Evaluation of Canal Instrumentation Using GT-Series-X™ versus ProSystem GT™

by

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Abstract

Preparation of the root canal system is recognized as being one of the most important stages in root canal treatment. A variety of instrumentation techniques have been described for this stage of root canal treatment. Two recently introduced rotary instrument systems are ProSystem GT™ and GT-Series-X™. The aim of this study is to compare the ability of two nickel-titanium rotary file systems, GT-Series-X™, and ProSystem GT™, to maintain the original canal path using a split-mold design (the endodontic cube). The hypothesis is that ProSystem GT™ will create greater canal center displacement in comparison with GT-Series-X™ files due to more chip spaces and fewer cutting flutes in the latter.

Methods: Mesial roots of 31 mandibular first and second molar teeth with separate ML and MB canals and curvatures ranging from 15 to 40 degrees were randomly divided into two groups. After access cavity preparation and working length determination, each tooth was embedded in composite resin using the endodontic cube as a mold. 1.5mm tooth-resin complex slices were made using a Buehler ™ slow speed saw. After reassembly of the sections, canals were instrumented with either GT-Series-X™ or ProSystem GT™ to size 30/06. AutoCAD™ software was used to measure root section images of instrumented canals. Data was analyzed using the t-test ($p<0.05$).

Results: The canal center displacement of the ProSystem GT™ was 0.08 ± 0.074mm while for GT-Series-X™ it was 0.064 ± 0.063mm (p<0.05).

Conclusion: Both systems tended to move the original canal toward the furcation, but ProSystem GT™ caused significantly greater canal center displacement.

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List of abbreviations

NiTi...Nickel Titanium

SS ....Stainless Steel

TF...Twisted File

LA...Long Axis method

CAA..Canal Access Angel

WL...Working Length

RPM ....Revolutions per Minute

CCD ....Canal Center Displacement

CW .... Canal Widening

N-INS .... None instrumented tooth

INS ....Instrumented tooth

GT files..Greater Taper files

R-CHCD .... Right Canal Horizontal Center Displacement

R-CVCD ....Right Canal Vertical Center Displacement

L-CHCD ....Left Canal Horizontal Center Displacement

L-CVCD ....Left Canal Vertical Center Displacement

R-CCD ....Right Canal Center Displacement

L-CCD ....Left Canal Center Displacement

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1. Introduction

One of the most important phases in root canal treatment is the preparation of the root canal system. An ideally prepared root canal is devoid of vital and necrotic tissue, infected root dentin, and bacteria (Schilder 1974). Several instruments and instrumentation techniques have been advocated to eliminate infection and prevent reinfection. Before introduction of Nitinol alloy into endodontics, all endodontic files and reamers were manufactured from carbon steel or stainless steel. Clinical use of these stainless steel files made them difficult to negotiate small, calcified and curved canals (Ponti et al. 2002). In 1988 Walia was the first one who utilized an entirely different metallurgical system, Nitinol nickel titanium orthodontic wire alloy, to make endodontic files. This alloy has super- elasticity, and up to 10% strain in the files made of this alloy can be entirely recovered (Serene et al. 1995).

The ProSystem GT™ nickel-titanium instruments (Tulsa Dental Specialties, Tulsa, OK) are designed with radial lands and non- cutting tips to maintain the canal pathway centered better than files having no radial lands and cutting tips (Buchanan 2005). In addition, theses instruments have variable pitch and variable tapers (0.04 to 0.12mm/mm) to minimize complete file engagement along the length of the canal (Buchanan 2005, Kosa et al. 1999).

The GT-Series-X™ Nickel-Titanium instruments (Tulsa Dental Specialties) have more strength and cutting efficacy because they are made of M- Wire which is a series of heat treatment during the drawing of the wire. This aspect of the files makes each cutting cycle longer, safer, and more effective. These files are manufactured in 0.04, 0.06, and 0.08 tapering and 20, 30, and 40 file sizes (Buchanan 2001).

Root canal instrumentation can be evaluated using an Endodontic Cube which is made of five brass sections with four vertical and one horizontal wall (Kuttler et al. 2001b). The grooves on the vertical wall provide the indexes for sectioning. All five pieces are held together by external fixations (Kuttler et al. 2001b). The Endodontic cube is a reproducible device that allows for assembly and disassembly of tooth sections. Also, AutoCAD™ drafting environment provided an effective, precise, and quick tool to perform measurements and comparisons of non-instrumented and instrumented root sections.

Such an investigation will provide an invaluable database of information for endodontics. It may assist in improving the future rotary instrument products or considering further modifications.

The aim of this study is to compare the canal transportation of curved canals using ProSystem GT™ and GT-Series-X™.

2. Review of the literature

2.1 Goal of instrumentation

The primary goal of the root canal treatment is cleaning and shaping of the root canal space (Schilder 1974) . The main objectives of root canal preparation are the prevention of periradicular disease and promotion of healing in cases where disease already exists through:

- elimination of vital and necrotic tissue from the root canal system
- making sufficient space for irrigation and medication
- maintenance of the integrity and location of the apical canal anatomy
- avoidance of iatrogenic damage to the canal system and root structure
- facilitation of root canal obturation
- prevention of future irritation and infection of the periradicular tissues
- preservation of sound root dentine as much as possible to allow long term function of the tooth (Hülsmann et al. 2005).

Schilder in 1974 stated five design and four biologic objectives for root canal treatment: (Schilder 1974)

Design objectives:

- Creating a continuously tapering funnel from orifice to the apex.
- Creating narrower cross sectional diameter at every point apically.

- Creating the root canal preparation which follows the shape of the original canal.
- Creating an apical opening as small as possible.
- Keeping the apical foramen at its original place.

Biologic objectives:

- Limit the instrumentation to the root canal
- Not to force the necrotic debris beyond the apex
- Remove all the tissue material from the canal space
- Create adequate space for irrigation and intra-canal medication

2.2 Characteristics of nickel–titanium files vs. stainless-steel files

Stainless Steel (SS) files have a high stiffness which increases with the instrument sizes. This stiffness causes high lateral forces in curved canals and attempts to return the instrument to its original shape during preparation, which influences the amount of dentin removed. This instrument's rigidity is responsible for canal straightening and canal transportation (Craig et al. 1968; Craig et al. 1968; Park and Yoon 1998; Park and Yoon 1998; Abou-Rass et al. 1980)(Alodeh et al. 1989).

Improvement in metals and alloys in endodontics have led to use of nickel-titanium (NiTi) rotary instruments in dental practice (Thomas et al. 1995). Nickel-titanium exhibits super-elastic behavior, allowing it to return to its original shape following substantial deformation. Also, NiTi is biologically acceptable, highly flexible, and considerably stronger in fatigue resistance than conventional stainless steel files (Thomas et al. 1995; Thomas et al. 1995; Walia et al. 1988; Walia et al. 1988). The unique property of super elasticity of NiTi files allows placing them in curved canals with less lateral forces. The NiTi file number 15 has two to three times more elastic flexibility in bending and torsion, as well as superior resistance to torsional fatigue, when compared to size 15 SS files (Thomas et al. 1995; Walia et al. 1988).

Nickel- titanium exists in an authentic crystalline phase. The transformation induced in the alloy occurs by a shear type of process to a phase called the martensitic or daughter phase. Almost no macroscopic shape change is detectable on the transformation, unless there is application of an excessive external force. The transition from the austensitic to martensitic phase can also occur as a result of application of stress (Thompson 2000).

NiTi can resume the original parent structure and orientation. The total atomic movement between adjacent planes of atoms is less than a full interatomic distance when based on normal atomic arrangement. This phenomenon is termed shape memory (Thompson 2000).

There are several alloys with super-elastic properties such as copper, zinc, copper-aluminum, titanium-niobium, and nickel-titanium. NiTi has the highest biocompatibility and excellent corrosion resistance amongst them all (Thomas et al. 1995).

NiTi, also known as nitinol, has been manufactured in China since 1979 as nitalloy (56% nickel and 44% titanium) (Yang et al. 1982).The first application of nickel-titanium in endodontics was reported in 1988 by Walia, using #15 files made-up from NiTi orthodontic alloy. In early 1992, NiTi files were introduced to students in the college of dental medicine at the University of South California. NiTi instruments are available in a variety of forms (files, pluggers, spreaders, burs, etc.)(Walia et al. 1988).

2.3 Different file design

Before the advent of NiTi instruments of greater tapers, all endodontic files and reamers were manufactured from stainless steel with 0.02 tapers (Bergmans et al. 2001). Besides variation in taper, the existing NiTi systems have different designs of blades, grooves, and tip. Also, the instruments can have specific characteristics such as rake angle, degree of twist, groove spacing and cutting or non-cutting tips (Bergmans et al. 2001).

GT instruments have rounded tips and cutting flutes with radial lands that more accurately maintain original canal paths than shaping files having sharp tips and flute edges (Buchanan 2005).

GT instruments have limited maximum flute diameters, allowing a wide range of tapered instruments to be safely taken to full length in root canals (Buchanan 2001). GT files have passive rounded tip geometry that dramatically reduces the chances of apical ledging (Buchanan 2005) (Figure 2-1).

Figure 2-1: Tip geometry of GT rotary file (Buchanan 2005).

The cutting flutes of GT instruments are landed. This flute design is much less likely to displace the canal paths (Buchanan 2005).

GT instruments have variable helical angles. This means that helical angles relative to the long axis of the file are different along their length. GT instruments have smaller helical angles at the shank end of the instruments and the bigger helical angles at their tip regions. The advantages of this design are as below:

- Bigger helical angles at the tip regions provide strength and reduce torsional stresses.
- Smaller helical angles in the stronger shank portion of the file eliminate the tendency of the file to thread into the canal during use. Also, it

provides more cutting ability in the stronger shank region where more dentin needs to be removed (Buchanan 2005).

There are four common size categories of GT instruments; the 20 series, the 30 series, the 40 series, and the 0.12 accessory series. The 20, 30, and 40 series GT files have the same range of tapers, 0.04,0.06,0.08, and 0.10mm/mm in each file set but vary by their tip size. GT files are also available as the hand files in 20/0.06, 20/0.08, 20/0.10, 35/0.12, 50/0.12, and 70/0.12. GT hand files have triangular cross sectional blade geometry and counter clockwise flute (figure 2-4, and Figure 2-3) (Buchanan 2005; Buchanan 2001).

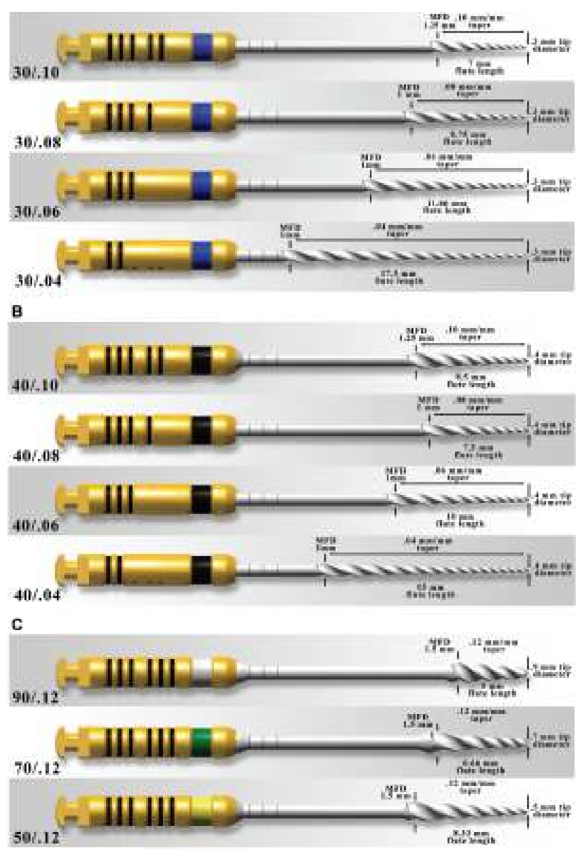

Figure 2-2: GT file; series 30 and 40 (Buchanan 2005).

Figure 2-3: GT hand files (Buchanan 2005).

The GT-Series-X™ (GTX) endodontic system was introduced in October 2007. These files are made of a new nickel titanium wire called “M-Wire” (Buchanan 2008). Through a series of heat treatment applied during the drawing of the wire, the resistance to cyclic fatigue - the most common cause of rotary file separation - has been greatly enhanced (Shen et al. 2006). While this could be misunderstood to mean that files made of this advanced metal can be used several times, it is rather intended to significantly reduce the chance of breakage when the instruments are used as before. Any file, regardless of design or metallurgy, will break when over-used (Buchanan 2008).

Another feature of GTX files is having variable land widths in different regions of the instrument (Figure 2-4). If the width of radial lands is too large, they don’t cut fast enough. It is claimed that if they are too small, they begin to transport curved canals like non-landed files (Buchanan 2008). Considering that transportation is a function of blade sharpness and the rigidity of the instrument at a given position along the file, the tip flutes could be safely narrowed to gain cutting efficiency without transportation in the highly curved apical regions of canals. Furthermore, at the shank end of the file the lands could also be thinned without danger, in spite of the stiffness of that part of the file. We know the shank end cuts through the straightest region of roots. With these efficiencies, it became apparent that the degree of stiffness in the middle section of the file dictated maintenance of the original land width to prevent straightening of mid-root canal curves. The outcome of this optimization was an at least 2X increase in cutting speed as well as less taper-lock during apical progress (Buchanan 2008).

There are more open blade angles in GT files. There is a consistent 30° helical angle along the length of GT-Series-X™ files. This increases the flexibility of these files and significantly extends the length of each cutting cycle. Where standard GT Files cut for about 4 to 6 seconds before clogging up, GT-Series-X™ Files are recommended to be advanced continuously for 10 to 12 seconds before they need to be removed and cleaned (Buchanan 2008).

The length of the handle is shorter than in the standard GT files from 13mm to 11mm. Also, the file set is reduced from 15 to 8 instruments (Buchanan 2008). It provides easy application and fewer inventories.

Figure 2-4: Variable width lands in GT- Series- X™ files (Buchanan 2008).

2.4 Mechanical properties of NiTi files

In comparison with stainless steel, nitinol has superior bending and torsional properties (Walia et al. 1988). Several studies have been done on mechanical properties of nickel titanium files such as torsional stress, cyclic fatigue, instrument fracture, cutting efficacy, hardness, sterilization effect, and centering ability of this alloy (Walia et al. 1988; Bergmans et al. 2001; Dalton et al. 1998; Gambill et al. 1996; Haïkel et al. 1999).

NiTi files provide more flexibility in compare with stainless steel files, but NiTi files separate more often without warning (Parashos and Messer 2006). Iqbal showed that NiTi rotary files separate seven times more frequently in comparison with stainless steel files (Iqbal et al. 2006).

The fracture of the NiTi rotary instruments could be due to torsional failure or cyclic fatigue (Sattapan et al. 2000). If the tip of the instrument binds and the remaining file continues to rotate, torsional failure will happen. In case of compressive and excessive force on the rotating file in a curved canal, cyclic fatigue will happen. The repeated application of these specific stresses can lead to weakening and fracture of the instrument, usually at the maximum point of flexure. Studies have found cyclic fatigue to be the primary cause of file separation (Shen et al. 2006; Haïkel et al. 1999; Parashos et al. 2004). On the other hand, Sattapan showed that torsional failure caused by excessive apical forces occurs more frequently than flexural fatigue (55.7% vs. 44.3%, respectively) (Sattapan et al. 2000).

As it is mentioned, GTX files are made of a new NiTi wire called M-wire. This wire undergoes a series of heat treatments during the preparation procedure (Buchanan 2008). The manufacturer claims that these files have more resistance to cyclic fatigue. Thomas in 2009 showed that there is no statistical difference when comparing the torque required to induce a torsional failure of Profile GT and GT-Series-X™ of identical file sizes. Also, the results showed that Profile GT rotates significantly more before separation under torsional stress than GT-Series-X™ for all file sizes except 20/04 (Kramkowski and Bahcall 2009). Thomas concluded that the variable radial land areas in the GTX files could potentially affect the fatigue behavior of the instrument.

Before discussing the cutting efficacy of NiTi rotary systems, it is important to realize that there are no clear standards for the cutting or machining effectiveness of endodontic files (Bergmans et al. 2001). It is claimed that NiTi instruments are less efficient since less force is applied to the dentin as the file is bent away from the surface. However, studies showed that NiTi instruments are as effective as or better than stainless steel instruments in machining dentin (Tucker et al. 1997). Hulsmann and Bluhm study showed Niti systems such as Flexmaster or ProTaper have better cutting abilities than hand instruments and GT files. In this study all instruments were used with the same rotational speed of 300 r.p.m, so the difference is due to the instrument design. Negative rake angle and convex diameter of Flexmaster and proTaper provide better cutting capability. On the other hand GT rotary instruments with their radial lands and U type cross- section may cut less efficiently (Hulsmann and Bluhm 2004).

Another aspect of NiTi is its hardness which is lower than stainless steel hardness. To improve NiTi hardness, application of boron or nitrogen seems promising, without affecting the super elastic properties (Lee et al. 1996).

Also, the study showed the negative effect of sterilization cycles under autoclave conditions. It decreases the cutting ability by altering the superficial structure of NiTi files (Rapisarda et al. 1999). Haikel showed that in-depth distribution of chemical composition is the main reason. The result is having more titanium oxide on the surface. However, sodium hypochlorite does not cause any difference in cutting efficacy (Haïkel et al. 1998). Most studies indicate that NiTi rotating systems are as good as, or better than SS hand instruments in removing superficial debris (Dalton et al. 1998). However, SEM studies showed that NiTi rotary files create a thicker smear layer particularly in the apical third (Laszkiewicz and Gambarini 1999).

Several studies studied NiTi canal preparation in terms of canal center displacement. They showed that NiTi maintained original canal shape better than stainless steel files (Glosson et al. 1995; Short et al. 1997). Also, a recent study compared the centering ability of an instrument produced by using the twisting method (TF) with the traditional NiTi grinding process (PathFile, ProTaper) and stainless steel K-files. The results showed that TF files produced the least transportation and had a better centering ability, followed by the PathFile, ProTaper system.

2.5 Different root canal curvature measurements techniques

There are different methods to measure the canal curvature angles. In 1971, Schneider performed pioneering work on measuring canal angulations. The Schneider method involves first drawing a line parallel to the long axis of the canal, in the coronal third. A second line is 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 Schneider angle is the intersection of these two lines (Schneider 1971).

The second method is the Weine method. In the Weine Technique, a straight line is drawn from the orifice through the coronal portion of the curve, and a second line is drawn from the apex through the apical portion of the curve. The Weine angle is the intersection of these lines (Gunday et al. 2005).

The third method is Long-Axis Method (LA). The LA technique involves drawing a line passing through the apical one-third of the canal; the angle formed by the intersection of that line with the long axis of the tooth is known as the LA angle (Hankins and Eldeeb 1996).

The fourth method is Linear Method: maximum Curvature Height. The maximum perpendicular linear distance from the point at which the mesial canal exits the root apically, to the mesial canal was recorded and defined as the maximum height of curvature (Kyomen et al. 1994).

The fifth method is “Curvature Radius” Measuring Method. The shape of any root canal curvature is more accurately described using two parameters: angle of curvature and radius of curvature. To determine these parameters, a straight line is drawn along the long axis of the apical portion of the canal. 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 or end the canal curvature. The curved portion of the canal is represented by a circle with tangents. Angle of curvature can be defined by the angle formed by perpendicular lines drawn from the points of deviation 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 curvature is the length of the radius of the circle measured on millimeters. The radius of 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 curvature is, the more abrupt the canal deviation is. 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).

The sixth method is Canal Access Angle (CAA). The canal orifice and apex were connected with a line. The angle formed by the intersection between this line and one drawn parallel to the long axis of the canal from the coronal part (used in the Schneider method), is defined as the CAA (Gunday et al. 2005).

Finally, the seventh method is based on numeric calculus. In mathematics, a curvature is described by means of hypothetical circles. The curvature at a specific point is described by selecting a circle that is optimally adapted to the configuration of the curve at that point. The smaller the curvature, the larger the hypothetical circle. The curvature dimension at a point is specified by the reciprocal value of the radius of the corresponding hypothetical circle.

2.6 Consequences of root canal center displacement

Zip: The tendency of the instrument to straighten a curved canal can cause zipping. It means that the instrument will over-enlarge the canal along the outer side of the curvature. At the same time it will under-prepare the inner aspect of the curvature at the apical end point. The result of zipping could be “teardrop” or “hour-glass shape” of the apical part (Hülsmann et al. 2005).

Elbow: This is a narrow region of the root canal at the point of maximum curvature as a result of irregular consistency and insufficient tapering. It occurs coronally along the inner aspect and apically along the outer aspect of the curve (Hülsmann et al. 2005).

Ledge: It can be found on the outer side of the curvature as a platform. It is usually difficult to bypass (Hülsmann et al. 2005). The ledge formation is related to the degree of the curvature and design of the instrument (Bergenholtz et al. 1979; Greene and Krell 1990).

Perforation: It could happen as a result of inflexible instrument application with a sharp cutting tip in a rotational movement (Hülsmann et al. 2005).

Strip perforation: This is a mid-root perforation, and results from over preparation and straightening along the inner aspect of the root canal (Hülsmann et al. 2005).

Insufficient cleaning: In case of canal center displacement, part of the original root canal will remain unprepared or at least under-prepared. This part of the canal may harbour microorganisms and toxins (Horiba et al. 1990; Perez et al. 1993; Nair et al. 1990).

2.7 Endodontic cube, a tool for studying instrumentation procedures

A split- mold technique was originally described by Bramante in 1987. Prior to that, root canal instrumentation was evaluated using the microscope (Coffae and Brilliant 1975; Klayman and David Brilliant 1975; Walton 1976), scanning electron microscope (Mizrahi et al. 1975) (Bolanos and Jensen 1980; Rubin et al. 1979), radiographs (Chenail and Teplitsky 1985), and photographs (Abou-Rass and Jastrab 1982; Morgan and Montgomery 1984).

When using the light microscope, the teeth were sectioned the teeth, and the tissue contact of each canal and isthmus was evaluated, quantities and recorded for each level (Coffae and Brilliant 1975).

The effectiveness of instrumentation could be judged using scanning electron microscope on the basis of quantity of debris and microorganisms remaining on the root canal walls (Mizrahi et al. 1975).

In using the radiographic technique, all teeth are imaged before and after instrumentation. Positive and negative transparencies were also made of all pre and postoperative films. The positive preoperative radiograph was overlaid on top a negative postoperative film. In this way, two images of the same tooth are superimposed exactly. The amount of displacement of the apical tip of files showed the discrepancies (Chenail and Teplitsky 1985).

Abou-Rass and Morgan used photographs to evaluate the instrumentation. In their technique, a panel of endodontists reviewed the three photographic views of the same model according to determined criteria. The specific criteria and overall quality were rated by each endodontist (Abou-Rass and Jastrab 1982).

The basic model system described by Bramante et al in 1987 is fabricated to evaluate the quality of root canal preparation. In his model, the root of a selected tooth was inserted into a colorless acrylic resin. After resin setting, the grooves were made around that. The third step was pouring the plaster stone around the resin to create the mold. This procedure allowed the root to be inserted into the colorless resin block and at the same time to be placed in the plaster stone, which served as a removable muffle. The muffle could be removed to section the resin block at different levels (Bramante et al. 1987).

McCann in 1990 introduced a Bramante modified mode. In his model, the tooth would be put in improved dental stone rather than colorless acrylic resin and formed into a pyramidal block. Guiding grooves are located in the set stone block; the same as the Bramante model. An acrylic resin muffle is then fabricated one half at a time. Following the placement of separating medium, the second half of the muffle is made. Acrylic resin should be pressure-cured to minimize porosity. The acrylic resin muffle was separated and the dimensions were reduced so as to reduce its bulk and yet maintain the strength of the system. The exterior surface of the resin muffle was polished (McCann et al. 1990).

In contrast to Bramante and McCann models which had the external indexing, Tamse introduced a model with the internal indexing. The Tamse model consisted of a cylindrical stand with two pairs of penetrating round holes, with diameters of 5mm and 2mm, respectively. The protruding part creates a positive seat in the subsequent investment material, which orients the apical section precisely in the assembly process. These larger pins are designated as orientation pins. The two narrow pins serve as stabilizers and verifiers of complete seating of the sections perpendicular to the orientation pins. The center of the metal stand has a projection for mounting the root tip. The tooth would be sectioned at the indexed spots. After processing using microscope or photography, the sections were reassembled. At the end of the assembly process, the sections secured with the stabilizing pins. Tamse claimed that his model is less time consuming, more reproducible and precise than the previous systems (Tamse and Pilo 1998).

Kuttler introduced the “Endodontic Cube” in 2001. It consists of five brass sections that are fixed together by external fixation to form a roofless cube (Figure 2-5). There are four vertical walls and one horizontal wall. Two of the vertical walls provide the internal indexing in the horizontal plane to section the resin- tooth model into 1.5mm slices (Figure 2-6). The other two vertical walls have longitudinal grooves to provide the guideline to reassemble the cube (Figure 2-7). As was mentioned, the outer brass sections are held together by external fixation screws. There are external grooves for correct alignment that provide a precise system for accurate assembly (Figure 2-8) (Kuttler et al. 2001a).

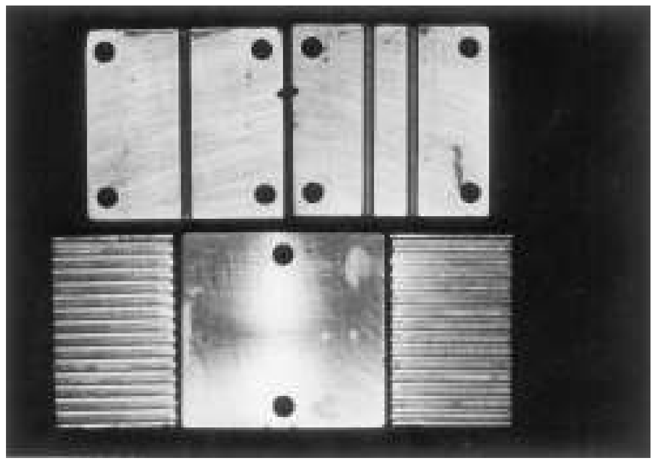

Figure 2-5: Five individual external sections that form the Endodontic Cube (Kuttler 2001).

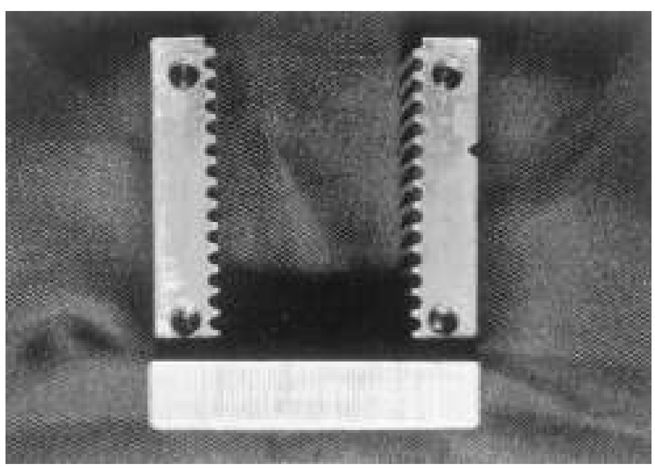

Figure 2-6: Machined horizontal grooves on opposing internal walls guide section rearrangement and prevent movement of sections within the cube (Kuttler 2001).

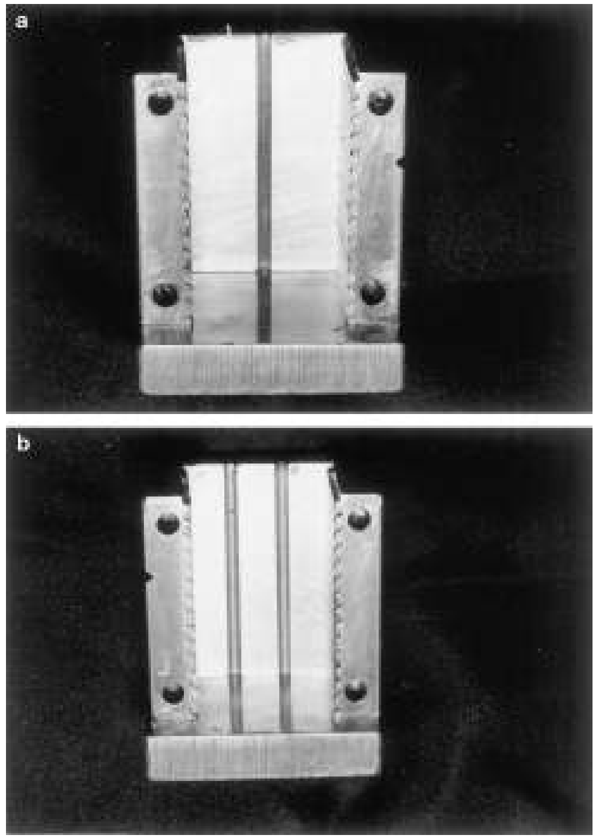

Figure 2-7: Vertical indexing grooves on opposing internal walls aid in correctly aligning and provide future retention for sections (Kuttler 2001).

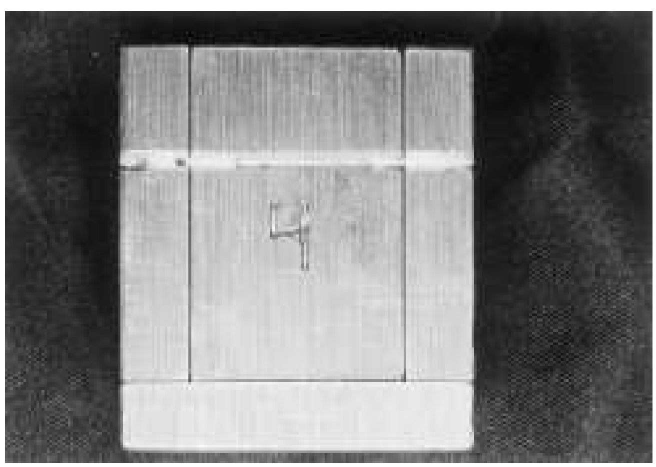

Figure 2-8: External grooves are used to verify the correct orientation of the cube (Kuttler 2001).

To use the “Endodontic Cube”, the tooth is immersed in methylene blue dye. After resin setting, the Endodontic Cube is disassembled and the embedded tooth is removed from the cube. By using the horizontal grooves, the resin block is sectioned into several specimens. Following evaluation the specimens, all sections are repositioned into the Endodontic Cube and the cube would be reassembled. It is possible to do instrumentation easily while the tooth-resin complex is in the cube. Following instrumentation, the cube would be disassembled, and all sections would be available for a further evaluation (Kuttler et al. 2001a).

The Endodontic Cube provides a practical device to compare pre and post-instrumentation samples. It has the capability of providing several sections as desired at précised locations with the ease of handling. Also, it has the external fixations which are not brittle in comparison to the plaster in some models. As opposed to some systems which are not able to be held together tightly, the Endodontic Cube is solid and satisfactorily maintained during instrumentation (Kuttler et al. 2001a).

2.8 Hypothesis

Instrumentation using ProSystem GT™ files is expected to have greater canal center displacement than instrumentation with GT-Series-X files, due to more chip spaces and fewer cutting flutes in the latter.

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3. Materials and methods

3.1 Specimen collection and selection

The teeth were from a pool of extracted human permanent mandibular molar teeth from South American and Middle Eastern decent. The teeth were stored in 5% normal-saline. In this study, 31 extracted human mandibular first and second molars with closed apices were used. All teeth were selected on the basis of mature apices, similar canal curvature (20-40 degrees), separate mesial canals, and no noticeable defects or abnormal root morphology.

3.2 Inclusion criteria

- Mesial roots having two canals via separate apical foramina
- No caries or fracture below the level of pulpal floor
- Total canal length form pulpal floor to the apex was 12-15mm
- Root canal curvature was between 20-40 degrees measured according to Schneider Method (Schneider 1971).

3.3 Exclusion criteria

- Teeth with external defects
- Teeth with root morphology anomalies
- Teeth with mesial root canals existing via one apical foramen

3.4 Sample preparation

Surface debris was removed with a #15 scalpel blade under running tap water. Access openings were prepared on the selected teeth using a high speed dental handpiece and carbide fissure burs. Also, the distal root was amputated at the height of the furcation, and the mesial roots were used for the study. A mesial- distal preoperative radiograph was made to confirm the canal configuration (Figure 4-1).

Working Length (WL) determination: A #10 stainless-steel K-file was introduced into each mesial canal until observing the file tip at the apical foramen under 5.1 magnifications (Global Surgical™). The working length was determined by subtracting 0.5mm from this length.

3.5 Canal curvature measurement technique

A number 15 file was placed in one mesial canal and one Hedstrom file in another mesial canal, and radiographs were made from both bucco-lingual and mesial-distal views to confirm the WL and evaluate the canal curvature (Figure 3-1 & Figure 3-2).

Canal curvature was measured using the Schneider method (Schneider 1971) in AutoCAD™ software (Figure 3-3). The larger curvature (mesiodistal or buccolingual) was documented as the canal curvature. Roots with abrupt changes in the direction or degree of curvature below 20 degree or above 40 degree were discarded. The remaining roots, either mesio –buccal or mesiolingual canals were randomly assigned to either ProSystem GT™ or GT-Series-X™ to be instrumented.

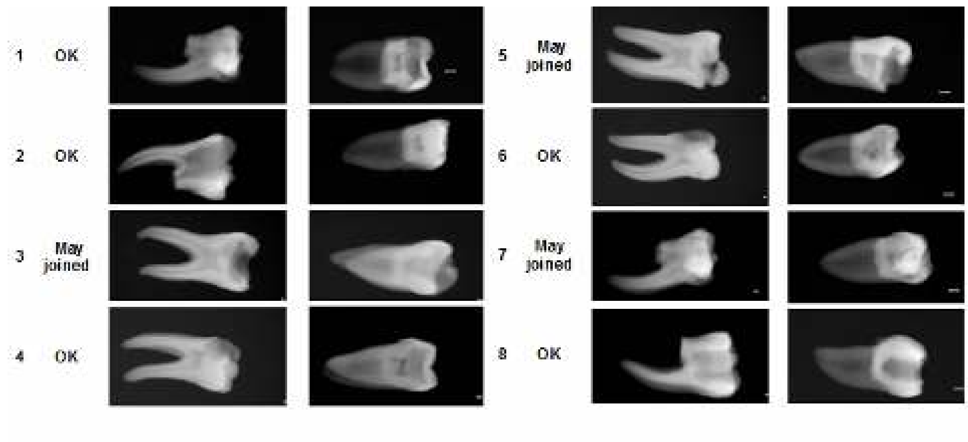

Figure 3-1: Radiographs taken from teeth specimen in bucco-lingual (left) and mesio-distal (right) projections.

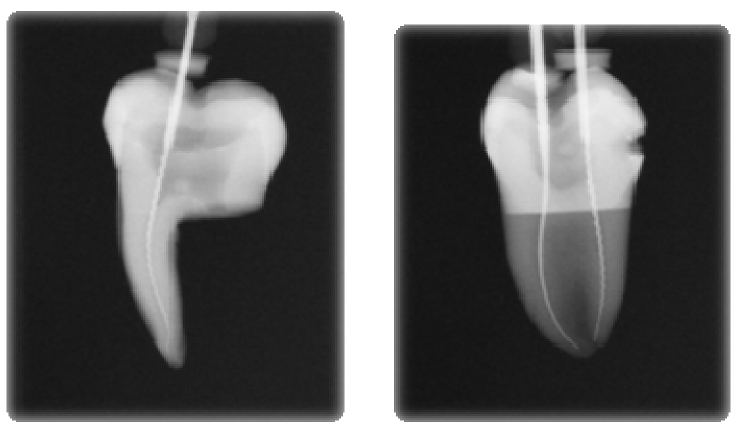

Figure 3-2: Two radiographs of a tooth specimen showing files inserted into the mesial root canals for the measurement of canal curvature.

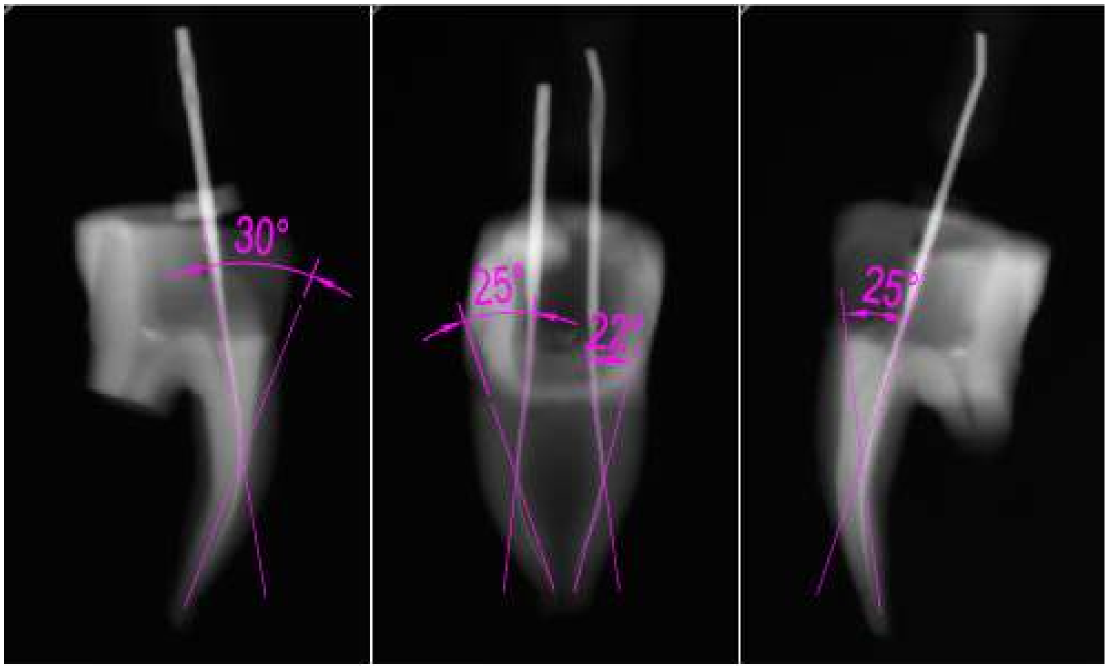

Figure 3-3: Root canal curvature based on Schneider method, using AutoCAD™ software.

3.6 Using the “Endodontic Cube” as a mold

The evaluation of root canal instrumentation in these extracted teeth was assisting by using the Endodontic Cube (Figure 3-4). Following working length and canal curvature determination, the apical foramina of each tooth were sealed with the pink base-plate wax to secure the canals from being blocked by the resin during mounting the teeth in the Endodontic Cube (Figure 3-5). The coronal portions of the teeth were covered utilizing the rope wax to cover the access cavity before incorporating each tooth in resin (Figure 3-6). Composite resin (Access Crown Self cure Temporary C&B Composite, Centrix Inc., Shelton) was flowed into the cube (Figure 3-7). The teeth with the attached rope wax were re- seated in the cube- resin complex.

The resin material was allowed to set for 5 minutes at room temperature, according to the manufacture (Figure 3-8). The Endodontic Cube was disassembled following setting the resin (Figure 3-9).

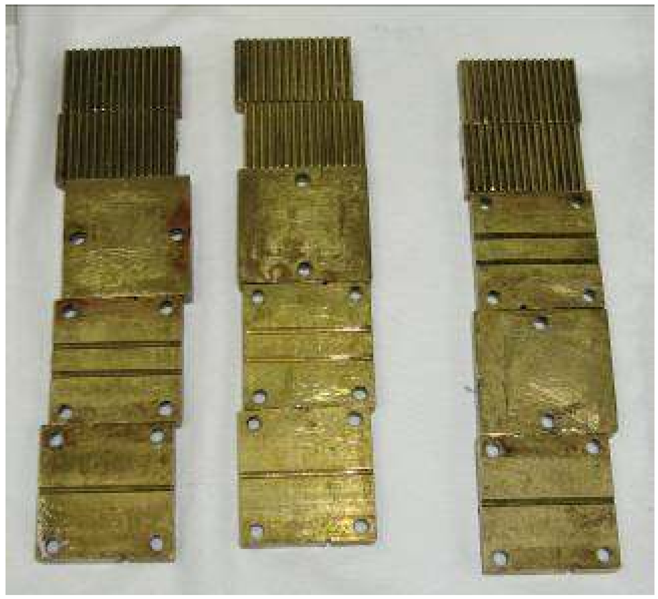

Figure 3-4: Five brass pieces of the Endodontic Cube.

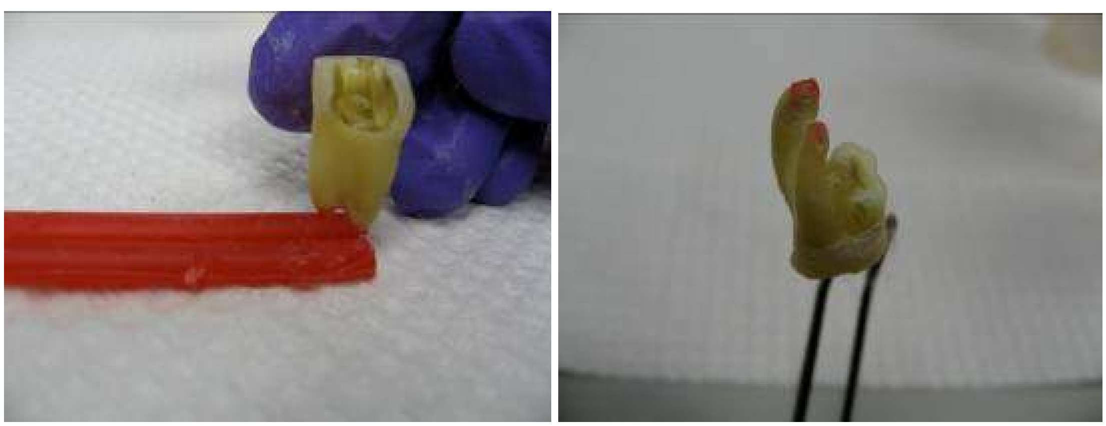

Figure 3-5: The apical foramina sealed to prevent canal blockage.

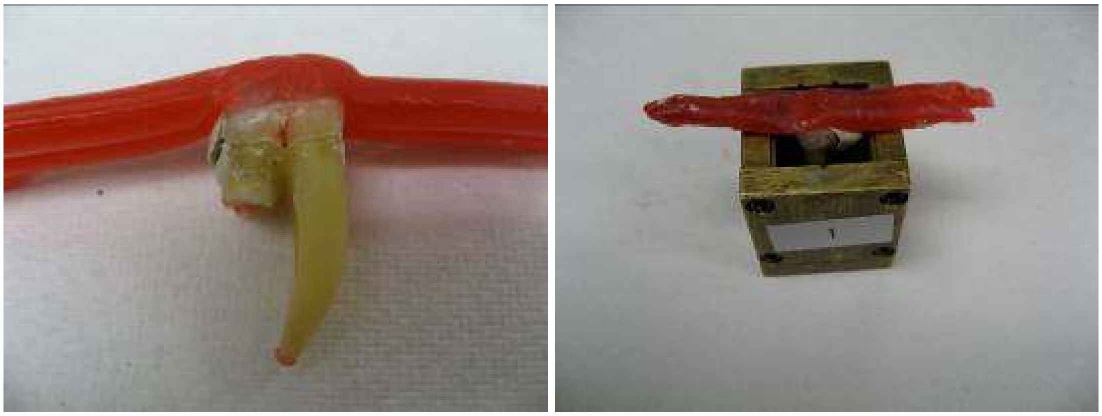

Figure 3-6: The rope wax utilized to secure and cover the tooth within the unset resin inside the cube.

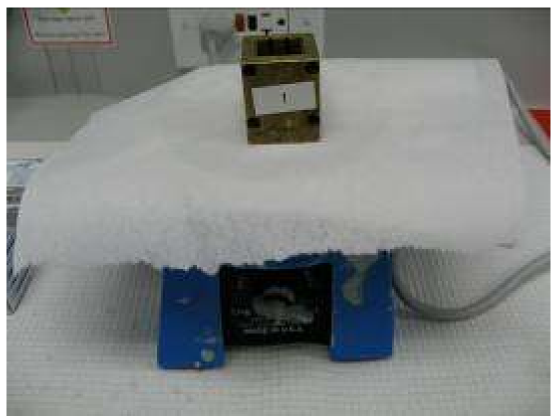

Figure 3-7: The resin poured into the “Endodontic Cube” while the assembly was placed on a laboratory vibrator.

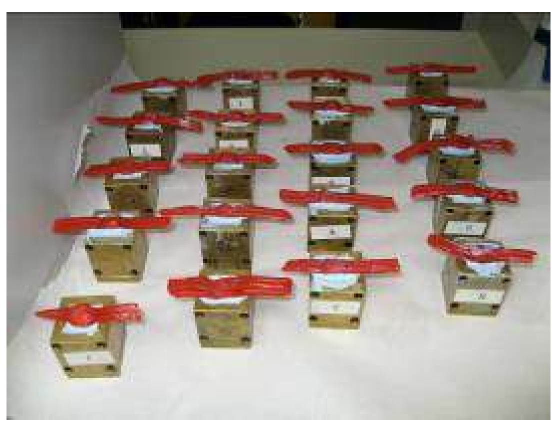

Figure 3-8: Letting the acrylic resin set.

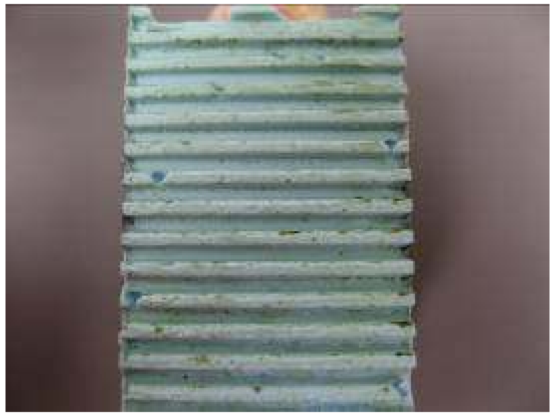

Figure 3-9: One tooth section from an endodontic cube showing that all debris have been removed.

Each resin block was attached to a Buehler low speed saw (Buehler Corp.,Evanston,IL) via a vise to have precise sectioning parallel to the horizontal grooves on the resin (Figure 3-10). The resin blocks were sectioned into four to eight sections by using the 0.15mm thick diamond disc at 300 RPM. Each section was washed, cleaned, and dried to remove the pulp tissue remnants. Each section was marked for the after instrumentation reference (Figure 3-11).

Figure 3-10: Buehler low speed saw sectioning the resin-tooth complex.

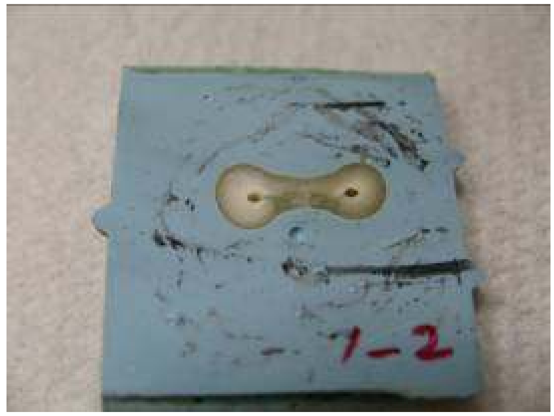

Figure 3-11: All debris has been removed from each section.

3.7 Instrumentation and imaging technique

The sections were attached to a horizontal framed glass and photographed under even magnification by using a camera (Sony Mavica MVC FD91 Digital SLR Camera). The photography assembly consisted of a customized jig which was secured to the arm of the dental operating microscope, and utilized a horizontally positioned piece of glass as a working platform. A digital camera recorded the digital images of each tooth section. The sections were reassembled to make the actual tooth in the Endodontic Cube, and then the instrumentation was done (Figure 3-12).

Figure 3-12: Photography assembly.

Each canal was randomly assigned to be instrumented by either ProSystem GT™ files or GT-Series-X™ files according to the following techniques:

A) ProSystem GT™ (Tulsa Dental Specialties): The canals were negotiated to length up to a size #15K- file to establish the glide path. Initial shaping began with the 20/10 instrument according to the manufacturer at 300 rpm. The 20/08, 20/06, and 20/04 were used progressively to reach the full length each. The instrumentation has been finished at 30/06. If 30/06 bound in the canal at length, apical gauging was completed, and canal shaping was done. If 30/06 did not bind at length, 30/04 was used, and then 30/06 went to the length easily. All the procedures were done in the presence of EDTA based lubricant, ProLube™, (Tulsa Dental Specialties).

B) GT- Series-X™ (Tulsa Dental Specialties): The patency was established to the terminus with a # 15 K-file. The shaping started with 20/06 GT-Series-X™ file with light apical pressure. If it did not go to length, it might be necessary to use the 20/04 GT- Series-X™ file to the length. The instrumentation has been finished with 30/06. It might be necessary to use 0.04 before being able to advance the 30/06 file to full working length.

All hand and rotary root canal instruments were used in only one canal and discarded. All root canal instrumentation procedures were performed by the same experienced operator. As mentioned earlier, Prolube™ was used as a lubricant, and 1ml of sterile water was used as an irrigant between each file set. The Endodontic Cubes were disassembled for the second time following the instrumentation, and each section photographed in the exact same position as before instrumentation.

3.8 Observation and measurement

Measurement of the magnitude of deviation of “instrumented root canal” from its original path, and estimation of some measures of deformation of canal section from its original shape, was emphasized.

3.8.1 Canal Center Displacement (CCD)

CCD was considered as a rational measure of canal’s deviation from its original path (Figure 3-20). The challenge was defining a center for non-circular shape sections (before and after instrumentation). Hence, center of fitted ellipse was considered as the center of the root canal. For most cases a circle, which essentially is an ellipse with identical Diameters, best fitted with the canal shape and the measurement was very straightforward.

Although deviation of instrumented canal from its original path was measured in both X and Y directions, the result of these deviations was deemed to be a reasonable measure for CCD.

It is noteworthy that, having both X & Y deviations would allow the user to determine any other directional deviation. This in turn provides a new tool to compare magnitude of CCD with respect to the direction of canal curvature / path.

3.8.2 Canal Widening (CW):

The other index which was studied was the magnitude of canal widening due to instrumentation. Typically, canal widening would be evaluated using the following 4 different parameters, namely:

1. Minor Diameter of canal before instrumentation
2. Major Diameter of canal before instrumentation
3. Minor Diameter of canal after instrumentation
4. Major Diameter of canal after instrumentation

Combinations of these variables results in four different permutations. Instead of examining the different permutations of these variables separately, a new measure for CW was defined. The average of Minor and Major Diameter of canal before instrumentation with average of Minor and Major Diameter of canal after instrumentation was compared.

To provide a rationale basis for comparison of results and diminish scaling errors, all CCD and CW values were normalized to the average of Minor and Major Diameter of canal before instrumentation and recorded as percent.

The analysis and measurement procedure, using AutoCAD™ Software, is also detailed below:

1. Import picture of Endo Ruler into AutoCAD™ drafting environment and calibrate AutoCAD™ to measure correct dimensions from pictures.

Note that all pictures were taken from the same distance and camera setting (Figure 3-13).

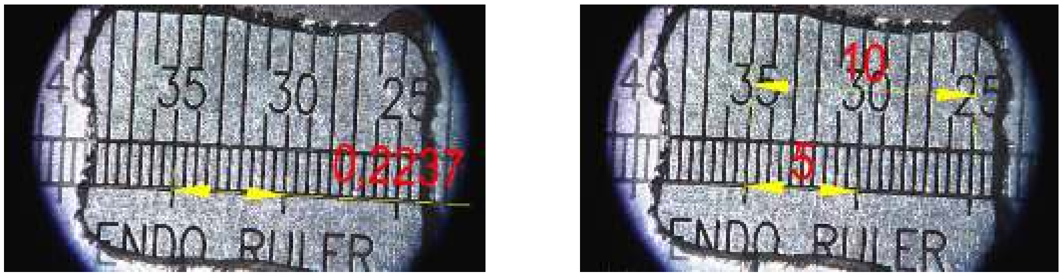

Figure 3-13: Dimensioning Before and After Scaling (Scale Factor = 5 mm / 0.2237 = 22.35).

2. Import picture of non-instrumented tooth section into AutoCAD™ drafting environment and draw an accurate free hand sketch along the border line of the tooth (use polyline - fit curve command). This border line would later be used to align different pictures of this segment, which have been taken through different stages of the test (yellow line in the Figure 3-14).

Note: All segments were photographed under a constant magnification via the same working platform (framed glass). The orientations of different sections varied slightly, but each segment was centered on the platform prior to photography.

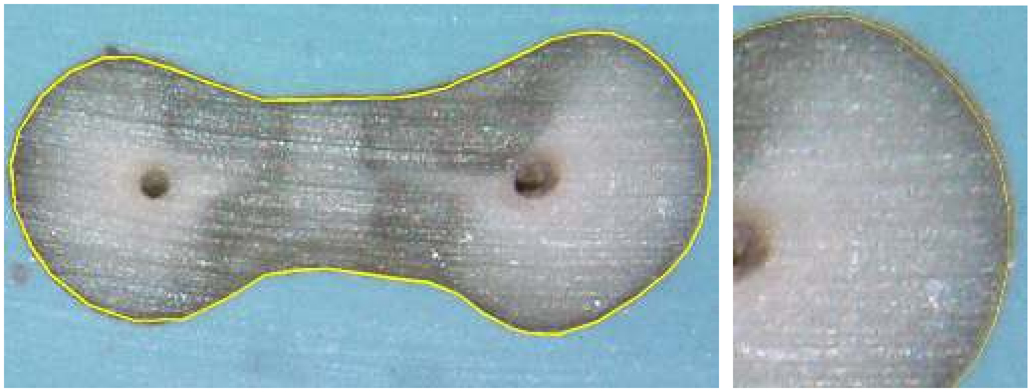

Figure 3-14: Drawing the border line of non-instrumented tooth.

Import picture of instrumented section into AutoCAD™ drafting environment and re-locate / reorient it to make sure that the tooth boundary would best covered by a copy of the boundary curve which has been fitted over not-instrumented tooth (Figure 2-15).

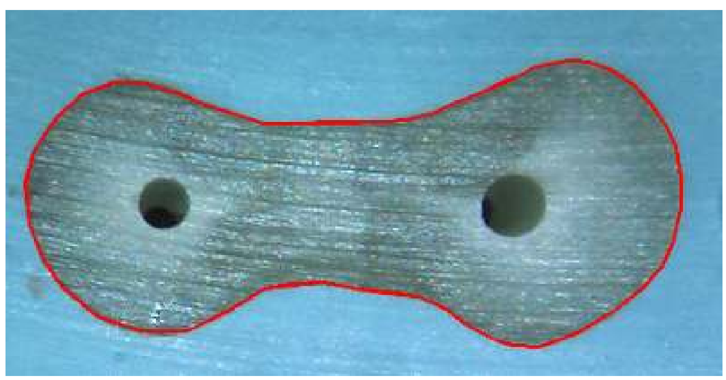

Figure 3-15: The instrumented section adjusted to match the borderline.

Draw ellipse / circle to best fit each canal's borderline, both for instrumented and not-instrumented tooth pictures (Figure 3-16 and Figure 3-17).

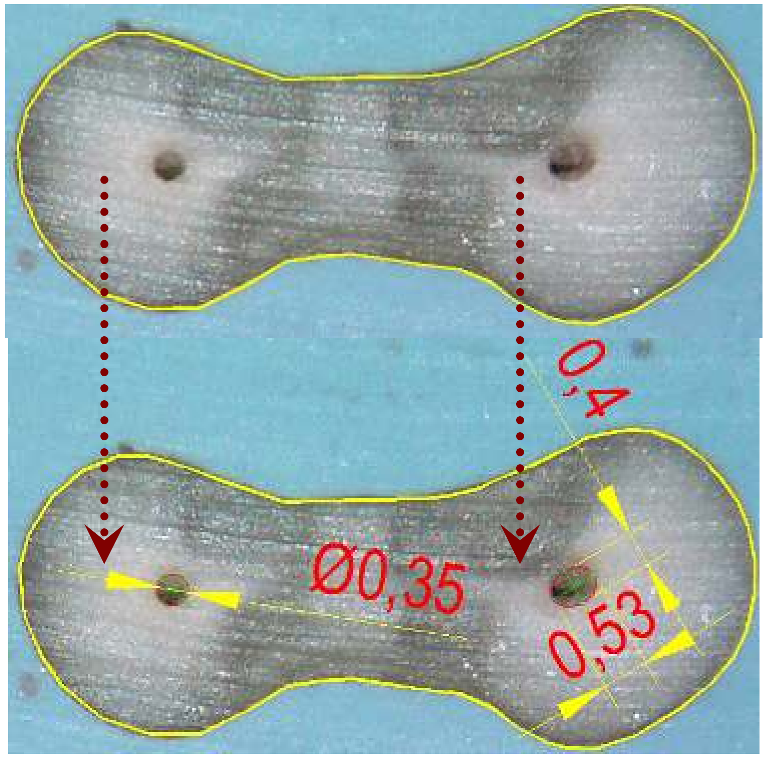

Figure 3-16: Non- instrumented tooth section (N-INS)

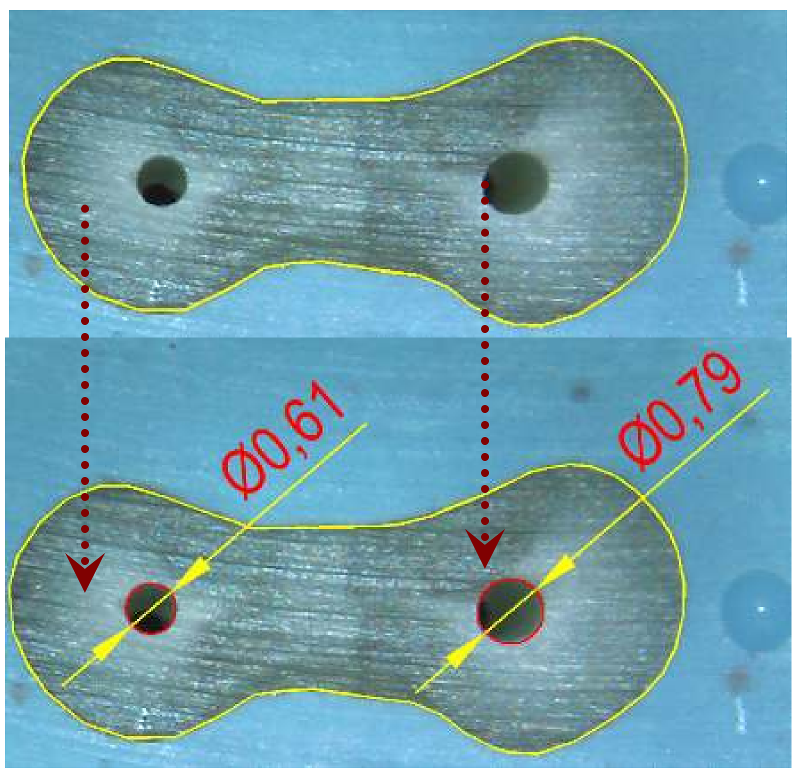

Figure 3-17: instrumented tooth section (INS)

3. Using a reference point of borderlines (matching point), move the picture of instrumented tooth and accurately overlay it on the picture of non-instrumented tooth. Matching point is utilized to make sure that both boundaries are precisely overlapping.

4. Make horizontal and vertical replication of picture of instrumented tooth along with its boundary (Figure 3-18).

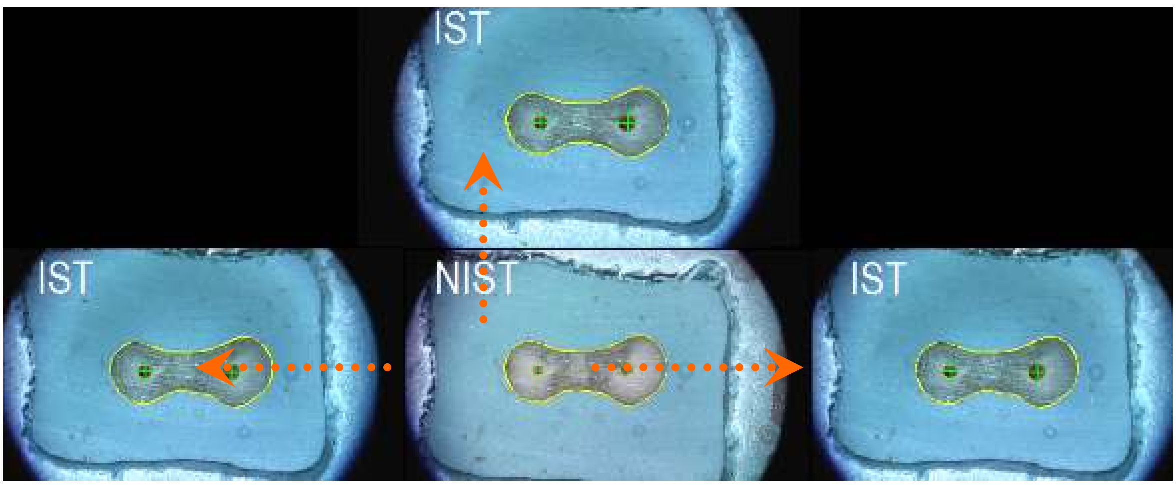

Figure 3-18: Orthogonal replication of INS beside/ aligned with N-INS.

5. Draw horizontal and vertical grid lines along edges of instrumented canal to reflect boundaries of instrumented canals on non-instrumented section (Figure 3-19).

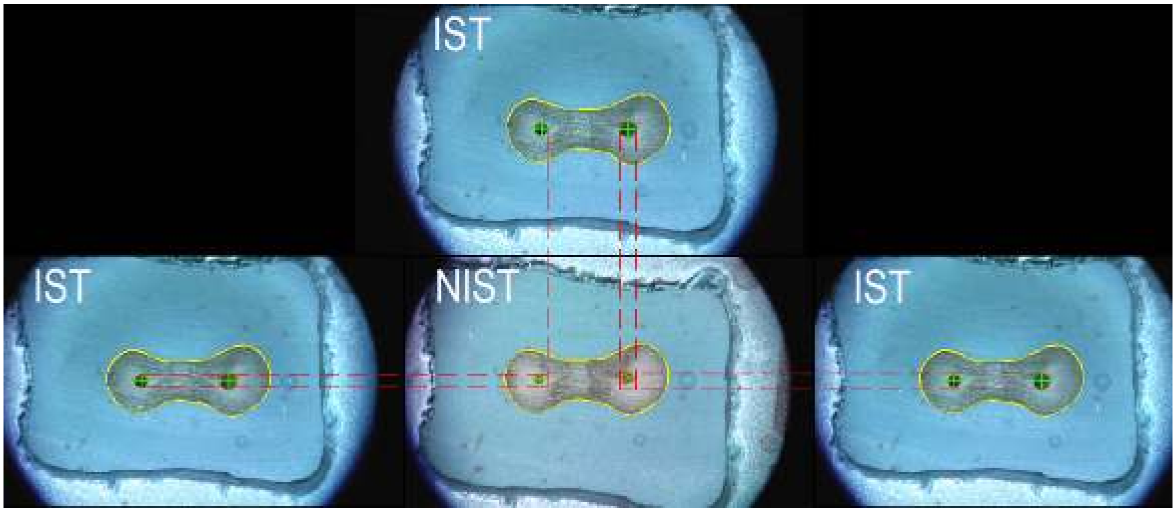

Figure 3-19: Orthogonal gridlines to reflect of INS sections on N-INS sections.

6. Measure Horizontal (X direction), Vertical (Y direction) and resultant CCDs for each canal (Figure 3-20).

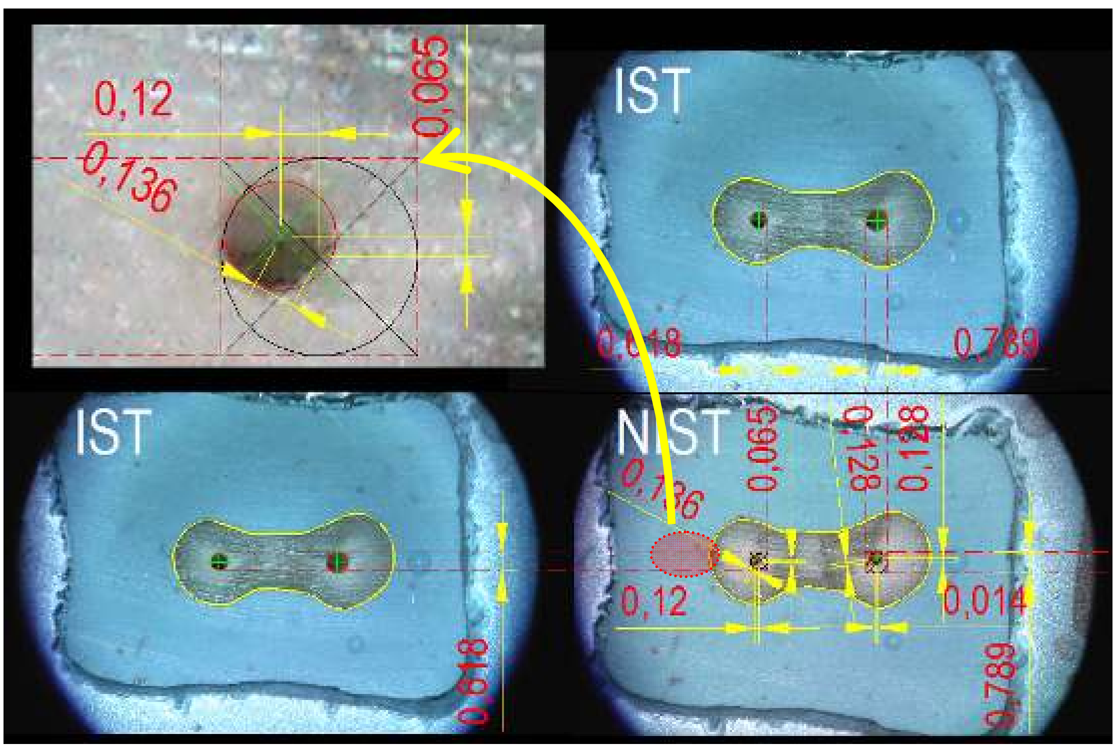

Figure 3-20: Measurement of X, Y, and resultant CCDs Blow-up of canals pre and post instrumentation borderline overlay.

7. Summary of the above measurements is presented in the “Table-1”.

- Non-Instrumented Tooth Section (N-INS) data presents properties of ellipse which was fitted on each canals section before any instrumentation.
- Instrumented Tooth Section (INS) data presents properties of ellipse which was fitted on each canals section after completion of instrumentation.
- Canals Center Displacement data presents horizontal, vertical and resultant displacement of the instrumented canal from its original point. Values were presented irrespective to curved canals plane.
- Normalized Measurements based on Original Average Diameter introduces a better measure of canals widening and CCD as present these values as percentage of canals original size.

Canal center displacements for each instrument were analyzed using SPSS 80 statistics software (SPSS inc., Chicago, IL). The independent sample t-test was used at a significant level of $P<0.05$ to measure the canal center displacement along the canal. Canal center displacement at different curvature regions were also analyzed using one way ANOVA.

Table 3-1: Canal diameter and canal center displacement data

Section	Parameter	Magnitude
Not-Instrumented Tooth Section (NITS)	Right Canal's Original Major Diameter =	0.530 mm
	Right Canal's Original Minor Diameter =	0.400 mm
	Right Canal's Original Average Diameter =	**0.465 mm**
	Left Canal's Original Major Diameter =	0.350 mm
	Left Canal's Original Minor Diameter =	0.350 mm
	Left Canal's Original Average Diameter =	**0.350 mm**
Instrumented Tooth Section (ITS)	Right Canal's Instrumented Major Diameter =	0.789 mm
	Right Canal's Instrumented Minor Diameter =	0.789 mm
	Right Canal's Instrumented Average Diameter =	**0.789 mm**
	Left Canal's Instrumented Major Diameter =	0.618 mm
	Left Canal's Instrumented Minor Diameter =	0.618 mm
	Left Canal's Instrumented Average Diameter =	**0.618 mm**
Canals Center Displacement	Right Canal Horizontal Center Displacement (R-CHCD)=	0.120 mm
	Right Canal Vertical Center Displacement (R-CVCD)=	0.065 mm
	Right Canal Center Displacement (R-CCD*)=	**0.136 mm**
	Left Canal Horizontal Center Displacement (L-CHCD)=	0.014 mm
	Left Canal Vertical Center Displacement (L-CVCD)=	0.128 mm
	Left Canal Center Displacement (L-CCD*)=	**0.128 mm**
% Canal Center Displacement	Right Canal's Instrumented Average Dia. / Right Canal's Original Average Diameter =	170%
	% Right Canal Widening=	**70%**
	Left Canal's Instrumented Average Dia. / Left Canal's Original Average Diameter =	177%
	% Left Canal Widening=	**77%**
	Right Canal Center Displacement (R-CCD) / Right Canal's Original Average Diameter =	29%
	% Right Canal Center Displacement=	**29%**
	Left Canal Center Displacement (L-CCD) / Left Canal's Original Average Diameter =	37%
	% Left Canal Center Displacement=	**37%**

* *CCD =* $\sqrt{(CHCD2 + CVCD2)}$

4. Results

Thirty-one roots with 62 canals were used in this study. The canal area was measured before instrumentation as well as after instrumentation. Then, the canal center displacement was measured utilizing AutoCAD™ drafting environment. Both instrument systems resulted in some degree of canal transportation

4.1 Canal Center Displacement

The extent of canal center displacement, when instrumenting root canals with ProSystem GT™, was measured by AutoCAD™. The mean ± SD of canals instrumented using ProSystem GT™ showed 0.08 ± 0.074 mm of displacement. Canal center displacement of canals instrumented using GT-Series-X™ files was 0.064 ± 0.063 mm using AutoCAD™. The independent t-test showed a significant difference between the two instruments with canals instrumented with ProSystem GT™ showing greater canal displacement ($P = 0.025$).

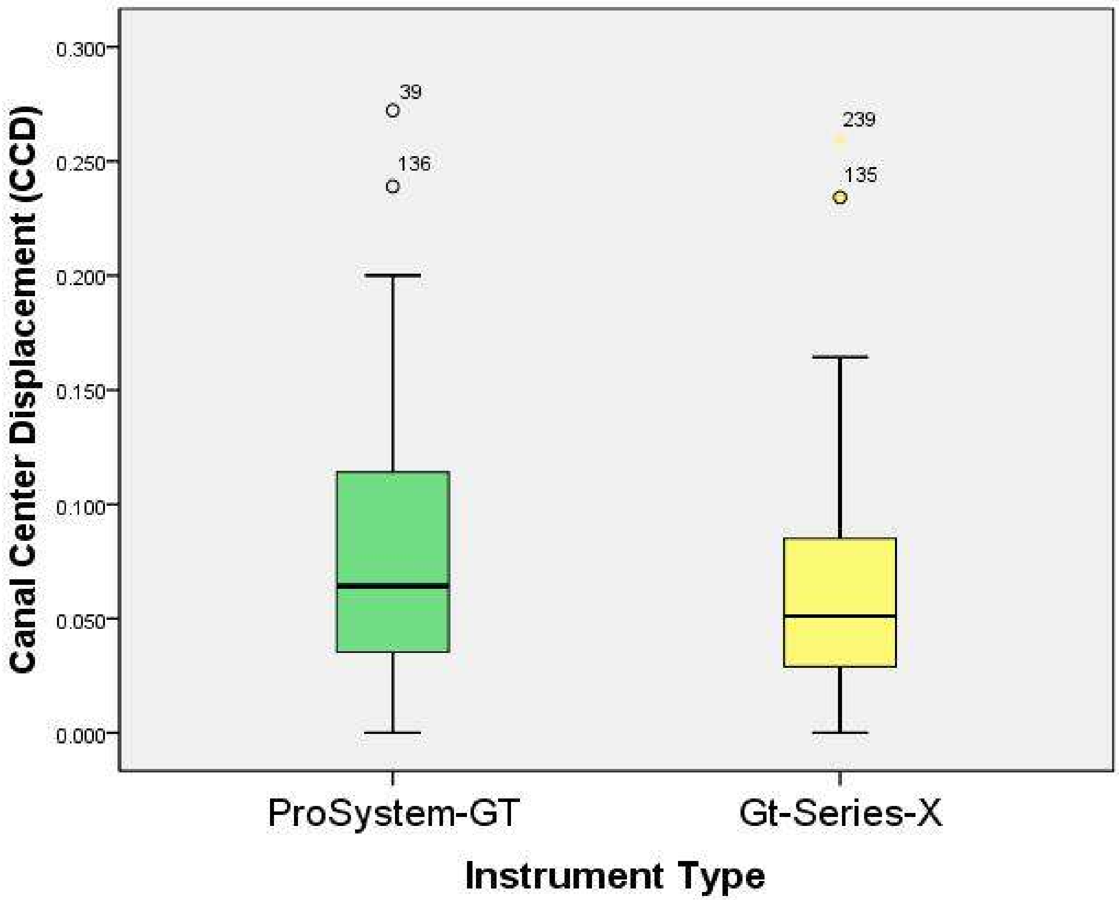

Figure 4-1: Comparison of canal center displacement between ProSystem GT™ and GT- Series-X™.

ProSystem GT™ Canal Center Displacement in different regions along the canal:

As expected, ProSystem GT™ showed the furthest transportation at “above the curved level” which was 0.11 ± 0.061 mm. ProSystem GT™ CCD at the “curved level” and “Below the curved level” were 0.06 ± 0.042 mm, and 0.05 ± 0.052 mm, respectively (Table 4-1) (Figure 4-2). One way ANOVA test showed a significant difference of displacement between the three levels for each of the rotary file systems used (P< 0.001).

Table 4-1: Canal Center Displacement employing ProSystem GT™ and GT-Series-X™.

	ProSystem GT™	GT-Series-X™	P- Value
Above the curve	0.11 ± 0.061	0.08 ± 0.052	0.154**
Curve	0.06 ± 0.042	0.05 ± 0.027	0.194**
Below the curve	0.05 ± 0.052	0.03 ± 0.045	0.470**
P- value	< 0.001*	<0.001*	N/A

** Measurements within the same system were compared using one way ANOVA.*

*** Two systems were compared by independent sample t-test.*

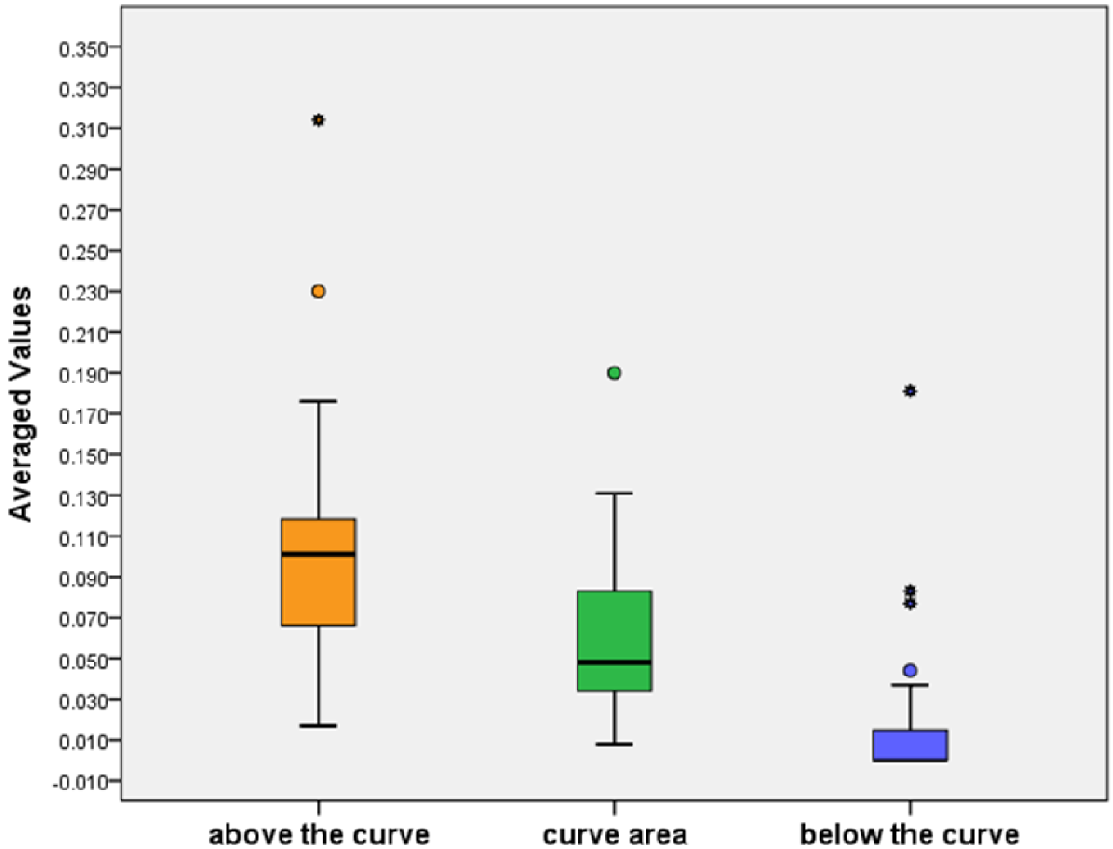

Figure 4-2: Amount of ProSystem GT™ canal center displacement at 3 different levels.

GT-Series-X™ Canal Center Displacement in different regions along the canal

The same as seen for ProSystem GT™, the greatest CCD of GT-Series-X™ files was at the "Above the curved level" as well. It was 0.08 ± 0.052 mm as it is shown in Table 5-1. The curved and "below the curved level" canal center displacement were 0.05 ± 0.027 mm, and 0.03 ± 0.045 mm, respectively (Table 5-1) (Figure 4-3). One way ANOVA analysis showed a significant difference of displacement among the three levels of curvature ($P < 0.001$).

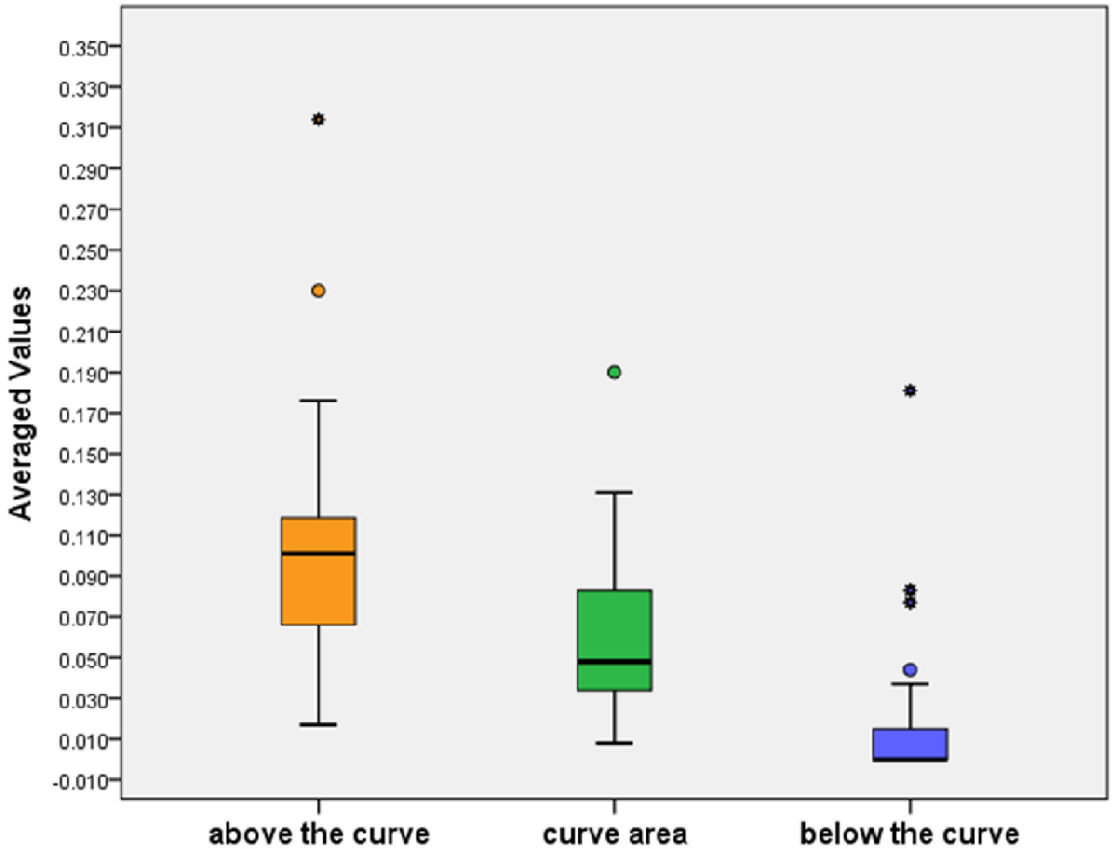

Figure 4-3: Amount of GT- series-X™ canal center displacement at 3 different levels.

4.1.1 CCD at "above the curved region"

Extent of the canal center displacement was studied at three different regions separately for both ProSystem GT™ and GT-Series-X™. At "above the curved region" extend of CCD did not show any significant difference (P= 0.154). Even though the difference was not significant, the degree of canal center displacement was greater for ProSystem GT™ (0.11 ± 0.061 mm) in comparison with GT-Series-X™ (0.08 ± 0.052 mm) (Figure 4-4).

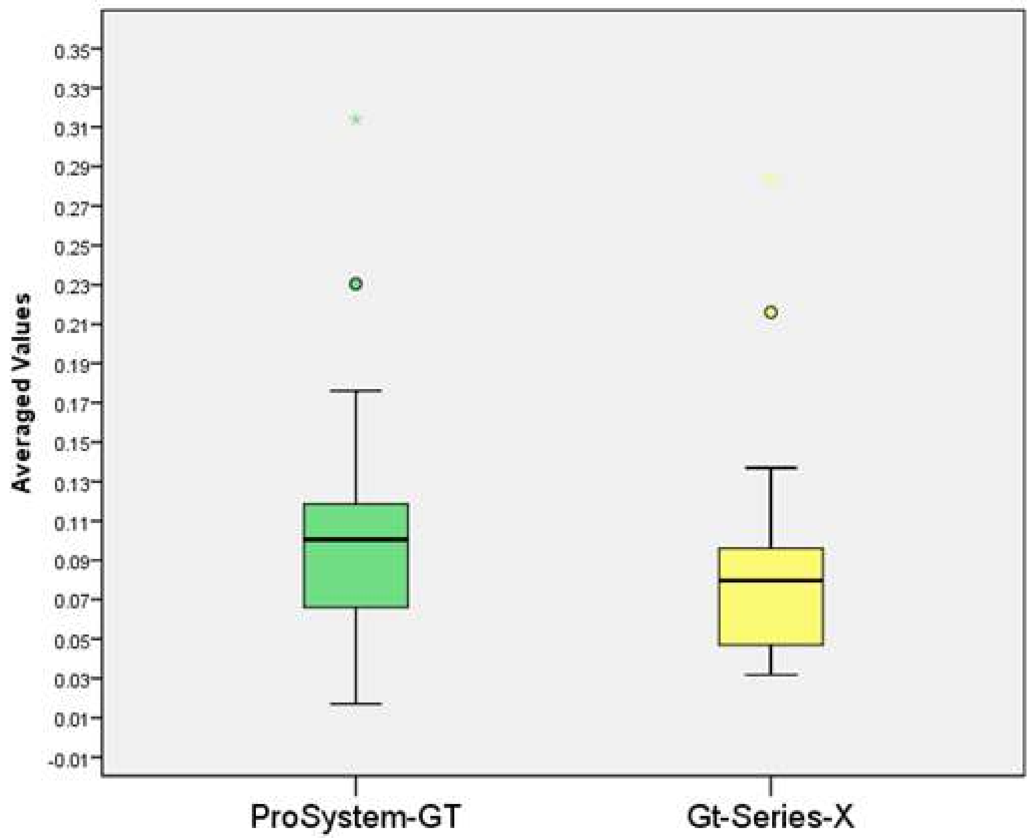

Figure 4-4: "Above the curved region" CCD for both rotary systems.

4.1.2 CCD at "curved region "

Canal Center displacement at the level of curved region did not show any significant difference between ProSystem GT™ and GT-Series-X™ (P=0.194). Even though the difference was not significant, the degree of canal center displacement was slightly greater for ProSystem GT™ (0.06 ± 0.042 mm) in comparison with GT-Series-X™ (0.05 ± 0.027 mm) (Figure 4-5).

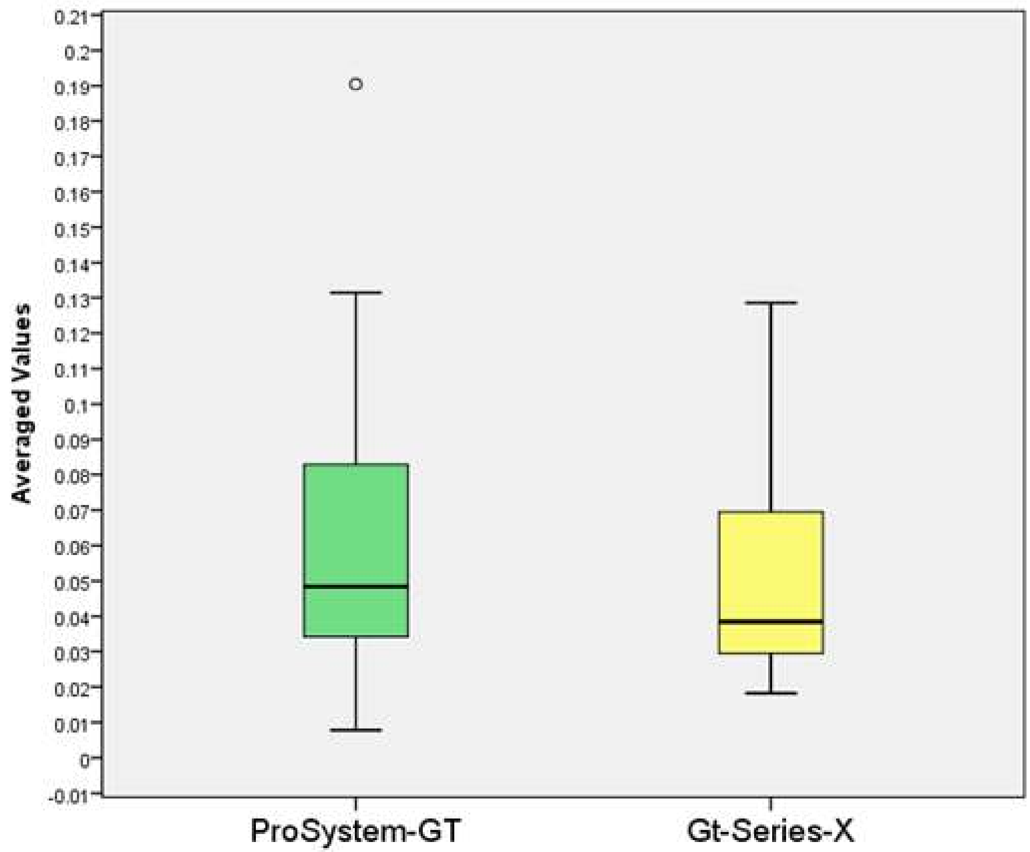

Figure 4-5: Curved region's CCD for both rotary systems.

4.1.3 CCD at "below the curved region"

The same as the two other curvature levels, canal center displacement degree did not show any significant difference at "below the curved region" between the two rotary instrument systems using independent sample t-test (P= 0.470). Also, as it was expected, the degree of ProSystem GT™'s CCD (0.05 ± 0.052 mm) was greater than the GT-Series-X™'s CCD (0.03 ± 0.045 mm) (Figure 4-6).

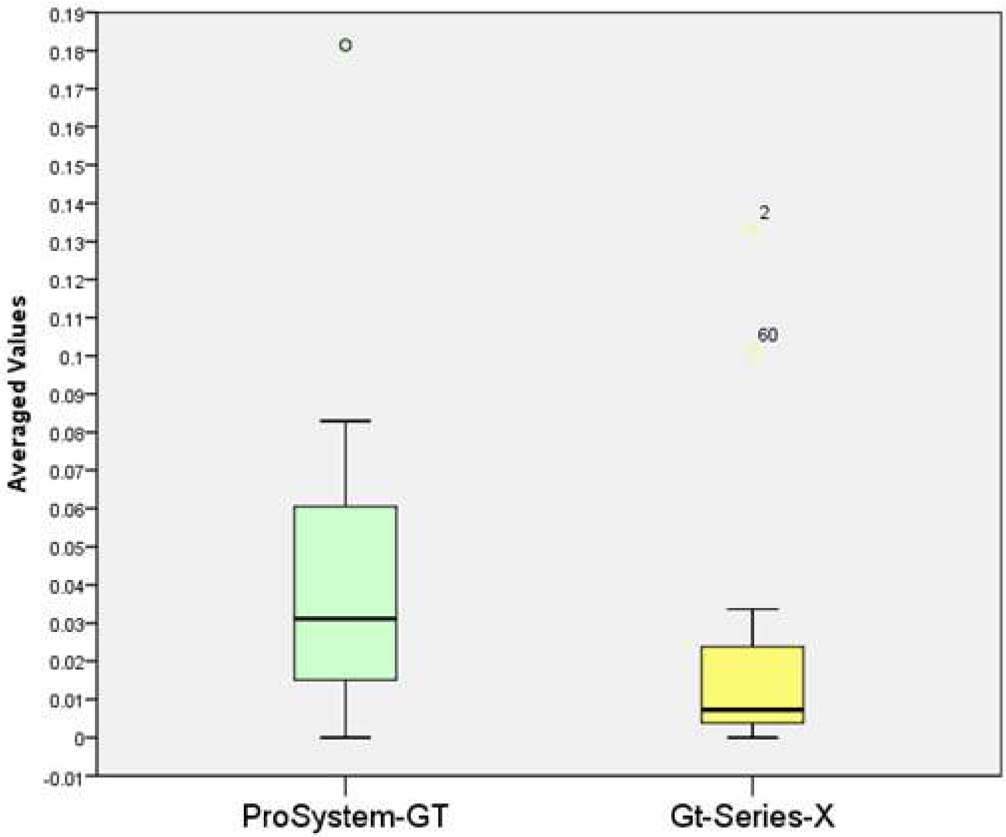

Figure 4-6: "Below the curved region" CCD for both rotary systems.

5. Discussion

The most important stage in root canal treatment is cleaning and shaping (Schilder 1974). There are several iatrogenic complications that can potentially happen while doing the root canal treatment such as zip, perforation, ledge formation, apical transportation, or deviation from the original canal pathway (Weine et al. 1975).

The present study is the first study which compares two rotary file systems, ProSystem GT™ and GT-Series-X™. In this study, the focus was on the canal center displacement of these two rotary file systems. Due to the some external defects, multiple root curvature, joined mesial canals, or abrupt curvature, a number of extracted teeth was excluded from the study. The remaining samples were 31 extracted mandibular first and second molars which were used to evaluate the canal center displacement using two rotary systems; ProSystem GT™ and GT-Series-X™.

5.1 Canal center displacement

The results of this investigation showed more canal center displacement while using ProSystem GT™ in comparison to GT-Series-X™, and the difference was significant. The difference in canal transportation may be due to the M-wire used to make the GT-Series-X™ files. This M-wire, a modification of Nickel- titanium, makes the files stronger. Also, M-Wire adds more cutting ability to the file, so there is potential of having less pressure during instrumentation. It can help keep the file more in the pathway of the canal and minimize deviation from the original axis of the root canal. Also, the canal center displacement results in our study could be because GT- Series-X files have larger chip spaces along the file. This feature has the advantage of taking much longer for the chips spaces to be filled. By having this advantage, not only there is more cutting ability, but there is less taper lock in the canal. The third reason could be because GT-Series-X™ files are more flexible than ProSystem GT™ files due to fewer cutting flutes, wider cutting flutes, more open blade angles, and M-Wire NiTi construction. Less stiffness and more flexible files could be another reason to have more centered canal preparation.

Another finding of this study was the canal center displacement in different regions along the canal (Table 5-1). If we classify the canal into three different portions as “above the curved region” “curved region” and “below the curved region”, we can study the canal center displacement at each section separately.

The results showed that in using ProSystem GT™ rotary system, “above the curved” regions showed more canal center displacement than in “curved regions”. Also, “curved regions” showed more canal center displacement than the “below the curved regions”, and the differences were significant for both files. This result is true for the GT-Series-X™ rotary files as well. Canal center displacement of “above the curved region” is greater than “curved region” while using GT-Series-X™. Also, “curved region” canal center displacement is higher than “below the curved region”, and this difference is significant.

It has been suggested that maybe there are different factors influencing the canal center displacement such as canal curvature, instrument design, physical properties of the alloy, and technique (Kosa et al. 1999). We can add another factor – that of the “region” of the canal. The reason for canal center displacement in different regions could be due to the instrument tapering. When we insert the instrument in the canal after having the glide path, it is passive. Considering the taper of the instrument, we remove more tooth structure from upper parts of the canal such as the cervical and middle part than from the apical part.

Another part of the results was comparing the canal center displacement of each region for both instruments. We compared the canal center displacement at “above the curved” region for both ProSystem GT™ and GT-Series-X™ rotary instruments. Even though, CCD was greater for ProSystem GT™ as expected, the difference was not statistically significant. Also, “curved” region, and “below the curved” region, CCD was greater for ProSystem GT™ than GT-Series-X™ as expected, but it was not significant as well. One explanation could be the sample size.

The difference observed between the two systems at different curvature levels, were not statistically significant. At least two reasons can be given to that. Firstly, the sample sizes were not large enough to reach the statistical significant difference. Secondly, there are no substantial differences between these two types of files. The differences I observed are relatively small, and seemingly they are of marginal clinical importance.

It is of note, that even though ProSystem GT™ caused significant greater canal center displacement (0.08 mm) compared to the GT-Series-X™(0.64)mm, it is still less than 0.10 mm which is the diameter of the tip of a #10 file. It is fair to say it may not be of clinical importance even though "it" is available in research.

5.2 Different root canal curvature measurement techniques

As it has been mentioned, there are different ways to measure the root canal curvature such as; Schneider method, Weine method, Long axis method, linear method, curvature radius measurements, Canal access angle, and method based on numeric calculus. I used Schneider method to measure the curvature angle since I was able to easily measure the angles using this technique. Also, Schneider method was easy to be used in AutoCAD™ software, and this method is reproducible, as well.

Weine techniques mainly consider the apical region curvature, not the whole canal curvature (Gunday et al. 2005). Also, the LA technique considers only the apical curvature of the canal and does not evaluate the overall root canal curvature (Gunday et al. 2005). Hankins et al. investigated widening techniques used for curved canals using the Schneider and LA angles and reported that the LA technique revealed changes in the apical curvature of the root canal better than the Schneider technique (Hankins and Eldeeb 1996).

In “Curvature Radius” method, the radius of curvature and the angle of curvature mathematically specify in the shape factors of a curved root canal system. The radius of curvature (in millimeters) is the radius of a circle that coincides with the path taken by the canal in comparison to a smaller radius of curvature. The angle of curvature is the degrees arc formed between the perpendicular lines drawn from the tangents intersecting at the center of the circle. The angle of curvature is independent of the radius. Thus, two canals with the same degree of curvature can have radically different radii (Pruett et al. 1997). Gunday cites that the angular values obtained using the curvature radius method introduced by Pruett et al were geometrically equivalent to the curvature angle measured using the Weine technique in the same canal (Gunday et al. 2005).

CAA is introduced to take into account the stress on instrumentation during canal preparation. An increase in the curvature distance results in displacement of the curvature point away from the canal entrance. In such a case, deformation and stress on the canal instrument intensify toward the tip. Most studies have used the Schneider method to determine root canal curvature. However CAA is as effective as the Schneider angle in evaluating root canal curvature with respect to its influence on the operation of root canal instruments. In addition, it is a better method to measure effectiveness of new root canal instruments (Gunday et al. 2005).

The aim of numeric calculus is to present a new method to provide data on any type of root canal curvature at any point of the long axis of the canal. The method offers a means of determining curvatures precisely without random specification of reference points. The method is also capable of registering only minor changes in curvature in the two-dimensional long axis of the canal (Sonntag et al. 2006). Also Sonntag quotes that numeric calculus method enables instrumentation-induced changes in the curvature of the small and large curve to be precisely described. In view of the good reproducibility of the measurements, the method can provide more valid results than can be obtained with data expressed in angles. The method is thus a suitable means of verifying canal curvature retention after root canal instrumentation (Sonntag et al. 2006).

In the studies of root canal curvature Schneider angle is usually used; the Schneider Technique mainly emphasizes the canal curvature in the coronal and middle region (Gunday et al. 2005). Also, the frequently quoted degree of curvature according to Schneider (Schneider 1971) describes an angle (that is, a change of direction) but not a curvature in the mathematical sense (Sonntag et al. 2006). Sonntag believes that when using Schneider's method to measure the change in curvature induced by rotary instrumentation, a difference of up to 5° between the measurements recorded by the two investigators was still referred to as tolerable (Sonntag et al. 2006). In this study, the Schneider method has been used which is more accurate to measure the coronal and middle curvature, and applicable to be used via AutoCAD™ software.

5.3 Endodontic cube (evaluate the anatomy of the extracted teeth)

To study the canal center displacement after the instrumentation, the "Endodontic Cube" was used. The Endodontic Cube provided the possibility of exact repositioning of the tooth sections, and later comparing the sections.

As mentioned, an "Endodontic Cube" has five walls; four vertical and one horizontal. There are vertical grooves on two opposite walls which are used as the guidelines to re-assemble the cube. On the other two vertical walls there are several grooves with 1.5mm intervals which are used as indices for disc placement and to make the cuts. Also, these indices are used to re-position the sections while re-assembling the cube (Kuttler et al. 2001a). It is important to have the sections immobile while instrumenting. Endodontic Cube provides this possibility with the rigid walls, and external fixations.

Another advantage of the "Endodontic Cube" is the ease of taking radiographs without having any metal noise on the way. Some systems have the limitation of taking a radiograph from one direction only because of metal parts like the walls or pins.(Tamse et al.1998) (Hülsmann et al. 1999).

The limitation of the “Endodontic Cube” is taking the time to assemble and dis-assemble the cubes, not having escapeways for the irrigation in studies where volume of irrigation is of concern (Kuttler et al. 2001a), and not being able to study the very thin sections (thinner than 1.5 mm).

5.4 Role of AutoCAD™ software in root canal measurements

AutoCAD™ drafting environment was used to compare the pre and post instrument images and perform the measurements. It provided the re-producible situation to measure the canal width before and after instrumentation. Also, it automatically measured the canal center displacement.

5.5 Study limitations

The limitations of this study could be summarized as below:

- Small sample size
- Time consuming process due to sectioning, assembling and dis-assembling
- Physical sectioning and possibility of unknown tissue changes
- Not having the sections thinner than 1.5 mm
- In-vitro study

The fact that I found statistically significant difference between two files despite the relatively small sample size means that the actual difference is larger. Other than sample size, the higher standard deviation could be associated with variability of tooth morphology, and operator skill (Ponti et al. 2002).

5.6 Conclusions

The following conclusions can be made in the context of this investigation:

- Both ProSystem GT™ and GT-Series-X™ tended to move the original canal toward the furcation.
- Both ProSystem GT™ and GT-Series-X™ files worked well and resulted in relatively small displacement. The ProSystem GT™ caused greater canal center displacement, and the difference was statistically significant.
- There were significant differences in CCD amongst the three regions of root canals instrumented using GT-Series-X™ or ProSystem GT™.

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