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Qualitative analysis of root canal preparation performed by BioRace, ProTaper Universal, Mtwo, HEROShaper and K3 rotary systems: an *ex vivo* study

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Abstract

Objective: Effective canal debridement and shaping are fundamental to endodontic success. The use of nickel–titanium (NiTi) rotary instruments has significantly improved the predictability and quality of root canal preparation, especially in curved canals. This study aimed to assess and compare canal taper and regularity achieved using five different NiTi rotary systems. Material and Methods: One hundred extracted human mandibular molars with three distinct canals were randomly allocated to five groups (n = 20), each instrumented using one of the following NiTi rotary systems: BioRace, ProTaper Universal, Mtwo, HEROShaper, and K3. Root canal impressions were made and evaluated under a stereomicroscope at 10× magnification. Each canal third (cervical, middle, and apical) was evaluated separately. The following criteria were used to classify canal shaping: RCTR – Regular canal with a conical shape; ICTR – Irregular canal with a conical shape; RCTS – Regular canal with a cylindrical shape; ICTS – Irregular canal with a cylindrical shape. Statistical analysis was performed using the Fisher's exact test ($p < 0.05$). Results: The RCTR category was predominant across all groups. BioRace and K3 systems demonstrated consistent performance among the root thirds, whereas ProTaper exhibited significant variation, with a higher frequency of RCTS in the cervical third and RCTR in the apical third ($p < 0.05$). Mtwo and HEROShaper showed intermediate outcomes without statistically significant differences across thirds. Conclusions: Although differences were more pronounced in the middle and apical thirds, the predominance of the RCTR pattern across groups indicates satisfactory shaping ability for all systems.

KEYWORDS: Endodontic Instruments; Mandibular Molars; NiTi; Root Canal Preparation; Shaping Ability.

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Introduction

Canal debridement and enlargement are essential steps in achieving endodontic success[1]. The disinfection process results from the synergistic action of mechanical instrumentation and chemical irrigant, complemented by the use of intracanal medication[1,2]. Root canal shaping aims to smooth and regularize the canal walls, enhancing the adaptation of the filling material and ensuring adequate obturation, thereby promoting effective sealing of the dentinal tubules[1].

The ideal approach to root canal preparation remains a subject of ongoing debate in endodontic science[2,3]. Within this context, two critical factors have emerged: the type of endodontic instrument and the technique employed[4-6]. Recent advances in the development of flexible instruments and novel rotary systems have markedly enhanced the predictability and quality of root canal shaping[7,8].

The adoption of nickel–titanium (NiTi) rotary instruments for shaping curved root canals has been supported by several advantages, including better maintenance of working length, more centralized and tapered canal preparations, and a reduced incidence of procedural errors[2,3,9,10]. These benefits collectively contribute to more reliable and reproducible outcomes.

The evaluation of instrumentation techniques described in the literature must be performed carefully, particularly when assessing the shaping ability and performance of different systems[11,12]. Given the anatomical complexity of certain teeth, the continuous assessment of newly developed rotary instruments remains crucial[11,13-18]. Therefore, the objective of the present study was to evaluate and compare two parameters (taper and regularity) of root canal preparation achieved using five NiTi rotary systems in extracted human teeth. The null hypothesis tested was that there would be no significant differences among the NiTi rotary systems with respect to the root canal preparation.

Materials and methods

This study was approved by the Research Ethics Committee of the Federal University of Goiás (Protocol number 042/2011). Informed consent was obtained from all participants prior to their inclusion in the study.

Sample selection

One hundred extracted human mandibular molars, obtained for various reasons from the Emergency Service of the School of Dentistry at the Federal University of Goiás, Goiânia, Brazil, were used in this study. The teeth were stored in 0.2% thymol solution (Fitofarma, Goiânia, GO, Brazil) and subsequently immersed in 5% sodium hypochlorite solution (NaOCl; Fitofarma) for 30 minutes to remove organic tissues from the external root surfaces.

Preoperative radiographs were taken for each tooth to confirm the absence of intracanal calcifications, previous endodontic treatment, intraradicular posts, and internal or external root resorptions, as well as to verify complete root apex formation. Periapical radiographs were obtained using the paralleling technique with a Spectro X70 device (Dabi Atlante, Ribeirão Preto, SP, Brazil), featuring a 0.8 mm × 0.8 mm focal tube and Kodak Insight-E films (Eastman Kodak Co, Rochester, NY, USA). A radiographic positioning platform was used for all specimens to ensure standardization of image acquisition. The films were processed in an automatic processor, and image evaluation was performed using a viewing box under dim lightning with aid of a magnifying lens.

Only molars with three distinct root canals (distal, mesiobuccal, and mesiolingual) were included in this study. All teeth had a total length of less than 22 mm and presented mesial roots with moderate curve[19].

Following initial periapical radiographs, access cavities were prepared using diamond round burs #1013 and #1014 (KG Sorensen, Barueri, SP, Brazil) and an Endo Z carbide bur

(Dentsply Maillefer, Ballaigues, Switzerland), both operated under high-speed rotation and water cooling. Working length (WL) was determined using direct method with K-File files (#10 and #15) (Dentsply Maillefer), inserted into the canal until their tips were visible at the apical foramen. The file was held in position, and its silicone stop was adjusted to the coronal reference point. It was then removed, and its length was measured using a digital caliper (Lee Tools, São Paulo, SP, Brazil). One millimeter was subtracted from this measurement to establish the final WL. The teeth were then randomly assigned to five experimental groups (n = 20) and prepared using the following systems: Group 1 - BioRaCe (FKG Dentaire, La Chaux-de-Fonds, Switzerland); Group 2 - K3 (SybronEndo, Orange, CA, USA); Group 3 – ProTaper Universal (Dentsply Maillefer); Group 4 - Mtwo (VDW, Munich, Germany); Group 5 – HEROShaper (Micro-Mega, Besançon, France).

Root canal preparation

In Group 1 BR0 (#25/.08) and BR1 (#15/.05) instruments were used for preparation of the cervical and middle thirds, respectively, while BR2 (#25/.04), BR3 (#25/.06), BR4 (#35/.04), and BR5 (#40/.04) were used for the apical third. In Group 2, the sequence used for the cervical and middle thirds was #25/.06 and #25/.04, followed by #25/.02, #30/.02, #35/.02, and #40/.02 for the apical third. In Group 3, the SX instrument was used for the cervical third, and the remaining instruments - S1, S2, F1, F2, F3, and F4 - were used throughout the entire WL. In Group 4, the entire canal was prepared using the following sequence: #10/.04, #15/.05, #20/.06, #25/.06, #30/.05, #35/.04, and #40/.04. In Group 5, the instruments used for the cervical and middle thirds were #25/.06 and #25/.04, and for the apical third: #25/.02, #30/.02, #35/.02, and #40/.02.

During instrumentation, the root canals were irrigated with 3 mL of 2.5% NaOCl solution (Fitofarma) after each instrument change. Nickel-titanium instruments were attached to an electric motor (X-Smart, Dentsply Maillefer) and operated according to the manufacturers' instructions. Each set of files was used for the preparation of a maximum of five teeth. Following instrumentation, canals were dried with sterile paper points (Dentsply Maillefer) and filled with 17% EDTA solution (pH 7.2) (Biodinâmica, Ibiporã, PR, Brazil) for 3 minutes to remove the smear layer. A final irrigation was performed with 3 mL of 2.5% NaOCl solution (Fitofarma).

All root canal procedures were performed by an endodontic specialist with over five years of clinical experience.

Root canal impression procedure

Impressions of the prepared root canals were made using Aquasil ULV® impression material (Dentsply Maillefer), prepared according to the manufacturer's instructions. The material was introduced through the coronal chamber into the canal orifices using a syringe with the same impression agent, while simultaneous aspiration was performed through the apical foramen using a vacuum pump.

After the material had set, the teeth were subjected to demineralization in 35% hydrochloric acid (Farmácia Santé, Anápolis, Goiás, GO, Brazil) for 48 hours to obtain the negative molds of the prepared root canals. The impressions were then stored in water to preserve their integrity. Using a digital caliper (Lee Tools), measurements were taken from the coronal reference point to the apical foramen. These values were divided by three to delimit the cervical, middle, and apical thirds of the root canal.

To assess the quality of the internal root canal morphology, the impressions were evaluated in mesiodistal and buccolingual views by two endodontic specialists using a stereomicroscope (INAHL, Mexico, Mexico) at 10× magnification and with appropriate lighting.

The evaluation criteria applied to the root canal impressions considered each third (cervical, middle, and apical) separately.

The analysis focused on taper and canal regularity, classifying the preparations as follows[11]: RCTR – Regular canal with a conical shape (Figure 1A); ICTR – Irregular canal with a conical shape (Figure 1B); RCTS – Regular canal with a cylindrical shape (Figure 1C); ICTS – Irregular canal with a cylindrical shape (Figure 1D).

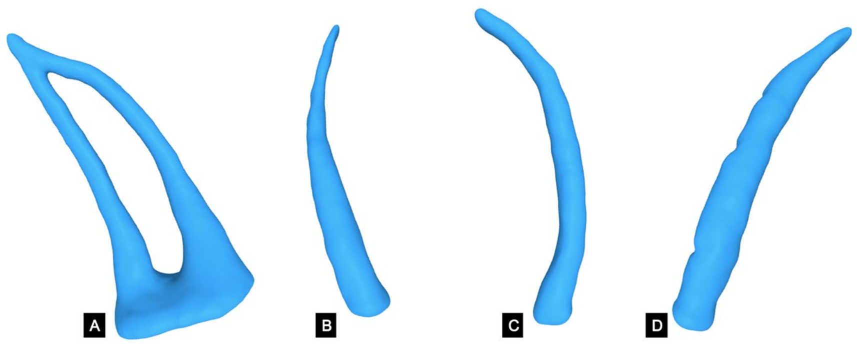

FIGURE 1 · Schematic representation of the impressions obtained from the root canals. **(A)** Regular canal with a conical shape; **(B)** Irregular canal with a conical shape; **(C)** Regular canal with a cylindrical shape; and **(D)** Irregular canal with a cylindrical shape.

Statistical analysis

Data were analyzed using IBM SPSS Statistics for Windows, version 21.0 (IBM Corporation, Somers, NY, USA). The analysis included frequency distribution and cross-tabulation. Comparative statistical analysis was performed using the Fisher's exact test, with the level of statistical significance set at 5% ($p < 0.05$).

Results

Mesiodistal view

As shown in Figure 2, RCTR was the predominant category in all groups. BioRace (76.7%) and K3 (56.7%) showed uniform distributions across root thirds ($p > 0.05$). Only the ProTaper group showed a significant association with root thirds ($p = 0.002$), with RCTS more frequent in the cervical third and RCTR in the apical third. Mtwo (RCTR: 50.0%, RCTS: 38.3%) and HEROShaper (RCTR: 55.0%, RCTS: 41.7%) showed no significant differences, though the latter approached significance ($p = 0.054$).

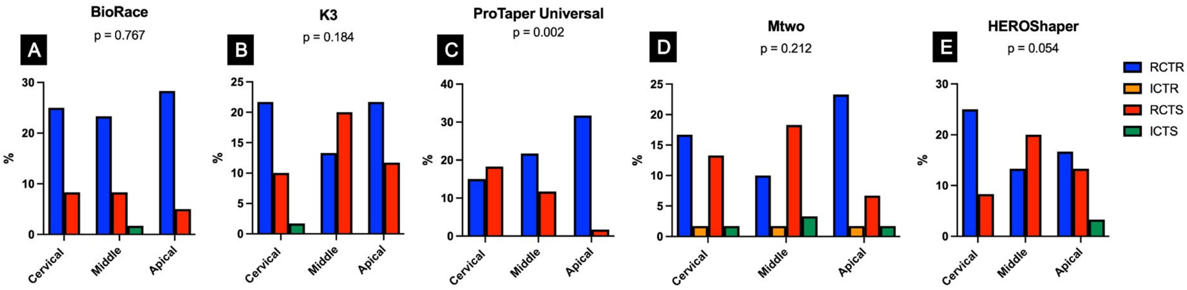

FIGURE 2 · Distribution of canal shape classifications observed in the impressions, categorized by instrumentation system. Mesiodistal view. RCTR – Regular canal with a conical shape; ICTR – Irregular canal with a conical shape; RCTS – Regular canal with a cylindrical shape; ICTS – Irregular canal with a cylindrical shape.

When the quality of canal preparation was assessed individually by root third, RCTR was the most common preparation pattern (61.3%), with significant differences among systems in the middle ($p = 0.047$) and apical thirds ($p = 0.026$) (Figure 3).

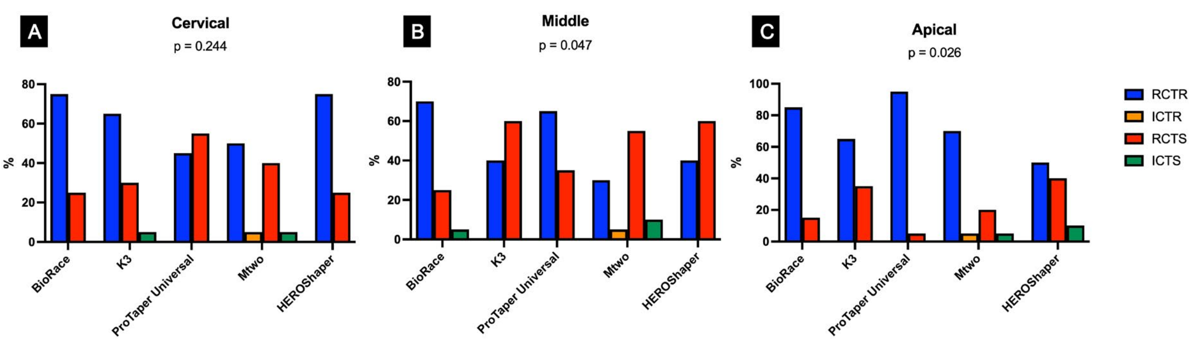

FIGURE 3 · Distribution of canal shape classifications observed in the impressions, categorized by root canal third. Mesiodistal view. RCTR – Regular canal with a conical shape; ICTR – Irregular canal with a conical shape; RCTS – Regular canal with a cylindrical shape; ICTS – Irregular canal with a cylindrical shape.

Buccolingual view

Figure 4 illustrates the distribution by group. All systems showed a predominance of RCTR. BioRace (75.0%) and K3 (68.3%) showed uniform distributions ($p > 0.05$). In the ProTaper group, RCTS predominated in the cervical and middle thirds, with statistical significance ($p = 0.019$). Mtwo (RCTR: 48.3%, RCTS: 40.0%) and HEROShaper (RCTR: 63.3%, RCTS: 26.7%) did not differ significantly across thirds.

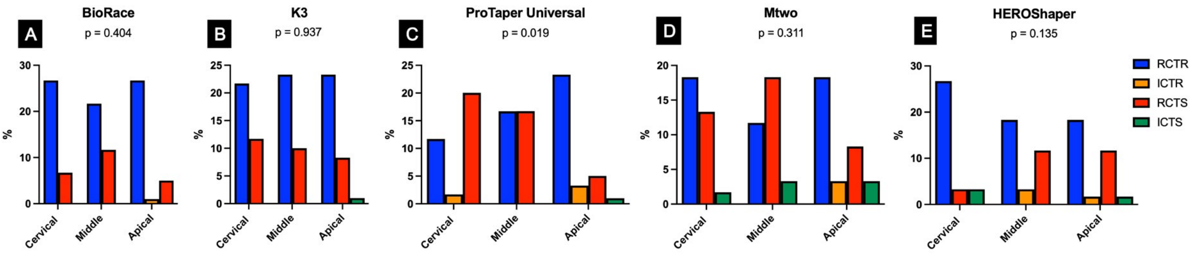

FIGURE 4 · Distribution of canal shape classifications observed in the impressions, categorized by instrumentation system. Buccolingual view. RCTR – Regular canal with a conical shape; ICTR – Irregular canal with a conical shape; RCTS – Regular canal with a cylindrical shape; ICTS – Irregular canal with a cylindrical shape.

As in the mesiodistal view, RCTR was most frequent (61.3%), with significant differences among systems only in the cervical third ($p = 0.011$) (Figure 5).

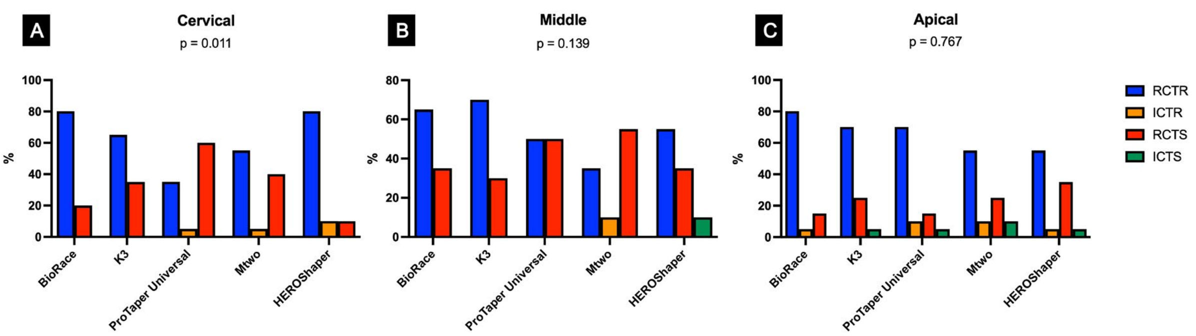

FIGURE 5 · Distribution of canal shape classifications observed in the impressions, categorized by root canal third. Buccolingual view. RCTR – Regular canal with a conical shape; ICTR – Irregular canal with a conical shape; RCTS – Regular canal with a cylindrical shape; ICTS – Irregular canal with a cylindrical shape.

Discussion

The selection of an ideal endodontic instrument requires a balanced integration of three key factors: comprehensive knowledge of root canal anatomy, technical proficiency, and critical understanding of the instrument's properties. This equilibrium is crucial to minimize the risk of procedural accidents and irreversible errors, particularly when managing anatomically complex root canals. In the present study, the quality of root canal preparation in mandibular molars was assessed after the use of different NiTi systems. The findings revealed that canal taper and regularity were significantly affected by the type of instrument employed. Thus, the null hypothesis was rejected.

Various methodologies have been employed to assess the final quality of root canal preparation, including artificial canals, anatomical sectioning, and imaging methods[5,7,9,11,20-25]. Simulated canals, typically made of transparent resin or acrylic blocks, offer excellent visualization of canal shaping and are considered non-invasive[24]. These models allow for standardization and reproducibility of canal morphology, making them suitable for comparing the shaping ability of different instruments and operators under controlled laboratory conditions[5,7,24]. However, their simplified morphology and restriction to a single curvature plane[24], along with the risk of thermal distortion caused by the heat generated during rotary instrumentation, may compromise the validity of findings[24]. Moreover, discrepancies between the physical and mechanical properties of resin and natural dentin must be considered when extrapolating results to clinical settings[5]. Anatomical sectioning allows direct observation of canal cross-sections before and after instrumentation, enabling evaluation of morphological changes and canal position[20,24]. However, it is inherently invasive and destructive, typically limited to three or four predetermined root levels[26]. Conventional radiographic methods, while reproducible and non-destructive[25], are limited by their two-dimensional (2D) nature, which hampers comprehensive assessment of complex canal anatomy[23,24]. Micro-computed tomography (Micro-CT) represents a non-destructive alternative that enables both qualitative and quantitative assessing three-dimensional (3D) evaluation changes of canal systems without altering the specimens[9,16,24]. Despite its high accuracy, the technique presents disadvantages such as elevated cost, extended scanning times, and the requirement for advanced in digital processing skills[24]. Cone-beam computed tomography (CBCT) offers faster image acquisition and the ability to detect procedural complications, such as instrument separation, perforations, and canal transportation[22,23]. Nonetheless, it shares similar limitations with Micro-CT regarding equipment cost and need for technical expertise. In the present study, the quality of canal preparation was assessed using the intracanal impression technique, which involves filling the prepared canals with high-precision materials followed by dentin demineralization to obtain three-dimensional molds[11,21]. While this method allows for direct 3D assessment of the canal morphology, it also presents significant limitations, including its destructive nature, technical difficulties in complex canal anatomies, and a high rate of specimen loss, which constrain its broader applicability[11,21].

It has been well established that the performance of specific instrumentation techniques, and consequently of endodontic instruments, is directly influenced by the internal anatomy of root canals[2]. Mandibular molars are commonly used in studies evaluating the quality of root canal preparation, due to their anatomical complexity and high clinical relevance[11,13-18]. These teeth are among the most frequently treated in endodontics[18,27], making them highly representative for translational research[15]. The mesial roots often exhibit considerable canal curvatures[15,28-30], which can compromise the ability to achieve a uniform and tapered canal shape during instrumentation[11]. As highlighted by Estrela *et al.*[31] (2008), curvature severity is a critical factor in selecting both the instrumentation technique and the file system. In this study, only mandibular molars with mesial roots exhibiting moderate curvature were included. Previous investigations have used teeth with curvatures ranging from 20° to 40°[15,30], 20° to 35°[17], and 25° to 37°[28, 29]. This anatomical variability presents a significant challenge when attempting to compare findings across studies.

Root canal preparation is a chemomechanical process that integrates the physical action of instruments with the chemical activity of irrigating solutions[2,3,32]. Advances in endodontics have led to the development of a wide array of instrumentation systems. Historically, canal enlargement was performed using stainless steel hand files; however, the introduction of nickel–titanium

(NiTi) rotary instruments has enhanced treatment predictability. NiTi instruments possess unique properties such as superelasticity and shape memory, which confer superior flexibility and increased resistance to cyclic fatigue and fracture[15,28]. These attributes help minimize procedural errors, including apical transportation, canal deviation, zips, and perforations[3,11,22,33]. Notable examples of commercially systems include BioRace, ProTaper Universal, Mtwo, HEROShaper, and K3.

The BioRace system is engineered for root canal preparation with a focus on safety, efficiency, and enhanced apical enlargement to improve disinfection outcomes[8,34]. BioRace instruments incorporate several features derived from the original RaCe system, including alternating cutting edges, a non-cutting tip, a triangular cross-sectional design without radial land, electropolished surfaces, and clear instrument identification[34]. The system is available in two kit configurations, with the basic kit comprising six instruments (BR0, BR1, BR2, BR3, BR4, and BR5) and is recommended for a wide range of root canal anatomies[8,34]. The ProTaper Universal system, an evolution of the original ProTaper design[32], is characterized by a multi-instrument strategy for root canal preparation[35,36]. These instruments feature a convex triangular cross-sectional design, a non-cutting tip, and variable tapers along the active portion of the file[37]. The kit includes shaping instruments (S1, SX, S2) and finishing instruments (F1, F2, F3, F4 and F5), each designed for specific regions and stages of canal instrumentation[35,36]. The Mtwo system was specifically developed for root canal preparation in cases with severe curvature[4,6]. Its design features an S-shaped cross-sectional with two cutting edges and a positive rake angle[5]. The instruments also have a non-cutting tip[4,5] and a progressively increasing distance between cutting edges from tip to shank. Additionally, Mtwo files possess a relatively small core diameter[4-6]. The basic series consists of eight instruments, with tapers ranging from .04 to .07 and tip sizes from ISO 10 to ISO 40[4,5]. The HEROShaper system, also known as HERO 642, is characterized by a slightly positive rake angle and the absence of radial lands[10]. It features a triangular cross-sectional design with three cutting edges and a non-cutting tip[10,38]. HEROShaper instruments are available in tapers of .06, .04, and .02 and in ISO tip sizes ranging from 20 to 40[3]. The K3 system was developed for the preparation of root canals with complex anatomical configurations[12,39]. Its instruments feature a slightly positive rake angle, radial land relief, and an asymmetrical cross-sectional design[10,12,37]. Additional characteristics include non-cutting safety tips and a rounded transition angle[12]. Although the files exhibit a constant taper, they incorporate variable pitch and helical angles. K3 instruments are available in ISO sizes ranging from 15 to ISO 60, with .02, .04 and .06 taper options[12].

Qualitative analysis of the root canal impressions revealed a predominance of regular, tapered canal shapes (Figures 2 and 4). Among the systems evaluated, BioRace and K3 demonstrated consistent performance across all root thirds. These results align with previous studies reporting that these systems produce preparations with appropriate geometric configuration[8,11,40]. Their capacity to achieve high-quality shaping is largely attributed to their design features, which enhance cutting efficiency, minimize friction, and reduce procedural errors—thereby enabling effective instrumentation while preserving the original canal anatomy[7,8,41,34]. Conversely, the ProTaper system exhibited a statistically significant variation in shaping outcomes across root thirds ($p = 0.019$). This discrepancy may be explained by the inherent complexity of root canal anatomy[17,24] and by the interaction between these anatomical intricacies and the design features of the instrument[26,42,43]. Although the ProTaper system was developed to offer efficient and predictable canal shaping, achieving an ideal preparation throughout the entire root length remains a clinical challenge[43].

Although differences among systems were more pronounced in the middle and apical thirds (Figures 3 and 5), the predominance of RCTR pattern across all groups suggests that the tested instruments provided satisfactory shaping performance overall. The complexity and variability of root canal anatomy play a crucial role in influencing the outcome of endodontic preparation[17,24]. This anatomical complexity is not uniform along the canal and presents distinct challenges in the cervical, middle, and apical thirds, affecting instrument performance differently at each level[42]. Typically, the cervical third is the most accessible region[4]. The crown-down technique, when used in conjunction with NiTi systems that include dedicated cervical enlargement file, as found in BioRace, ProTaper, K3, and HEROShaper systems, facilitates the creation of a well-tapered canal shape[44]. A notable distinction of the Mtwo system is the absence of an instrument specifically designed for cervical preflaring[45]. Its protocol recommends using all instruments to full working length from the beginning, without progressive enlargement. The middle third often represents a transition zone between the wider, straighter cervical region and the narrower, more curved apical portion. Shaping the apical third is generally regarded as the most delicate phase of instrumentation, as this region tends to have smaller diameters, greater curvature, and frequent anatomical complexities such as lateral canals and apical deltas[17,24]. A lack of understanding of critical instrument design features, such as flexibility, cross-sectional geometry, taper, and tip configuration, combined with limited operator experience, can significantly compromise the success of root canal shaping procedures. These factors influence how the instrument interacts with complex root canal anatomy and may increase the risk of procedural errors.

Although this *ex vivo* study does not fully replicate clinical conditions, its findings enhance the understanding of root canal preparation complexity and may guide future research toward safer and more effective instruments and techniques for improved clinical outcomes.

Conclusion

All tested NiTi rotary systems were effective in producing predominantly conical and regular root canal preparations (RCTR). BioRace and K3 showed the most uniform performance across root thirds, while ProTaper exhibited greater variability. Differences among systems were more evident in the middle and apical thirds.

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Análise qualitativa do preparo do canal radicular realizado pelos sistemas BioRace, Protaper Universal, Mtwo, HEROShaper e K3: um estudo *ex vivo*

Resumo

Objetivo: A desinfecção e o preparo adequado dos canais radiculares são essenciais para o sucesso do tratamento endodôntico. Instrumentos rotatórios de níquel-titânio (NiTi) têm proporcionado maior previsibilidade na modelagem dos canais, especialmente em raízes curvas. Este estudo teve como objetivo avaliar e comparar a conicidade e a regularidade dos preparos obtidos por cinco sistemas rotatórios de NiTi. Material e Métodos: Cem molares inferiores humanos, com três canais distintos, foram aleatoriamente distribuídos em cinco grupos (n = 20), e preparados com os sistemas BioRace, ProTaper Universal, Mtwo, HEROShaper e K3. Após a instrumentação, moldagens dos canais foram realizadas e analisadas sob estereomicroscópio com aumento de 10×. Cada terço do canal (cervical, médio e apical) foi avaliado separadamente com base nos seguintes critérios: CRFCO – Conicidade regular com formato cônico; CIFCO – Conicidade irregular com formato cônico; CRFCI – Conicidade regular com formato cilíndrico; CIFCI – Conicidade irregular com formato cilíndrico. A análise estatística foi realizada por meio do teste exato de Fisher ($p < 0,05$). Resultados: A categoria CRFCO foi predominante em todos os grupos. Os sistemas BioRace e K3 demonstraram desempenho consistente entre os terços radiculares, enquanto o ProTaper apresentou variação significativa, com maior frequência de CRFCI no terço cervical e CRFCO no terço apical ($p < 0,05$). Mtwo e HEROShaper apresentaram resultados intermediários, sem diferenças estatisticamente significativas entre os terços. Conclusões: Embora as diferenças tenham sido mais evidentes nos terços médio e apical, a predominância do padrão CRFCO entre os grupos indica uma capacidade de modelagem satisfatória para todos os sistemas.

PALAVRAS-CHAVE: Instrumentos Endodônticos; Molar Inferior; NiTi; Preparo do Canal Radicular, Capacidade de Modelagem.

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