

Buckling resistance, bending stiffness, and torsional resistance of various instruments for canal exploration and glide path preparation

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Objectives: This study compared the mechanical properties of various instruments for canal exploration and glide-path preparations. **Materials and Methods:** The buckling resistance, bending stiffness, ultimate torsional strength, and fracture angle under torsional load were compared for C+ file (CP, Dentsply Maillefer), M access K-file (MA, Dentsply Maillefer), Mani K-file (MN, Mani), and NiTiFlex K-file (NT, Dentsply Maillefer). The files of ISO size #15 and a shaft length of 25 mm were selected. For measuring buckling resistance ($n = 10$), the files were loaded in the axial direction of the shaft, and the maximum load was measured during the files' deflection. The files ($n = 10$) were fixed at 3 mm from the tip and then bent 45° with respect to their long axis, while the bending force was recorded by a load cell. For measuring the torsional properties, the files ($n = 10$) were also fixed at 3 mm, and clockwise rotations (2 rpm) were applied to the files in a straight state. The torsional load and the distortion angle were recorded until the files succumbed to the torque. **Results:** The CP was shown to require the highest load to buckle and bend the files, and the NT showed the least. While MA and MN showed similar buckling resistances, MN showed higher bending stiffness than MA. The NT had the lowest bending stiffness and ultimate torsional strength ($p < 0.05$). **Conclusions:** The tested instruments showed different mechanical properties depending on the evaluated parameters. CP and NT files were revealed to be the stiffest and the most flexible instruments, respectively. (*Restor Dent Endod* 2014; 39(4):270-275)

Key words: Bending stiffness; Buckling resistance; Glide path; Nickel-titanium rotary file; Stainless steel file; Torsional resistance

Introduction

The clinical success of endodontic treatment is basically decided upon the completeness of bacterial removal.¹ The root canal exploration after access opening is the initial step to minimize missing canals that contain bacterial toxins and infected tissues. Mechanical instrumentation using files is a basic procedure for achieving the purpose of root canal preparation.² Contemporary root canal preparation using nickel-titanium (NiTi) rotary files not only is easier and faster but also has a better success rate than that with handheld stainless steel (SS) instruments, as the preparation is well tapered and relatively clean with a low tendency towards aberration.^{3,4} However, clinicians need to establish a glide path during the initial preparation before

introducing the NiTi files in order to reduce the torsional fracture of these rotary instruments.⁵⁻⁷

Unprepared root canals have minimal lumens and tight irregular conditions. Thus, the instruments usually selected for canal exploration, canal negotiation, and glide path preparation are small and flexible.⁸⁻¹⁰ These initial instruments should have small dimensions but possess sufficient mechanical resistance to the loads generated during the initial instrumentation. During exploration using small files, sometimes, the instruments succumb to the forces applied: this is referred to as 'buckling'.¹¹ Instruments that have low resistance to buckling may develop elastic or plastic deformation that hinders their apical progression in the canal.¹² Adequate buckling resistance may facilitate both the exploration of the canal orifices and the negotiation of the narrow canal walls.¹³

During the glide path preparation, the instrument is guided apically, and then, various rotational movements are applied.^{12,14,15} Therefore, the instruments should have adequate torsional resistance as well as adequate flexibility to minimize canal deviation and preserve the original root canal curvature.¹⁶ Recently, NiTi rotary instruments that are engine-driven have become available specifically for glide path preparation.¹⁴ However, conventional SS files are still used for the canal exploration and negotiation. While the mechanical properties of shaping instruments, particularly the NiTi rotary files, have been studied extensively, rare studies have investigated the small instruments used manually for canal exploration and negotiation.^{3,17-20}

Therefore, the aim of this study was to compare the mechanical properties of various instruments for initial root canal preparation procedures, such as canal exploration and glide path preparation.

Materials and Methods

This study compared the buckling resistance, bending stiffness, and ultimate torsional strength, and fracture angle under torsional load were compared for C+ file (CP, Dentsply Maillefer, Ballaigues, Switzerland), M access K-file (MA, Dentsply Maillefer), Mani K-file (MN, Mani, Tochigi, Japan), and NiTiFlex K-file (NT, Dentsply Maillefer). Among them, NT is made of a NiTi alloy, while the others are made of SS. The ISO size of the tested files was #15, and a shaft length of 25 mm was selected.

The tests were conducted using a customized device (AEndoS, DMJ system, Busan, Korea). For measuring buckling resistance ($n = 10$), the instrument handle was connected to the device, and the instrument tip was placed in a small cavity prepared in a palladium metal plate. Then, the file was loaded in the axial direction of the shaft at the crosshead speed of 1.0 mm/s, while the file tip was restrained in a point location. The axial load was plotted during the loading and the file's deflection, and the maximum load was defined as the buckling resistance (Figure 1a).

The bending stiffness and the torsional resistance were measured by following the American National Standard/

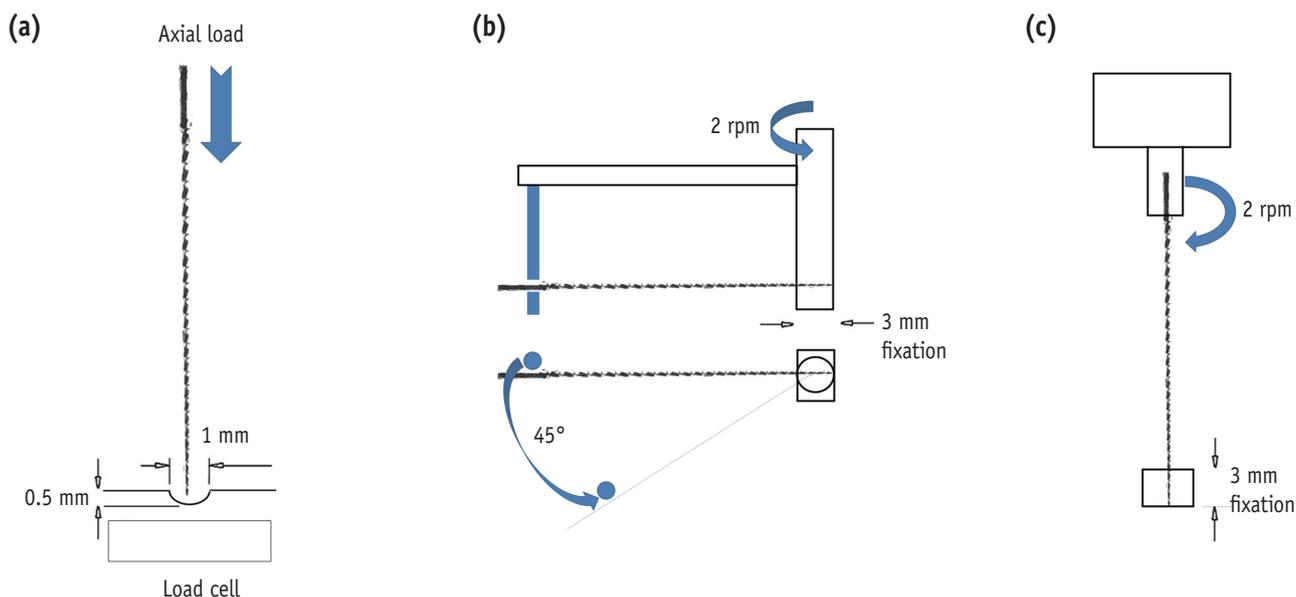


Figure 1. Test designs of (a) buckling resistance; (b) bending stiffness; (c) torsional resistance.

American Dental Association Specification No. 28 and ISO Specification 3630-1.^{21,22} The files ($n = 10$) were fixed at 3 mm from the tip and then bent 45° with respect to their long axis, while the bending moment was recorded by a load cell of the same device (Figure 1b). For measuring the torsional properties, the files ($n = 10$) were also fixed at 3 mm from the tip and uniform clockwise rotations at a rate of 2 rotations per minute (rpm) were applied to the files in a straight state. The torsional load and the distortion angle were recorded until the files succumbed to the torsional load.

The data were first analyzed to evaluate the assumption of normality. Then, they were analyzed statistically by using a one-way analysis of variance (ANOVA) and Duncan's *post-hoc* comparison, to check for any differences between the groups at a significance level of 95%. All statistical analyses were conducted using the relevant statistics software (SPSS Statistics 20, IBM Corp., Armonk, NY, USA).

Representative specimens of the test instruments ($n = 3$) were embedded in an acrylic resin (Orthodontic resin, Dentsply caulk, Milford, DE, USA) and examined using a stereomicroscope (MZ16FA, Leica, Heerbrugg, Switzerland) for the analysis of the instrument's cross-sectional design.

Results

The results for the buckling test, bending stiffness, and torsional resistance are presented in Table 1. Statistical analysis showed a significant difference in the maximum load necessary to buckle the tested instruments ($p < 0.05$). The CP was shown to require the highest load to buckle and bend the files, and the NT showed the least ($p < 0.05$). While MA and MN showed similar buckling resistances, MN showed higher bending stiffness ($p < 0.05$). The NT had the lowest bending stiffness and ultimate torsional strength ($p < 0.05$). The distortion angle until torsional failure was minimal with the CP ($p < 0.05$). Stereomicroscopic examination showed that the cross-sections of all instruments except NT were square. CP had the largest

cross-sectional area followed by MA and MN, and NT. The NT having a triangular cross-section had the least area (Figure 2).

Discussion

Owing to the advancement of microscope dentistry, clinicians are more likely to find existing root canals and have an increased clinical success rate. After locating the canal orifices, canal exploration and negotiation should follow for chemo-mechanical preparation. During these initial procedures, the tiny constricted canal is a challenging situation. Even by using small files, sometimes, it is not possible to negotiate and pass through the sclerotic root canals. Therefore, appropriate mechanical properties are the basic necessities of the instruments to form a path to the apical area. Although nowadays many kinds of NiTi rotary instruments have been used for mechanical instrumentation, SS instruments are still used for the exploration of narrow curved canals. However, only a few studies have investigated some of the mechanical properties of these instruments.^{9,10,12}

A sufficient buckling resistance enables clinicians to easily penetrate an existing canal, which is usually narrow and occasionally sclerotic. An instrument that is too weak cannot negotiate a tight orifice and canal area, and thus, files need to have an appropriate buckling resistance. However, sometimes, files having a strong buckling resistance are stiff, and the power of stiffness might be more than that needed clinically. The use of stiff instruments can result in some canal aberrations such as ledges and perforations during the negotiation and may then jeopardize the clinical outcome.^{13,23} Because small conventional K-type SS instruments (*i.e.*, sizes #06, 08, and 10) usually show a reduced resistance to buckling, they are sometimes unable to negotiate and penetrate narrow calcified canals to the full working lengths. Hence, size #15 was selected in this study.⁸ By virtue of selecting size #15, NT could be included. #06, 08, and 10 NT are not

Table 1. Mechanical behavior under torsional load (ultimate strength and fracture angle), bending stiffness, and buckling resistance (mean \pm standard deviation)

Groups	Buckling resistance (Kgf)	Bending stiffness (Ncm)	Ultimate strength (Ncm)	Fracture angle (degree)
C+ (CP)	0.100 \pm 0.006 ^a	0.31 \pm 0.03 ^a	0.55 \pm 0.09 ^a	321.0 \pm 112.6 ^d
Mani (MN)	0.058 \pm 0.005 ^b	0.23 \pm 0.03 ^b	0.35 \pm 0.06 ^b	1033.2 \pm 88.2 ^a
M access (MA)	0.057 \pm 0.003 ^b	0.16 \pm 0.03 ^c	0.37 \pm 0.05 ^b	0768.4 \pm 105.0 ^c
NiTi Flex (NT)	0.011 \pm 0.000 ^c	0.04 \pm 0.00 ^d	0.11 \pm 0.01 ^c	0906.7 \pm 92.3 ^b

^{a,b,c,d} Groups with different superscript letters indicate a statistically significant difference between instruments ($p < 0.05$).

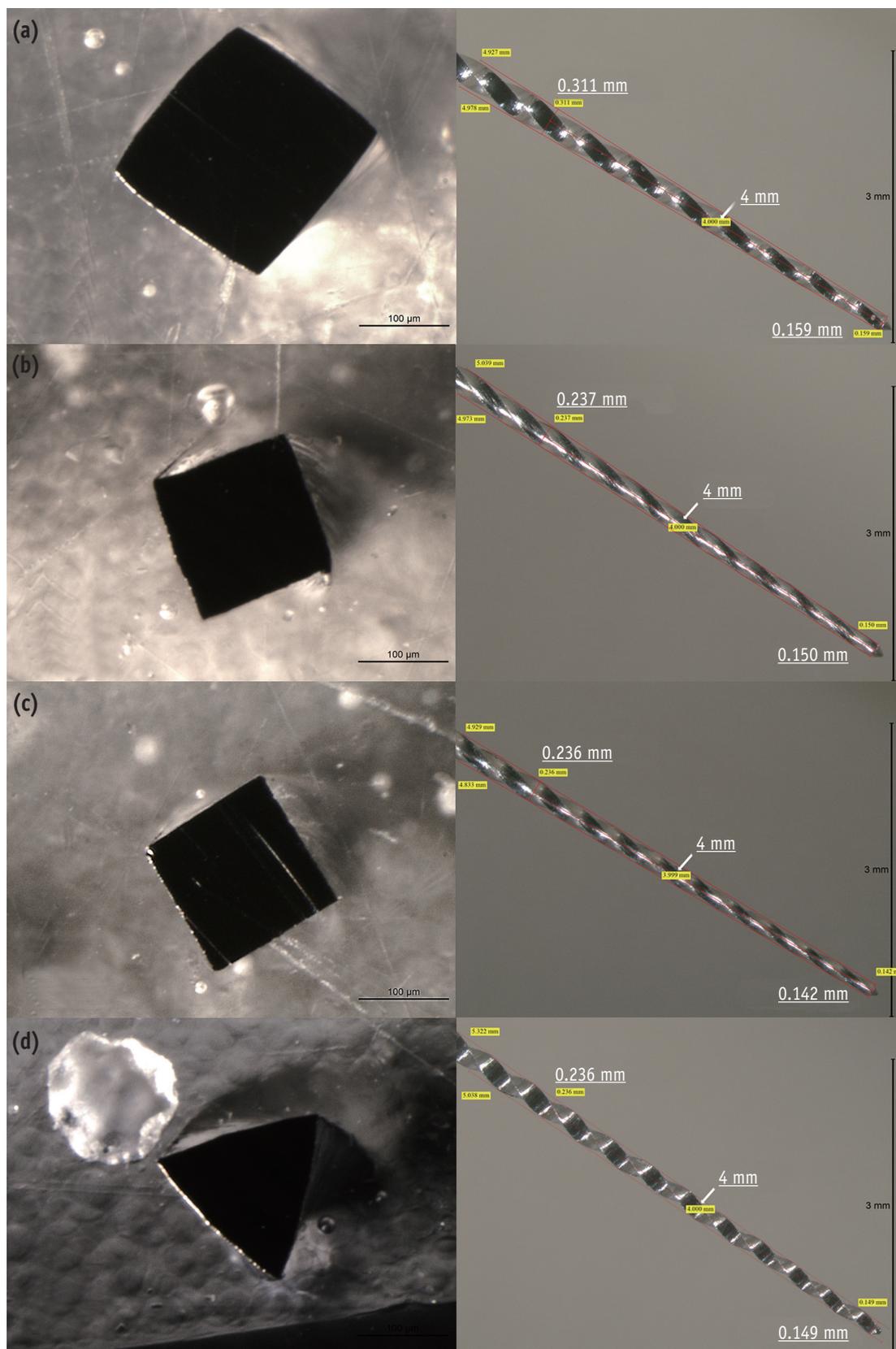


Figure 2. Stereomicroscopic images of (a) C+ file; (b) M access K-file; (c) Mani K-file; (d) NiTiFlex K-file (left column, cross-sections at 3 mm from the tip; right column, lateral aspects at the apical part).

commercially available (the manufacturer does not produce files smaller than #15). From the results, CP was revealed to have a sufficient buckling resistance to negotiate the orifices and for a path to the apical canal. On the other hand, NT showed a minimal buckling resistance as compared to the others. This soft tendency implies that the flexibility and elasticity of a NiTi file may help to preserve the apical canal curvature and reduce the aberrations in the apical canal.¹⁵

Small instruments, when used in the early stages of root canal shaping, are more prone to torsional fracture because they are more likely to be exposed to greater torsional stresses owing to contact with the canal.^{14,24} In particular, for the NiTi rotary instruments, it is highly recommended to prepare a glide path defined as a smooth radicular tunnel from the orifice of the canal to the apical terminus of the root canal.^{5,6,14} Blum *et al.* suggested that glide paths be created using small flexible SS hand files, and Berutti *et al.* recommended pre-flaring the root canal manually to create a glide path before using NiTi rotary instruments.^{6,25} For this purpose, the small instruments should have flexibility as well as torsional resistance.

From the results of the present study, we found that bending stiffness that implies flexibility and torsional resistance have opposite tendencies. Thus, the file having higher flexibility has a lower torsional resistance. CP was revealed to be the stiffest instrument among the tested groups, and NT was the most flexible. CP, in the stereomicroscopic examination, was shown to have a 4% instrument taper 4 mm from the apical tip and 2% along the rest of the shaft.¹² Thus, at the test level of 3 mm from the tip, CP showed the highest bending stiffness and torsional strength because it had the largest cross-sectional area (approximately $0.045 \mu\text{m}^2$). However, CP showed the least fracture angle. Considering that high angular distortion values may serve as a safety factor for the instruments used for rotational movements because clinicians may have an extended opportunity to see the distorted instruments. In this regard, conventional SS K-files and NT are better than CP.

The instruments tested in this study were made of different metallic alloys and had different geometries including cross-section, taper, and pitch. The resultant difference can be explained by the different tapers and mechanical behaviors of the metallic alloys (SS versus NiTi). For instance, the higher buckling resistance of CP may be related to its larger taper of 4% along the apical 4 mm length. Therefore, in comparison with the other instruments, CP had greater torsional strength. On the other hand, NT had the lowest resistance to buckling and lower bending stiffness (*i.e.*, higher flexibility), and these resulted from the fact that this system is the only instrument system made of the NiTi alloy, which has a lower modulus of elasticity than the SS alloy.¹² Of

course, the triangular cross-section of NT had the least cross-sectional area (approximately $0.019 \mu\text{m}^2$ for the NT and $0.026 \mu\text{m}^2$ for both MA and MN) among the tested instruments. This was the main factor leading to its least bending stiffness and buckling resistance.^{16,19}

The torsional resistance of NT was lower than that of the other instruments evaluated in this study. Taking into account that the instruments with a lower torsional strength may have higher flexibility, during clinical rotation, the use of NT will result in minimal transportation at the apical canal that has moderate to severe curvature. Thus, it can be said that NT has better properties than CP for the apical glide path preparation. Considering the four parameters examined in this study, we found that MA has slightly close characteristics as compared to NT with less bending stiffness (*i.e.*, higher flexibility) but with a similar buckling resistance and higher torsional strength than MN. On the other hand, MN showed the greatest distortion angle.

Similar to the other studies on instruments for the shaping procedure, further clinical and mechanical tests are recommended to verify how the geometric characteristics and the alloy influence the mechanical properties of the endodontic instruments.^{16,26}

Conclusions

Under the conditions of this study, the mechanical properties of the instruments for canal exploration and glide path preparation are different according to the file's geometries and alloy types. In conclusion, the examined parameters in this study would be considered in explorative procedures and glide path preparations for selective usages.

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

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