The minimum residual root thickness after using ProTaper, RaCe and Gates-Glidden drills: A cone beam computerized tomography study

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ABSTRACT

Objective: The aim of this study was to evaluate the minimum residual root thickness (MRRT) of the danger zone after preflaring of the mesio-buccal (MB) canal of mandibular first molars using ProTaper, RaCe and Gates-Glidden (GG) drills as coronal shapers by cone beam computed tomography (CBCT). Materials and Methods: In this experimental study, the initial CBCT scans of 75 MB canals of mandibular first molars were provided within 1, 2, 3 and 4 mm of the furcation level. The samples were divided into three groups. The samples of ProTaper and RaCe groups were prepared up to F2 and #25.04 as the master apical file (MAF), respectively. The coronal preparation of the samples in the GG group was done using GG drills #2, #3 and #4 and canals were prepared till MAF # 25. After obtaining the postinstrumentation images, the MRRT and the amount of removed dentin were analyzed by t-test and ANOVA statistical analyses. Results: The GG drills removed significantly more dentin than RaCe at all the sections (P < 0.05) and more than ProTaper at 3 mm from the furcation. Statistically there was no significant difference between ProTaper and RaCe groups (P > 0.05). There was no significant difference in MRRT between the groups (P > 0.05). The mean MRRT was not < 0.75 mm at all sections. Conclusion: Based on the results of this study, when an appropriate root thickness is initially present, all of the instruments that were investigated may safely be used as coronal shapers in MB canals of mandibular first molars.

Key words: Dental instruments, dentin, instrumentation, root canal preparation

INTRODUCTION

Coronal flaring is recommended for eliminating middle and coronal third interferences in root canals. It results in better control of files during apical preparation[1,2] and also facilitates the working length (WL) determination and apical enlargement.[3-7] Preflaring allows a deeper penetration of irrigation needles and thereby permits more effective debridement.[8] On the other hand, over-preparing the coronal third of the root canal can increase the risk of perforation especially in the furcation area.[9] Furthermore, preflaring results in thinning of the canal walls and increase the risk of tooth fracture.[1]

Gates-Glidden (GG) drills are the most common instruments used in coronal flaring. The low cost, high cutting potential, and easy use of GG drills, have made them widely-used instruments for coronal preparation of root canals.[10] GG drills #1 and #2 used in the coronal third of mesio-buccal (MB) canals of mandibular molars do not significantly decrease the residual dentin thickness.[11,12] On the other hand, it was reported that regardless of the size of the GG drill and the depth of penetration, it weakens the furcation area of mandibular molars.[13]

Nickel-titanium (Ni-Ti) instruments effectively improve the funnel shape of canals and have the least
risk of root canal transportation.\textsuperscript{[14,15]} Rotary files not only make facilitate and hasten preparations, but also produce a predictable and reproducible root canal shape with less iatrogenic damage.\textsuperscript{[16,17]} Different Ni-Ti file systems with specific coronal shapers have been introduced to the market.\textsuperscript{[18]}

The ProTaper rotary file system has three coronal shapers (S1, S2 and SX), and the RaCe rotary system has two coronal shapers (#35.08 and #40.10).

Numerous studies have compared the Ni-Ti files\textsuperscript{[17,19]} but few have evaluated coronal enlargers.\textsuperscript{[20‑22]} The aim of this study was to evaluate the minimum residual root thickness (MRRT) of danger zone after canal preparation using GG drills, ProTaper and RaCe rotary files in MB canals of mandibular first molars by cone beam computerized tomography (CBCT).

**MATERIALS AND METHODS**

A total of 135 mandibular first molars, extracted from the patients aged 35 to 55 years due to periodontal disease, were collected and disinfected by immersion in a 5.25% NaOCl solution for 1 h, then stored in saline until further use. All teeth with external or internal root resorption, open apices, visible cracks, fractures, caries, and previous root canal treatment were excluded. The root canals with lengths of 9–12 mm (from furcation level to the apex) were used in this study. Access cavities were prepared and distal roots were cut from 1 mm below the furcation level using diamond discs. The presence of two separate mesial canals was confirmed by simultaneous placement of two K-files #10 (Maillefer, Ballaigus, Switzerland) in the canals. Canal patency was checked by visualizing the tip of the K-files #10 from the apical foramen of the MB canal. Root canals with apical stops up to file #15 were included, and those beyond #15 were excluded. To determine the canal curvature, a K-file #10 was placed in the MB canal and parallel radiographs were provided in bucco-lingual and mesio-distal directions. Using Schneider’s technique,\textsuperscript{[23]} canal curvature was determined. Only teeth with a curvature ranged 20°–35° were included. Eventually, 75 mandibular first molars were coded for further assessment.

**Preparation images**

The teeth were placed halfway into acrylic resin molds with their buccal surface facing upwards. To facilitate the orientation of canal in the CBCT sections (Somatom Sensation 16 computerized tomography [CT] Scanner, Siemens, Berlin, Germany), a copper filament was inserted into the resin, parallel to the long axis of the tooth, near the mesio-lingual line angle. The samples were then randomly stabilized on a fiber board, on which all furcations were aligned and tooth codes were recorded. Due to the slice thickness of the CBCT scan (0.8 mm) and the slice distance of 0.2 mm, sections were obtained of 1, 2, 3 and 4 mm from the furcation level. Teeth were then fixed and placed in the CBCT scanner and the initial images were provided. The minimum initial root thickness (MIRT) of the furcation area in the MB canal was evaluated in the mentioned sections by Syngo CBCT software VB20 (Siemens AG, Erlangen, Germany); Siemens program [Figure 1]. Then the samples were randomly divided into three groups by the table of random numbers (Group G, Group R and Group PT). The average MIRT was assessed in the three groups and hence that no significant difference would be present.

**Canal preparation procedures**

In Group G, based on the passive step-back technique,\textsuperscript{[24]} the coronal shaping was done using GG drills #2, 3 and 4 (Dentsply, Maillefer, Switzerland) respectively by a conventional motor at low speed of 2500 rpm. The penetration depth of GG drills was as follow: #2 maximum to the coronal half of the canal, #3 to the coronal third, and #4 to the canal orifice. Canal preparation of the middle and apical thirds was done using k-Flexofiles #15–25 (Maillefer, Ballaigus, Switzerland). File #25 was considered as master apical file (MAF).

In Group R, the canals were prepared with RaCe rotary files (FKG-Dentaire) as follows: File #40.10, #35.08, #25.06 for the coronal two-thirds and #25.04 to the WL as MAF.

**Figure 1:** The cone beam computerized tomography scans of the pre and postpreparation images of the mesio-buccal canals of mandibular first molars
In Group PT, canal preparation was done by ProTaper (Dentsply, Maillefer, Switzerland) files SX, S1, S2, F1, and F2 respectively as instructed by the manufacturer and F2 was selected as MAF. A motor controller (X-smart, Maillefer/Dentsply, Ballaigus, Switzerland) with the recommended torque and speed was used for each rotary file. In order to avoid perforations, the anti-curvature method was used.

After using each file, the canals were irrigated with 2 mL of regular saline and 1 mL of 2.5% NaOCl, while file #10 was used to ensure patency. An endodontist (NMA) prepared all the canals and each instrument was used for the preparation of 5 canals. The number of strokes for each of the instruments was five.

**Postpreparation images**

After canal preparation, the samples were placed again in the initial molds and CBCT scans were obtained in a similar fashion to the initial imaging. Subsequently, the MRRT was assessed [Figure 1]. The amount of the dentin removal (DR) was calculated by subtracting the amount of the residual root thickness (RRT) from the initial root thickness (IRT). In this study, the relative percentage of DR was calculated by dividing the amount of DR to IRT (DR/IRT) ×100.\(^\text{25}\)

**Statistical tests**

To compare the thicknesses of pre and postpreparation in each group and in each section, the paired \(t\)-test was used. For comparison of the MIRT, MRRT, and the amount of DR in each group, the repeated measure ANOVA was used. Furthermore, to compare the mentioned values among the groups, the ANOVA test was applied. The significance level was set at 5%.

**RESULTS**

**Evaluation of the minimum initial root thickness**

The MIRT in the furcation area of the MB canals in all the groups and for all the sections was determined [Figure 2 and Table 1].

In intra-group comparison, there was a statistically significant difference among the sections in each group \((P < 0.001)\). In inter-group comparison of each section, no significant difference could be detected \((P > 0.05)\).

| Sections | Groups | \(P\) |
|----------|--------|------|
| 1 mm     | PT     | 1.20±0.19 |
|          | RaCe   | 1.10±0.18 |
|          | GG     | 1.19±0.19 |
| 2 mm     | PT     | 1.13±0.16 |
|          | RaCe   | 1.06±0.16 |
|          | GG     | 1.12±0.19 |
| 3 mm     | PT     | 1.08±0.14 |
|          | RaCe   | 1.03±0.14 |
|          | GG     | 1.08±0.18 |
| 4 mm     | PT     | 1.08±0.15 |
|          | RaCe   | 1.00±0.15 |
|          | GG     | 1.06±0.18 |
| \(P\)    |        | 0.09    |

**Evaluation of the minimum residual root thickness**

In intra-group comparison of the root thickness of pre and postcanal preparation there was a significant difference in each of the groups \((P < 0.05)\) [Figure 3 and Table 2].

In inter-group comparisons, there was no significant difference between the groups \((P > 0.05)\).

**The amount of dentin removal**

In intra-group assessments, no significant difference was detected in any of the groups \((P > 0.05)\). In inter-group comparisons, there was a significant difference \((P < 0.05)\).

The amount of DR by GG drills was significantly greater in all the sections than the R group, whereas compared with PT group; it was only greater in sections that were 3 mm from the furcation. Groups R and PT had no significant difference for the amount of DR in any of the sections [Table 3].

The lowest relative percentages (LRP) of DR/IRT and the greatest relative percentages (GRP) of DR/IRT in the three groups were as follows:

\[ \]
Mishaps
There were no deformities, broken instruments, or perforations during root canal preparation.

DISCUSSION
This study compared the MRRT of the furcation area of MB canals of mandibular first molars using RaCe, ProTaper and GG drills by CBCT method. When measuring the amount of DR, there was no significant difference in intra-group comparisons. This suggests that the DR was uniform in all the groups.

In this study, in inter-group comparisons, RaCe and ProTaper systems removed similar amounts of dentin with no significant difference, whereas GG drills significantly removed more when compared with RaCe system.

In comparing different techniques and instruments or anatomical evaluations, among the different techniques, the CBCT method has the capability of three-dimensional description of the root canal.\cite{26,27}

This was especially evident in the coronal and middle thirds, which are the major areas altered by enlarging endodontic instruments.\cite{28,29}

In this study, a CBCT method with slice thickness of 0.8 and slice distance of 0.2 was used.

The samples used in this study had 20°–35° root canal curvature in bucco-lingual or mesio-distal radiographs. Such a limited range for curvature cannot be seen in many studies.\cite{20,21}

Considering that age is an influential factor in the IRT, for better comparison, teeth from the patients aged 35–55 years were selected.

Some previous researchers have\cite{8,30,31} mentioned that the area within 3–4 mm below the root canal orifice is the most sensitive area during rotary preparation of mesial canals of molar teeth. Therefore, similarly to previous studies,\cite{9,19,20} this evaluation was conducted regarding the danger zones of furcation area.

In the present study, MIRT of MB canal of mandibular first molars in the danger zones was more than 1 mm in all the sections except in the 4 mm from the furcation. In all groups, the amount of MIRT gradually decreased from 1 mm to 4 mm from the furcation.

Berutti and Fedon\cite{32} reported that the root thickness of the mesial canal of mandibular first molars was smallest (1.2–1.3 mm) within 1.5 mm of the furcation.

**Table 2: The mean±SD of the MRRT at different sections of the MB canals of mandibular first molars in the three groups (in mm)**

| Sections | PT  | RaCe | GG  | P     |
|----------|-----|------|-----|-------|
| 1 mm     | 0.96±0.20 | 0.94±0.18 | 0.89±0.21 | 0.46   |
| 2 mm     | 0.91±0.18 | 0.87±0.16 | 0.84±0.21 | 0.35   |
| 3 mm     | 0.86±0.19 | 0.84±0.17 | 0.78±0.20 | 0.25   |
| 4 mm     | 0.84±0.19 | 0.80±0.20 | 0.75±0.21 | 0.25   |

**Table 3: The mean±SD of the DR at different sections of the MB canals of mandibular first molars in the three groups (in mm)**

| Sections | PT  | RaCe | GG  | P     |
|----------|-----|------|-----|-------|
| 1 mm     | 0.25±0.15 | 0.16±0.14 | 0.30±0.11 | 0.002  |
| 2 mm     | 0.22±0.14 | 0.19±0.11 | 0.29±0.08 | 0.012  |
| 3 mm     | 0.22±0.14 | 0.18±0.10 | 0.31±0.07 | 0.000  |
| 4 mm     | 0.25±0.13 | 0.20±0.13 | 0.30±0.01 | 0.021  |

**Group PT**
- The LRP of DR/IRT was 19% at the section 2 and the GRP of DR/IRT was 23% at the section 4 mm from the furcation.

**Group R**
- The LRP of DR/IRT was 14% at the section 1 and the GRP of DR/IRT was 20% at the section 4 mm from the furcation.

**Group G**
- The LRP of DR/IRT was 25% at the section 1 and the GRP of DR was 29% at the section 3 mm from the furcation.

**Figure 3:** The minimum residual root thickness of the furcation area in different sections of the mesio-buccal canals of mandibular first molars (in mm)

**Table 2:** The mean±SD of the MRRT at different sections of the MB canals of mandibular first molars in the three groups (in mm)

| Sections | Groups | P     |
|----------|--------|-------|
| PT       | RaCe   | GG    |
| 1 mm     | 0.96±0.20 | 0.94±0.18 | 0.89±0.21 | 0.46   |
| 2 mm     | 0.91±0.18 | 0.87±0.16 | 0.84±0.21 | 0.35   |
| 3 mm     | 0.86±0.19 | 0.84±0.17 | 0.78±0.20 | 0.25   |
| 4 mm     | 0.84±0.19 | 0.80±0.20 | 0.75±0.21 | 0.25   |

**SD:** Standard deviation, **MB:** Mesio-buccal, **PT:** ProTaper, **GG:** Gates-Glidden, **MRRT:** Minimum residual root thickness

**Table 3:** The mean±SD of the DR at different sections of the MB canals of mandibular first molars in the three groups (in mm)

| Sections | Groups | P     |
|----------|--------|-------|
| PT       | RaCe   | GG    |
| 1 mm     | 0.25±0.15 | 0.16±0.14 | 0.30±0.11 | 0.002  |
| 2 mm     | 0.22±0.14 | 0.19±0.11 | 0.29±0.08 | 0.012  |
| 3 mm     | 0.22±0.14 | 0.18±0.10 | 0.31±0.07 | 0.000  |
| 4 mm     | 0.25±0.13 | 0.20±0.13 | 0.30±0.01 | 0.021  |

**SD:** Standard deviation, **MB:** Mesio-buccal, **PT:** ProTaper, **GG:** Gates-Glidden, **DR:** Dentin removal

**Group PT**
- The LRP of DR/IRT was 19% at the section 2 and the GRP of DR/IRT was 23% at the section 4 mm from the furcation.
Akhlaghi, et al.: Residual root thickness

Mahran and AboEl-Fotouh\textsuperscript{[20]} evaluated the effect of HeroShaper, ProTaper system, and GG drills in the coronal portion (within 3 mm from the furcation) of MB canals of the mandibular first molars and similar to the present study, reported that the mean IRT was more than 1 mm.

In a study conducted by Coutinho-Filho et al.,\textsuperscript{[10]} the average IRT at a 3 mm distance from the furcation area in the mesial canal of mandibular first molars was 0.8 mm $\pm$ 0.17 mm. Akhlaghi et al.\textsuperscript{[25]} stated that, at the coronal level (1–2 mm from the furcation), the mean of IRT of distal and distolingual walls of MB canal in mandibular first molars were $<$1 mm (0.94 and 0.78 mm respectively). Garala et al.\textsuperscript{[33]} reported the IRT is the most important factor in determining the RRT after the root canal preparation.

In a study by Uyanik et al.,\textsuperscript{[27]} the amount of DR in the coronal third was not significantly different between RaCe and ProTaper systems, as seen in the present study. Mahran and AboEl-Fotouh\textsuperscript{[29]} showed that ProTaper files removed less dentin compared to GG drills in the furcation area of the MB canal of mandibular first molars.

Considering that the mean MRRT in all the groups of this study had no significant difference and were $>$0.75 mm, each of these instruments may be used as safe coronal enlargers.

The results of the current study showed that, if rotary instruments are used in brushing movements and in an anti-curvature style, a proper and safe root thickness would be maintained. Lim and Stock\textsuperscript{[34]} showed that the MRRT after preparation should be no $<$0.3 mm to resist against the forces during root canal obturation. According to their results, MB canals of mandibular first molars after rotary instrumentation have sufficient resistance to root canal obturation.

Unlike this study, Wu et al.\textsuperscript{[13]} reported that using GG drills in mandibular molars weakens the furcation area, regardless of the size of the instrument or the penetration depth. They mentioned that using the anti-curvature method does not lower the risk of strip perforation.

Zuckerman et al.\textsuperscript{[11]} evaluated the RRT of mesial canals of mandibular molars with curvatures $<$30° using the light speed system and GG drills and similar to this study, reported no significant difference between the IRT and RRT.

In the present study, the average of the MRRT in all sections and groups was $<$ 1 mm. Raiden et al.\textsuperscript{[35]} have shown that at least 1 mm of root thickness must be maintained around the post, to resist against vertical fracture. Akhlaghi et al.\textsuperscript{[25]} indicated that the RRT of the MB canal of mandibular first molars in the distal and disto-lingual walls of the furcation area after canal preparation was $<$1 mm (0.72 and 0.53 mm respectively). Therefore, it seems that the mesial canals of mandibular first molars are not sufficiently resistant to vertical fractures when posts are inserted in them.

**CONCLUSIONS**

Based on the results of this study, GG drills removed significantly more dentin than RaCe rotary files in furcation area. However, the MRRT was not significantly different among the groups. Considering the limitations, when optimum IRT are present, GG drills, RaCe and ProTaper systems may safely be used for preflaring the MB canals of mandibular first molars without weakening the furcation area.

**REFERENCES**

1. Isom TL, Marshall JG, Baumgartner JC. Evaluation of root thickness in curved canals after flaring. J Endod 1995;21:368-71.
2. Schilder H. Cleaning and shaping the root canal. Dent Clin North Am 1974;18:269-96.
3. Davis RD, Marshall JG, Baumgartner JC. Effect of early coronal flaring on working length change in curved canals using rotary nickel-titanium versus stainless steel instruments. J Endod 2002;28:438-42.
4. Barroso JM, Guerisoli DM, Capelli A, Saquay PC, Pécora JD. Influence of cervical preflaring on determination of apical file size in maxillary premolars: SEM analysis. Braz Dent J 2005;16:30-4.
5. Vanni JR, Santos R, Limongi O, Guerisoli DM, Capelli A, Pécora JD. Influence of cervical preflaring on determination of apical file size in maxillary molars: SEM analysis. Braz Dent J 2005;16:181-6.
6. Schmitz MdA S, Santos R, Capelli A, Jacobovitz M, Spanó JC, Pécora JD. Influence of cervical preflaring on determination of apical file size in mandibular molars: SEM analysis. Braz Dent J 2008;19:245-51.
7. Ibelli GS, Barroso JM, Capelli A, Spanó JC, Pécora JD. Influence of cervical preflaring on apical file size determination in maxillary lateral incisors. Braz Dent J 2007;18:102-6.
8. Abou-Rass M, Frank AL, Glick DH. The anticurvature filing method to prepare the curved root canal. J Am Dent Assoc 1980;101:792-4.
9. Coutinho-Filho T, De-Deus G, Pinto TC, Gurgel-Filho ED, Maniglia-Ferreira C A. Computer evaluation of the dentin remaining after cervical preparation in curved canals: Gates-glidden drills vs orifice shaper. Braz J Oral Sci 2002;1:116-20.
10. Coutinho-Filho T, De-Deus G, Gurgel-Filho ED, Rocha-Lima AC, Dias KR, Barbosa CA. Evaluation of the risk of a stripping perforation with Gates-Glidden drills: Serial versus crown-down sequences. Braz Oral Res 2008;22:18-24.
11. Zuckerman O, Katz A, Piló R, Tamse A, Fuss Z. Residual dentin thickness in mesial roots of mandibular molars prepared with Lightspeed rotary instruments and Gates-Glidden reamers. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;96:351-5.
12. Duarte MA, Bernardes RA, Ordinola-Zapata R, Vasconcelos BC, Bramante CM, Moraes IG. Effects of Gates-Glidden, LA Axxess and orifice shaper burs on the cervical dentin thickness and root canal area of mandibular molars. Braz Dent J 2011;22:28-31.
13. Wu MK, van der Sluis LW, Wesselinck PR. The risk of furcal perforation
in mandibular molars using Gates-Glidden drills with anticurvature pressure. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005;99:378-82.
14. Thompson SA, Dummer PM. Shaping ability of ProFile. 04 Taper Series 29 rotary nickel-titanium instruments in simulated root canals. Part 2. Int Endod J 1997;30:8-15.
15. Thompson SA, Dummer PM. Shaping ability of ProFile. 04 Taper Series 29 rotary nickel-titanium instruments in simulated root canals. Part 1. Int Endod J 1997;30:1-7.
16. Schirmeister JF, Strohl C, Altenburger MJ, Wrbas KT, Hellwig E. Shaping ability and safety of five different rotary nickel-titanium instruments compared with stainless steel hand instrumentation in simulated curved root canals. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;101:807-13.
17. Özgür Uyanik M, Cehreli ZC, Ocigen Mocan B, Tasman Dagli F. Comparative evaluation of three nickel-titanium instrumentation systems in human teeth using computed tomography. J Endod 2006;32:668-71.
18. Dietschi JM, Dietschi D, Krejci I. Nickel-titanium rotary instruments: Review and strategy for development of a new instrument. Pract Proced Aesthet Dent 2001;13:385-9.
19. Plotino G, Grande NM, Falanga A, Di Giuseppe IL, Lamorgese V, Somma F. Dentine removal in the coronal portion of root canals following two preparation techniques. Int Endod J 2007;40:852-8.
20. Mahran AH, AboEl-Fotouh MM. Comparison of effects of ProTaper, HeroShaper, and Gates Glidden Burs on cervical dentin thickness and root canal volume by using multislice computed tomography. J Endod 2008;34:1219-22.
21. Akhlaghi NM, Naghdi A, Bajgiran LM, Behrooz E. Computed tomography evaluation of residual root thickness after pre-flaring using gates Glidden drills: The sequence effect. J Conserv Dent 2014;17:142-5.
22. Carvalho-Sousa B, Costa-Filho JR, de Almeida-Gomes F, Maniglia-Ferreira C, Gurgel-Filho ED, Albuquerque DS. Evaluation of the dentin remaining after flaring using Gates Glidden drills and protaper rotary files. RSBO 2011;8:194-9.
23. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol 1971;32:271-5.
24. Torabinejad M. Passive step-back technique. A sequential use of ultrasonic and hand instruments. Oral Surg Oral Med Oral Pathol 1994;77:402-5.
25. Akhlaghi NM, Kahali R, Abtahi A, Tabatabaei S, Mehrvarzfar P, Parirokh M. Comparison of dentine removal using V-taper and K-Flexofile instruments. Int Endod J 2010;43:1029-36.
26. Karatas OH, Toy E. Three-dimensional imaging techniques: A literature review. Eur J Dent 2014;8:132-40.
27. Nur BG, Ok E, Altunsoy M, Aglarci OS, Colak M, Gungor E. Evaluation of the root and canal morphology of mandibular permanent molars in a south-eastern Turkish population using cone-beam computed tomography. Eur J Dent 2014;8:154-9.
28. Hervás A, Forner L, Llena C, Zaragoza E. Evaluation of morphological changes produced by orifice opener systems using computerized tomography (CT). Med Oral Patol Oral Cir Bucal 2009;14:e674-9.
29. Gluskin AH, Brown DC, Buchanan LS. A reconstructed computerized tomographic comparison of Ni-Ti rotary GT files versus traditional instruments in canals shaped by novice operators. Int Endod J 2001;34:476-84.
30. Kessler JR, Peters DD, Lorton L. Comparison of the relative risk of molar root perforations using various endodontic instrumentation techniques. J Endod 1983;9:439-47.
31. McCann JT, Keller DL, LaBounty GL. A modification of the muffle model system to study root canal morphology. J Endod 1990;16:114-5.
32. Berutti E, Fedon G. Thickness of cementum/dentin in mesial roots of mandibular first molars. J Endod 1992;18:545-8.
33. Garala M, Kuttler S, Hardigian P, Steiner-Carmi R, Dorn S. A comparison of the minimum canal wall thickness remaining following preparation using two nickel-titanium rotary systems. Int Endod J 2003;36:636-42.
34. Lim SS, Stock CJ. The risk of perforation in the curved canal: Anticurvature filing compared with the stepback technique. Int Endod J 1987;20:33-9.
35. Raiden G, Koss S, Costa L, Hernández JL. Radiographic measurement of residual root thickness in premolars with post preparation. J Endod 2001;27:296-8.