the ProTaper® group the mean curvature was 16.6 degrees. The samples were subjected to independent samples *t*-test to test if the samples are homogenous and if the teeth in the two groups were similar in severity of canal curvature before instrumentation. The curvature ranged from 7.4 to 26.9 degrees for K-Flexofiles group, and from 7.2 to 26.6 degrees for the ProTaper® group.

Since the measurements of the canal curvatures were done twice and the average was taken as the canal curvature, the data was subjected to independent samples *t*-test for the equality of variances. The P-value for the test of equality of variances is 0.52, i.e. non-significant. Thus, the two group measurements can be assumed to be homogenous. To test if the canal curvatures before preparation were evenly distributed between the two groups, the test of equality of means were done and the P-value for the test of equality of means is 0.59, i.e. non-significant. Thus, there was no significant difference between the two groups.

5.2 INSTRUMENTATION RESULTS

5.2.1 ANALYSIS OF CANAL CURVATURES

The canal curvatures after preparation were measured using post-operative radiographs. 34 canals were evaluated for ProTaper® group, whereas 40 canals were evaluated for the K-Flexofiles group. Eight canals were excluded due to fracture of instruments (n=6) and lateral perforation (n=2) one from each group.

As two types of data were involved (curvature before and after) in this study, a paired sample t-test was used to measure if there is a difference in mean curvature before and after preparation for all the samples, at $\alpha = 0.05$. The mean curvature before preparation was 16.6° while after preparation was 10.9°. The results indicated that there is a significant difference in mean curvatures before and after preparation. The P-value for the test of equality of means before and after is less than 0.001, which is statistically significant.

5.2.2 COMPARISON OF CANAL STRAIGHTENING BETWEEN GROUPS

Further tests were carried out to compare the canal straightening between the two groups. General Linear Models Repeated Measures were used to test if there is a difference in curvature reduction between the two instrument types (refer to Table **5.1**, Figure **5.1** and Appendix **6)**. First, the test for the difference in time was done to check the difference in mean curvatures before and after treatment for all the specimens. Then, the test for the difference in type was done to check if there is a difference in the reduction in mean curvatures between the two types of instrumentation. Lastly, the test for difference in time*type interaction was done to determine the rate of curvature reduction according to the instrument type.

Table 5.1 Mean curvature before and after preparation by instrument type

Group	n	Curvature before preparation(degrees) Mean ±SD	Curvature after preparation(degrees) Mean ±SD	Curvature reduction(degrees) Mean±SD
ProTaper®	34	16.40 ± 5.58	12.41 ± 5.11	3.99±4.41
SS	40	16.79 ± 4.60	9.69 ± 4.39	7.10±3.54
Total	74	16.61 ± 5.04	10.94 ± 4.89	5.67±4.17

n= Sample size SD= Standard Deviation
(*level of significance set at $p<0.05$)

The P-value for the test for difference in time is less than 0.001, which is less than 0.05. Thus, there is a significant difference in mean curvatures before and after treatment. The P-value for the test for difference in type is 0.277, which is more than 0.05. Thus, there is no significant difference in mean curvatures between the two types. The P-value for the test of difference in time*type interaction is less than 0.001, which is less than 0.05. Thus, there is a significant difference in mean curvature reduction between the two instrument types. The rate of reduction in SS is more compared to that of ProTaper® (P-value < 0.05).

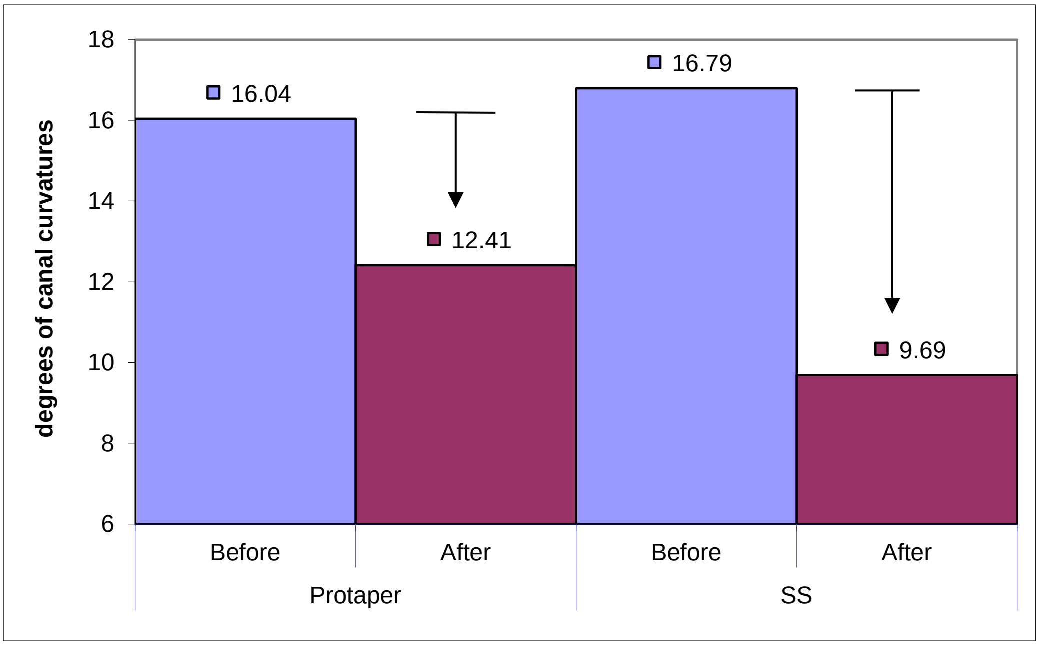


Figure 5.1 Bar chart showing comparison of difference in curvature reduction

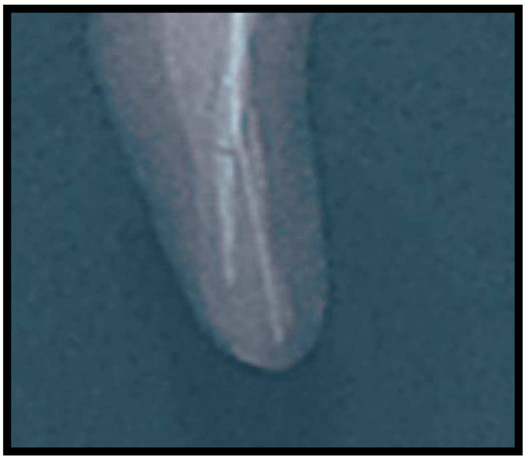
5.2.3 COMPARISON OF APICAL TRANSPORTATION AND LATERAL PERFORATION

Apical transportation in clinical view radiographs

Apical transportation in clinical view was noted in 5 samples in the ProTaper® group (n=40) with 1 canal severely transported (in this canal it has caused fracture of the file), three canals with lateral perforation and one canal slightly transported. The images of transportation have been shown below (Figures **5.2**).

Only 40 canals were evaluated for ProTaper® group, whereas 41 canals were evaluated for the K-Flexofiles group. One canal from the ProTaper® Group was excluded from the entire evaluation of procedural errors and instrument separation. This specimen (mesiolingual canal C4) has a fractured instrument

(ProTaper® for hand use F3) inside the canal. This fracture occurred after the canal preparation was completed and can affect the results especially measurements of apical zipping and ledges. Since it can also affect the performance of the ProTaper® group, all the data obtained for this specimen were abstained from the statistics.

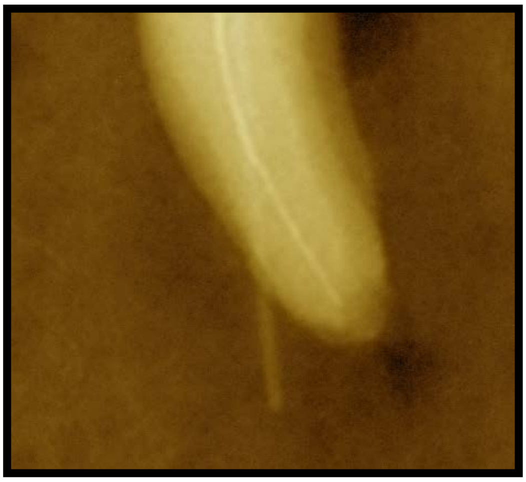


Lateral perforation **Severe transportation**

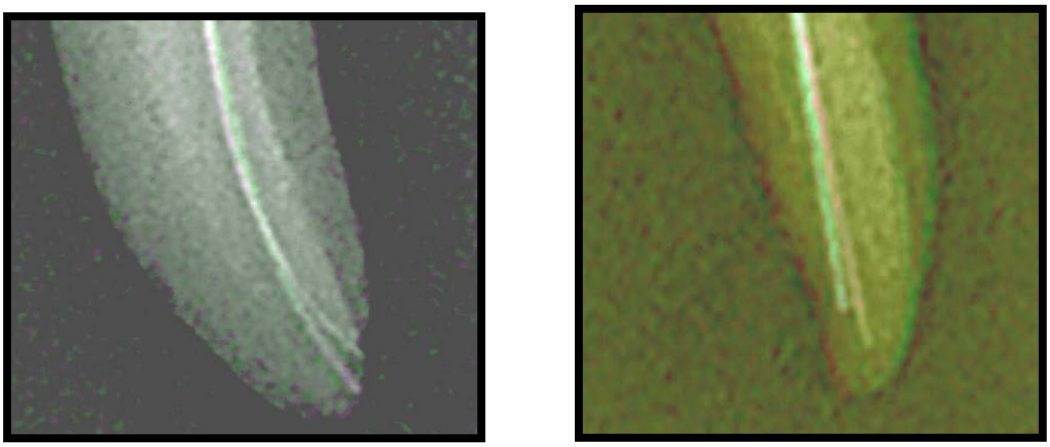
Figures 5.2 Lateral perforation & apical transportation (clinical view) in ProTaper® group

Apical transportation in clinical view in K-Flexofiles group (n=41) was noted in 7 samples and examples has been shown in Figures **5.3.** Two canals showed severe transportation, one canal with lateral perforation and four canals showed slight transportation.

Cross-tabulation with Fisher's exact test was used to test if there is an association between instrument type and apical transportation. The significance level was set at 0.05. The P-value for Fisher's exact test is 0.264, which is more than 0.05. Thus, there is no association between instrument type and apical transportation. No significant differences were found between the two groups. Cross-tabulation with Fisher's exact test was also used to test if there was an association between instrument type and lateral perforation, at a significance level of 0.05. The P-value for Fisher's exact test is 0.359, which is more than 0.05. Thus, there is no association between instrument type and lateral perforation. No significant differences were found between the two groups. Bar chart (Figure **5.4)** shows the amount of apical transportation in clinical view radiographs and lateral perforation for the two instruments.



Lateral perforation



Severe transportation **Slight transportation**

Figures 5.3 Lateral perforation & apical transportations (clinical view) in K-Flexofiles group

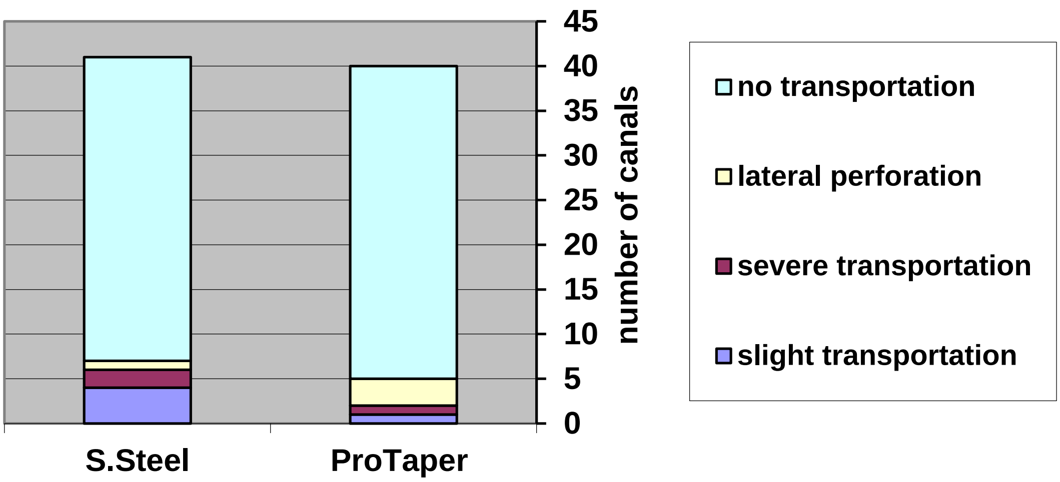
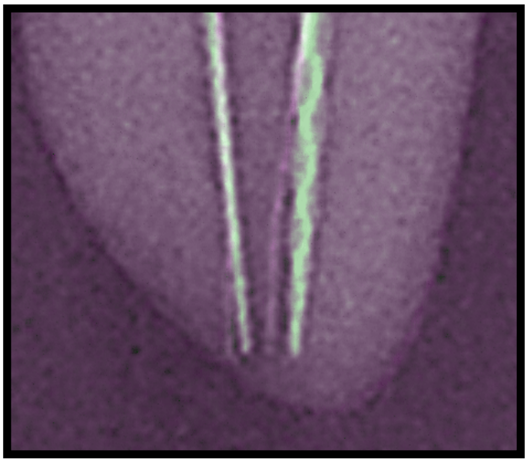


Figure 5.4 Bar chart showing the amount of apical transportation in clinical view for the two instruments

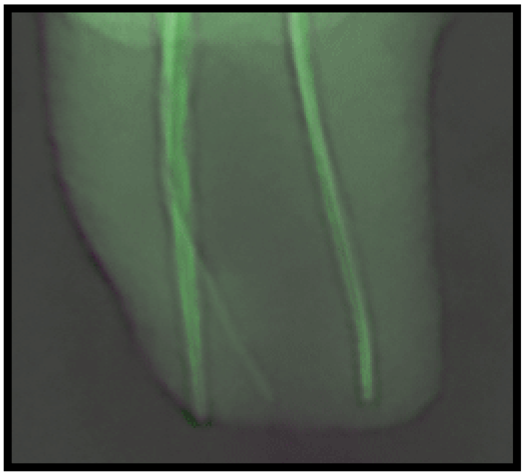
Apical transportation in proximal view radiographs

Apical transportation in the proximal view was noted in 10 samples in the ProTaper® group (n=40) where 4 canals showed severe transportation and 6 canals showed slight transportation. Out of 4 canals with severe transportation, 2 were severely transported in clinical and proximal view (sample no C20 and C24). In 2 of the canals from the ProTaper®group, there was no transportation evident in the clinical view, however, severe transportation was noted in the proximal view (Figures **5.5**). Two samples showed severe transportation and lateral perforation when observed in clinical view however no transportation was recorded in the proximal view radiographs. No lateral perforations could be noted in the proximal view as they occur on the lateral side of the root and be visible on the clinical view only.

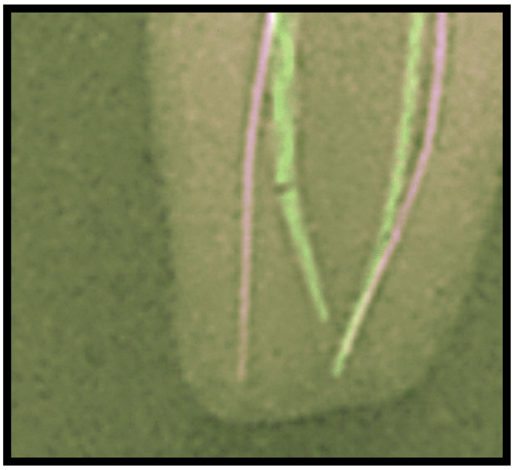
In the K-Flexofiles group, apical transportation in the proximal view was noted in 7 samples with 3 showing severe transportations and 4 with slight transportations. The same 3 samples which showed severe apical transportation in clinical view (sample no C22, C33 and C39) also showed severe or slight transportation in proximal view. One sample (C29) didn't show transportation in clinical view but severe transportation was noted in proximal view.



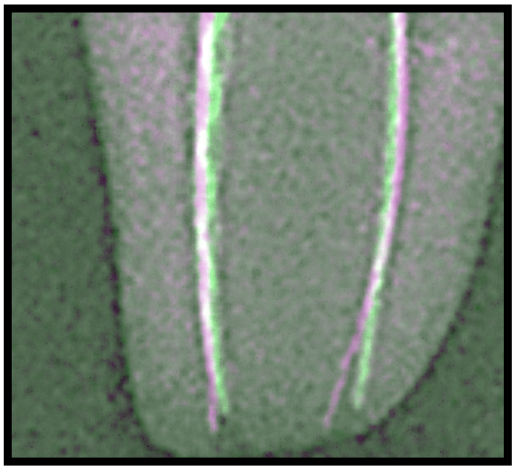
a. Severe transportation in both files



b. Severe transportation in ProTaper®



c. Severe transportation with file fracture in ProTaper®



d. Severe transportation in K-Flexofiles and slight transportation in ProTaper®

Figures 5.5 Samples showing transportation in proximal view radiographs

Cross-tabulation with Fisher's exact test was used to test if there is an association between instrument type and apical transportation in the proximal view. The significance level was set at 0.05. The P-value for Fisher's exact test is 0.424, which is more than 0.05. Thus, there is no association between instrument type and apical transportation. No significant differences were found between the two groups.

Bar chart (Figure **5.6)** shows the amount of apical transportation in proximal view radiographs for the two instruments.

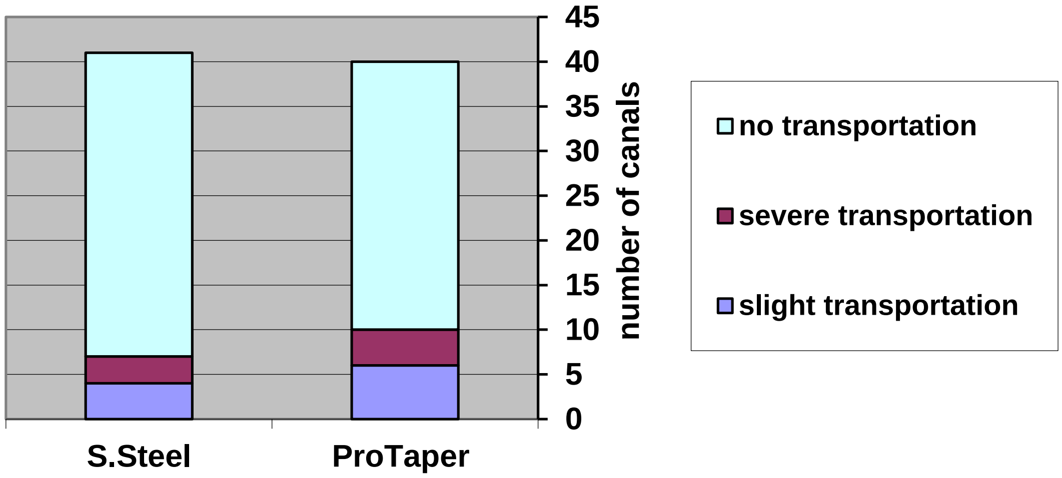


Figure 5.6 Bar chart showing the amount of apical transportation in proximal view for the two instruments.

5.2.4 COMPARISON OF CANAL SHAPE AFTER PREPARATION

The occurrences of ledges, elbows, zipping and over instrumentation were compared between the two groups using cross-tabulation with Fisher's exact test. There were a total of 6 ledges with 4 occurred in the ProTaper® group and 2 in the K-Flexofiles group. As for the elbows, the ProTaper® group (n=40) showed 9 while there was only one elbow in the K-Flexofiles group (n=41). Apical zipping was found in 5 of the samples in the ProTaper® group and 6 in the K-Flexofiles group. Only one canal from each group showed over instrumentation (apical preparation larger than desired).

The P-values for Fisher's exact test for ledge, zipping and over instrumentation between groups are 0.432, 0.518 and 0.747, respectively (P>0.05). Thus, there is no association between instrument type and ledge, zipping and over instrumentation. Bar chart (Figure **5.7**) shows differences in canal aberrations between groups

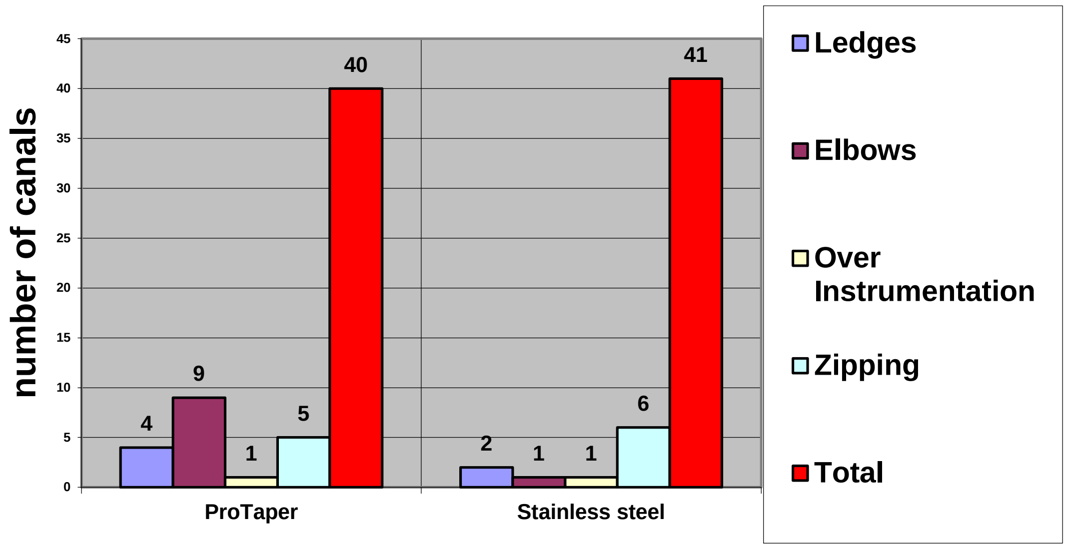


Figure 5.7 Bar chart showing differences in canal aberrations between groups

As for occurrence of elbows, the P-value for Fisher's Exact test is 0.007(α=0.05). Thus, there is an association between instrument type and presence of elbows. Among ProTaper® there are 22.5% elbows, while there are only 2.4% in K-Flexofiles group (Figure **5.8**).

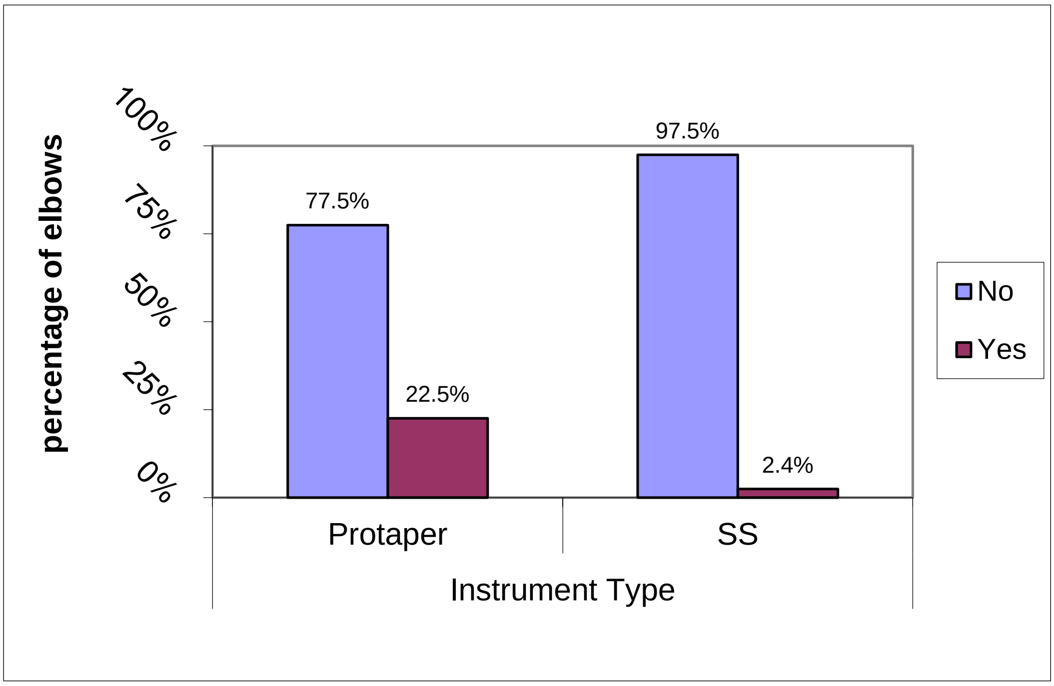
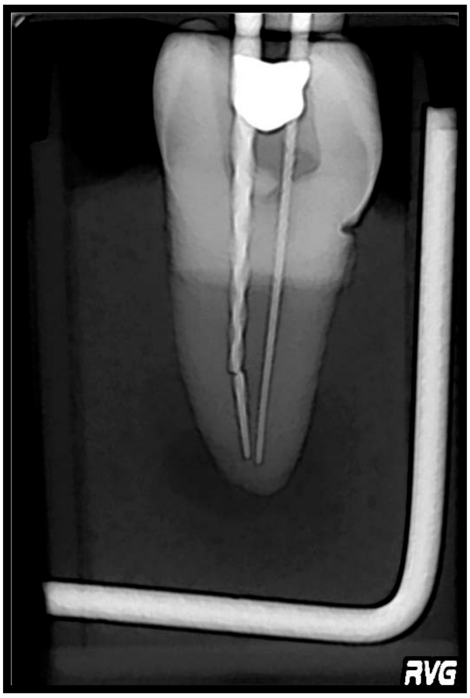


Figure 5.8 Bar chart showing comparison of difference in occurrences of elbows

5.2.5 INSTRUMENT SEPARATION

There were six cases of instrument separation recorded in this study. All the fractures occurred in the ProTaper® group. One fracture occurred after canal preparation has completed during the taking of post-operative radiograph with hand-ProTaper® size F3 (sample c4). Five of the ProTaper® rotary files fractured during canal preparation procedures; 3 of them were ProTaper® F3 files and 2 were ProTaper® F2 files (refer figures **5.9** & **5.10**).The association between instrument type and instrument separation was studied using cross-tabulation with Fisher's exact test. The P-value for Fisher's exact test is 0.026 ($P< 0.05$). Thus, there is an association between instrument type and instrument separation. ProTaper® instruments separated more often than stainless steel K-Flexofiles.



Sample c4 Fracture F3 (hand use)

Sample c5 Fracture F3 (rotary)

Figures 5.9 Fractured ProTaper® instruments

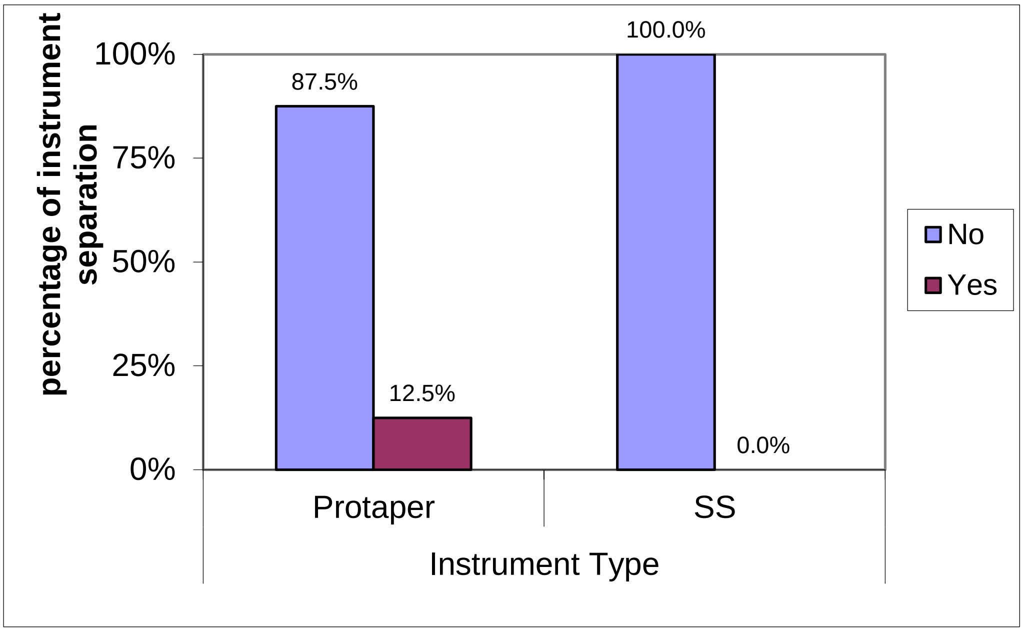


Figure 5.10 Bar chart showing comparison of difference in instrument separation

6.0 DISCUSSION

6.1 METHODOLOGY

6.1.1 SAMPLE COLLECTION

The tooth samples, mandibular first molars were collected from private clinics around Kuala Lumpur and from the Oral Surgery Departments clinic in Faculty of Dentistry, University of Malaya regardless of age, race and gender of the patient. The samples were used within 6 months after the extraction. Tooth samples were immersed in 5.25% sodium hypochlorite (NaOCl) for about 20 minutes immediately after extraction to remove soft tissues from the root surfaces. The samples were then stored in distilled water until the time of use to prevent bacterial colonization and dehydration of teeth. No other chemicals or disinfectants were used as they may alter the properties of dentine.

6.1.2 SAMPLE SELECTION

Mandibular first molars with two curved mesial root canals with separate apical foramina were selected for this study. Mesial root canals were used because they show more curvatures and have a rounder canal (Slowey, 1979; Weine, 1995; Burns & Herbranson, 1998). Many previous researchers have used mesial canals of mandibular first molars for assessing root canal preparations (Glosson *et al*., 1995; Gilles & Del Rio, 1990; Nagy *et al*., 1997; Leseberg & Montgomery, 1991; Davis *et al*., 2002; Ponti *et al.,* 2002; Tan & Messer, 2002; Garala *et al*., 2003; Bergman *et al*., 2003; Hulsmann *et al*., 2003; Iqbal *et al.,* 2004; Paque *et al.,* 2005). Furthermore, the presence of two canals in a single root is an added advantage in that each canal can be prepared using a different instrument; in this study ProTaper® and K-Flexofiles were used. This allows better comparison of two different instruments as variables such as dentin hardness; canal morphology and canal curvature can be controlled to a certain extent or approximately standardized.

Both the groups had equal number of specimens; the ProTaper® group had 41 canals with 21 mesiobuccal and 20 mesiolingual canals while the K-Flexofiles group had 41 canals with 20 mesiobuccal and 21 mesiolingual canals and the instruments were used alternatively in buccal and lingual canals of consecutive samples to compensate for possible differences in the canal morphology. According to the P-values obtained, the degree of the canal curvature in both the groups were distributed evenly and well balanced (refer homogeneity of samples, Pg 93).

6.1.3 ROOT CANAL PREPARATION

The desirable final size of apical preparation still remains controversial. The first concept aims at complete circumferential removal of dentine. The traditional rule has been, to prepare at least three sizes beyond the first file that binds at working length (Hulsmann *et al.,* 2005). The second concept aims to keep the apical diameter as small as practical (Schilder, 1971). This concept for apical preparation includes scouting of the apical third, establishing apical patency with a size #10 instrument passively inserted 1mm through the foramen, gauging and tuning the apical third and finally finishing the apical third at least to size #20.

ProTaper® finishing instruments (F1, F2 and F3) have apical diameters ranging from 0.20 to 0.30mm (Hulsmann *et al*., 2005). Canal preparation can be finished at ISO sizes #20, #25 or #30. In the present study, the maximum diameter of the unprepared canal was set to be size #10 and the canals should be prepared to at least #25. However, all root canals were uniformly prepared to size #30 as the greatest file of the ProTaper® system limited the instruments diameters.

Step-down technique was chosen for the K-Flexofiles group as they provided straight-line access to the apical third of the root canal (Goerig *et al*., 1982). Step down techniques commence preparation using larger instruments at the canal orifice, working down the root canal with progressively smaller instruments. Major goals of step-down techniques are reduction of periapically extruded necrotic debris and minimization of root canal straightening. Since during the step down there is less constraint to the files and better control of the file tips, it has been expected that apical zipping is less likely to occur (Hulsmann *et al*., 2005). This technique is widely taught in dental schools for preparing curved canals of anterior and posterior teeth. Furthermore, this technique is very much similar to the crown-down technique used with ProTaper® rotary system where in both techniques the coronal section of the teeth is prepared before proceeding to the apical preparation. Flexible stainless steel K-files with modified non-cutting tips were used in preparing root canals because they were found to be superior to conventional stainless-steel K-files with regard to better cutting efficiency and avoidance of undesirable canal shapes, such as straightening, ledging and zip formation (Schafer, 1997).

ProTaper® system incorporates instruments of progressive multitaper design with sharp cutting blades. Comparing the ProTaper® system with other systems, one can note that other file systems (ProFile™ *Series 29 0.04 tapers, ProFile™ *Series 29 0.06 tapers and K3™ systems) focus on one taper within a file and tend to combine a series of files to achieve the necessary effect. In contrast, ProTaper® has varying tapers within one file ranging from 2% to 19%, which makes it possible to shape specific section of root canal with one file. For example, ProTaper® file S1 is designed to shape mainly the coronal section of the root canal; in comparison, S2 is designed to the middle section of the root canal system (Clauder & Baumann, 2004). The advantage of this progressive taper, whereby only a limited part of the instruments' cutting surface makes contact with the root canals wall, together with the absence of radial lands, is likely to be a reduction of torsional loads on the instruments (Ruddle, 2002).

During shaping, instruments might lock or thread (screw) into the canal. Locked instruments are subjected to high levels of stress, frequently leading to separation. Yared *et al.* (2001) and Gabel *et al.* (1999) demonstrated that NiTi rotary instrument failures are less likely to occur at a lower rotational speed. Torque is another parameter that might influence the incidence of instrument deformation and separation. Different types of motors are used in conjunction with NiTi instrumentation. When a high torque control motor is used, the instrument is very active and the incidence of instrument locking and, consequently, deformation and separation would tend to increase. Recently, a generation of low and very low torque control motors has been introduced. These motors take into consideration the low torque at failure values of NiTi rotary instruments. The setting for the torque and speed were followed according to the standard setting incorporated in the ATR Technika Torque Control Motor. To minimize the risk of separation, it is recommended that inexperienced users take advantage of torque-controlled endodontic motors as even experienced operators can reduce risk of separation by working with recommended range of torque.

The use of new instruments also reduces the risk of instrument fracture significantly. Each set of files was used to prepare 10 canals in this study. In some of the researches performed on ProTaper® system, one set of instrument was used to prepare 5 canals (Iqbal *et al.,* 2004), 2 canals (Schafer & Vlassis, 2004), while more recent researchers have used a new set of instruments for the preparation of a single canal (Calberson *et al*., 2004; Guelzow *et al*., 2005). However, in calculating the limit of use, it has been suggested that all ProTaper® instruments can be used to prepare 4 molar teeth, 20 premolar teeth and 50 incisors except for the ProTaper® instrument S1, which is advised to be used on only 2 molar teeth, 12 premolar teeth and 25 incisor teeth. General advice relating to the number of uses is for five or six teeth, without any distinction between molar and incisor (Guettier, 2003).

6.1.4 MEASUREMENTS OF CANAL CURVATURES

The wide range of variations in the three-dimensional root canal morphology makes standardization difficult. Variables include root canal length and width, dentine hardness, irregular calcifications or pulp stones, size and location of the apical constriction and in particular angle, radius, length and location of root canal curvatures including three dimensional nature of curvatures (Hulsmann *et al.,* 2005). Studies on post-operative root canal shape or changes in root canal morphology, respectively, have been performed in mesial root canals of mandibular molars (Cunningham & Senia, 1992; Iqbal *et al.,* 2003; Bergmans *et al.,* 2003; Jodway & Hulsmann, 2006). These teeth in most cases show a curvature at least in the mesiodistal plane (Cunningham & Senia, 1992). Several techniques have been developed to determine the characteristics of the curvature, the most frequently used described by Schneider (1971). It measures the degree of the curvature in order to categorize root canals as straight (5° curvature or less), moderately (10-20°) or severely curved (more than 20°) (Hulsmann *et al.,* 2005). The methodology in this study followed that of Weine *et al.* (1976) and Cunningham & Senia (1992) who used files in canals to determine canal configuration of molars and Schneider's method to calculate canal curvatures. This method has been accepted as the most reliable method used to determine the degree of root canal curvatures (Kartal & Cimilli, 1997).

Using a radiographic technique with files to canal length inherently introduces minor errors in measuring canal curvature. The file will approximate the actual canal shape but may not conform exactly, especially where a canal is large and the file does not remain centered (Cunningham & Senia, 1992). For the purpose of minimizing the errors that might take place in this study, care was taken to maintain complete adaptation of the canal instruments into the root canal during the initial radiograph taking. In addition, the initial canal size of the samples was confined to size #10 K-files. Moreover, the root canal curvatures were examined at x30 magnification, thus minimizing the rate of error and values closer to real measures. However, the objective of measuring canal curvature in this study was to measure the degree of curvature at the apical one-third that the endodontic instrument must negotiate to reach the apical foramen.

In their studies on canal curvatures, Cunningham & Senia (1992) have stated that mesial roots of mandibular molars exhibit secondary curvatures in the clinical view (2.5%), even though not as much as in the proximal view (30%). Some of the samples in this study also demonstrated secondary curvatures in the clinical view during the measurement of canal curvatures in the pre-operative radiographs using AutoCAD software. In such instances, both the curvatures were calculated (using method described by Cunningham & Senia, 1992; pg 37) but only the greater curve, which always lies in apical region, was taken into the records. This is because according to studies by Roane *et al.* (1985) and Cunningham & Senia (1992) coronal flaring decreases the canal curvature at coronal part of the canal as it alters the entry angle of the instrument. Only acute curvatures and secondary curvatures in the apical third were not altered to a significant degree by coronal flaring. However, these curves can be altered by canal preparation using rotary or hand instrumentation and are more relevant to the study as we are measuring the canal straightening cause by two different instruments.

In this study, post-operative canal curvatures were measured with ProTaper® F3 for hand use (6% taper at coronal & 9% taper at apical extent) in the prepared canal for the ProTaper® group while in the K-Flex group NiTi flex K-file size #30 (2% taper through out) were used. This is due to F3 ProTaper® file could exactly fit in the prepared canal hence the measurement would be more accurate. In contrast, in the stainless steel group, the NiTi flex file only fit at the apical part of the prepared canal because of the smaller taper. The file can be moved freely at the coronal part as the canal has been flared using Gates-Glidden drills. If the files handle touches any part of the access cavity, the curvature measurement can change and this could influence the accuracy of curvature measurement of the prepared canals in the stainless- steel group to a certain extent. NiTi flex K-file size #30 (2% taper) was then used with the stainless-steel group so that their memory shape properties could make the file remain centered during x-ray taking. It was ensured that the files handle doesn't rest on the access cavity wall by using longer files (25mm) in these cases. Another method that had been proposed to avoid this problem, the canals can be filled with a radiopaque medium such as mercury (Jardine & Gulabivala, 2000) and radiographs can be taken in the clinical view. However as the mesial root have two canals; super imposition might occur if the radiopaque medium is not completely removed after each x-ray. That is why few studies conducted had used only one of the mesial canals of mandibular molar or curved buccal roots (single canal) from maxillary molars and filling them with radiopaque mediums to prevent superimposition (Peters *et al.,* 2003; Guelzow *et al*., 2005).

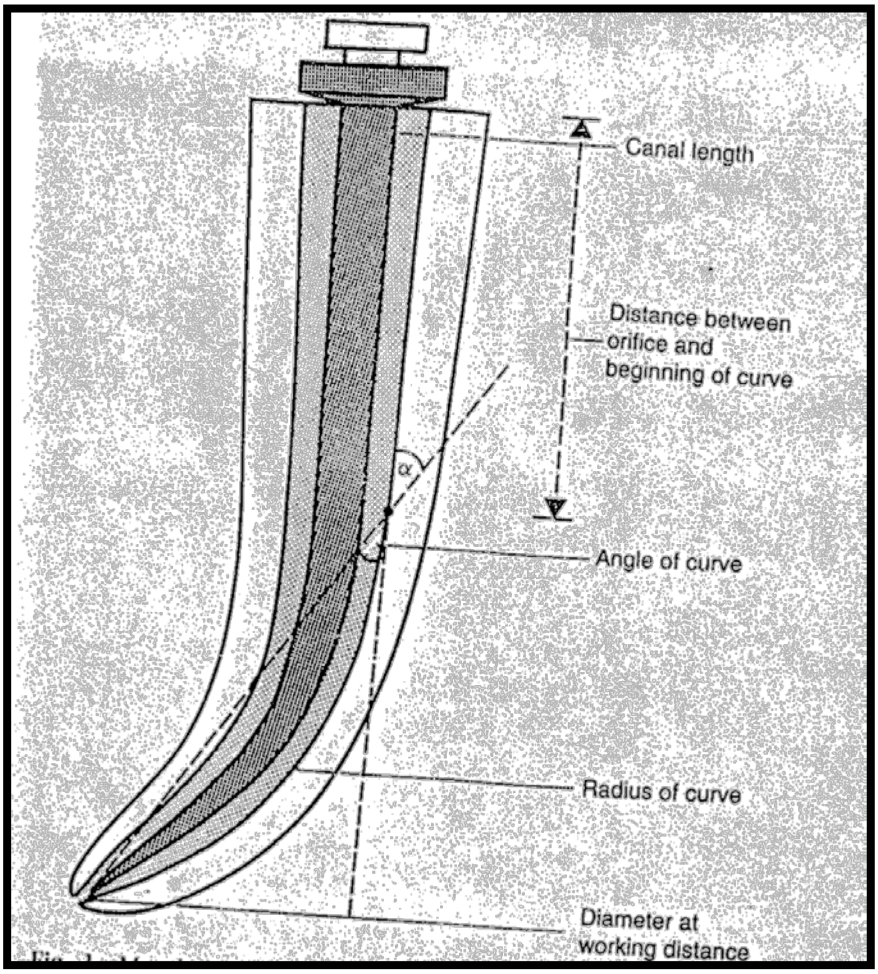


Figure 6.1 Technique used for determining the radius of the curve in a curved canal (Thomson *et al*., 1995)

In the present study, canals with moderate curvatures were used and selection was based on angle of curvatures only (refer to Figure **3.2**; pg 37). This is due to the large number of samples (41 mandibular molars) required for this study and difficulty in obtaining suitable samples. Severity of canal curvatures can also be measured and classified according to the radius of the curvatures (Figure **6.1**). In addition to angle of the canal curvature, the length over which a given curvature occurred might be an important factor affecting the ability of an instrument to negotiate the curvature (Backman *et al.*, 1992).

According to Pruett *et al.* (1997), using only one parameter to describe the canal shape does not differentiate the canal shape by abruptness or radius of curvature. Two canals measured at the same angle in degrees by the Schneider method could have very different radii or abruptness of curvature, thus having a very different impact on the difficulty of canal instrumentation and instrument fatigue (Pruett *et al.*, 1997). Thomson and his group (1995) have illustrated the ways of measuring the radius of curvature manually using radiographs in their research. Radius of curvatures can also be measured using AutoCAD software (Iqbal *et al*., 2004).

Ruddle (2003) has stated that a 5mm radius of curvature results in flexural fatigue of rotary instruments twice that of a 10mm radius. Explanation of the effect of radius is complex, but can be grossly simplified by stating that stress on the instrument is inversely proportional to the radius of the curvature. Therefore, as the radius of curvature decreases, instrument stress and strain increases, and the fatigue life decreases (Pruett *et al.*, 1997). Generally, molars have a radius of canal curvature of 5mm (Ruddle, 2003) and only canals with severe curvatures exhibit radius less than 5mm. A number of researches done on canal preparations using severely curved canals have included radius of curvatures as the selection criteria (Schafer & Lohmann, 2002b; Schafer & Schiligemann, 2003; Schafer & Vlassis, 2004; Iqbal *et al*., 2004). Researches done on moderately curved canals doesn't take the radius into account (Southard *et al.*, 1987; Davis *et al*., 2002) as larger radius measurement in moderately curved canals doesn't influence the performance of the instrument as much as smaller radius does in acute curves (Backman *et al.,* 1992).

6.1.5 RADIOGRAPHIC PLATFORM

The radiographic technique used in this study was first described by Southard *et al.* (1987) and further developed by other researchers (Sydney *et al*., 1991; Backman *et al*., 1992; Iqbal *et al.,* 2003; Iqbal *et al.,* 2004). Even though it was originally designed for conventional x-ray film, the platform design has been modified for taking digital radiographs. Unlike the original platform, the sensor of the digital radiographic unit was secured to the Plexiglas wall located behind the sample table (refer to Figures. **4.3**; **4.4**; **4.5** and **4.6**; pgs 73 & 74) (Iqbal *et al*., 2003; Iqbal *et al.,* 2004). Digital radiographs in both clinical and proximal view were taken using two separate radiographic platforms. In this study, the double radiographic superimposition method where radiographs taken before and after root canal preparation provide means for two dimensional study of the longitudinal shape of the root canal. Usually the clinical (buccal) and proximal views can be used for evaluation of apical transportation (Iqbal *et al.,* 2003) and compared. Similarly, in this study, both the clinical view and proximal view were used, as it is useful to have a 3-dimentional idea on the extent of apical transportation inside the canals.

6.1.6 RADIOPAQUE MEDIUM

In this study, barium sulphate (BaSO4) powder was mixed into a paste with water and used as the radiopaque medium by applying it onto the canal walls using lentulo spirals size #30. Even though using BaSO4 powder was enough to delineate the canal walls compared to other materials, repeated x-rays need to be exposed to obtain a satisfactory result. These X-rays were then colored using Trophy Windows software so that the margin of the prepared canals and procedural errors can be seen clearly. Nevertheless, the method used in this study together with the Trophy Windows software provided a cheap yet reliable result in detecting procedural errors.

6.1.7 DIGITAL RADIOGRAPH

Direct Digital Radiographs (DDR) is becoming increasingly popular in canal preparations studies. Many recent studies conducted have their researchers using digital radiographs in their works (Iqbal *et al*., 2003; Iqbal *et al*., 2004; Garala *et al*., 2003; Guelzow *et al*., 2005; Friedlander *et al*., 2002 and Paque *et al*., 2005). DDR images are easy to be imported into other soft wares and measurements can be done conveniently hence eliminating human errors. In this study, Elitys Trophy X-ray unit attached with Trophy Windows 2000 software and digital sensor was used. Advantages of digital radiographs are; they were able to provide instant images, convenience of taking repeated radiographs and require lesser radiation. Images can be magnified immediately and specific details (working length, location of apex and perforation) can be observed. The sensor can be positioned stationary in the Plexiglas jig and new or better images can be obtained simply by altering the position of the file or sample. Another added advantage is that the images taken can be numbered and grouped immediately as the digital programs allow creation of markers or notes of specific details in the image. Digitized images offer a lot advantages over conventional x-ray films with regards of storage and measurements of variables such as curvatures and transportations.

Other methods to obtain digital images are by using phosphorus plates and by scanning of conventional films. However changing of the conventional film or phosphor plate for each radiograph can be time consuming and may also alter the position of the image. In addition, numbering and classification of the images can also be time consuming. The images taken using digital system are as accurate as other conventional X-ray systems when taken in straight views (0°) and vertical angulations of 15°. Nevertheless when taken in vertical angulations of 30° the quality of the digital image offered is diminished (Garcia *et al.,* 1997). However this was not a concern as all the images were not taken at 30° vertical angulations.

6.1.8 SOFTWARE USED IN THE STUDY

The Trophy windows 2000 software attached to the digital X-ray system allows us to save the images and add colors to the images according to the intensity of the radiographic images. Using this software, images can be enlarged, numbered, grouped and distance between two points can be measured. It can also perform various other functions not related to the study. However, it cannot be used to measure the angle of curvature or to super impose images.

To assist in these tasks, 2 types of software were used in this study: AutoCAD release 14 and Adobe Photoshop version 7.0. The AutoCAD software can perform various function like to measure distance between two points, diameter of a circle, angle created by intersection of lines, radius of a curve and many other dimensions in precision. It can be used to create lines, dots, circles and various objects on an image. It can also be used to rotate, elongate, enlarge or transform the image into 3-dimensional. Adobe Photoshop software is used mainly to improve and add qualities to the existing image. It can be used to add contrast, sharpen, blur, and posterize edges of an image. It can also be used to add or remove different colors, to make an image transparent and super impose on another image.

In this study, the digital radiographs were copied from the Trophy windows digital radiographic system and imported into Adobe Photoshop. The images were first passed through artistic filters to posterize the edges by choosing the maximum values in the submenu for better contrast. The posterized images were then transferred into AutoCAD software to draw the central axis of the file and for measurement of curvatures. Drawing the central axis manually can introduce human errors in the calculation of the angle. Therefore to minimize this, the images were magnified to 100 times, circles were drawn on the enlarged file image and the image size was reduced again before drawing the central axis (refer figure **4.11**; pg 84). Two reading were taken for the calculation of angles and the average was taken as curvature angle. The post instrumentation radiographs were processed in a similar manner as the preoperative radiograph. Measurement of curvatures can also be done manually but this will introduce human errors and might not be as accurate as the computer.

The images in the Adobe Photoshop were passed through colour filters and the different coloured pre and post instrumentation radiographs were super imposed and compressed using the software. The apical area was magnified to 200 times and position of the file tips was recorded. The same technique has been used in a few research works namely by Iqbal *et al.* (2003) and Iqbal *et al.* (2004). Superimposition of radiographs can also be done manually by printing the enlarged radiographs on transparencies and superimposing them. However, during the pilot study this method proved to be inferior as accurate super imposition was almost impossible.

6.1.9 EXAMINER RELIABILITY

Intra examiner and inter examiner reliability tests were performed to ensure examiner consistency and minimizing variations. Intra examiner tests were performed on the data on curvature measurements and apical transportation. Inter examiner reliability tests were performed in the data on procedural errors. No reliability tests were performed on the data on instruments separation and lateral perforations as they were just observations on the image and no measurements were involved.

The researcher used the AutoCAD software to calculate two sets of curvature measurements for each pre and post-operative images. The Percentage agreement test showed a very good agreement between the two sets of data obtained. The intra-class correlation coefficient index (ICC) was 0.98. This was possible because AutoCAD software, which was already calibrated, was used. As for the apical transportation, intra examiner reliability measured with Percentage agreement test was almost 100% in the percentage agreement. The data in this section was very few as only a small number of samples showed apical transportation. The measurement was taken using calipers and a metric ruler on the enlarged image (100% enlargement) obtained from the superimposition of pre and post-operative radiograph (using Adobe Photoshop) and the readings were very consistent.

As for the inter-examiner reliability, two independent evaluators were involved in evaluating five parameters namely ledges, elbows, over instrumentation, zipping and instrument separation. Having two independent observers will introduce inter-examiner variability in the results. In order to minimize this, the examiners were allowed to discuss and standardize the method of observation before evaluating the samples. Furthermore, since the scale of measure was in the nominal scale, a percentage (%) agreement test was performed to ensure inter-examiner reliability. The inter-examiner correlation coefficient showed a moderate agreement of 0.68. Kappa percentage agreement method cannot be used in this situation because only a few samples showed procedural errors, as this method requires a minimum of 40 readings. However looking into the different parameters, most of the data obtained showed a good inter-rater agreement except for the elbows recorded. Out of the 10 elbows recorded only 3 were in agreement with both the evaluators and this result should be interpreted with caution.

6.2 RESULTS

6.2.1 CANAL STRAIGHTENING

In comparing K-Flexofiles to ProTaper® rotary files, K-Flexofiles straightened the canals significantly. Greater flexibility of the ProTaper® system shows a superior ability to maintain curvature even in severely curved canals. Maintaining the original canal curvatures as far as possible is a pre-requisite during preparation; thus iatrogenic complications arising from cleaning and shaping can be avoided. However, minor procedural errors in the canal wall occur subtly, and an acceptable extent of transportation of canal or foramen has not been evaluated so far. A previously published study compiling data on older automated systems has stated that straightening of the canal should not be tolerable, if values of curvature reduction between 5 degrees and 7.7 degrees are reached (Guelzow *et al.*, 2005; Hulsmann, 2000). Many previous studies conducted on curved canals in extracted human teeth also demonstrated the original canal shape was maintained better when using rotary nickel-titanium instruments compared to hand-preparation technique with stainless steel K-Flexofiles (Campos & del Rio, 1990; Luiten *et al*., 1995; Bertrand *et al*., 2001; Guelzow *et al.*, 2005).

6.2.2 APICAL TRANSPORTATION AND LATERAL PERFORATION

Comparisons of apical transportation in clinical and proximal view radiographs

From the 81 canals (one canal excluded) instrumented in this study, 24 canals showed some amount of transportation in the radiographs either in clinical view, proximal view or both the views. Thirteen canals in the ProTaper® Group were transported while 11 canals were transported in the K-Flexofiles group. Only 5 samples; 2 from the ProTaper® group and 3 from the K-Flexofiles group showed transportation in both the views. In the ProTaper® group, 3 canals showed lateral perforation towards the outer aspect of the canals and severe transportation was evident in the clinical view but only one of these samples showed transportation in the proximal view. Only one sample (sample 33) in this study showed apical transportation in both the groups tested (refer Appendix **8**).

In the clinical view, more transportations were seen in the K-Flexofiles group (7 canals) compared to the ProTaper® group (5 canals). In the proximal view radiographs, greater amount of transportations were noted in the ProTaper® group (10 canals) compared to K-Flexofiles group (7 canals). However, when only severe transportations were taken into account, no significant differences were noted in the amount of transportations the clinical and proximal view radiographs in both the groups. There were also not many differences in the amount of transportation between the two groups (ProTaper n= 4 & K-Flexofiles n=3).

Transportations occur more freely in the proximal area may be due to the low density of the dentine in these area and rotating instruments cut more rapidly due to the high lateral forces in curved canals (Bergmans *et al*., 2001; Iqbal *et al.*, 2004)). Furthermore, the presence of oval shaped canal apical cross-sections in some of the mesial canals of mandibular molars (Tan & Messer, 2002) makes round preparation almost impossible to achieve. When radiograph are taken in proximal view after canal preparation the file tends to deviate to the unprepared area causing apical transportation to be noted. In a research by Foschi *et al*. (2004), under SEM inspection they noted that pre-dentine, dentin grooves and depressions were observed in the apical thirds after preparation with ProTaper instruments. Their presence suggested that several areas of dentine was not cut and shaped by these instruments. It is possible that greater number of wall irregularities of this portion of canal such as depression and grooves may be responsible for the presence of uninstrumented areas and apical transportations (Foschi *et al*., 2004).

One important finding in this experiment is that 12 canals tested in this study didn't show any transportation in the clinical view radiographs but transportation was evident in the proximal view radiographs. ProTaper® instruments produced 8 transportation where 2 of the canals showed severe transportations (more than 3.0mm) in the proximal view (refer Appendix **8**). K-Flexofiles showed 4 transportations in proximal view out of which one with severe transportation. As clinicians, we take radiographs in the clinical view regularly to assess the apical transportation but transportation in proximal view cannot be observed. Even though the clinical radiograph looks normal without transportation, there is no assurance that there is no transportation proximally especially when using rotary instruments like ProTaper®. This results supports the view of Schafer & Vlassis (2004) who stated that on average the apical third of the canals was less clean than the middle and coronal thirds regardless of instrument used (including ProTaper®) (Schafer & Vlassis, 2004).

This transportation can also affect the quality of the obturation. As rotary techniques such as ProTaper® are generally shown to produce rounder preparations in cross-section which were cleaner and maintained the original canal shape (Jardine & Gulabivala, 2000), obturation with single core ProTaper® gutta-percha should be accomplished easily. But in cases with apical transportations, unclean area and voids may be present where debris may be packed and bacteria may be trapped. This can also lead to inadequate adaptation of the filling material and subsequently failure of root canal treatment (Bowmen & Baumgartner, 2002; Foschi *et al*. 2004).

Even though statistically there is no significant difference compared to K-Flexofiles, canal transportation was evident with ProTaper® files. This may due to the variable tapers along the cutting surfaces of these files and the combination with the sharp cutting edges. Certainly, the decreasing taper sequence of the finishing files enhances the strength of the files, but this will then increases the stiffness of their tips. For example, the taper at the tip of a ProTaper® size #30 (F3) is 9% whereas the taper of a size #20 (F1) is only 7% (Schafer & Vlassis, 2004). Since, the larger instruments are stiffer and cause high lateral forces in curved canals, these restoring forces attempt to return the file to its original shape and act on the outer side of the canal wall during preparation. The resulting transportation leaves a certain portion of the canal wall uninstrumented (Bergmans *et al*., 2001). This transportation is consistent with previous comparative studies done on ProTaper® files (Bergmans *et al*., 2003; Cosby *et al.*, 2003; Schafer & Vlassis, 2004).

Apical transportation were also noted in the K-Flexofiles group as the tendency of a stainless-steel file to straighten during filing motion tends to transport the root canal in the apical third towards the mesial. Furthermore, filing motion will also cause the instrument to wander from the center of the root canal producing eccentric preparation (Gilles & Del Rio, 1990).

6.2.3 PROCEDURAL ERRORS / ABERRATIONS

Even though numerous researches (Bergman *et a*l., 2003; Peters *et al.,* 2003; Iqbal *et al.,* 2004; Schafer & Vlassis, 2004; Calberson *et al.,* 2004; Guelzow *et al.,* 2005, Paque *et al.,* 2005) have been done on the performance of ProTaper® rotary system in the recent years, investigations on the occurrences of procedural errors such as ledges, apical zips, elbows and over instrumentation are relatively few. Most researchers (Bergman *et a*l., 2003; Peters *et al.,* 2003; Iqbal *et al.,* 2004; Schafer & Vlassis, 2004; Calberson *et al.,* 2004; Guelzow *et al.,* 2005; Paque *et al.,* 2005) have confined their works on parameters like apical transportation, canal cleanliness, straightening, fracture of instruments and preparation time.

Theoretically, shaping aberrations such as ledges, apical zip and elbows are expected to increase as canal curvature increases and as the file flexibility decreases (Eldeeb & Boraas, 1985). It is ideal to keep the apical canal diameter smallest possible. Canal preparations with ProTaper® instruments can be completed at size #17 (S1) or size #20 (S2/F1) if the canal is very curved, narrow and constricted. ProTaper® files are very flexible at the smaller sizes (S1, S2 and F1) but the larger files of sizes #25 and #30 (F2 and F3) are stiffer. The larger ProTaper® instruments, with their active cutting design can remove tissue excessively if left in the canal too long (Calberson *et al*., 2004).

In this study, the occurrences of elbows were significantly higher in ProTaper® group (22.5% of samples). Ledges were also more but the difference was not significant. This may be because the canals in ProTaper® group were enlarged to at least size of #25 or #30 (last instrument ProTaper® F3), irrespective of the initial size of the canals. A stainless steel hand file size #30 was used to check the final size of the prepared canal (refer pg 80). The ProTaper® finishing files (F1, F2 and F3) have progressively different parabolic tapers. The rate of increase in the diameter of the tip is therefore greater than that of other rotary files (Yun & Kim, 2003) and the result is a thicker instrument especially at the apical third of the instruments with the same apical size (Calberson *et al*., 2004). As a nickel-titanium instrument tends to straighten when rotating in curved canals, the incidences of elbows and ledges tends to increase. If the final apical size of the canal preparation for the narrower canals has been limited to size #20 (F1) or lesser, the occurrence of elbows and ledges could have been reduced. Furthermore, it was difficult to monitor the time the instruments were left inside the canal after it has reached the desired depth. The time taken to reach the desired length also affects the performance, as constricted and narrow canals require more time to reach working length.

The result on elbows and ledges in this study is also consistent with a study done (Calberson *et al*., 2004) on simulated canals using ProTaper® rotary files. They concluded that ProTaper® instruments removed more resin on the inner side of the curvature in comparison with the outer side of the curvature. Under the conditions of their study, ProTaper® instruments produced aberrations following the use of the F2 and F3 instruments. In a report (Berruti *et al*., 2003), in which torsional and bending stresses of two theoretical cross-sections (convex for ProTaper® versus concave for ProFile®) were compared, they concluded that the ProTaper® files were more indicated to prepare narrow and curved canals, but only during the initial phase of shaping. According to the authors, the final shaping in curved canals should better be preformed with a U-file design (Profile®) because of its greater elasticity.

6.2.4 FRACTURE OF INSTRUMENTS

The ProTaper® rotary instruments recorded 5 fractures during instrumentation. One F3 hand ProTaper® file fractured while taking the postoperative radiographs. None of the fractures occurred in the first use and all the fractures occurred during or after the fourth use during canal preparation. The frequency of use affects the performance of these instruments. Although the stress developed over the ProTaper® instruments may be less intense and more uniformly distributed mathematically (Berutti *et al*., 2003), they have been reported to fail more frequently and without warning (Ankrum *et al*., 2004). After clinical or simulated uses, an instrument is likely to be worn to a certain degree, which may predispose it to breakage (Peng *et al*., 2005). These kinds of failures or fractures are termed as ‘fatigue failure’.

During this experiment, the same set of file was used in canals of different curvature and radius. Alternating a material at high strain is more likely to lead to the formation of fatigue-crack as well as speeding up the rate of fatigue-crack propagation (Reed-Hill & Abbaschian, 1992; Cheung, 2003). It has been shown that in NiTi alloy that transforms "super elastically" during every cycle of repeated loads, the fatigue crack grows at a higher rate than the same alloy that is stable or non-transforming (McKelvey & Ritche, 1999; Cheung, 2003). Furthermore, at high strain-rate, heat is generated which is detrimental to the fatigue life of NiTi alloy- the material will fail in a much shorter interval than one would aspect (Cheung, 2003). As the ProTaper® instruments were used to prepare 10 canals in this study; it might be a contributing factor. During the time of this study was done, the manufacturers recommended a set of ProTaper® instruments to be used to prepare 10 canals but currently they recommended single use only if the canal is severely curved. However, Fife *et al.* (2004) concluded that other factors rather than the fatigue mechanism might be more accountable for intracanal separation of ProTaper® instruments. Furthermore, a research by Spanaki-Voreadi *et al.* (2006) has concluded that the fracture of ProTaper® instruments is caused by a single overloading incident that causes ductile fracture during chemomechanical preparation of root canals.

Experience of the operator also plays an important role in the number of instrument separations. In a study on the operator's proficiency on ProTaper® failures by Yared *et al.* (2003), it has been found that the least experience operator separated more files than the well-trained ones and more fractures were found with S1

ProTaper® instruments. Least trained operator probably exerted excessive apical pressure on the ProTaper® instruments or used them too long in the canal or both (Yared *et al.,* 2003). In this study no S1 files were separated even though the operator had a limited experience.

In the present study, all the fractures were noted with F3 and F2 files. The first file to fracture was F3 hand ProTaper® file which was used during post-operative x-rays. This file fractured after taking a number of x-rays and this may be due to "fatigue failure". This file has been in flexed condition for too long in curved canals, as we have to leave it inside the canal during the radiograph sessions. After this incident, care was taken not to leave the F3 hand ProTaper® file too long inside the canal and new files were changed after five radiographs. From the remaining five fractures, four file fractures occurred while working in much curved canals (curvatures more than 18°) and after multiple uses. However, one of the F3 files fractured during the fourth use (specimen C24) and it was in a relatively straight canal (13.4°). This fracture probably occurred because of the severe transportation as it can be noticed that the fractured tip lies in a different path away from the original canal path (refer to Figures **4.12; 4.13** and **5.2**; pgs 87,88 & 97).

This result is in accordance to a study done by Schafer & Vlassis (2004) where they found two fractured F3 ProTaper® instruments after preparing 24 curved root canals (a set of instruments for 2 canals) on extracted human teeth. Calberson *et al.* (2004) also found more instrument deformations on ProTaper® F3 files after canal preparation on simulated canals even after a single use. The same pattern of instrument distortion was seen in another study on simulated canals (Yun & Kim, 2003), in which 50% of the F3 files deformed. An explanation was found in the taper of the instruments as result of the multitaper design. With a taper of 0.09 (9%), the F3 performs like the 0.04/45, 0.04/50, or 0.06/40 instruments at the apical third of the canal. The stiffness of the file and the resistance of the dentin or resin block may result in an unwinding of the instrument, which leads to deformity or fracture (Calberson *et al.,* 2004).

When a root canal instrument is confined to a curvature and rotates continuously, any particular points within it (except those in the centre or on the neutral axis) are subject to repeated tensile or compressive strains. The farther away from the central axis, the greater the imposed strain at the point. This explains why instruments of a larger diameter are affected by fatigue more so than smaller ones. Repeated loading, especially at high strain values, leads to the damage of the crystal structure of the material and, eventually, the formation or micro-cracks. This is the onset of the fatigue phenomenon. The fatigue crack(s) then propagates incrementally in each revolution, until the remaining bulk of material is unable to withstand the same load and fails catastrophically (Cheung, 2004).

Among the factors that could influence instrument fractures are exertion of excessive apical pressure on the ProTaper® instruments or using them too long in the canal, or both. Repeated application of stress can initiate crack on the surface where it propagates and causes sudden fracture (metal fatigue). Strain amplitude (radius of curvature), stress concentration factor and rotational speed can also affect the fatigue of NiTi rotary instruments (Cheung, 2004). Other factors such as severe canal curvature, narrow canal diameter, and tilting of the hand piece so that the file becomes diverted from the long axis of the canal lead to the increased load on the instrument resulting in instrument separation. Mechanized preparations are not possible for all root canals and certain canals are best prepared by using manual, mechanical, or a combination of both. If ProTaper® instruments meet resistance to apical movement, it should be immediately withdrawn and a manual instrumentation technique used. In the present study, no combination technique was used even if resistances were met during canal preparation and this could be a contributing factor for the fractures. In cases of resistance, the rotary file was withdrawn and a file smaller to the size, used to further enlarge the apical part. This was followed by irrigation and the same file was reintroduced.

6.2.5 LIMITATION OF STUDY

Due to the shortcomings of acrylic resin blocks such as the difference in hardness plane of curvature and overheating of resins, the use of natural teeth has an advantage when assessing preparation techniques and new endodontic instruments. However, the major confounding factor is the variation in the canal anatomy. A partial solution for this is to balance the groups for anatomy as recommended by Dummer *et al.* (1993). In this study, both the groups were well balanced in term of canal curvatures before preparation and types of canal used.

Other potential source of variation includes the wear and reduced sharpness of instruments as the same set of files were used to prepare 10 canals (refer to pg 110). The goals of root canal irrigation are to flush pulpal debris and dentin slurry from the root canal and to help lubricate endodontic instruments, thereby facilitating their cutting action (Saunders & Saunders, 1997). Irrigants can prevent packing of the infected hard and soft tissue apically in the root canal and into the periapical area. NaOCl is the most widely used irrigant solution. Minor variations in the sodium hypo-chlorite regimes could have occurred as their preparation were done at the time of use. As the procedures of instrumentation were not identical, the volume of the irrigation used per canal could have been a minor source of variation. These could have affected the cleanliness and shape of the prepared canal to a certain extent in the present study. A lubricant such as Glyde or RC prep should be used in combination with NaOCl for irrigation as recommended in the instrumentation protocol of ProTaper® instruments. However, no other lubricants were used in this study in order to standardize the irrigation regime between both the groups. This might explain the high incidence of instrument fracture in the ProTaper® group.

In this study radiographs were used to compare canal shape before and after preparation. Its advantage is that no physical interventions like sectioning of teeth or grinding is required, however, it only provides a two-dimensional image and the cross-section of the root canal is impossible to observe. As for the occurrence of procedural errors, the defects can only be viewed and assessed in one plane (proximal) only. The clinical view radiographs cannot be used for this purpose because superimposition of mesiolingual and mesiodistal canals in this view after the placement of barium sulphate. However this is possible if a root with single canal is used for the study i.e. distal root of mandibular first molar or mesiobuccal root of maxillary first molar.

The final size for apical preparation in ProTaper® group was F3.This size is rather stiff for small curve roots such as mesial roots of mandibular molars used in this study. It would have been more appropriate to use ProTaper® rotary files of size F1 or F2 and keep the size of apical preparation smaller.

6.2.6 RECOMMENDATION FOR FUTURE STUDY

Future study can be oriented towards investigating and comparing the changes in the canal preparation when finished in size #20 (F1) and #30 (F30). The goal of this work would be to record and analyze the changes in angle, apical transportation and other canal aberrations when a curved canal is over prepared or enlarged too big than necessary. A more detailed study on the occurrences of elbows can be done. Single rooted curved canals such as can be used to facilitate superimposition of radiograph in both the clinical and proximal views.

6.3 CONCLUSIONS

Under the condition of this study, ProTaper® instruments were capable of preparing canals with improved characteristics (in terms of maintaining canal curvatures) and without major procedural errors (except elbows) in curved canals as compared to stainless-steel instruments;

- ProTaper® instruments maintained the curvatures better than stainless-steel instruments
- Performed equally well in terms of apical canal transportations
- Performed equally well in terms of lateral perforation, ledges, apical zips and over instrumentations
- Stainless-steel K-Flexofiles performed better in terms of occurrence of elbows. ProTaper® instruments produced more elbows compared to stainless-steel instruments. A more detailed study is needed to confirm the findings on elbows
- Incidences of fractures appeared to be higher with increasing size of ProTaper® files; most fractures occurred with file size #30 (F3) and #25 (F2).

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APPENDIX

Appendix 1: SAMPLE OF EVALUATION FORMS GIVEN TO THE ENDODONTISTS

Comparisons of canal shapes after preparation

Occurrence frequency record

Sample name		Instrument separation	Ledge	Elbows	Tips	Zipping
C1	Buccal					
	Lingual					
C2	Buccal					
	Lingual					
C3	Buccal					
	Lingual					
C4	Buccal					
	Lingual	Yes				
C5	Buccal	Yes		Yes		
	Lingual					
C6	Buccal					Yes
	Lingual					
C7	Buccal					
	Lingual		Yes			
C8	Buccal					
	Lingual					
C9	Buccal					
	Lingual					
C10	Buccal					
	Lingual					

Appendix 2 **DATA COLLECTED FROM THE MEASUREMENT OF CURVATURES USING AUTOCAD SOFTWARE**

SAMPLE NAME		First Try			Second Try			Average		
		Curvature Before Prep	Curvature After Prep	Curvature Dimension Changes	Curvature Before Prep	Curvature After Prep	Curvature Dimension Changes	Curvature Before Prep	Curvature After Prep	Curvature Dimension Changes
C 1	Buccal	22.5378	18.3467	4.1911	23.1286	17.4391	5.6895	22.8332	17.8929	4.9403
	Lingual	19.9524	15.0462	4.9062	19.9722	13.2003	6.7719	19.9623	14.1233	5.8391
C 2	Buccal	21.8650	12.7903	9.0747	19.0508	11.0920	7.9588	20.4579	11.9412	8.5168
	Lingual	20.6209	16.4764	4.1445	22.4851	14.3810	8.1041	21.5530	15.4287	6.1243
C 3	Buccal	21.9047	19.0869	2.8178	20.9101	19.6716	1.2385	21.4074	19.3793	2.0282
	Lingual	14.8518	6.7987	8.0531	15.9474	6.5122	9.4352	15.3996	6.6555	8.7442
C 4	Buccal	22.0849	12.2557	9.8292	21.8360	12.8272	9.0088	21.9605	12.5415	9.4190
	Lingual	20.5300	#	#VALUE!	21.9427	#	#VALUE!	21.2364	#DIV/0!	#DIV/0!
C 5	Buccal	20.0044	#	#VALUE!	18.6429	#	#VALUE!	19.3237	#DIV/0!	#DIV/0!
	Lingual	18.3775	9.1976	9.1799	19.0202	10.8298	8.1904	18.6989	10.0137	8.6852
C 6	Buccal	20.4769	16.5931	3.8838	20.6607	15.6868	4.9739	20.5688	16.1400	4.4289
	Lingual	15.7248	11.7475	3.9773	15.8144	10.9956	4.8188	15.7696	11.3716	4.3981
C 7	Buccal	18.5618	11.5154	7.0464	17.9921	11.3516	6.6405	18.2770	11.4335	6.8435
	Lingual	19.1731	15.9475	3.2256	18.7135	15.5082	3.2053	18.9433	15.7279	3.2155
C 8	Buccal	17.5815	7.9753	9.6062	17.0411	8.1116	8.9295	17.3113	8.0435	9.2679
	Lingual	16.5803	7.2493	9.3310	17.5840	6.3899	11.1941	17.0822	6.8196	10.2626
C 9	Buccal	16.4935	10.2701	6.2234	15.9541	11.4537	4.5004	16.2238	10.8619	5.3619
	Lingual	10.8356	13.0489	-2.2133	9.6560	12.6793	-3.0233	10.2458	12.8641	-2.6183
C 10	Buccal	21.4433	21.4271	0.0162	20.1893	22.3575	-2.1682	20.8163	21.8923	-1.0760
	Lingual	20.5788	9.3703	11.2085	19.8999	10.5562	9.3437	20.2394	9.9633	10.2761

Appendix 2 **Continued**

SAMPLE NAME		First Try			Second Try			Average		
		Curvature Before Prep	Curvature After Prep	Curvature Dimension Changes	Curvature Before Prep	Curvature After Prep	Curvature Dimension Changes	Curvature Before Prep	Curvature After Prep	Curvature Dimension Changes
C 11	Buccal	24.9802	14.2267	10.7535	24.8694	14.1901	10.6793	24.9248	14.2084	10.7164
	Lingual	26.6445	19.4914	7.1531	26.5611	19.5162	7.0449	26.6028	19.5038	7.0990
C 12	Buccal	16.2990	3.5844	12.7146	17.2640	4.0429	13.2211	16.7815	3.8137	12.9679
	Lingual	9.0377	7.3300	1.7077	8.8302	7.8054	1.0248	8.9340	7.5677	1.3663
C 13	Buccal	10.1782	8.2178	1.9604	10.0178	8.9036	1.1142	10.0980	8.5607	1.5373
	Lingual	18.0975	#	#VALUE!	18.2162	#	#VALUE!	18.1569	#DIV/0!	#DIV/0!
C 14	Buccal	19.5916	14.3383	5.2533	20.3871	15.3409	5.0462	19.9894	14.8396	5.1498
	Lingual	14.3377	10.2668	4.0709	14.6552	11.0193	3.6359	14.4965	10.6431	3.8534
C 15	Buccal	21.4533	14.9176	6.5357	21.1336	16.5226	4.6110	21.2935	15.7201	5.5734
	Lingual	29.8100	20.1039	9.7061	31.0684	20.5612	10.5072	30.4392	20.3326	10.1067
C 16	Buccal	18.5196	#	#VALUE!	18.5074	#	#VALUE!	18.5135	#VALUE!	#DIV/0!
	Lingual	24.3332	8.8179	15.5153	24.8661	9.1848	15.6813	24.5997	9.0014	15.5983
C 17	Buccal	16.0846	9.9813	6.1033	14.7473	10.6428	4.1045	15.4160	10.3121	5.1039
	Lingual	19.2496	#	#VALUE!	18.7588	#	#VALUE!	19.0042	#DIV/0!	#DIV/0!
C 18	Buccal	20.0206	13.5908	6.4298	20.1566	14.2014	5.9552	20.0886	13.8961	6.1925
	Lingual	16.7278	6.5884	10.1394	17.7366	7.4826	10.2540	17.2322	7.0355	10.1967
C 19	Buccal	11.1494	7.9421	3.2073	11.3911	8.7390	2.6521	11.2703	8.3406	2.9297
	Lingual	14.3756	8.4254	5.9502	13.8777	9.2245	4.6532	14.1267	8.8250	5.3017
C 20	Buccal	13.2571	Perforation	#VALUE!	12.3738	PERFORATION	#VALUE!	12.8155	#DIV/0!	#DIV/0!
	Lingual	20.4834	21.7788	-1.2954	21.2746	22.9778	-1.7032	20.8790	22.3783	-1.4993

Appendix 2 **Continued**

SAMPLE NAME		First Try			Second Try			Average		
		Curvature Before Prep	Curvature After Prep	Curvature Dimension Changes	Curvature Before Prep	Curvature After Prep	Curvature Dimension Changes	Curvature Before Prep	Curvature After Prep	Curvature Dimension Changes
C 21	Buccal	19.5773	15.0402	4.5371	19.4058	15.5787	3.8271	19.4916	15.3095	4.1821
	Lingual	14.7388	10.1015	4.6373	17.3215	9.8209	7.5006	16.0302	9.9612	6.0690
C 22	Buccal	26.7876	Perforation	#VALUE!	27.0493	Perforation	#VALUE!	26.9185	#DIV/0!	#DIV/0!
	Lingual	23.1315	14.6014	8.5301	24.6234	14.0088	10.6146	23.8775	14.3051	9.5724
C 23	Buccal	13.3208	13.6741	-0.3533	14.4215	13.0380	1.3835	13.8712	13.3561	0.5151
	Lingual	19.2058	12.5207	6.6851	18.8553	11.8331	7.0222	19.0306	12.1769	6.8537
C 24	Buccal	19.9032	16.1894	3.7138	19.7705	16.3988	3.3717	19.8369	16.2941	3.5428
	Lingual	12.9607	#	#VALUE!	13.8015	#	#VALUE!	13.3811	#DIV/0!	#DIV/0!
C 25	Buccal	14.8749	11.7541	3.1208	14.3560	11.5353	2.8207	14.6155	11.6447	2.9708
	Lingual	12.9968	7.0485	5.9483	13.7578	6.5218	7.2360	13.3773	6.7852	6.5922
C 26	Buccal	13.0413	6.1256	6.9157	12.5800	6.4956	6.0844	12.8107	6.3106	6.5001
	Lingual	7.9363	7.8024	0.1339	7.5878	8.6112	-1.0234	7.7621	8.2068	-0.4447
C 27	Buccal	20.9644	14.5993	6.3651	21.1827	14.2660	6.9167	21.0736	14.4327	6.6409
	Lingual	17.7538	12.7162	5.0376	18.3374	11.2931	7.0443	18.0456	12.0047	6.0410
C 28	Buccal	24.3196	15.2028	9.1168	24.4651	15.3630	9.1021	24.3924	15.2829	9.1095
	Lingual	13.7713	8.1832	5.5881	13.4516	7.7301	5.7215	13.6115	7.9567	5.6548
C 29	Buccal	11.7051	6.6410	5.0641	11.5800	6.4945	5.0855	11.6426	6.5678	5.0748
	Lingual	12.9859	6.0218	6.9641	13.0697	5.6531	7.4166	13.0278	5.8375	7.1904
C 30	Buccal	19.3183	13.6301	5.6882	19.7129	12.7707	6.9422	19.5156	13.2004	6.3152
	Lingual	18.9992	22.6197	-3.6205	18.8605	21.4851	-2.6246	18.9299	22.0524	-3.1226

Appendix 2 **Continued**

SAMPLE NAME		First Try			Second Try			Average		
		Curvature Before Prep	Curvature After Prep	Curvature Dimension Changes	Curvature Before Prep	Curvature After Prep	Curvature Dimension Changes	Curvature Before Prep	Curvature After Prep	Curvature Dimension Changes
C 31	Buccal	10.3679	11.0495	-0.6816	10.3098	11.5442	-1.2344	10.3389	11.2969	-0.9580
	Lingual	12.1252	5.9927	6.1325	12.0787	6.6051	5.4736	12.1020	6.2989	5.8031
C 32	Buccal	11.4779	4.5241	6.9538	11.4561	3.7459	7.7102	11.4670	4.1350	7.3320
	Lingual	13.2342	12.3938	0.8404	13.0821	12.4285	0.6536	13.1582	12.4112	0.7470
C 33	Buccal	14.7420	14.1732	0.5688	14.8836	14.8008	0.0828	14.8128	14.4870	0.3258
	Lingual	21.1811	13.1086	8.0725	20.8045	13.3536	7.4509	20.9928	13.2311	7.7617
C 34	Buccal	19.4184	8.8022	10.6162	20.0653	9.2661	10.7992	19.7419	9.0342	10.7077
	Lingual	11.8499	8.2047	3.6452	11.9853	7.5416	4.4437	11.9176	7.8732	4.0445
C 35	Buccal	19.6398	16.7195	2.9203	19.5667	17.0569	2.5098	19.6033	16.8882	2.7151
	Lingual	21.4924	10.7013	10.7911	21.3164	11.1086	10.2078	21.4044	10.9050	10.4995
C 36	Buccal	7.3557	3.2665	4.0892	7.3645	3.6483	3.7162	7.3601	3.4574	3.9027
	Lingual	11.6832	6.6441	5.0391	11.8662	6.1560	5.7102	11.7747	6.4001	5.3747
C 37	Buccal	13.0483	4.4475	8.6008	12.5341	4.7005	7.8336	12.7912	4.5740	8.2172
	Lingual	10.4900	7.0679	3.4221	10.7221	7.6918	3.0303	10.6061	7.3799	3.2262
C 38	Buccal	6.8651	5.1308	1.7343	7.4921	5.7225	1.7696	7.1786	5.4267	1.7520
	Lingual	18.2728	2.0313	16.2415	18.4282	2.0888	16.3394	18.3505	2.0601	16.2905
C 39	Buccal	15.6719	9.2407	6.4312	14.8921	8.5003	6.3918	15.2820	8.8705	6.4115
	Lingual	15.3377	3.5534	11.7843	15.0471	3.0678	11.9793	15.1924	3.3106	11.8818
C 40	Buccal	7.9665	3.0002	4.9663	7.7303	1.1742	6.5561	7.8484	2.0872	5.7612
	Lingual	12.6037	10.4521	2.1516	12.7833	10.4940	2.2893	12.6935	10.4731	2.2205
C 41	Buccal	6.9629	3.5791	3.3838	7.5149	3.3782	4.1367	7.2389	3.4787	3.7603
	Lingual	11.8696	5.9307	5.9389	11.5224	5.8786	5.6438	11.6960	5.9047	5.7914

Appendix 3

SUMMARY OF LEDGES, ELBOWS, OVER INSTRUMENTATION AND ZIPPING					
	Instrument separation	Ledge	Elbows	Over Instrumentation	Zipping
DR TAN	6	5	7	2	10
DR ZETI	6	5	6	2	10
AGREE	6	4	3	2	9
NOT AGREE	0	2	7	0	2
TOTAL	6	6	10	2	11

Appendix 4

DATA ON TYPES OF INSTRUMENTS AND CANAL ABERRATIONS

SAMPLE NAME		Average			Instruments	Canal aberrations						
		Curvature Before Prep	Curvature After Prep	Curvature dimension changes	ProTaper® / Stainless steel	Ledge	Elbows	Over Instrumentation	Zipping	Apical transportation		Lateral perforation
										Clinical view	Proximal view	
C 1	Buccal	22.8332	17.8929	4.9403	PROTAPER®	Yes						
	Lingual	19.9623	14.1233	5.8391	SS	Yes						
C 2	Buccal	20.4579	11.9412	8.5168	SS							
	Lingual	21.5530	15.4287	6.1243	PROTAPER							
C 3	Buccal	21.4074	19.3793	2.0282	PROTAPER							
	Lingual	15.3996	6.6555	8.7442	SS							
C 4	Buccal	21.9605	12.5415	9.4190	SS							
	Lingual	21.2364	#DIV/0!	#DIV/0!	PROTAPER	Not evaluated due to file fracture after canal preparation in the ProTaper group						
C 5	Buccal	19.3237	#DIV/0!	#DIV/0!	PROTAPER		Yes				Slight tn(1.5mm)	
	Lingual	18.6989	10.0137	8.6852	SS							
C 6	Buccal	20.5688	16.1400	4.4289	PROTAPER		Yes		Yes			
	Lingual	15.7696	11.3716	4.3981	SS							
C 7	Buccal	18.2770	11.4335	6.8435	SS							
	Lingual	18.9433	15.7279	3.2155	PROTAPER	Yes	Yes					
C 8	Buccal	17.3113	8.0435	9.2679	PROTAPER			Yes	Yes	Severe TN		Yes
	Lingual	17.0822	6.8196	10.2626	SS			Yes	Yes			
C 9	Buccal	16.2238	10.8619	5.3619	SS							
	Lingual	10.2458	12.8641	-2.6183	PROTAPER		Yes					
C 10	Buccal	20.8163	21.8923	-1.0760	PROTAPER							
	Lingual	20.2394	9.9633	10.2761	SS				Yes		Slight tn(1.5mm)	

Appendix 4 **Continued**

SAMPLE NAME		Average			Instruments	Canal aberrations						
		Curvature Before Prep	Curvature After Prep	Curvature dimension changes	ProTaper® / Stainless steel	Ledge	Elbows	Over Instrum entation	Zipping	Apical transportation		Lateral perforation
										Clinical view	Proximal view	
C 11	Buccal	24.9248	14.2084	10.7164	SS							
	Lingual	26.6028	19.5038	7.0990	PROTAPER							
C 12	Buccal	16.7815	3.8137	12.9679	PROTAPER	Yes	Yes					
	Lingual	8.9340	7.5677	1.3663	SS							
C 13	Buccal	10.0980	8.5607	1.5373	SS				Yes		Slight TN(1mm)	
	Lingual	18.1569	#DIV/0!	#DIV/0!	PROTAPER							
C 14	Buccal	19.9894	14.8396	5.1498	PROTAPER		Yes				Slight TN(2.0mm)	
	Lingual	14.4965	10.6431	3.8534	SS					Slight TN		
C 15	Buccal	21.2935	15.7201	5.5734	SS							
	Lingual	30.4392	20.3326	10.1067	PROTAPER							
C 16	Buccal	#	#VALUE!	18.5074	PROTAPER							
	Lingual	24.5997	9.0014	15.5983	SS							
C 17	Buccal	15.4160	10.3121	5.1039	SS							
	Lingual	19.0042	#DIV/0!	#DIV/0!	PROTAPER						Slight tn(1.0mm)	
C 18	Buccal	20.0886	13.8961	6.1925	PROTAPER							
	Lingual	17.2322	7.0355	10.1967	SS				Yes			
C 19	Buccal	11.2703	8.3406	2.9297	SS	Yes					NA	
	Lingual	14.1267	8.8250	5.3017	PROTAPER		Yes				NA	
C 20	Buccal	12.8155	#DIV/0!	#DIV/0!	PROTAPER				Yes	Severe TN	Severe TN (14mm)	Yes
	Lingual	20.8790	22.3783	-1.4993	SS							

Appendix 4 **Continued**

SAMPLE NAME		Average			Instruments	Canal aberrations						
		Curvature Before Prep	Curvature After Prep	Curvature dimension changes	ProTaper® / Stainless steel	Ledge	Elbows	Over Instru mentati on	Zipping	Apical transportation		Lateral perforation
										Clinical view	Proximal view	
C 21	Buccal	19.4916	15.3095	4.1821	SS							
	Lingual	16.0302	9.9612	6.0690	PROTAPER					Severe TN		Yes
C 22	Buccal	26.9185	#DIV/0!	#DIV/0!	SS		Yes			Severe TN	Slight TN (1.5mm)	Yes
	Lingual	23.8775	14.3051	9.5724	PROTAPER							
C 23	Buccal	13.8712	13.3561	0.5151	PROTAPER							
	Lingual	19.0306	12.1769	6.8537	SS							
C 24	Buccal	19.8369	16.2941	3.5428	SS							
	Lingual	13.3811	#DIV/0!	#DIV/0!	PROTAPER					Severe TN	Severe TN (8.0mm)	
C 25	Buccal	14.6155	11.6447	2.9708	PROTAPER							
	Lingual	13.3773	6.7852	6.5922	SS							
C 26	Buccal	12.8107	6.3106	6.5001	SS				Yes			
	Lingual	7.7621	8.2068	-0.4447	PROTAPER							
C 27	Buccal	21.0736	14.4327	6.6409	PROTAPER							
	Lingual	18.0456	12.0047	6.0410	SS							
C 28	Buccal	24.3924	15.2829	9.1095	SS							
	Lingual	13.6115	7.9567	5.6548	PROTAPER							
C 29	Buccal	11.6426	6.5678	5.0748	PROTAPER	Yes			Yes		Severe (8.0mm)	
	Lingual	13.0278	5.8375	7.1904	SS						Severe (5.0mm)	
C 30	Buccal	19.5156	13.2004	6.3152	SS							
	Lingual	18.9299	22.0524	-3.1226	PROTAPER						Slight (2.0mm)	

Appendix 4 **Continued**

SAMPLE NAME		Average			Instruments	Canal aberrations						
		Curvature Before Prep	Curvature After Prep	Curvature dimension changes	ProTaper® / Stainless steel	Ledge	Elbows	Over Instrumentation	Zipping	Apical transportation		Lateral perforation
										Clinical view	Proximal view	
C 31	Buccal	10.3389	11.2969	-0.9580	PROTAPER							
	Lingual	12.1020	6.2989	5.8031	SS							
C 32	Buccal	11.4670	4.1350	7.3320	SS							
		13.1582	12.4112	0.7470	PROTAPER							
C 33	Buccal	14.8128	14.4870	0.3258	PROTAPER						Severe tn (5.0mm)	
	Lingual	20.9928	13.2311	7.7617	SS					Severe TN	Severe tn (3.5mm)	
C 34	Buccal	19.7419	9.0342	10.7077	SS					Slight TN		
	Lingual	11.9176	7.8732	4.0445	PROTAPER		Yes					
C 35	Buccal	19.6033	16.8882	2.7151	PROTAPER							
	Lingual	21.4044	10.9050	10.4995	SS							
C 36	Buccal	7.3601	3.4574	3.9027	SS							
	Lingual	11.7747	6.4001	5.3747	PROTAPER					Slight TN		
C 37	Buccal	12.7912	4.5740	8.2172	SS							
	Lingual	10.6061	7.3799	3.2262	PROTAPER							
C 38	Buccal	7.1786	5.4267	1.7520	PROTAPER				Yes		Slight (1.5mm)	
	Lingual	18.3505	2.0601	16.2905	SS						Slight (1.5mm)	
C 39	Buccal	15.2820	8.8705	6.4115	PROTAPER		Yes				Slight (2.5mm)	
	Lingual	15.1924	3.3106	11.8818	SS				Yes	Severe TN	Severe (6.0)	
C 40	Buccal	7.8484	2.0872	5.7612	SS					Slight TN		
	Lingual	12.6935	10.4731	2.2205	PROTAPER							
C 41	Buccal	7.2389	3.4787	3.7603	PROTAPER							
	Lingual	11.6960	5.9047	5.7914	SS					Slight TN		

Appendix 5 **DATA ON PROCEDURAL ERRORS/CANAL ABERRATIONS BY TWO INDEPENDENT EVALUATORS**

SAMPLE NAME		Instrument separation		Ledge		Elbows		Over instrumentation		Zipping	
		Dr Tan	Dr Zeti	Dr Tan	Dr Zeti	Dr Tan	Dr Zeti	Dr Tan	Dr Zeti	Dr Tan	Dr Zeti
C 1	Buccal			YES	YES						
	Lingual			YES	YES						
C 2	Buccal										
	Lingual										
C 3	Buccal										
	Lingual										
C 4	Buccal										
	Lingual	YES	YES								
C 5	Buccal	YES	YES				YES				
	Lingual										
C 6	Buccal					YES					YES
	Lingual										
C 7	Buccal										
	Lingual				YES	YES					
C 8	Buccal							YES	YES	YES	YES
	Lingual							YES	YES	YES	YES
C 9	Buccal										
	Lingual					YES	YES				
C 10	Buccal										
	Lingual									YES	YES
C 11	Buccal										
	Lingual										
C 12	Buccal			YES	YES		YES				
	Lingual										

Appendix 5 **Continued**

C 13	Buccal									YES	YES
	Lingual	YES	YES								
C 14	Buccal										
	Lingual					YES					
C 15	Buccal										
	Lingual										
C 16	Buccal	YES	YES								
	Lingual										
C 17	Buccal										
	Lingual	YES	YES								
C 18	Buccal									YES	YES
	Lingual										
C 19	Buccal			YES	YES						
	Lingual					YES	YES				
C 20	Buccal									YES	YES
	Lingual										
C 21	Buccal										
	Lingual										
C 22	Buccal										
	Lingual					YES					
C 23	Buccal										
	Lingual										
C 24	Buccal	YES	YES								
	Lingual										

Appendix 5 **Continued**

C 25	Buccal										
	Lingual										
C 26	Buccal									YES	YES
	Lingual										
C 27	Buccal										
	Lingual										
C 28	Buccal										
	Lingual										
C 29	Buccal									YES	YES
	Lingual									YES	
C 30	Buccal										
	Lingual										
C 31	Buccal										
	Lingual										
C 32	Buccal										
	Lingual										
C 33	Buccal										
	Lingual										
C 34	Buccal										
	Lingual			YES			YES				
C 35	Buccal										
	Lingual										
C 36	Buccal										
	Lingual										

Appendix 5 **Continued**

C 37	Buccal										
	Lingual										
C 38	Buccal										
	Lingual										
C 39	Buccal					YES	YES				
	Lingual									YES	YES
C 40	Buccal										
	Lingual										
C41	Buccal										
	Lingual										
TOTAL		6	6	5	5	7	6	2	2	10	10
PROCEDURAL ERRORS/CANAL ABERRATIONS		Instrument separation		Ledge		Elbows		Over instrumentation		Zipping	
INDEPENDENT EVALUATORS		Dr Tan	Dr Zeti	Dr Tan	Dr Zeti	Dr Tan	Dr Zeti	Dr Tan	Dr Zeti	Dr Tan	Dr Zeti

APPENDIX 6-STATISTICAL ANALYSIS

Objective1

To test if there is a difference in mean curvature between the two groups at baseline (Curvatures Before)

Statistical test used: **Independent samples t-test**

Table 1: Mean curvature at baseline

				Test of equality of variances		Test of equality of means	
Instrument Type	N	Mean	Std. Deviation	F	p-value	t	p-value
ProTaper	41	16.5892	5.29735	0.424	0.517	0.547	0.586
SS	41	17.0392	4.80553				

(*level of significance set at p<0.05)

The p-value for the test of equality of variances is 0.517, which is more than 0.05.
Thus, the two group measurements can be assumed to be homogenous.

The p-value for the test of equality of means is 0.586, which is more than 0.05.
Thus, the means of two group measurements do not differ from each other significantly.

Appendix 6-Statistical analysis- **Continued**

Objective 2

To test if there is a difference in mean curvature before and after preparation for both groups

Statistical test used: **Paired samples t-test**

Table 2: Mean curvature before and after preparation

	Mean	N	Std. Deviation	t	p-value
Curvature Before Preparation	16.6137	74	5.03746	12.538	<0.001
Curvature After Preparation	10.9425	74	4.89319		

(*level of significance set at $p<0.05$)

The p-value for the test of equality of means before and after is less than 0.001, which is less than 0.05. Thus, there is a significant difference in mean curvatures before and after preparation. The mean curvature after preparation is less than the mean curvature before preparation.

Appendix 6-Statistical analysis- **Continued**

Objective 3

To test if there is a significant difference in mean curvature reduction between the two instrument types.

Statistical test used: **<u>General Linear Models Repeated Measures</u>**

Table 3: Mean curvature before and after preparation by instrument type

	Instrument Type	Mean	Std. Deviation	N
Curvature Before	ProTaper	16.4037	5.57590	34
	SS	16.7923	4.59567	40
Curvature After	ProTaper	12.4132	5.11087	34
	SS	9.6923	4.38474	40

Test for difference in time		Test for difference in type		Test for difference in time*type interaction	
F	p-value	F	p-value	F	p-value
175.46	<0.001	1.201	0.277	13.79	<0.001

(*level of significance set at p<0.05)

The p-value for the test for difference in time is less than 0.001, which is less than 0.05. Thus, there is significant difference in mean curvatures before and after treatment. The p-value for the test for difference in type is 0.277, which is more than 0.05. Thus, there is a no significant difference in mean curvatures between the two types.

The p-value for the test for difference in time*type interaction is less than 0.001, which is less than 0.05. Thus, there is a significant difference in mean curvature reduction between the two instrument types. The rate of reduction in SS is more compared to that of ProTaper®.

Appendix 6-Statistical analysis- **Continued**

Objective 4 A
To test if there is an association between instrument type and apical transportation in the clinical view
Statistical test used: **Cross tabulation with Fisher's Exact test.**.

Table 4 Instrument type vs. apical transportation (clinical view)

Instrument type	Apical Transportation		Total
	None	Present	
ProTaper	38 95.0%	2 5.0%	40 100.0%
SS	35 85.4%	6 14.6%	41 100.0%
Total	73 90.1%	8 9.9%	81 100.0%

(*level of significance set at $p<0.05$)

The p-value for Fisher's exact test is 0.140(1-sided).
The p-value for Fisher's exact test is 0.264(2-sided), which is more than 0.05.
Thus, there is no association between instrument type and apical transportation in the clinical view

Appendix 6-Statistical analysis- **Continued**

Objective 4 B
To test if there is an association between instrument type and lateral perforation
Statistical test used: **Cross tabulation with Fisher's Exact test.**.

Table 4 Instrument type vs. lateral perforation

Instrument type	Lateral perforation		Total
	None	Present	
ProTaper	37	3	40
	92.5%	7.5%	100.0%
SS	40	1	41
	97.6%	2.4%	100.0%
Total	73	8	81
	90.1%	9.9%	100.0%

(*level of significance set at $p<0.05$)

The p-value for Fisher's exact test is 0.298(1-sided).
The p-value for Fisher's exact test is 0.359(2-sided), which is more than 0.05.
Thus, there is no association between instrument type and lateral perforation

Appendix 6-Statistical analysis- **Continued**

Objective 4 C
To test if there is an association between instrument type and apical transportation in the proximal view
Statistical test used: **Cross tabulation with Fisher's Exact test.**.

Table 4 Instrument type vs. apical transportation (proximal view)

Instrument type	Apical Transportation		Total
	None	Present	
ProTaper	30 75.0%	10 25.0%	40 100.0%
SS	34 82.9%	7 17.1%	41 100.0%
Total	64 79.0%	17 21.0%	81 100.0%

(*level of significance set at $p<0.05$)

The p-value for Fisher's exact test is 0.274(1-sided).
The p-value for Fisher's exact test is 0.424(2-sided), which is more than 0.05.
Thus, there is no association between instrument type and apical transportation in the proximal view

Appendix 6-Statistical analysis- **Continued**

Objective 5

To test if there is an association between instrument type and ledge

Statistical test used: **Cross tabulation with Fisher's Exact test.**

Table 5: Instrument type vs. ledge

Instrument type	Ledge		Total
	No	Yes	
ProTaper	36 90.0%	4 10.0%	40 100.0%
SS	39 95.1%	2 4.9%	41 100.0%
Total	75 92.6%	6 7.4%	81 100.0%

(*level of significance set at $p<0.05$)

The p-value for Fisher's exact test is 0.326(1-sided).
The p-value for Fisher's exact test is 0.432(2-sided), which is more than 0.05.
Thus, there is no association between instrument type and ledge.

Appendix 6-Statistical analysis- **Continued**

Objective 6

To test if there is an association between instrument type and zipping

Statistical test used: **Cross tabulation with Fisher's Exact test**.

Table 6: Instrument type vs. zipping

Instrument type	Zipping		Total
	No	Yes	
ProTaper	35 87.5%	5 12.5%	40 100.0%
SS	35 85.4%	6 14.6%	41 100.0%
Total	70 86.4%	11 13.6%	81 100.0%

(*level of significance set at $p<0.05$)

The p-value for Fisher's exact test is 0.518 (1-sided).
The p-value for Fisher's exact test is 1.0(2-sided), which is more than 0.05.
Thus, there is an association between instrument type and zipping.

Appendix 6-Statistical analysis- **Continued**

Objective 7

To test if there is an association between instrument type and over instrumentation

Statistical test used: **<u>Cross tabulation with Fisher's Exact test.</u>**

Table 7: Instrument type vs. over instrumentation

Instrument type	Over instrumentation		Total
	No	Yes	
ProTaper	39 97.5%	1 2.5%	40 100.0%
SS	40 97.6%	1 2.4%	41 100.0%
Total	79 97.5%	2 2.5%	81 100.0%

(*level of significance set at $p<0.05$)

The p-value for Fisher's exact test is 0.747 (1-sided).
The p-value for Fisher's exact test is 1.0(2-sided), which is more than 0.05.
Thus, there is an association between instrument type and over instrumentation.

Appendix 6-Statistical analysis- **Continued**

Objective 8

To test if there is an association between instrument type and Elbow

Statistical test used: **Cross tabulation with Fisher's Exact test.**

Table 8: Instrument type vs elbows

Instrument type	Elbows: No	Elbows: Yes	Total
ProTaper	31 77.5%	9 22.5%	40 100.0%
SS	40 97.6%	1 2.4%	41 100.0%
Total	71 87.7%	10 12.3%	81 100.0%

0(*level of significance set at p<0.05)

The p-value for Fisher's exact test is 0.006 (1-sided).
The p-value for Fisher's exact test is 0.007(2-sided), which is **less than 0.05**.
Thus, there is an association between instrument type and elbow. The difference was **significant.**
Among ProTaper® there are 22.5% elbows, while there is only 2.4% in SS.

Appendix 6-Statistical analysis- **Continued**

Objective 9
To test if there is an association between instrument type and instrument separation

Statistical test used: **Cross tabulation with Fisher's Exact test.**

Table 9 Instrument type vs. instrument separation

Instrument type	Instrument Separation		Total
	No	Yes	
ProTaper	35 87.5%	5 12.5%	40 100.0%
SS	41 100.0%	0 .0%	41 100.0%
Total	76 93.8%	5 6.2%	81 100.0%

(*level of significance set at $p<0.05$)

The p-value for Fisher's exact test is **0.026** (1-sided).
The p-value for Fisher's exact test is **0.026** (2-sided)**,** which is **less than 0.05.**
Thus, there is an association between instrument type and instrument separation. The difference was **significant**.
Among ProTaper® there is12.5% separation, while there is none in SS.

Appendix 7-Statistical analysis- intra examiner reliability test of apical transportation

SAMPLE NAME		Slight transportation			Severe transportation			Lateral perforation
		First try	2nd try	Average	First try	2nd try	Average	
C 1	Buccal							
	Lingual							
C 2	Buccal							
	Lingual							
C 3	Buccal							
	Lingual							
C 4	Buccal							
	Lingual	Not evaluated due to file fracture after canal preparation in the ProTaper group						
C 5	Buccal							
	Lingual							
C 6	Buccal							
	Lingual							
C 7	Buccal							
	Lingual							
C 8	Buccal							Yes
	Lingual							
C 9	Buccal							
	Lingual							
C 10	Buccal							
	Lingual							
C 11	Buccal							
	Lingual							
C 12	Buccal							
	Lingual							
C 13	Buccal							
	Lingual							
C 14	Buccal							
	Lingual	2.00mm	2.00mm	2.00mm				
C 15	Buccal							
	Lingual							
C 16	Buccal							
	Lingual							
C 17	Buccal							
	Lingual							
C 18	Buccal							
	Lingual							
C 19	Buccal							
	Lingual							
C 20	Buccal							Yes
	Lingual							
C 21	Buccal							
	Lingual							Yes

Appendix 7-Statistical analysis- intra examiner reliability test of apical transportation

SAMPLE NAME		Slight transportation			Severe transportation			
		First try	2nd try	Average	First try	2nd try	Average	Lateral perforation
C 22	Buccal							Yes
	Lingual							
C 23	Buccal							
	Lingual							
C24	Buccal							
	Lingual				14.00mm	14.00mm	14.00mm	
C 25	Buccal							
	Lingual							
C 26	Buccal							
	Lingual							
C 27	Buccal							
	Lingual							
C 28	Buccal							
	Lingual							
C 29	Buccal							
	Lingual							
C 30	Buccal							
	Lingual							
C 31	Buccal							
	Lingual							
C 32	Buccal							
	Lingual							
C 33	Buccal							
	Lingual				13.00mm	13.00mm	13.00mm	
C 34	Buccal	3.00mm	2.5mm	2.75mm				
	Lingual							
C 35	Buccal							
	Lingual							
C 36	Buccal							
	Lingual	3.00mm	3.00mm	3.00mm				
C 37	Buccal							
	Lingual							
C 38	Buccal							
	Lingual							
C 39	Buccal							
	Lingual				5.00mm	5.5mm	5.25mm	
C 40	Buccal	2.00mm	2.00mm	2.00mm				
	Lingual							
	Buccal							
C41	Lingual	3.00mm	2.5mm	2.75mm				

Intra examiner reliability test was done to check the reliability of the readings using percentage agreement and the test showed 100% agreement.

Appendix 8-Comparison of apical transportation between the two instrument types

APICAL TRANSPORTATION IN PROTAPER GROUP				
No	Sample number	Initial Canal curvature (degrees)	Transportation in clinical view	Transportation on proximal view
1	C5	19.3237	nil	Slight (1.5mm)
2	C8	17.3113	Severe(perforated)	nil
3	C14	19.9894	nil	Slight (2.0mm)
4	C17	19.0042	nil	Slight (1.0mm)
5	C20	12.8155	Severe (perforated)	Severe (14.0mm)
6	C21	16.0302	Severe (perforated)	nil
7	C24	13.3811	Severe (14.0mm)	Severe (18.0mm)
8	C29	11.6426	nil	Severe (8.0mm)
9	C30	18.9299	nil	Slight (2.0mm)
10	C33	14.8128	nil	Severe (5.0mm)
11	C36	11.7747	Slight (3.0mm)	nil
12	C38	07.1786	nil	Slight (1.5mm)
13	C39	15.2820	nil	Slight(2.5mm)

APICAL TRANSPORTATION IN K-FLEXOFILES GROUP				
No	Sample number	Canal curvature	Transportation in clinical view	Transportation on proximal view
14	C10	20.2394	nil	Slight (1.5mm)
15	C13	10.0980	nil	Slight(1.0mm)
16	C14	14.4965	Slight (2.0mm)	nil
17	C22	26.9185	Severe (perforated)	Slight (1.5mm)
18	C29	13.0278	nil	Severe (5.0mm)
19	C33	20.9928	Severe(13.0mm)	Severe(3.5mm)
20	C34	19.7419	Slight (2.75mm)	nil
21	C38	18.3505	nil	Slight (1.5mm)
22	C39	15.1924	Severe (5.25mm)	Severe (6.0mm)
23	C40	07.8484	Slight (2.0mm)	nil
24	C41	11.6960	Slight (2.75mm)	nil