Fracture Resistance of Roots in Mandibular Premolars Following Root Canal Instrumentation of Different Sizes

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Objective: *To measure the fracture resistance of mandibular premolar roots following root canal instrumentation with different sizes.*

Methods: *A total of 100 human permanent mandibular premolars with a straight single canal were decoronated and assigned to 10 groups (n = 10) by block randomisation. In the control group, the roots were uninstrumented, whereas roots in the nine experimental groups were instrumented to different master apical files (MAF) and tapers (MAF/taper): 40/0.05, 45/0.05, 50/0.05, 55/0.05, 60/0.05, 40/0.10, 40/0.15, 45/0.10 and 45/0.15. All roots were subjected to vertical loading until fracture.*

Results: *Fracture load values for instrumented roots were lower than the intact roots of the control group. In 50/0.05, 55/0.05, 60/0.05, 40/0.15 and 45/0.15 groups, the fracture load values were significantly lower than the fracture load value for the control group ($P < 0.05$) with a 30% decrease. No significant differences in the fracture modes were detected among the 10 groups ($P > 0.05$).*

Conclusion: *Mechanical instrumentation adversely affects the fracture resistance of roots. When the roots of mandibular premolars were instrumented to a MAF equal to or larger than 50 with a taper of 0.05 or to a MAF of 40 or 45 with a taper of 0.15, the fracture load values significantly decreased.*

Key words: *tooth fractures, root canal preparation, mandibular premolars*

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The mechanical instrumentation of the root canal is a primary procedure in root canal treatment[1]. Compared with conservative instrumentation, which cannot produce satisfactory cleaning and shaping, larger instrumentation can contribute to removing infected tissue, achieving appropriate penetration of irrigants, and creating space for the delivery of medications and subsequent obturation materials[2-5]. However, aggressive instrumentation may weaken tooth structure and increase the risk of perforation, ledge, and transportation of canal.

At present, little is known about optimal instrumentation sizes and how instrumentation affects the mechanical properties of teeth. Different results have been reported regarding the effect of instrument size on tooth fracture susceptibility, due to variations in tooth type and instrument size in the experimental designs of previous studies[6-9].

The purpose of this study was to measure the fracture resistance of mandibular premolar roots with different final canal instrumentation sizes.

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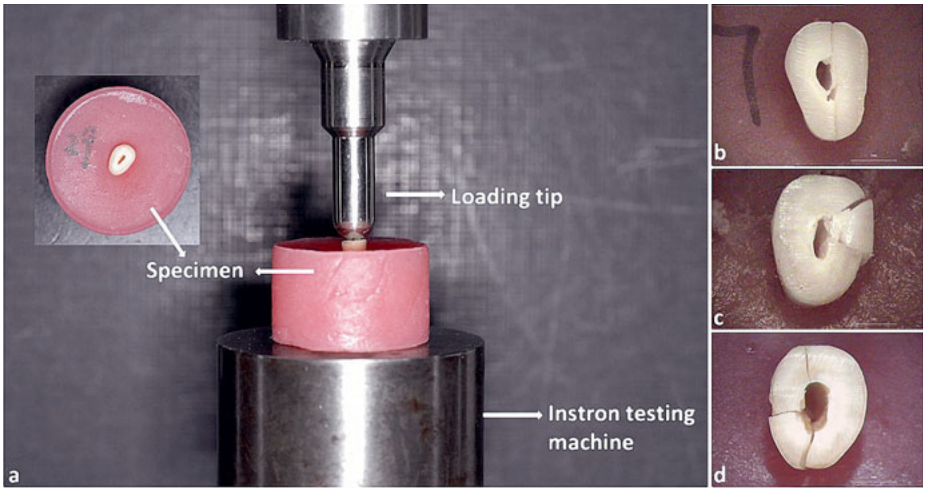

Fig 1 Setting used for static strength testing (a) and specimen fracture modes, (b) buccolingual fracture, (c) mesiodistal fracture and (d) compound fracture.

Materials and methods

Newly extracted permanent mandibular premolars were collected, and buccolingual and mesiodistal radiographs were obtained. Teeth were included in the study after the radiographs indicated a single canal with a curvature of less than 10 degrees (Schneider method), and a ratio between the internal long diameter and the short diameter of < 2 at a level of 5 mm from the apex. An examination was performed using a stereomicroscope (Zoom-630E, Chang-Fang Optical Instrument, Shanghai, China) at 15x magnification to exclude teeth with immatureness, fractures or cracks. Teeth with an apical foramen larger than size 15 were also excluded. A total of 100 teeth were included and kept in distilled water at 4°C until use.

All included teeth were decoronated at, or below, the cementoenamel junction using a high-speed diamond bur under copious water coolant, leaving roots with a 13 mm length. Root weights were calculated using a digital precision balance (Ohaus Corporation, Shanghai, China) after the roots were dried with cotton balls and paper points.

Instrumentation

The roots were randomly assigned to 10 groups (n = 10) by block randomisation according to weight.

The roots included in the control group were uninstrumented, whereas the roots in the nine experimental groups were instrumented to different master apical files (MAF) and tapers (MAF/taper) as follows: 40/0.05, 45/0.05, 50/0.05, 55/0.05, 60/0.05, 40/0.10, 40/0.15, 45/0.10 and 45/0.15.

The working length was established by a no. 10 K-file at 1 mm short of the apical foramen. Canal preparation was performed using hand K-files (M access, Dentsply Maillefer, Ballaigues, Switzerland) according to the step-back technique. The file sizes and increments are shown in Table 1. Distilled water was used as irrigant between each instrument. When the instrumentation was completed, all samples were examined using a stereomicroscope at 15x magnification. No cracks or craze lines were found.

Fracture Resistance Testing

All roots were vertically embedded in acrylic resin (Palavit G, Heraeus Kulzer, Hanau, Germany) with a 2 mm coronal exposure. The roots were subjected to vertical compressive loading using an universal testing machine (Instron, Canton, MA, USA) with a crosshead speed of 0.5 mm/minute (Fig 1). The loading force was applied via a stainless-steel ball with a diameter of 8 mm. The occurrence of fracture was determined when the applied load suddenly decreased. The fracture load values were recorded in Newtons (N) at the peak of the load-displacement curve. For most specimens, an audible crack was also heard. Fracture modes were observed using a stereomicroscope at 15x magnification and categorised as buccolingual, mesiodistal and compound fracture (Fig 1).

Statistical Analysis

The one-way analysis of variance (ANOVA) and the Tukey post-hoc test were used to compare the fracture load values. Fisher's exact test was performed to analyse the root fracture modes. The statistical significance level was set at $\alpha = 0.05$.

Table 1 Instrument sizes at different levels of roots in each group.

Distance from apical stop (mm)	Group (MAF/taper)								
	40/0.05	45/0.05	50/0.05	55/0.05	60/0.05	40/0.10	45/0.10	40/0.15	45/0.15
0	40	45	50	55	60	40	45	40	45
1	45	50	55	60		50	55	55	60
1.5							60		70
2	50	55	60		70	60		70	
2.5							70		
3	55	60		70		70		80	90
3.5							80		
4	60		70		80	80		100	100
5		70		80					
6			80		90				

MAF, master apical files.

Table 2 Fracture load values (N) of roots with different instrumentation sizes and reduction in comparison with control group (%).

Instrumentation size (MAF/Taper)	Fracture load (N)	Reduction (%)
Uninstrumented	1444 ± 155[a]	0
40/0.05	1339 ± 131[a,b]	7.3
45/0.05	1287 ± 144[a,b,c]	10.9
50/0.05	1027 ± 128[b,c,d]	28.9
55/0.05	994 ± 150[c,d]	31.2
60/0.05	983 ± 166[c,d]	31.9
40/0.10	1246 ± 331[a,b,c,d]	13.7
40/0.15	1026 ± 270[b,c,d]	28.9
45/0.10	1180 ± 296[a,b,c,d]	18.3
45/0.15	956 ± 279[d]	33.8

[a-d]Means with the same superscript letter did not differ significantly ($P > 0.05$); N, Newtons.

Results

The statistical analysis of root weights revealed no significant differences among the groups ($P > 0.05$).

The fracture load values were lower for roots after instrumentation than for the intact ones in the control group (Table 2). In the 50/0.05, 55/0.05, 60/0.05, 40/0.15 and 45/0.15 MAF/taper groups, the fracture load values were significantly lower than those of the control group, with a decrease of approximately 30% ($P < 0.05$). The fracture load values for the control group and the 40/0.05, 40/0.10, 45/0.05 and 45/0.10 groups did not differ significantly ($P > 0.05$). The reduction was between 7.3% and 18.3%.

The fracture modes were determined for all specimens. No significant differences in the fracture mode were observed among the 10 groups ($P > 0.05$). In total, most samples fractured in a buccolingual direction (57%), followed by the compound fracture (32%), whereas the mesiodistal fracture (11%) was less frequently observed.

Discussion

In the present study, freshly extracted mandibular premolars with a straight round canal were selected, and the length of the roots in each group were standardised. Roots with fractures or cracks were excluded. The samples were balanced according to weight. These procedures were implemented with the objective of ensuring that sound data were obtained[10,11]. Distilled water was used as irrigant, thereby avoiding the effects of NaOCl on the properties of dentine[12].

The dynamic and static loadings were protocols mostly used for investigating the fracture resistance of teeth or roots. The dynamic loading was more likely to correlate with clinical conditions and provoke the fatigue phenomenon. However, there is variation in the designs of the dynamic loading; thus comparing results may be hard. In the present study, the linear compressive (static) loading was used to test the fracture resistance of the root. It is a frequently applied method due to its efficiency and comparable outcome parameters[13]. In the present study, all roots were vertically embedded in acrylic resin without simulation of periodontal ligament, similarly to previous studies[6,14]. In other studies, the embedded teeth have been coated with polystyrene resin or plastic paint to simulate the periodontal ligament[9,12]. The studies by Soares et al[15] and Marchionatti et al[16] suggested that fracture resistance under a constant static load would not be affected by simulation of the periodontal ligament.

The results of this study indicate that mechanical instrumentation adversely affects the fracture resistance of roots. The detrimental effect of mechanical instrumentation on the fracture resistance of roots has also been observed in prior studies[6,8,17]. In the present study, the force required to fracture premolars when instrumented to 50/0.05, 55/0.05, 60/0.05, 40/0.15 or 45/0.15 was 30% lower than that of their intact counterparts. Prado et al[9], observed that the fracture resistance of premolars decreased by 43.7% even after instrumentation to only 45/0.02. The use of K3 nickel-titanium (NiTi) instruments and 6% NaOCl irrigant may have contributed to the larger decrease of fracture resistance observed in the above mentioned study. Nevertheless, the study indicates that clinical practitioners should regard overzealous instrumentation with caution.

Mechanical instrumentation and irrigation are sound endodontic principles and essential components of successful endodontics. For diseased teeth, conservative apical preparations could not result in satisfactory cleaning[18]. The penetration of irrigants to the apical third of canals and the removal of debris are dependent on the final size of the instruments that are used[2,5]. With respect to proper instrumentation size, the use of a MAF three sizes larger than the initial apical file (IAF) has been recommended[19]. However, the size of the IAF tends to be relatively small, potentially resulting in inadequate cleaning[20,21]. Other sources like textbooks provide additional recommendations regarding which instrumentation sizes to use for each type of tooth. For example, it has been suggested that for satisfactory cleaning, mandibular premolars with a single canal should be instrumented to at least 40-70 with no recommended taper[22-24]. In the present study, the force required to fracture a root, significantly decreased after the roots of the mandibular premolars were instrumented to 50 or larger with a relatively small taper (0.05). Certain scholars have advocated instrumentation with larger tapers but not necessarily larger diameters. In this study, significant reductions in the force required to fracture a root were observed when the roots of mandibular premolars were instrumented to a taper of 0.15, regardless of whether the MAF was 40 or 45. In the present study, we observed that an instrumentation size above 45/0.10 could cause the change of fracture resistance of the premolars.

In a clinical preparation scenario, when the canal is prepared with ProTaper Universal F2, F3 or F4, the apical enlargement at 1 mm, 2 mm or 3 mm from the apex are smaller compared to the MAF/taper 45/0.05 observed here. However, when prepared with F5, the enlargement will be comparable to the 50/0.05 from the present study. This result indicates that the preparation using ProTaper Universal F5 may significantly weaken mandibular premolars.

In the present study, the fracture load values of the mandibular premolars decreased as the apical diameter (from 40 to 60) and the taper (from 0.05 to 0.15) increased. This decrease may be partially explained by the loss of root structure. Wilcox et al[25] showed that the fracture susceptibility of roots was directly related with the dentine wall thickness. The effects related to stress distribution may also contribute to changes in the fracture load values[26]. The fracture mode analysis in this study showed that the fractures predominantly occurred in the buccolingual direction even though dentine is typically thicker in this direction than in the mesiodistal direction. This result was consistent with the findings of prior studies[17,27]. Lertchirakarn et al[17] suggested that this phenomenon might be attributed to the concentration of tensile stress on the inner surface of the buccolingual canal wall. The observed distribution of fracture modes indicates that the dentine wall thickness was not the only factor affecting the fracture resistance.

Along with the loss of tooth structure and altered stress on the root, crack initiation may also be a reason for mechanical weakening of the root. In the present study, no cracks or craze lines on the outer surface of roots were detected after the completion of mechanical instrumentation. The potential weakening effect of cracks were not taken into consideration in this study.

Apart from the static loading technique, different approaches, such as the finite element analysis based upon micro-computed tomography (micro-CT) images has also been useful to investigate the fracture susceptibility of teeth. Sathorn et al[28] created a finite element analysis model of the midroot region of a mandibular incisor and found that the notional load at fracture decreased as the dentine removal increased. As for research employing micro-CT, there is few published data evaluating the effect of mechanical instrumentation, possibly due to cost and accessibility.

To conclude, this study observed the effect of root canal preparation size on the root fracture resistance, and provided reference for clinical selection of preparation sizes and tapers for mandibular premolars. The present work showed that the fracture load values were significantly reduced when the roots of mandibular premolars were instrumented to an apical size equal to or larger than 50 with a taper of 0.05, or to an apical size of 40 or 45 with a taper of 0.15. When clinical practitioners determine the root canal preparation size, the potential weakening effect of large instrumentation size should be taken into consideration. The appropriate preparation size for teeth of different types with various anatomical characteristics is still subject to further study.

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Conflicts of interest

The authors reported no conflicts of interest related to the study.

Author contribution

Dr Shi Yu TIAN designed the study, conducted the experiments, collected the data, undertook the statistical analysis and prepared the manuscript; Dr Wei BAI conducted the experiments and collected data; Dr Wei Ran JIANG undertook the statistical analysis and revised the manuscript; Dr Yu Hong LIANG designed the study and revised the manuscript.

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