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Possibility of Bypassing Three Fractured Rotary NiTi Files and Its Correlation with the Degree of Root Canal Curvature and Location of the Fractured File: An *In Vitro* Study

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ABSTRACT

Introduction: This study aimed to evaluate the success rate of bypassing three NiTi rotary files (RaCe®, Hero 642®, and K3®), fractured in various root canal locations of extracted mandibular molars with two different canal curvatures. **Materials and Methods:** Ninety freshly extracted human first or second mandibular molars were selected. Three millimeters of the file tip (RaCe®, Hero 642®, and K3®), was fractured intentionally in the mesiobuccal root canal of each tooth by weakening the file in the last 3 mm of files #30 with 4% taper and preparing the root canals with two different degrees of curvature (n=30). Then, bypass possibility of the fractured files was evaluated using #8, #10, and #15 K-files and compared in different groups. In addition, the rate of accidental procedural errors was compared between these groups. Data were analyzed with univariate analysis and logistic regression models at a significance level of 0.05. **Results:** The overall success rate of bypassing was 61.1%. RaCe® files had the highest and the K3® files had the lowest bypass possibility rates (P=0.01); the greater the degree of canal curvature, the less successful the bypass procedure (P=0.01). The fracture of the files used to bypass was the most prevalent error. **Conclusion:** Based on this *in vitro* study the type of fractured file and the amount of canal curvature affected the success rate of the bypassing technique. In RaCe® files and the mild curvature group, the success rate was the highest.

Keywords: Bypass; Fractured File; Root Canal Preparation; Root Canal Treatment; Rotary Instruments

Introduction

Various root canal instruments and techniques have been proposed to clean and shape the root canal(s) of teeth [1-3]. Nickel-titanium (Ni-Ti) endodontic instruments were introduced to facilitate the preparation of curved canals. Ni-Ti instruments are two to three times more flexible and more resistant to torsional failure than stainless-steel instruments. Several studies have claimed that the preparation of curved canals with minimum transportation is achieved using Ni-Ti rotary systems [2, 4-8]. Moreover, more rounded/centered root canals can be achieved using these instruments [9].

However, when clinicians use Ni-Ti rotary canal preparation, they might encounter some problems, such as file fracture [6, 10]. Some investigations have shown that one problem with rotary Ni-Ti instruments might be a higher possibility of file fracture, especially in curved canals [11, 12]. The incidence of fractured rotary NiTi files in studies ranges from 0.4% to 4.6% [7].

Depending on the pulp status, canal infection, canal anatomy, broken file position, and the type of the fractured instrument, the clinician should decide whether to remove the file, bypass it or leave it in the canal [13]. If the file fractures in the canal, to ensure that the cleaning and shaping process is completed with no remnants of pulp tissue and bacteria, the clinician should do their best to remove the instrument from the root canal [14, 15]. Such an attempt might result in ledge formation, transportation, over-enlargement, vertical root

fracture, and extrusion of the separated file [9, 16, 17]. Studies have come up with new ideas and suggested several ways to remove broken files, including ultrasonic tips and operating microscopes [7, 9]. On the other hand, some other studies have reported clinicians should always try to bypass the fractured segments initially instead of handling the broken file manually because it is a procedure that can usually be successful *in vivo* [18]. Even in attempting file fracture removal, bypassing a fractured file is usually the first option.

This study aimed to compare the possibility of bypassing three fractured Ni-Ti rotary instruments naming Hero 642 (Micro Méga, Besançon, France), RaCe®(KG Dentaire, La-Chaux-de-Fonds, Switzerland) and K3 (SybronEndo, Orange, CA, USA) by considering the importance of root canal curvature and the fractured file's location in the root canal because the highest rate of file fracture and greatest curvature is in the apical region [11, 19, 20].

Materials and Methods

In this *in vitro* study, 90 extracted intact human mandibular molars were used. After removing residual periodontal tissues and debris, all the specimens were dipped in 2.5% sodium hypochlorite (Golrang, Tehran, Iran) for 1 h [20]. Root surfaces were assessed under a stereomicroscope (Motic Digital Microscopic, Wetzlar, Germany) at 10× magnification to exclude any teeth with pre-existing root fractures, cracks, open apices, or root caries. The teeth then underwent radiography to exclude any teeth with calcification, internal or external resorption, or previous root canal therapy.

After access cavity preparation, teeth with an average working length of 21±2 mm in the mesiobuccal root canal were selected by a small-size hand K-file and radiographed. After exploring the patency, the working length was set at 0.5 mm shorter than the radiographic root canal length. Moreover, the canal curvature was determined by inserting a #15 K-file (Mani, Tochigi, Japan) and taking a preoperative radiograph. Schneider method [21] and parallel radiographic technique were used for measuring the curvature. Then the root canals were divided into two groups (n=45): mild curvature (<20°) and severe curvature (>35°) [5]. Then, 45 teeth in each group were randomly assigned to three equal groups (n=15).

Root canal preparation was carried out by the step-back technique using intermittent irrigation with 2.5% sodium hypochlorite to the apical #20 hand K-file (Mani, Togichi, Japan) [20]. One of the Ni-Ti rotary files (Race: FKG Dentaire, Switzerland; Hero 642: Micro Mega, France; K3: Sybron Endo, USA) was selected randomly and intentionally fractured in mesiobuccal root canals. To facilitate file breakage, they were deflected at 90° in two directions with a piece of pliers in the last 3 mm of files #30 with 4% taper. Instruments were operated at 600 rpm using a high-torque endodontic electric motor (NSK, Nakanishi, Japan). The torque value was set at 1 Ncm on the motor. The root canals were irrigated with 2.5% sodium hypochlorite after each instrument.

The instrument was used until the file fractured. Each tooth underwent a radiographic technique to determine the location of the broken file. If the file was fractured in the apical or middle thirds of the root canal, the sample was included in the study; otherwise, it was excluded.

The bypassing process was carried out by a trained third-year postgraduate student of endodontics, blinded to the fractured file's brand in each root canal [22]. After a sharp deflection in the tip, a #10 file was dipped in RC-Prep (Premier Dental, Philadelphia, PA, USA) and used in the root canal with watch-winding movements. If a #10 file could bypass the fractured file, the apical canal preparation continued up to #15 K-file. Also, the time spent on bypassing was recorded. The data based on file brands, curvatures, positions relative to curvature (before curvature, at curvature, and after curvature), and canal locations were recorded. If the bypassing process was not completed in 15 min, it was considered unsuccessful. In addition, the samples were closely evaluated radiographically and by direct visualization to assess the possibility of perforation or fracture of the bypassing file. Furthermore, the double-exposure technique was used for measuring transportation [23]. The samples with errors were considered as not bypassed.

Statistical analyses

The data were analyzed by univariate analysis (chi-squared test) and multivariate logistic regression to evaluate possible simultaneous effects on the success rate of bypassing at a significance level of P<0.05.

Results

Table 1 presents the success rates of bypassing the fractured files with different brands, curvatures, positions relative to curvature (before curvature, at curvature, and after curvature), and locations of the canal (apical, middle). The overall success rate of bypassing the fractured files was 61.1%. Perforation occurred in one tooth, and the bypassing file fractured in six teeth. Transportation was not observed in any of the samples. The mean times for bypassing RaCe®, Hero 642, and K3 files were 3.88, 4.63, and 5.61 min, respectively. The survival analysis (Cox regression) was performed to evaluate the effect of canal curvature and type of fractured file on bypass time, indicating that the time spent on bypassing had a significant effect (P=0. 001)

Univariate analysis

The success rates of bypassing fractured files in the middle and apical thirds of the canals did not exhibit statistically significant differences (*P*=0.56). Comparison of success rates in terms of the position of fractured files relative to curvature revealed that when the file was fractured before, at, or after the curvature, bypassing the fractured file was not significantly different (*P*=0.78). The group with severe canal curvature exhibited a significantly lower success rate than the group with mild curvature (*P*=0.01). There was a significant difference between different brands of Ni-Ti rotary instruments in the success rates of bypassing fractured files (*P*=0.01).

Multivariate

The results of multivariate analysis showed that the chance of bypassing in Race files is 6.76 and 3.05 times more than K3 (*P*=0.003) and Hero (*P*=0.077) files, respectively. In addition, mild curvature increases the chance of bypassing by 5.3 times compared to severe curvature (*P*=0.001). The results showed that areas and position variables had no significant effect on bypassing chance (Table 2).

Discussion

This study aimed to evaluate the success rate of bypassing three NiTi rotary files fractured in various root canal locations of extracted mandibular molars, with two different canal curvatures.

In the present study, the overall success rate of bypassing the fractured files was 61.1%. Considering the complexity of bypassing fractured files in the mesiobuccal canals of mandibular molars, it can be concluded that this technique has a relatively high success rate [24]. However, the success rate of bypassing fractured files might be higher in more straight root canals.

Table 1. The success rates of bypassing the fractured files

	Bypass possibility		
	No	**Yes**	***P*-value**
Location of the fractured instrument			
Middle	10 (28.6%)	25 (71.4%)	0.56
Apical	25 (45.5%)	30 (54.5%)	
Position of the broken file			
Before curvature	3 (37.8%)	5 (62.2%)	0.78
After curvature	19 (38.8%)	30 (61.2%)	
Within curvature	13 (39.4%)	20 (60.6%)	
Degree of canal curvature			
Mild	10 (22.2%)	35 (77.8%)	0.01
Severe	25 (55.6%)	20 (44.4%)	
Type of instrument			
K3	17 (56.7%)	13 (43.3%)	0.01
Hero 642	12 (40.0%)	18 (60.0%)	
RaCe®	6 (20.0%)	24 (80.0%)	

The success rate of bypassing fractured Ni-Ti rotary files located before the curvature was 62.2%, with 60.6% within the curvature and 61.2% beyond the curvature, indicating no statistically significant differences. Shahabinejad *et al.* [20] evaluated the success rate of the ultrasonic technique in removing fractured rotary NiTi endodontic instruments and reported a success rate of 80%. This finding is different from the present study, which might be attributed to differences in methods, sample teeth, and root lengths. Shen *et al.* [24] reported an overall success rate of 53% for bypassing fractured instruments, 44% of which could be retrieved, whereas most fractured instruments were detected at or beyond the root canal curvature, with a success rate lower than our study [24]. This difference was attributed to the type of instruments used in Shen's study, *i.e.*, Profile and NiTi K-file.

In Nevares's study [25], if the fragments were not visible under a dental operating microscope, bypassing was attempted, and the success rate in the non-visible fragment group was 47.7%. In that study, the curvature of the canal was not reported.

In the present study, multivariate analysis showed that the group with severe curvature had a significantly lower success rate in bypass possibility than more straight root canals, consistent with Shen *et al.* [24].

In the current study, the success rates of bypassing fractured files were 43.3%, 60%, and 80% with K3, Hero, and RaCe® files, respectively. These different success rates might be attributed to their cross-sectional designs. The RaCe® files have a triangular cross-section with two alternating cutting edges and no radial lands; therefore, bypassing these files' flutes might be easier than the two others. Conversely, Adl *et al.* [2] reported no significant difference between the groups regarding the rate of bypassing [2]. In the

Table 2. Adjusted odds ratio (AOR) of bypassing for area, position, curvature and file type variables

	AOR	**95% CI for AOR**	
		Lower	**Upper**
Area			
Apical	1.12	0.17	6.20
Middle	1		
Position			
In curve	1.06	0.19	5.94
After curve	0.94	0.17	5.14
Before curve	1		
Canal curvature			
Mild	5.30	1.95	14.40
Severe	1		
File type			
K3	6.76	1.92	23.81
Hero	3.05	0.89	10.53
RaCe	1		

current study, the canal curvature was mild, and the fractured file was in the middle third of the canal. Also, in this study, the highest success rate was in the RaCe® group, consistent with the present study. Some studies reported that instrument type did not affect the success of removing fractured instruments [13, 24].

The rate of procedural errors during bypassing fractured files was 13.2%, including the fracture of the bypassing files, transportation, and perforation of the root canal.

The mean times for bypassing RaCe®, Hero 642, and K3 files were 3.88, 4.63, and 5.61 min, respectively. The minimum bypass time was in the RaCe® group, which can be attributed to the cross-sectional design, consistent with the study by Adl *et al.* [2]. In the present study, the working time for bypassing the fractured instruments was set at 15 min because if more time is spent, the operator's fatigue will increase the risk of procedural accidents [13]. In the study by Adl *et al.* [2], the time for bypassing was considered 30 min, but in this study, more samples were bypassed in 13 min. In non-bypassed samples, increasing the time to 30 min did not result in a significant difference [2].

The mesiobuccal root canals of mandibular molars were evaluated in the present study. According to Wu and Suter, it is more likely to find a broken file in the mesiobuccal root canal than in other canals [1, 13]. Moreover, the mesial root canals have greater curvatures in molar teeth and are more difficult to treat [26].

The degree of root canal curvature is one of the most fundamental reasons for metal fatigue in rotary files [27]. Because the canals with moderate and mild curvature and the canals with moderate and severe curvature are slightly different, and we wanted the difference to be clear, we decided to compare the mild and severe chromium.

The Schneider method was used in this study to measure the degree of curvature [21]. Pruett *et al.* [5] used this technique as described by Schneider to determine the radius and angle of curvature [5]. In the current study, the root canals were divided into two groups: with mild curvature (<20°) and with severe curvature (>35°) to evaluate the effect of root canal curvature on the success rate of bypass possibility.

We intentionally made a 90° deflection twice in two directions to facilitate instrument breakage with a piece of pliers in the terminal 3 mm of previously used #30 files. Similar studies have used a high-speed diamond bur to make a notch depth of half the instrument thickness 2.5 mm [28] and 4 mm away from the tip [7]. Other researchers have used separated file fragments in dentin blocks to simulate separated files in root canals [29]. We thought the experimental file fracture in our method might better simulate clinical situations. This means that the extracted tooth specimen simulates the clinical condition better than the acrylic specimen.

In the current study, 58.8% of instrument fractures occurred in the apical third of the root canals, with a lower rate in the middle third. Similar to our findings, other studies have shown that when the fragment is localized before the curvature, removal attempts are more successful than when it is localized at or beyond the curvature [9, 24]. Some studies have shown that if removal is attempted in the apical third of the root canal, the perforation potential is higher [13], possibly due to greater curvature in the apical third and small root canal space in this area [24, 30]. On the other hand, according to some other investigations, the degree of curvature is not an essential factor for removing a fractured file, and the coronal visibility and accessibility are more significant factors. Suter *et al.* reported no significant differences in root and tooth type in removal success rates [13].

Conclusions

The present study demonstrated significant differences in success rates of by passibility between different brands of Ni-Ti rotary instruments. Among the three types of files, the success rate of bypassing RaCe® was higher than those of K3 and Hero 642. In cases where the file fractured before the curvature, bypassing the fractured file was more successful. In addition, the group with severe curvature exhibited significantly lower success rates.

Conflict of Interest: 'None declared'.

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