ORIGINAL ARTICLE

COMPARATIVE ANALYSIS OF THE MECHANICAL PROPERTIES OF TYPE K STAINLESS STEEL MANUAL INSTRUMENTS: A STUDY OF DIFFERENT BRANDS

ANÁLISE COMPARATIVA DAS CARACTERÍSTICAS MECÂNICAS DE INSTRUMENTOS MANUAIS DE AÇO INOXIDÁVEL TIPO K: UM ESTUDO DE DIFERENTES MARCAS

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ABSTRACT

The present study aimed to compare the geometric and mechanical characteristics of six different brands of type K stainless steel manual instruments. Instruments in sizes 15 and 0.20 were analyzed, through buckling and torsional resistance tests, following ISO 3630 standards. -1 and ANSI/ADA 101. Micromorphometry evaluated diameters and conicities at specific points (D0 and D3). The results indicated that the TDK 15 and Angelus 0.20 instruments presented greater resistance to buckling, while variations in diameter in D0 were observed mainly in the TDK 15 and Perfect 15 instruments. In relation to torsional resistance, the Maillefer 0.20 instruments stood out due to the greater angular deflection before fracture, suggesting greater flexibility. Thus, the TDK 15 and Angelus 0.20 instruments proved to be more suitable for negotiating atretic canals and endodontic retreatment, however variations in the diameter of the TDK 15 and Perfect 15 instruments may compromise the adaptation of cones during the obturation phase. The Maillefer 0.20 instruments, with greater flexibility, are more suitable for curved canals.

Keywords: Dental instruments, Stainless steel, Endodontics, Root canal preparation, Root canal treatment, Assessment of Mechanical Properties.

RESUMO

O presente estudo teve como objetivo comparar as características geométricas e mecânicas de seis marcas diferentes de instrumentos manuais de aço inoxidável tipo K. Foram analisados instrumentos nos tamanhos 15 e 0,20, por meio de testes de resistência à flambagem e torção, seguindo as normas ISO 3630-1 e ANSI/ADA 101. A micromorfometria avaliou diâmetros e conicidades em pontos específicos (D0 e D3). Os resultados indicaram que os instrumentos TDK 15 e Angelus 0,20 apresentaram maior resistência à flambagem, enquanto variações no diâmetro em D0 foram observadas principalmente nos instrumentos TDK 15 e Perfect 15. Em relação à torção, os instrumentos Maillefer 0,20 destacaram-se pela maior deflexão angular antes da fratura, sugerindo maior flexibilidade. Assim, os instrumentos TDK 15 e Angelus 0,20 mostraram-se mais adequados para a negociação de canais atrésicos e retratamento endodôntico, porém as variações no diâmetro dos instrumentos TDK 15 e Perfect 15 podem comprometer a adaptação de cones na fase de obturação. Já os instrumentos Maillefer 0,20, com maior flexibilidade, são mais indicados para canais curvos.

Palavras-chave: Instrumentos odontológicos, Aço inoxidável, Endodontia, Preparo de canal radicular, Tratamento de canal radicular, Avaliação de Propriedades Mecânicas.

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INTRODUCTION

Mechanical instrumentation plays a fundamental role in endodontics, directly influencing the success and long-term prognosis of endodontic treatments (1,2). The endodontic instruments used for this purpose should ideally be small and have mechanical resistance to twisting and buckling, in order to withstand the loads imposed on them during apical progression (3,4).

According to ISO (International Organization for Standardization), the working part of a Kerr (K) type instrument is 16 mm long and has a taper of 0.02 mm/mm (5). Instruments with adequate resistance to buckling can facilitate both the location of the canal orifices and access to the apical third. On the other hand, instruments with low buckling resistance may develop elastic or plastic deformations that hinder their apical progression (4,6,7). On the other hand, instruments with high buckling resistance may present greater stiffness than clinically necessary. The use of rigid instruments can result in some complications, such as steps and perforations during instrumentation, compromising the clinical result (8).

Since the introduction of mechanized nickel-titanium (NiTi) instruments in endodontics, there has been a tendency to replace manual stainless steel instruments (9,10). Though, one of the main disadvantages of NiTi instruments is the possibility of fracture without visible changes during clinical use (11). For this reason, stainless steel instruments continue to be widely used for recognizing and establishing the canal path before the use of mechanized instruments (12,13). This clinical step, known as glide-path, is recommended to avoid modeling errors and reduce the rate of instrument fracture in calcified and narrow canals (14,15).

Unlike NiTi instruments, which have been widely studied, there are few studies on the mechanical and physical characteristics of stainless steel instruments (16,17). Given the diversity of brands available on the market, it is likely that there will be variations in their physical properties, which may influence their clinical performance. With the emergence of new brands, it becomes essential to characterize and evaluate their mechanical properties.

This study aims to carry out a comparative analysis of the geometric and mechanical characteristics of six different brands of type K stainless steel manual instruments with a length of 25mm and dimensions 15 and 0.20, through micromorphometry, buckling and torsion tests.

METHODS

Stainless steel manual instruments measuring 25 mm in length were used from the manufacturers Angelus (Londrina, Brazil), TDK (Curitiba, Brazil), MK Life (Porto Alegre, Brazil), Perfect (Shenzhen, China), All Prime (Tan Huong, Pho Yen municipality, in Thai Nguyen Province, Vietnam) and Dentsply-Maillefer (Baillagues, Switzerland), with diameters of 15/0.02 and 0.20/0.02. The number of elements measured was established in accordance with item 6.3 of ANSI/ADA standard nº 101.

Buckling test

For the buckling test, a load was applied in the axial direction of each instrument using an EMIC DL 200MF universal testing machine (EMIC São José dos Pinhais, Brazil) (figure 1). The maximum resistance to buckling (lateral elastic deformation) was obtained according to previously published studies (7,18). A 20 N load cell was used. The rod of the instrument was fixed to the head of the universal testing machine by a mandrel, and the tip of the instrument was axially compressed against an aluminum plate with a rough surface. The test was performed at a speed of 1 mm/min, and the maximum force for lateral displacement was recorded.

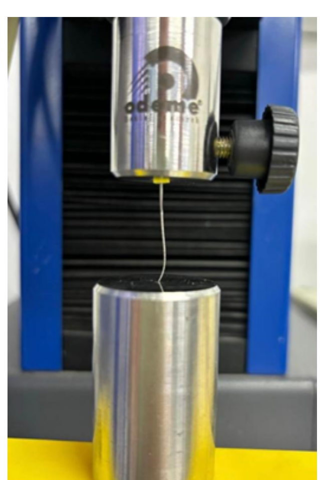

Figure 1: Photograph of the buckling test. After axial compression, the instrument presented lateral deformation.

Micromorphometric analysis

To perform micromorphometry, images of the instruments were captured using an Opticam stereoscopic magnifying glass coupled to a digital camera. Measurements were carried out using the TSView 7.2.1.7 software. The diameters of the instruments were determined from D0 to D5, with intervals of 1.0 mm between each measurement. The taper was calculated as specified in ANSI/ADA standard no. 101, item 6.3.3.2, using diameters D5 and D1. The taper was calculated using the formula: C=(D5-D1)/4, in which the difference between diameters is divided by the distance between them.

The diameters of the instruments were obtained by drawing tangent lines (red lines in Figure 2) to the upper and lower crests of the active part of the instruments.

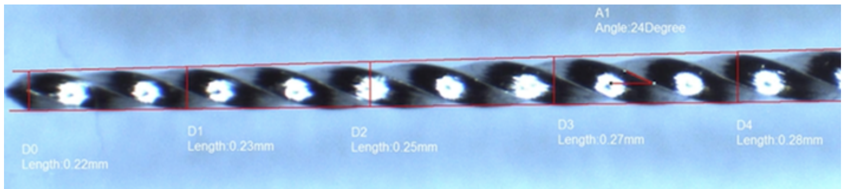

Figure 2: Micromorphometry photography. The diameters of the instruments.

Torsional Test

For the torsional test, each instrument was fixed 3 mm from the tip, using a vise coupled to a load cell with a torque sensor. The instrument shaft was fixed in an opposing mandrel, being driven by a motor (figure 3). To prevent the induction of axial compressive stress in the instrument during the torsional test, a “U-piece” was used, which allowed the vise to slide laterally, immobilizing the tip of the instrument. All instruments were driven clockwise at a speed of 2 rpm until fracture. The torque load (Ncm) and angular deflection (º) were continuously monitored using software on the TT100 torquemeter (Odeme, Luzerna, SC, Brazil). The maximum fracture torque and angular deflection were obtained by the torquemeter software (Odeme Analysis TT, Odeme).

Sample calculation

Three pilot tests were carried out to calculate the sample size using the G* Power 3.1.9.4 program (Franz Foul, University of Kiel, Germany). An effect size of 12 elements was estimated, two for each group. For greater reliability, and due to the availability of material, five tests were carried out per group, totaling 30 instruments.

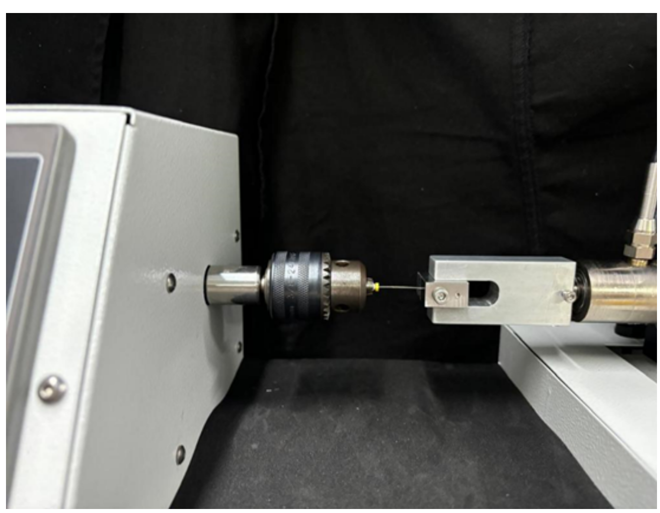

Figure 3: Photograph of the torsion test. Seizing the instrument to perform the torsional test on the left was a Jacob mandrel to which the handle was fixed and on the right was a vise that allowed the instrument to be fixed 3mm from the tip. It is also possible to observe the “U” device that allows the vise to slide, preventing normal tensions from causing the instrument to buckle.

Statistical analysis

Preliminary data analysis revealed a bell-shaped distribution, according to the Shapiro-Wilk test. For the normality test, the Minitab Student program was used. The hypothesis test selected was analysis of variance (ANOVA), complemented by the Student-Newman-Keuls post-hoc test. For hypothesis testing, the Primer of Biostatics version 6.0 program (McGraw-Hill, New York, NY, USA) was used. For all tests, the type α error was 5%.

RESULTS

The results obtained in the mechanical tests are presented in tables 1 and 2.

Buckling Test

For type 15 instruments, the Angelus brand had the lowest buckling resistance followed by the Maillefer brand, while TDK had the highest buckling resistance (P<0.05). No significant differences were observed in buckling resistance between the Perfect, MKLife and All Prime brands (P>0.05). For type 0.20 instruments, Angelus showed the highest buckling resistance, while Maillefer the lowest (P<0.05). No differences were observed in buckling resistance between the brands Perfect, TDK, MKLife and All Prime (P>0.05).

Torsional Test

In the evaluation of type 15 instruments, no differences were observed in the maximum fracture torque between the brands (P>0.05). Regarding type 0.20 instruments, the Maillefer brand presented the greatest resistance to angular deflection. The other brands had no significant difference (P>0.05). No differences were observed in torsional torque resistance between brands (P>0.05).

Table 1: Mean + SD (standard deviation) of mechanical tests carried out on instruments with a diameter of 0.15 mm. Different superscript letters indicate a statistically significant difference (p<0.05).

INSTRUMENT	BUCKLING (gf)	TORSIONAL(º)	TORSIONAL(N.mm)
MAILLEFER (MAI)	142+10.8^{A}	644.77+164.55^{A}	3.35+0.38^{A}
PERFECT (PER)	171+11.3^{B}	712.01+111.39^{A}	3.9+0.17^{A}
TDK	236+16.8^{C}	821.19+198.36^{A}	5.4+0.49^{A}
MKLIFE (MKL)	173+6.5^{B}	797.89+108.76^{A}	3.02+0.56^{A}
ANGELUS (ANG)	128+10.3^{E}	880.48+218.61^{A}	2.84+0.25^{A}
ALLPRIME (ALL)	161+12.4^{B}	742.14+101.40^{A}	3.07+0.76^{A}

Buckling resistance: TDK>PER=MKL=ALL>MAI>ANG
Torsional resistance (angle): MAI= ALL=ANG=MKL=PERF=TDK
Torsional resistance (torque): MAI= ALL=ANG=MKL=PERF=TDK

Table 2: Mean + SD of mechanical tests carried out on instruments with a diameter of 0.20 mm. Different superscript letters indicate a statistically significant difference (p<0.05).

INSTRUMENT	BUCKLING (gf)	TORSIONAL(º)	TORSIONAL(N.mm)
MAILLEFER (MAI)	239±10.2^{A}	1033.23±153.26^{A}	3.52±0.24^{A}
PERFECT (PER)	270±19.2^{B}	701.44±125.8^{B}	3.84±0.52^{A}
TDK	292±29.2^{B}	569.39±92.77^{B}	3.32±0.26^{A}
MKLIFE (MKL)	311±45.1^{B}	653.33±71.12^{B}	3.02±0.26^{A}
ANGELUS (ANG)	342±11.8^{E}	574.81±191.31^{B}	3.26±0.39^{A}
ALLPRIME (ALL)	267±13.4^{B}	751.12±194.00^{B}	3.46±0.41^{A}

Buckling resistance: ANG>MKL=TDK=PER=ALL>MAI
Torsional resistance (angle): MAI > ALL=ANG=MKL=PERF=TDK
Torsional resistance (torque): MAI=ALL=ANG=MKL=PERF=TDK

Micromorphometry Analysis

Tables 3 and 4 describe the results of the micromorphometric analysis showing the average diameter in D0 and average conicity of instruments 0.15 and 0.20.

The micromorphometric analysis of the instruments demonstrated that the 0.20 MK Life and TDK type instruments had an increased conicity of 0.03 mm/mm, while the type 15 instruments from all manufacturers met the standardization recommended by ANSI/ADA nº101.

In relation to D0, instruments 15 from the Maillefer and All Prime brands had a tip diameter smaller than that accepted by the tolerance. And the 0.15 Perfect and TDK instruments had a larger diameter than recommended. In K 0.20 instruments, only the Perfect brand met the standard's recommendation.

Table 3: Mean diameters in D0 and mean conicity of instruments 0.15.

INSTRUMENT	MAILLEFER	PERFECT	TDK	MKLIFE	ANGELUS	ALLPRIME
1	0.14	0.15	0.16	0.13	0.14	0.12
2	0.12	0.16	0.16	0.16	0.14	0.16
3	0.16	0.18	0.19	0.17	0.13	0.17
Mean D0	0.14	0.16	0.17	0.15	0.14	0.15
Mean conicity	0.02	0.02	0.02	0.02	0.02	0.02

Table 4: Mean diameters in D0 and mean conicity of instruments 0.20.

INSTRUMENT	MAILLEFER	PERFECT	TDK	MKLIFE	ANGELUS	ALLPRIME
1	0.19	0.2	0.15	0.17	0.19	0.15
2	0.22	0.21	0.19	0.14	0.18	0.2
3	0.17	0.22	0.2	0.15	0.17	0.22
Mean D0	0.19	0.21	0.18	0.15	0.18	0.21
Mean conicity	0.02	0.02	0.03	0.03	0.02	0.02

DISCUSSION

The glide-path is a protocol that ensures safe and efficient passage of NiTi instruments along the entire working length (19). Given the frequent exposure of these materials to bending and torsional stresses, it is essential to investigate their physical characteristics and composition.

The TDK type 15 and Angelus type 0.20 instruments, which are commonly used in the glide-path, demonstrated the highest buckling resistance. Clinically, this may be interesting for negotiating atretic canals and in cases of endodontic retreatment. However, both presented D0 values higher than those recommended by the clinical pattern, which could cause problems at the time of filling. The stop generated by the last instrument used may not properly anchor the main gutta-percha cones, resulting in material extrusion (5).

Instruments with greater metallic mass tend to present better resistance to twist and buckling, factors that can significantly influence canal negotiation procedures and the establishment of a glide-path for the apical region of the root canal (12). However, Angelus and Maillefer type 15 instruments and Maillefer type 0.20 instruments demonstrated reduced resistance to buckling loads, which corroborate with results of a previous study (13).

These specific instruments have a greater degree of flexibility, a critical attribute for their performance in endodontic procedures (13). Increased flexibility offers specific advantages, particularly in negotiating the curvature of the apical region. This feature is especially valuable during the recognition phase, minimizing the risk of accidents, such as broken instruments. Although advantageous in many scenarios, it is worth recognizing that increased flexibility and reduced buckling resistance can present challenges in fully negotiating constricted and calcified root canals (6).

The model used in the present study to perform micromorphometry was the same used by Ribeiro et al., 2016 (20), which consists of drawing tangent lines to the instruments' helices. In this way, the measurement simulates the shape of the instrument preparation in the root canal. According to item 4.2 of ANSI/ADA standard no. 101, instrument diameters have a tolerance of + 0.025 mm. The average conicity of all instruments evaluated for the study is within the standard recommended. Nevertheless, regarding D0, type 15 instruments from the Maillefer and All Prime brands had a smaller tip diameter than acceptable. The 0.15 Perfect and TDK instruments had a larger diameter than recommended. In K 0.20 instruments, only the Perfect brand met the standard's recommendation. This diameter is of great importance, as it represents the region of mechanical preparation that will define the stop for filling in the apical critical zone (21).

Observing the D0 of the instruments used in the present study, the lack of precision during manufacturing became evident. Small diameter instruments may have dimensional variations due to the critical manufacturing process (22). The failure in the manufacture of instruments creates difficulties during instrumentation, when using instruments with larger diameters and when filling the canals, since the diameters found are not in accordance with recommendations. Thus, the calibrated cones used at the time of filling will not adjust to the preparation (23). Dias et al. when analyzing the morphometrics of type K files from the manufacturers Angelus and Maillefer found that none of them fully comply with ANSI standard 101 (5).

Although it is known that the minimum width of a glide-path should be size 0.10 (24), previous studies have described an initial preparation, generally with a small taper (0.02) and a size of at least 15 or 0.20 to avoid the instrument from blocking (25,26). Torsional stresses affecting shaping instruments have been reported to be reduced by creating a glide-path up to these apical sizes (25,27). To overcome the challenges inherent in performing glide-path procedures, an endodontic instrument must have great flexibility, high buckling resistance, and torque resistance with high angular deflection under torsional forces (28). Glide-path instruments do not always present the sum of these characteristics. For example, in general, the more flexible the instrument, the lower its resistance to buckling (19).

TDK type 15 instruments had the highest buckling resistance, while Angelus demonstrated the lowest. Clinically, high buckling resistance is preferred during root canal exploration, allowing the instrument to advance axially in the apical direction. However, there is an inverse relationship between flexibility and buckling resistance. Both mechanical properties are related to the geometry and alloy of the instrument. Furthermore, diameter and conicity have a strong influence on the buckling test (29). This explains why TDK has greater buckling resistance than the other instruments tested. Despite demonstrating conicity within the standards required by the pattern, it was the instrument that presented the largest diameter in D0, which implies greater structural rigidity and, consequently, greater resistance to buckling (18). On the other hand, the lower buckling resistance of Angelus type 15 instruments may be related to the smaller diameter in D0, which makes them more flexible and, consequently, less rigid within the other groups.

Exploring a constricted curved canal is often a challenge for the endodontist. Accidents such as protrusions and perforations can occur during the exploration of narrow curved canals, compromising the treatment outcome (1). The incidence of protrusion formation when using more flexible files is lower compared to more rigid files. The metallic memory of stainless steel to return to a straight position increases the tendency to carry or protrude a canal and eventually drill curved canals (30).

The TDK and Perfect type 15 instruments showed greater resistance to buckling. This property, theoretically, provides greater ability to negotiate narrow root canals, though, as they are more rigid, they are not indicated in cases of curved canals, such as molar canals. With the increased chance of the development of steps and deviations (19), the Angelus instrument appears to be the least suitable for this procedure.

Regarding type 0.20 instruments, the Angelus had the highest buckling resistance, while the Maillefer were less resistant. Although the Angelus do not have the largest diameter in D0 nor the largest conicity among the instruments evaluated, their greater resistance to buckling is possibly due to the composition of the instrument's alloy, as occurred with the Maillefer, also demonstrating conicity and size in D0 recommended by the pattern.

Torsional strength tests were performed as suggested by ISO 3630-1 and have been reported in previously published studies (31,32). For torsional tests, the immobilization point at D3 is the critical point at which the material will fail when shear stresses are applied (5). Two different properties were obtained from this test: the maximum torque and the angular deflection. The maximum torque is requested when an instrument is clamped inside the root canal and continues to be activated (11). The greater the touch for the fracture, the safer the instrument (24). In this regard, none of the tested brand stood out.

Instruments from different brands have similar transversal designs, diameters and conics, which favored equivalence in torsional properties. Interestingly, Maillefer type 0.20 instruments demonstrated greater angular deflection before fracture, as well as lower resistance to buckling, demonstrating greater flexibility of the instrument. Angular deflection works as a safety mechanism during the use of instruments, as the greater the plastic deformation, it can be seen more easily, allowing the affected instrument to be discarded (15). In our study, the 15 instruments showed no significant differences.

This mixture of mechanical properties makes these instruments less suitable for use as glide path instruments, especially in cases of narrow root canals. However, they are more suitable for curved canals, as they are more flexible (28). Instruments with characteristics such as greater conicity and larger diameters tend to be less flexible, more resistant to buckling and end up withstanding greater torsional stress (33), which corroborates the findings of this study.

CONCLUSION

The TDK 15 and Angelus 0.20 instruments proved to be more suitable for negotiating atretic canals and endodontic retreatment, even though variations in the diameter of the TDK 15 and Perfect 15 instruments may compromise the adaptation of cones during the obturation phase. The Maillefer 0.20 instruments, with greater flexibility, are more suitable for curved canals. Further studies are needed to validate these data and explore new endodontic approaches.

The authors declare no conflicts of interest.

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