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Shaping ability and cyclic fatigue resistance between Genius ProFlex, ZenFlex, and TruNatomy rotary systems: an experimental study

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ABSTRACT

Objectives: The aim of this study was to investigate the efficacy of three newly introduced rotary endodontic systems: Genius ProFlex (Medidenta), TruNatomy (Dentsply Maillefer), and ZenFlex (Kerr).
Methods: Forty-five mandibular molars with root canal curvatures <5° were utilized. Micro-computed tomography scans were performed pre- and post-preparation to assess apical transportation, centralization, percentage of dentin wear, and canal volume alterations. Eight instruments of each diameter underwent cyclic fatigue testing.
Results: The percentage of dentin wear on mesial and distal walls showed no significant differences among ZenFlex, TruNatomy, and Genius ProFlex at 1, 2, 3, and 4 mm from the apical foramen and root canal orifice ($p > 0.05$). Centering ability varied in the mesiolingual canal ($p < 0.05$). No notable differences were observed in transportation ($p > 0.05$). Genius ProFlex demonstrated lower volumetric changes ($p < 0.05$). There were significant differences in cyclic fatigue, with higher values for Genius ProFlex and lower values for TruNatomy ($p < 0.05$).
Conclusions: The three nickel-titanium rotary instruments are safe and efficient for root canal preparation, with Genius ProFlex exhibiting superior cyclic fatigue resistance.

Keywords: Dental alloys; Nickel; Root canal preparation; Root canal therapy; Titanium

INTRODUCTION

Endodontic science has focused on the advancement and studying materials that facilitate the preparation of the root canal system, giving rise to the development of mechanized rotary systems [1–3]. The disinfection of the complex system of root canals is the current challenge of endodontics due to the presence of accessory canals and anatomical anfractuosities, which are not affected by instrumentation and irrigating solutions, reducing the chances of a favorable prognosis after endodontic treatment [4,5]. Effective preparation and enlargement

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Carlos Alberto Spironelli Ramos is currently retired.

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of root canals are essential as microorganisms inhabit dentinal tubules and anatomical irregularities, necessitating mechanical removal [6]. Subsequently, the root canal filling is responsible for preventing coronal micro infiltration and entrapping residual microorganisms [7].

Over the decades, considerable progress has been achieved, including the development of more flexible instruments capable of navigating diverse curvatures to enhance apical enlargement. This advancement improved disinfection, reduced working time, and minimized the risk of canal transportation [8]. Furthermore, heat-treated instruments offer several advantages over traditional stainless steel and conventional nickel-titanium (NiTi) instruments, including increased flexibility, enhanced cutting efficiency, and greater resistance to cyclic fatigue. Consequently, these instruments contribute to better preservation of root canal morphology, leading to more centralized preparation and preservation of the apical foramen [9–11].

Recently, two novel endodontic systems have emerged: the Genius ProFlex (Medidenta, Las Vegas, NA, USA) and the ZenFlex (Kerr, Brea, CA, USA). Introduced in 2021, the ZenFlex system features a 1-mm shaft diameter for maneuverability and a non-cutting tip aimed at minimizing canal transportation and preserving dental structure in the cervical region, thereby reducing the risk of root fracture [12]. The NiTi utilized possesses controlled memory with a triangular section and is available in tapers 0.04 and 0.06, ranging in sizes from 0.20 to 0.55 mm tip diameter. Similarly, the Genius ProFlex, a recently introduced engine-driven rotary file, undergoes three custom heat treatments in sequence, tailored to the file's metal mass. The diameter of the NiTi wire used to produce the Genius ProFlex is 1.0 mm. Moreover, the system exhibits variable cross-sectional shapes depending on the instrument's diameter [13]. The TruNatomy system (Dentsply Maillefer, Ballaigues, Switzerland) has also entered the global market, prioritizing substantial apical enlargement while conservatively managing the cervical portion. Manufactured using heat-treated NiTi, TruNatomy features a distinctive thin wire construction with a maximum diameter of 0.8 mm, as opposed to the conventional 1.2 mm. Furthermore, it incorporates an eccentric parallelogram-shaped section, designed to enhance debris removal capacity, as per the manufacturer's specifications.

To the best of our knowledge, no studies have yet examined the shaping ability of ZenFlex and its cyclic fatigue resistance at body temperature for Genius ProFlex and ZenFlex, which could notably impact the flexural resistance of NiTi files by altering their transformation temperatures [14,15]. Therefore, this study aims to evaluate the cyclic fatigue resistance, root canal transportation, centering ability, percentage of dentin wear, and final volume post-root canal preparation using three recently introduced mechanized systems: Genius ProFlex, TruNatomy, and ZenFlex.

METHODS

This study was evaluated by the Ethics Committee in Human Research of Bauru Dental School, University of São Paulo (No. 40185120.2.0000.5417).

Sample selection and preparation

A sample size calculation was conducted using G*Power 3.1 software (Heinrich Heine University, Dusseldorf, Germany), based on data from a prior study [16], which determined a requirement of 15 teeth per group. Forty-five mandibular molar teeth were selected, featuring mesial canal curvatures below 5° and mesial canals originating and terminating in distinct apical foramina. Curvature analysis was conducted using micro-computed tomography (CT) (SkyScan 1174v2; Bruker-microCT, Kontich, Belgium) with the following parameters: a voxel size of 22.9 μm, 50 kV, 800 mA, 180° rotation with a 0.8° step size, and a resolution of 1,024 × 1,304 pixels. The degree of curvature of the samples was quantified using the method proposed by Schneider [17]. Mesiobuccal and mesiolingual canals were analyzed separately. The pairing of teeth was based on anatomical similarities, such as canal volume and curvatures, as outlined in a prior study [16]. Homogeneity across groups was confirmed via the Tukey statistical test ($p > 0.05$).

The teeth were standardized to 15 mm using a diamond cutting disc. The working length was established 1 mm short of the apex. Initial exploration was conducted using stainless steel no. 10 K-files (Dentsply Maillefer) up to the actual tooth length of 15 mm, with instrumentation carried out at a 14-mm working length.

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Root canal preparation

The specimens were randomly (https://www.random.org/) separated into three groups (n = 15), based on the instrumentation system utilized: TruNatomy, ZenFlex, and Genius ProFlex, following manufacturers' protocols. For the TruNatomy system, the following sequence was used: TruNatomy Small 20.04, TruNatomy Prime 26.04, and TruNatomy Medium 36.03. For the ZenFlex system, the sequence consisted of 20.04, 25.04, and 35.04. For the Genius ProFlex system, the sequence used was 20.04, 25.04, and 35.04. Throughout instrumentation with the VDW Silver engine (VDW, Munich, Germany), TruNatomy and ZenFlex systems operated at 500 revolutions per minute (rpm) and 1.5 N, while Genius ProFlex operated at 400 rpm and 1.5 N. Files were advanced apically using an in-and-out pecking motion with a 3-mm amplitude, applying gentle apical pressure. Each canal received 20 mL of 2.5% sodium hypochlorite irrigant delivered via a 5-mL disposable syringe (Ultradent, South Jordan, UT, USA) and a 30-gauge NaviTip needle (Ultradent). After three cycles of insertion and removal, the instrument was removed and cleaned with gauze. Following root canal preparation, irrigation involved 2 mL of 17% ethylenediaminetetraacetic acid solution for 3 minutes, followed by 5 mL of saline solution. Each instrument was utilized for the preparation of three teeth before being discarded. A single, trained operator performed instrumentation across all groups.

After instrumentation, specimens underwent a new micro-CT scan, adhering to the previously mentioned parameters.

Micro-computed tomography analysis after instrumentation

The software NRecon version 1.6.3 (Bruker-microCT) was employed to generate three-dimensional (3D) models, enabling visualization of the internal tooth structure. Subsequently, data viewer software (Bruker-microCT) was utilized to co-register pre-preparation and post-preparation 3D image models, employing a customized combination of a registration module based on image intensity similarities, achieving an accuracy greater than 1 voxel. The surface area (mm^2) and total volume (mm^3) of the canal were calculated using CTan software (Bruker-microCT) [16].

Dentin thickness on the mesial and distal walls was assessed at 1, 2, 3, and 4 mm from the apical foramen and the root canal orifice, using measurements X2 and Y2, respectively. This involved subtracting the thicker dentin thickness from the thinner dentin thickness before and after instrumentation. The corresponding equations applied to the mesial and distal sides were (X2 – X1) and (Y1 – Y2), respectively. Dentin thickness was then used to calculate the percentage of dentin wear.

Canal transportation and centering ability were evaluated at 1, 2, 3, and 4 mm from the apical foramen and the root canal orifice. The formula suggested by Gambill *et al*. [18], (X1 – X2) – (Y1 – Y2), was applied to measure canal transportation on both mesial and distal sides. X1 and Y1 denoted the shortest distance from the external root surface to the uninstrumented canal periphery before preparation, on the mesial and distal sides respectively. The X2 and Y2 denoted the shortest distance from the external root surface to the instrumented canal periphery after preparation, on the mesial and distal sides respectively. A result of 0 signified no canal transportation. A positive value indicated transportation towards the mesial side, corresponding to the inner curve towards the furcation area, while a negative value indicated transportation towards the distal side, corresponding to the outer curve opposite to the furcation area. The X1, Y1, X2, and Y2 measurements at the apical third and coronal third were also used to evaluate the centering ability according to the equation suggested by Gambill *et al*. [18]: (X1 – X2) / (Y1 – Y2) or (Y1 – Y2) / (X1 – X2). The smaller of the two values was used as the numerator in the formula, with a result of 1 indicating optimal centering ability.

The CTan software was used to assess the root canal volume, calculating the total number of root canal voxels (100%) and the number (%) that was kept after preparation. With the CTvol software (Bruker-microCT), a comparison was made between the models before and after preparation, performing an overlap of the pre- and post-preparation scans. To allow this analysis, a color pattern was defined: red to mark the surfaces before preparation and green after preparation.

Cyclic fatigue test

A sample calculation was conducted using G*Power version 3.1 software for the mechanical test, opting for the Wilcoxon-Mann-Whitney test from the *t*-test family. Parameters included an alpha error of 0.05, a beta power of 0.95, and a ratio of N2/N1 set at 1. This yielded an ideal sample size of eight specimens per group.

A total of eight instruments per diameter (n = 48) were employed: Genius ProFlex 25/0.04 and 35/0.04, ZenFlex 25/0.04 and 35/0.04, and TruNatomy 26/0.04 and 36/0.03. Prior to mechanical testing, all instruments underwent inspection for potential defects or deformities using a stereomicroscope (Stemi 2000C; Carl Zeiss, Jena, Germany) at ×16 magnification.

The cyclic fatigue test was conducted using an apparatus designed to simulate the curvature of an artificial stainless-steel canal, as detailed in prior studies [11,19]. This apparatus featured a 60° curvature and a 5-mm radius. The curvature adjustment was achieved using a guide cylinder (5-mm radius) and an outer arc with a 1-mm deep groove, facilitating the rotation of instruments while maintaining them within the curvature. The cyclic fatigue test was conducted at simulated body temperatures (36°C ± 1°C) using histology water bath equipment (Leica HI 1210; Leica Biosystems, Nussloch, Germany), enabling precise temperature control. A total of 600 mL of water was utilized to fill the equipment container to the required level, ensuring the simulated canal remained submerged. Temperature monitoring was achieved using both the digital thermometer of the equipment and an infrared thermometer throughout the test. An electric motor, VDW Reciproc Silver (VDW), was coupled to this apparatus, and instruments were operated with continuous rotary motion at a speed of 400 rpm and a torque of 1.5 N/cm. The time taken for instrument fracture was measured using a digital stopwatch and corroborated by simultaneous filming. Subsequently, the number of cycles until fracture (NCF) was calculated using the following formula: time to fracture (in seconds) multiplied by speed (rpm), divided by 60.

Afterward, transverse images of the fractured instruments were obtained using a scanning electron microscope (SEM) (JSM-TLLOA; JEOL, Tokyo, Japan) to determine the topographic features of the fractured surface. Before SEM evaluation, the instruments were ultrasonically cleaned (L100; Schuster Equipamentos Odontológicos, Santa Maria, Brazil) in saline solution for 3 minutes. Instruments were examined at ×200 magnification.

Statistical analysis

Intragroup analysis for shaping ability data was conducted using the Wilcoxon test ($p > 0.05$). Comparison of canal volume (mm^3) and surface area (mm^2) between pre- and post-instrumentation periods was performed separately to ensure similar anatomical conditions across groups, employing the Kruskal-Wallis and Dunn tests for intergroup comparisons.

For cyclic fatigue data, normality was confirmed, and subsequent analysis involved a one-way analysis of variance and Tukey test to compare instruments within each system and diameter, considering time and NCF. The Student *t*-test was used to compare the diameters of 0.25 and 0.35 mm (0.26 and 0.36 mm for TruNatomy) within the same system.

RESULTS

Percentage of dentin wear

Table 1 displays the percentage of dentin wear (%) for the mesiobuccal and mesiolingual canals, including their respective mesial and distal walls, for each instrument system. Statistical analysis revealed no significant difference in the percentage of dentin wear among ZenFlex, TruNatomy, and Genius ProFlex at distances of 1, 2, 3, and 4 mm from the apical foramen and the root canal orifice ($p > 0.05$).

Centering ability

Table 2 illustrates the centering ability analysis. Significant differences were observed only for ZenFlex compared to TruNatomy in the mesiolingual canal at the 3-mm apical level ($p < 0.05$).

Root canal transportation

Regarding transport, Table 3 shows no significant differences between the instruments tested at any level in the mesiobuccal and mesiolingual canals ($p > 0.05$).

Root canal volume

Table 4 displays data regarding total volumetric al-

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Table 1. The percentage of dentin wear of each instrument system, for the mesiobuccal and mesiolingual root canals, and their mesial and distal walls

Instrument system	Mesiobuccal								Mesiolingual							
	1 mm		2 mm		3 mm		4 mm		1 mm		2 mm		3 mm		4 mm	
	Mesial	Distal	Mesial	Distal	Mesial	Distal	Mesial	Distal	Mesial	Distal	Mesial	Distal	Mesial	Distal	Mesial	Distal
ZenFlex																
Cervical	5.7 (0.8–15.8)	11.2 (1.1–32.4)	8.3 (1.1–16.3)	11.8 (2.7–30.7)	9.1 (1.6–20.3)	9.1 (2.4–22.7)	8.2 (−2.9 to 15.8)	7.6 (−4.8 to 18.7)	5.7 (0.8–15.8)	16.2 (3.3–27.3)	8.3 (1.1–16.3)	11.8 (2.7–24.8)	9.1 (1.6–20.3)	9.9 (3.8–24.7)	8.2 (−2.9 to 15.8)	10.4 (−4.8 to 14.3)
Apical	5.2 (0–12.1)	3.6 (0–10)	7.3 (1–11.7)	6.2 (0–11.6)	7 (0.3–12.5)	8.1 (0–12.7)	9 (1.2–15.8)	7.6 (0–19.7)	7.1 (0–15.9)	6.3 (0.8–16.4)	6.5 (0.5–16.5)	10.4 (4.1–15.6)	9.1 (3.9–17.9)	10.4 (4.1–15.6)	9.7 (2.5–20.3)	10.6 (0–29.4)
TruNatomy																
Cervical	8 (1.8–17.6)	17.8 (5.8–31.6)	6.8 (0.5–21.4)	17.4 (0.8–24.8)	8.4 (2.0–17.4)	8.4 (1.1–19.9)	8.7 (0–23.5)	8.1 (0.1–13.9)	8 (1.8–17.6)	16.6 (1.6–32.4)	6.8 (0.5–21.4)	14.1 (0.8–37.9)	8.4 (2.0–17.4)	9.7 (2.4–29.5)	8.7 (0–23.5)	8 (3.8–17.6)
Apical	6.5 (0.5–15.8)	6.3 (0.8–25.9)	7.3 (−1.4 to 15.10)	6.7 (2.4–19.5)	9.1 (3.9–18.2)	10.4 (2.8–15.6)	9.1 (2.4–19.7)	7.8 (0–29.4)	8.4 (0–15.8)	3.6 (0–19.1)	7.3 (1.0–17.0)	8 (0–14.9)	9.2 (0.3–20.3)	8.1 (0–14.0)	9.6 (1.2–27.4)	7.8 (0–19.7)
Genius ProFlex																
Cervical	6.1 (1.8–15.9)	17.3 (1.6–27.3)	6.9 (2.1–14.3)	15.2 (5.2–37.9)	9.6 (3.1–16.0)	10.4 (3.8–29.5)	11.2 (3.2–18.2)	10.4 (0.7–17.6)	6.1 (1.8–15.9)	15.8 (1.1–27.9)	6.9 (2.1–14.3)	13.5 (1.8–30.7)	9.6 (3.1–16)	9.7 (1.1–22.2)	11.2 (3.2–18.2)	8.6 (0–18.7)
Apical	10.7 (0.3–15.9)	8.5 (0.4–19.1)	10.8 (0.5–17)	8.6 (2.3–14.9)	13 (4.4–20.3)	9.5 (0.1–15.6)	9.7 (2.5–27.4)	8.2 (0.7–17.5)	6.3 (0.5–15.8)	7.7 (0.7–25.9)	8.4 (−1.4 to 15.1)	4.4 (2.4–12.4)	8.2 (5.0–18.2)	8.6 (1.3–13.4)	8.7 (2.4–16.0)	6.6 (1.6–18.9)

Values are presented as median (range).
There are no statistically significant differences between the instruments analyzed ($p > 0.05$).

teration. Genius ProFlex has the smallest percentage change in total and apical volumes compared to the other systems, especially for the mesiobuccal canal ($p < 0.05$). Additionally, when comparing apical volume across the systems, no significant differences were observed ($p > 0.05$).

Figure 1 illustrates micro-CT reconstructions and cross sections at coronal and apical levels of representative samples evaluated before and after instrumentation, utilizing ZenFlex, TruNatomy, and Genius ProFlex.

Cyclic fatigue and scanning electron microscope

Table 5 presents the times in seconds and the NCF until fracture due to cyclic fatigue of the examined instruments. Comparison across systems revealed significant differences ($p < 0.05$), with higher values observed for Genius ProFlex and lower values for TruNatomy, for both diameters of 0.25 and 0.35 mm (0.26 and 0.36 mm for TruNatomy), in terms of time and NCF. Comparing different diameters within the same system, except for TruNatomy, where no difference was observed between diameters of 0.26 and 0.36 mm, statistically lower values were noted for diameter 35 in the other systems ($p < 0.05$).

Figure 2 displays SEM images of the fractured 0.25 and 0.35 mm instruments from each system. These images depict characteristic features indicative of cyclic fatigue behavior observed under SEM.

DISCUSSION

This study assessed the shaping ability and cyclic fatigue resistance of three thermally treated NiTi rotary systems. This multimethod analysis aimed to provide insights for clinicians regarding the safety of these systems during root canal preparation of moderately curved canals. Micro-CT was employed as it offers a nondestructive imaging technique, facilitating comprehensive morphometric analysis with high resolution and precision. This technique enables the evaluation of volumetric differences, thickness patterns, dentin remnants, centralization, transportation, and other anatomical details [20].

The findings of this study indicate that the Genius ProFlex, TruNatomy, and ZenFlex rotary systems exhibit comparable transport and centering ability in

Table 2. Instrument systems' centering ability in mesiobuccal and mesiolingual root canals

Instrument system	Mesiobuccal				Mesiolingual			
	1 mm	2 mm	3 mm	4 mm	1 mm	2 mm	3 mm	4 mm
ZenFlex								
Cervical	0.59 (0.20–0.88)[A]	0.49 (0.10–0.88)[A]	0.78 (0.40–0.98)[A]	0.64 (0–0.98)[A]	0.53 (0.23–0.97)[A]	0.66 (0.24–0.98)[A]	0.79 (0.23–0.96)[A]	0.54 (0–1)[A]
Apical	0.60 (0.10–1)[A]	0.53 (0.24–0.93)[A]	0.79 (0.18–0.98)[A]	0.66 (0–0.88)[A]	0.67 (0.25–1)[A]	0.50 (0.10–1)[A]	0.69 (0.40–0.98)[A]	0.53 (0.19–0.96)[A]
TruNatomy								
Cervical	0.64 (0.09–1)[A]	0.55 (0.17–1.72)[A]	0.62 (0.20–0.96)[A]	0.49 (0–1)[A]	0.64 (0.09–1)[A]	0.55 (0.17–1.72)[A]	0.78 (0.20–1.72)[A]	0.57 (0–1)[A]
Apical	0.44 (0–1)[A]	0.61 (0.22–0.96)[A]	0.48 (0.03–2.63)[A]	0.64 (0.33–1)[A]	0.44 (0–1)[A]	0.59 (0.22–0.96)[A]	0.48 (0.03–2.63)[B]	0.65 (0.33–1.72)[A]
Genius ProFlex								
Cervical	0.45 (0.19–0.97)[A]	0.45 (0.16–0.84)[A]	0.61 (0.20–0.97)[A]	0.54 (0.18–1)[A]	0.65 (0.1–0.93)[A]	0.45 (0.16–0.84)[A]	0.61 (0.14–0.97)[A]	0.54 (0–1)[A]
Apical	0.63 (0.14–0.92)[A]	0.67 (0–0.98)[A]	0.66 (0.31–0.97)[A]	0.59 (0.18–1.72)[A]	0.63 (0.19–0.90)[A]	0.48 (0.22–0.95)[A]	0.66 (0.18–1.72)[A,B]	0.60 (0.18–0.94)[A]

Values are presented as median (range).
Different capital letters indicate differences between the file systems ($p < 0.05$).

Table 3. Canal transportation (mm) of each instrument system, for mesiobuccal and mesiolingual root canals

Instrument system	Mesiobuccal				Mesiolingual			
	1 mm	2 mm	3 mm	4 mm	1 mm	2 mm	3 mm	4 mm
ZenFlex								
Cervical	−0.04 (−0.2 to 0.08)	−0.02 (−0.11 to 0.04)	−0.01 (−0.07 to 0.09)	0.01 (−0.11 to 0.09)	−0.01 (−0.15 to 0.03)	0 (−0.06 to 0.08)	0.02 (−0.08 to 0.14)	0.05 (−0.09 to 0.15)
Apical	−0.01 (−0.15 to 0.09)	0 (−0.09 to 0.09)	0.01 (−0.07 to 0.13)	0.04 (−0.08 to 0.14)	−0.04 (−0.14 to 0.07)	0 (−0.09 to 0.09)	0.01 (−0.07 to 0.09)	0.01 (−0.11 to 0.09)
TruNatomy								
Cervical	−0.02 (−0.15 to 0.1)	0 (−0.07 to 0.09)	0.04 (−0.07 to 0.16)	0.05 (−0.06 to 0.15)	−0.11 (0.02–0.09)	0.05 (−0.02 to 0.15)	−0.01 (−0.11 to 0.16)	0.04 (−0.07 to 0.08)
Apical	−0.01 (−0.06 to 0.05)	0.01 (−0.08 to 0.09)	0.01 (−0.07 to 0.09)	0.02 (−0.04 to 0.08)	0.02 (−0.21 to 0.09)	0 (−0.10 to 0.09)	0.01 (−0.07 to 0.09)	0.03 (−0.08 to 0.13)
Genius ProFlex								
Cervical	−0.01 (−0.21 to 0.09)	−0.01 (−0.24 to 0.08)	0 (−0.14 to 0.09)	0.01 (−0.07 to 0.07)	0 (−0.21 to 0.09)	0.04 (−0.08 to 0.08)	−0.01 (−0.14 to 0.09)	0 (−0.08 to 0.07)
Apical	0 (−0.19 to 0.12)	−0.03 (−0.09 to 0.08)	0 (−0.1 to 0.06)	0.01 (−0.09 to 0.10)	0 (−0.07 to 0.12)	−0.03 (−0.15 to 0.10)	0.01 (−0.06 to 0.05)	0.04 (−0.03 to 0.08)

Values are presented as median (range).
There are no statistically significant differences between the instruments analyzed ($p > 0.05$).

the mesiobuccal and mesiolingual canals, except for ZenFlex, which differed from TruNatomy at the apical 3-mm level. Only one published study has evaluated the shaping ability of Genius ProFlex files. The authors observed no significant differences in volume, surface area, removal of dentin debris, and unprepared areas between the preparation of lower molars using Genius ProFlex, TruNatomy, and Vortex Blue files [21]. These findings are partially consistent with those reported in our study. The Genius ProFlex resulted in the smallest percentage change in total and apical canal volumes, particularly in the mesiobuccal canal. This suggests that the canal volume was less altered compared to other file systems. However, no differences were found in the apical volume. Regarding the shaping ability of ZenFlex, only one study has been published in the literature. In this study, the authors evaluated the effect of instrument cooling on the preparation of lower premolars using ZenFlex and ProTaper Next files. The authors did not find any statistically significant differences between

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Table 4. Volume (mm^3) before, after, and relative (%) after using file systems for mesiobuccal and mesiolingual root canals

Instrument system	Mesiobuccal			Mesiolingual		
	Before	After	%	Before	After	%
Zenflex						
Total	0.91 (0.35–14.49)^{A}	2.07 (1.00–15.26)^{B}	121.70 (5.34–319.90)^{a}	1.13 (0.43–11.40)^{A}	2.00 (1.00–12.08)^{B}	68.30 (6.02–198.20)^{a}
Apical	0.23 (0.08–1.88)^{A}	0.5 (0.18–1.99)^{B}	79.25 (5.93–437.50)^{a}	0.28 (0.10–0.76)^{A}	0.49 (0.25–0.85)^{B}	62.81 (1.49–253.30)^{a}
TruNatomy						
Total	0.9 (0.47–11.40)^{A}	1.77 (1.03–12.08)^{B}	101.50 (6.02–236.80)^{a}	1.18 (0.35–6.30)^{A}	1.78 (1.47–8.05)^{B}	82.57 (13.21–319.90)^{a}
Apical	0.25 (0.13–0.45)^{A}	0.48 (0.27–0.72)^{B}	89.35 (0.59–274.70)^{a}	0.18 (0.08–0.66)^{A}	0.43 (0.18–0.66)^{B}	99.09 (0.50–437.50)^{a}
Genius ProFlex						
Total	1.41 (0.51–6.3)^{A}	2.00 (0.86–8.05)^{B}	47.72 (13.21–165.30)^{b}	0.95 (0.51–14.49)^{A}	2.27 (0.86–15.26)^{B}	98.92 (5.34–236.80)^{a}
Apical	0.29 (0.10–0.77)^{A}	0.45 (0.25–0.85)^{B}	33.33 (0.50–253.30)^{a}	0.25 (0.12–1.88)^{A}	0.51 (0.23–1.99)^{B}	61.48 (0.59–257.10)^{a}

Values are presented as median (range).
Different lowercase letters indicate statistically significant differences between the instruments analyzed ($p < 0.05$). Different capital letters indicate differences between the total and apical volume ($p < 0.05$).

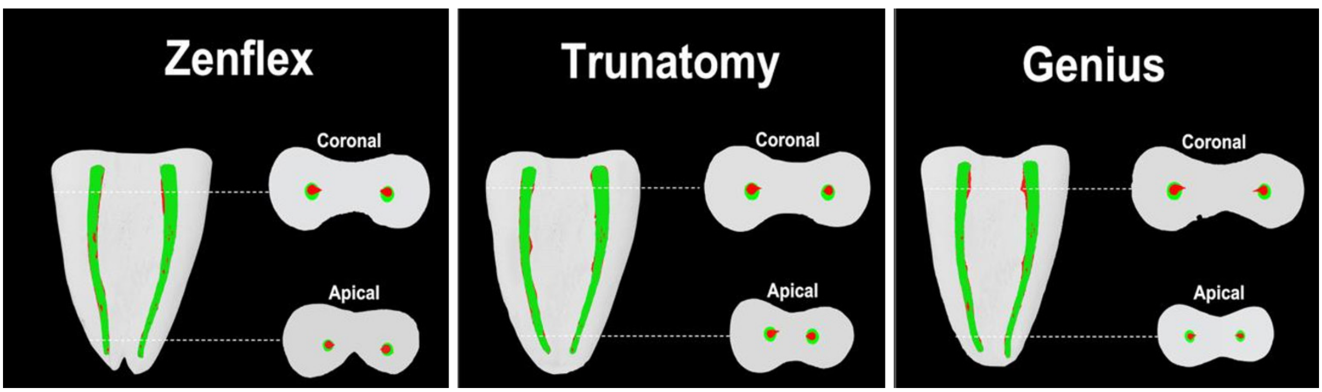

Figure 1. Representative micro-computed tomography reconstructions of mesial root canals and cross sections at coronal and apical levels. The red and green colors represent root canal anatomy before and after root canal preparation.

Table 5. Time and number of cycles to fracture (NCF) of the instruments

Instrument system	Time (sec)	NCF
Genius ProFlex		
25/0.04	1,045 ± 56.6^{aA}	6,969 ± 377.1^{aA}
35/0.04	374.3 ± 12.2^{aB}	2,496 ± 81.6^{aB}
TruNatomy		
26/0.04	83.5 ± 6.7^{cA}	556.7 ± 44.9^{cA}
36/0.03	77.8 ± 7.6^{cA}	518.8 ± 51.0^{cA}
ZenFlex		
25/0.04	234.6 ± 27.7^{bA}	1,564 ± 184.7^{bA}
35/0.04	138.4 ± 14.5^{bB}	922.7 ± 96.7^{bB}

Values are presented as mean ± standard deviation.
Different lowercase letters indicate statistically significant differences between the instruments analyzed ($p < 0.05$). Different capital letters indicate differences between instruments with diameters of 0.25 and 0.35 mm within the same system ($p < 0.05$).

the evaluated groups [22]. While limited published studies on the behavior of Genius ProFlex and ZenFlex systems are available, previous research has investigated the TruNatomy system. For instance, a study by Kabil *et al.* [23] reported canal transportation values similar to those observed in the present study. Similarly, regarding centralization capacity, the TruNatomy system demonstrated values consistent with findings reported by Kabil *et al.* [23], ranging from 0.44 to 0.65 mm apically in both canals. Moreover, Silva *et al.* [24] investigated TruNatomy system transportation and obtained low values (less than 0.1 mm), aligning with our study's findings.

When considering the clinical implications of the findings, Wu *et al.* [25] suggested that apical canal transportation of less than 0.3 mm would have minimal impact on treatment prognosis. In this study, all three

Figure 2. Scanning electron microscope micrographs (×200) of the fractured instruments after the cyclic fatigue test.

instrument systems tested exhibited canal transportation of less than 0.3 mm in the mesiobuccal and mesiolingual canals across all root levels. These consistent results suggest that the utilization of these systems can be deemed safe.

In a supplemental analysis, we compared the cervical and apical thirds within the same group regarding centering ability, root canal transportation, and percentage of dentin wear in both mesial and distal root canals (Wilcoxon test). The data revealed no statistically significant differences between the cervical and apical thirds concerning centering ability, root canal transportation, and percentage of dentin wear ($p > 0.05$). However, a statistically significant difference was observed in the percentage of dentin wear on the distal surface, where the cervical third exhibited a greater percentage of wear compared to the apical third ($p < 0.001$). This pattern was consistent across all groups analyzed (Genius ProFlex, ZenFlex, and TruNatomy), indicating increased wear on the distal surface of the cervical third compared to that of the apical third.

In summary, the Genius ProFlex system demonstrated the most conservative behavior, exhibiting the lowest percentage of total volumetric change. However, when assessing changes in the apical region, no significant differences were found among the groups, indicating only slight disparities in the cervical third. Analysis of dentin thickness further revealed that the systems removed more percentage of dentin in the middle cervical third of the mesiobuccal and mesiolingual canals, particularly at 1 to 2 mm on the distal walls when using TruNatomy and Genius ProFlex. Given that the instruments shared a comparable taper, this resulted in a more conservative preparation with no discernible difference in apical volume. Variations in thermal treatment and cross-sectional design may contribute to differences in centralization ability among the instruments. Clinical studies are warranted to evaluate the effectiveness of these instruments.

The cyclic fatigue resistances of two new systems, ZenFlex and Genius ProFlex, were compared with that of the TruNatomy system, for both diameters of 0.25 and 0.35 mm (0.26 and 0.36 mm for TruNatomy). The experiments were conducted under static conditions but at a temperature of 36°C ± 1°C, aiming to simulate clinical conditions for instrument usage as closely as possible. Previous studies have shown that temperature, influenced by the instrument's heat treatment, plays a crucial role in its resistance to cyclic fatigue. Elevated temperatures approach the transformation temperatures of heat-treated alloys, leading to a higher proportion of austenite crystals with an enhanced elastic modulus. This increase in austenite crystals also raises the hardness of the alloy, making it less resistant to cyclic fatigue [12,19,26].

The Genius ProFlex system demonstrated significantly higher resistance to cyclic fatigue for both diameters. This system features customized heat treatment for different files in the sequence and an S-shaped cross-section, providing enhanced flexibility [15]. Despite being conducted under different temperature conditions, the results align with those reported by Silva *et al.* [21], who found that the Genius ProFlex system exhibited greater cyclic fatigue resistance for size 25 files compared to the TruNatomy files. Conversely, the ZenFlex system, with its control memory martensitic heat treatment and triangular cross-section, may exhibit lower resistance due

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to differences in metal mass. The TruNatomy system exhibited the lowest values, with the Prime instrument featuring an International Organization for Standardization 26 tip size, an overall decreasing taper averaging 0.04, and a parallelogram cross-section. The cross-section's higher metal mass in the central core and differences in heat treatment may contribute to TruNatomy's lower resistance. A previous study [27] reported higher values than those observed in this study, which could be attributed to differences in testing conditions; the previous study conducted the cyclic fatigue test at 20°C, while the present study employed 36°C ± 1°C. The increase in temperature favors a higher presence of austenitic crystals, increasing the rigidity of the instrument and making it more susceptible to cyclic fatigue, as observed in previous studies [28,29].

In this study, the cyclic fatigue resistance of instruments with diameters of 0.35 and 0.36 mm was also analyzed. The highest values were observed in the Genius ProFlex system, followed by ZenFlex, while the lowest values were found in TruNatomy. Although TruNatomy has an average taper of 0.03, compared to 0.04 in the other systems, variations in the core, heat treatment, and cross-section may also account for significant differences in resistance. Enlarging the canals to a diameter of 0.35 mm promotes a closer approximation to the average anatomical diameter of molars [10,30,31] and provides a higher percentage of touched walls [32].

In a supplementary examination of cyclic fatigue resistance, we analyzed the cross-sectional configurations of each instrument at 5 mm from the tip using SEM and software (AutoCAD; Autodesk, Inc., San Francisco, CA, USA) [33]. The area measurements revealed that while the Genius and ZenFlex instruments of diameters of 0.25 exhibited similar areas (69.37 mm² and 69.74 mm², respectively), the TruNatomy instrument of diameter of 0.26 had a significantly larger area (81.21 mm²). The diameter of 0.35 mm instruments displayed greater variability in cross-sectional area, with the Genius measuring 101.39 mm² and the ZenFlex 83.29 mm². Additionally, the TruNatomy instrument of diameter of 0.36 mm measured 70.87 mm². These findings suggest that while a larger metallic mass may enhance resistance to cyclic fatigue [33], factors such as instrument design and thermal treatment must also be considered [11,13].

The experimental model employed in our study to evaluate cyclic fatigue resistance was conducted under static conditions, as previously reported in previous studies [11,13,15,21]. Static tests can offer valuable insights into how different design features or pre-treatments (such as heat or surface treatments) affect cyclic fatigue, which is crucial for the development and optimization of new NiTi files [10]. Dynamic tests may introduce torsional stress due to the bending tube used, which complicates the differentiation between torsional and cyclic fatigue fractures [34,35]. Additionally, achieving consistent axial movement without lateral forces is challenging, and lateral movement can create additional bending points, potentially skewing the results of dynamic tests [36]. Consequently, this study utilized the static test method, as dynamic analysis could introduce additional variables beyond those related to the instrument type, due to its increased sensitivity.

Our study evaluated the cyclic fatigue and shaping ability of three endodontic instruments with similar NiTi wire diameters. Consistent with Grande *et al.* [37], who found that the metal volume at the point of maximum stress influences the fatigue life of NiTi rotary instruments, our results showed similar cyclic fatigue values between the Genius ProFlex and ZenFlex instruments, both of which have similar maximum diameters of 1 mm. The authors also noted that instruments with similar metal volumes per mm exhibit comparable cyclic fatigue resistance. Moreover, the observed differences in shaping ability among the instruments in our study might be attributed to variations in core diameter, as differing core metal mass can affect shaping performance [38,39]. However, it is important to consider that factors related to the thermal treatment of the instruments can also influence these outcomes [16].

Despite the limitations of our study, the recent introduction of the ZenFlex and Genius ProFlex instruments highlights a significant gap in the literature, as only a limited number of articles have compared their efficacy and performance. To date, just one study has evaluated the Genius ProFlex [21] and only three have assessed the ZenFlex files [12,22,40]. This study provides valuable additional information about these instruments, enhancing our understanding of their clinical safety and performance. The insights gained from this research are important for clinicians in selecting the most suitable instruments for their specific clinical situations. However, further studies should be conducted to evaluate these systems dynamically and assess their metallurgical characteristics.

CONCLUSIONS

In this study conditions, the TruNatomy, ZenFlex, and Genius ProFlex systems were efficient and safe for preparing the mesiobuccal and mesiolingual canals in lower molars. These systems had similar shaping ability in the coronal third. Also, Genius ProFlex provided the highest cyclic fatigue resistance.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

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