Buckling resistance of pathfinding nickel-titanium rotary instruments in narrow root canal: an in vitro study

Key words  buckling resistance, endodontic instruments, endodontic treatment, glide path, narrow root canal

Introduction: Exploration is an important step of root canal preparation, because it allows the clinician to negotiate the canal to its terminus and determine its complexity. Different instruments have been developed specifically for this purpose. This study compared the buckling resistance of hand stainless steel and pathfinding nickel-titanium rotary instruments in artificial canals with different depths. Materials and methods: A total of 30 PathFile, ScoutRace and C-Pilot instruments were evaluated. The buckling resistance was tested using acrylic resin blocks with a flat surface or with 3 mm and 6 mm deep artificial canals. The load required to generate a lateral displacement of 1 mm was recorded. Data were statistically analysed using one-way analysis of variance (ANOVA) and Student-Newman-Keuls test for multiple comparisons at a significance level of $P < 0.05$. Results: On the flat surface, C-Pilot showed the greatest buckling resistance. In 3 mm deep canals, PathFile showed resistance similar to that of C-Pilot files on the flat surface. In 6 mm deep canals, both nickel-titanium instruments showed greater buckling resistance than C-Pilot on the flat surface ($P < 0.001$). Conclusions: The buckling resistance of nickel-titanium pathfinding instruments increases with the depth of the canal.
whereas NiTi instruments are engine-driven. For preparing the glide path, several authors have recommended the use of NiTi pathfinding instruments only after using hand-operated SS K-files. According to Lopes et al, SS pathfinding instruments present greater buckling resistance than NiTi pathfinding instruments. Therefore, SS instruments should be used initially, in the coronal portion of calcified canals, whereas NiTi instruments may be used in the middle and apical portions.

In this study the dependent variable was the maximum force (gf), measured in different instruments, which are the independent variables. The null hypothesis tested was that there would be no difference in the mean maximum force among groups. With this in mind, the purpose of this study was to investigate the null hypothesis that buckling resistance of hand-operated SS files and pathfinding NiTi rotary instruments in artificial canals with different depths are the same.

### Materials and methods

#### Instruments

The following pathfinding instruments were evaluated in this study: C-Pilot 10/.02 (VDW, Munich, Germany); PathFile 13/.02 (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA); and ScoutRace 10/.02 (FKG Dentaire, La Chaux-de-Fonds, Switzerland). C-Pilot is a hand file made of SS, while PathFile and ScoutRace are rotary NiTi instruments. All files used were 25 mm long, with a taper of 0.02 (2%) along the entire shaft. All instruments were examined before the experimental procedure to detect any possible surface defects.

#### Acrylic resin blocks

Five acrylic resin blocks were prepared for the buckling resistance test. Acrylic resin was inserted into polyvinyl chloride (PVC) tubes measuring 25 mm in length and 25 mm in diameter, closed at one end. One of the tubes was completely filled with acrylic resin up to its rim. After setting, the resin developed a rough surface. This resin block simulated a canal calcified at its entrance. All types of files were subjected to buckling resistance testing on this flat surface. The SS instruments were only tested on this surface. The results from the buckling resistance test for SS files served as the basis for comparison of these instruments with the NiTi instruments on the rough resin surface, as well as in the 3 mm and 6 mm deep artificial canals created in the other four resin blocks. The other four tubes were prepared to test the buckling resistance of the PathFile and ScoutRace NiTi instruments. Artificial canals measuring 3 mm...
or 6 mm in depth were created by filling the tubes with acrylic resin and introducing rotary NiTi instruments previously lubricated with petroleum jelly into the resin, before the material was set. After setting, the NiTi instruments were removed and 3 mm or 6 mm deep artificial canals were created in each block (Fig 1). The resin blocks to test the ScoutRace and PathFile instruments were different, since these files have different nominal diameters (0.10 mm and 0.13 mm, respectively). Therefore, the artificial canals have the same size as the tested files.

The resin blocks prepared specifically for testing the NiTi instruments aimed to simulate the conditions found during initial exploration of root canals calcified at different depths.

Ten instruments of each brand were subjected to the buckling resistance test, with their active tips resting on the rough resin surface. In addition, 20 PathFile and ScoutRace instruments (10 instruments of each brand) were tested for buckling resistance with their tips inserted into the 3 mm and 6 mm deep canals, aiming to simulate partial exploration at different depths.

**Buckling test**

During the buckling resistance test, a progressively increasing load was applied in the axial direction of each instrument by using a universal testing machine (Emic DL, 10.000, São José dos Pinhais, PR, Brazil) equipped with a load cell of 20 N, and the maximum load to buckle each instrument (elastic lateral deformation) was recorded. The instrument handle was attached to the head of the universal testing machine, and the instrument tip was in contact with the resin block.1

After connecting each instrument to the device, a load was applied in the axial direction from the handle toward the tip at a crosshead speed of 1 mm/min, until a 1 mm compressive displacement was observed along the instrument shaft. The universal testing machine was programmed to stop the motion after 1 mm of deformation. During the test, a diagram of load (N) × deformation (mm) was created for each instrument. The maximum load required to induce elastic displacement of 1 mm was defined as the buckling resistance of each instrument (Fig 2).1,5

The ANOVA, followed by Duncan’s post hoc test, were selected to test the hypothesis. A parametric test was performed since the assumptions of normality and homogeneity of the variance were not rejected. All data were analysed using ANOVA with the Student-Newman-Keuls (SNK) test for multiple comparisons, with the significance level set at $P < 0.05$.

**Results**

Table 1 shows the means and standard deviations of the maximum force to buckle (gf) obtained from each group. For the instrument tips resting on the rough surface of the resin block, the results revealed statistically significant difference among groups ($P < 0.001$). The highest values were observed for C-Pilot files and the lowest for ScoutRace files.

**Table 1** Descriptive statistics of maximum force according to groups and ANOVA results ($P$ value).

<table>
<thead>
<tr>
<th>Groups</th>
<th>Mean</th>
<th>SD</th>
<th>95% confidence interval</th>
<th>ANOVA Statistic F</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-Pilot (surface)</td>
<td>68.9a</td>
<td>3.9</td>
<td>66.1-71.7</td>
<td>714.0</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>PathFile (surface)</td>
<td>32.5b</td>
<td>2.9</td>
<td>30.4-34.6</td>
<td>55.8</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>ScoutRace (surface)</td>
<td>20.4c</td>
<td>1.8</td>
<td>19.2-21.7</td>
<td>810.2</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>C-Pilot (surface)</td>
<td>68.9a</td>
<td>3.9</td>
<td>66.1-71.7</td>
<td>810.2</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>PathFile (3 mm)</td>
<td>68.0a</td>
<td>4.6</td>
<td>64.7-71.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ScoutRace (3 mm)</td>
<td>51.3b</td>
<td>4.1</td>
<td>48.4-54.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-Pilot (surface)</td>
<td>68.9c</td>
<td>3.9</td>
<td>66.1-71.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PathFile (6 mm)</td>
<td>166.7a</td>
<td>5.9</td>
<td>162.5-170.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ScoutRace (6 mm)</td>
<td>114.8b</td>
<td>6.2</td>
<td>110.4-119.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Different letters show statistically significant differences by Duncan’s test; SD, standard deviation.
instruments. In the NiTi instruments groups, when their tips were inside the artificial canals (3 mm and 6 mm deep), the results revealed that for the same instrument the greater the depth of the artificial canal, the higher the maximum axial force required to buckle the instrument. Comparison of the mean loads between the NiTi groups showed that PathFile had significantly greater resistance to buckling compared with ScoutRace instruments.

Discussion

Initial canal exploration prior to chemo-mechanical preparation allows the clinician to verify the possibility of accessing the apical portion. When dealing with wide canals, this is normally a simple procedure. However, narrow and calcified canals may present obstacles to initial exploration due to the presence of anatomical variations, calcified pulp nodules, or severe calcification in curved canals.1,8

In addition to overcoming natural anatomical interferences throughout the extension of the root canal, carrying out an effective initial exploration allows each subsequent instrument (normally of greater diameter) to penetrate the entire extension of the canal safely and efficiently. Undoubtedly, this procedure also contributes to a significant reduction in the occurrence of ledges and deviations from the natural canal path, which may lead to endodontic treatment failure.9-11

For an instrument to advance in the apical direction of a narrow and calcified root canal, it must present adequate mechanical properties that enable it to perform the clinical task. Among these mechanical properties, the resistance to buckling is highlighted. The manufacturer (Dentsply Maillefer) itself recommends the initial exploration of narrow and calcified root canal by a stainless steel instrument prior to the use of the NiTi instrument for this purpose. Nevertheless, it is worth remembering that the manufacturer does not provide information on the mechanical behaviour of the instruments. Therefore, the aim of this study is to inform the professional about the buckling resistance of the tested pathfinder instruments.

Development of SS endodontic files specifically for initial exploration has rendered this procedure safer and more efficacious in difficult-to-access canals.1 Although the geometric features of these files make them more resistant to buckling, they also make these instruments less flexible than their conventional counterparts.1,5 This reduced flexibility may induce undesirable changes in root canal anatomy when these files are used in the middle and apical portions, even with instruments of small nominal diameter.5-12 Therefore, these files should be used in the initial millimetres of the root canal (initial exploration of the coronal portion). One of the models of this study (acrylic platform) was made for the buckling test of both stainless steel and NiTi instruments. The flat surface without the creation of a canal allowed the tip of the instrument to rest on this surface to determine the buckling resistance, simulating an attempt to penetrate into a narrow and calcified root canal. The result of the test on the acrylic platform with the C-Pilot files served as a control to determine if the buckling resistance of the NiTi instruments at a depth of 3 mm and 6 mm was similar to that obtained by the C-Pilot files in the flat platform. Based on that, it was decided to test the SS endodontic instrument only on the flat surface.

The artificial canals were standardised for each type of tested instrument, respecting its dimensions. The instruments have different nominal diameters; therefore, in order to mimic a calcified canal an artificial canal with the same nominal diameters as the instrument tested was used.

Instruments made of NiTi alloy with small diameters have been recommended for catheterisation of narrow and calcified root canals associated with stainless steel instruments. The use of stainless steel instruments followed by NiTi instruments of equal size (diameter) is suggested due to the low buckling resistance of the latter.5 The lower the resistance to the advancement of the instrument inside a narrow root canal, the greater the buckling resistance. Thus, NiTi instruments with small diameters fail to initiate catheterization of narrow and calcified root canals making it necessary to enlarge the root canal with stainless steel instruments of equal size. The need to safely explore the middle and apical portions of narrow root canals has prompted the development of rotary instruments made of NiTi, taking advantage of the superelasticity of this alloy. Nonetheless,
NiTi instruments are contraindicated for exploring the initial millimetres of calcified root canals, due to their low resistance to buckling. This mechanical behaviour may result in elastic or plastic deformation of the instrument, which may hinder or even prevent its apical progression.2,4,5

The comparison was among the instruments tested to know at which depth the instruments had similar buckling resistance. The results of the buckling tests revealed that NiTi instruments should only be used clinically after using a stainless steel instrument at a depth of 3 mm and 6 mm apically.

At present, few studies have focused on the difficulties encountered during initial exploration of narrow and calcified canals using SS or NiTi instruments.1,4,5,11,13,14 The buckling test conducted in this work was proposed by Lopes et al and allowed comparison between different endodontic instruments. Moreover, the results are in agreement with the nominal diameters at D0 and with the mechanical behaviour (flexibility and buckling) described for the alloys from which these instruments were manufactured.5

Table 1 shows that when the instrument tip was resting on the surface of the resin block, the SS instruments required significantly greater forces to buckle than NiTi files (P < 0.05). The maximum axial force to buckle the C-Pilot files was 112% greater than that required to buckle PathFile, and 245% than for ScoutRace. The greater resistance to buckling of C-Pilot is due to the greater modulus of elasticity of SS compared with NiTi. The modulus of elasticity is a material property that describes its stiffness. It is defined as the angle between the applied load to a given material and the deformation it causes at the stress strain curve.1,15,16 The greater the attraction between the atoms, the greater the modulus of elasticity and, consequently, the greater the resistance to buckling of an endodontic instrument.16,17

Comparison between the NiTi instruments showed that the axial force to buckle PathFile was 62.5% greater than that required to buckle ScoutRace, which may be explained by the different nominal diameter of these instruments (PathFile D0 = 0.13 mm, ScoutRace D0 = 0.10 mm). Although the instruments evaluated in the present study have differences in their nominal diameter and in the type of alloy of the working portion, they all share the same taper and cross-sectional design (square cross section) and are clinically recommended for the exploration of calcified canals.1,5

The mean axial force to buckle PathFile instruments in the 6 mm deep artificial canal was 146% greater than in the 3 mm deep canal. Comparison between different instruments in canals with the same depth showed that the axial force to buckle was 45% and 33% greater for PathFile than for ScoutRace in 6 mm and 3 mm deep canals, respectively. When the files were tested for buckling resistance with their tips resting on the resin surface, the entire length of the instrument (25 mm) was considered. In that situation, the mean buckling resistance of PathFile was 31.5 gf and for ScoutRace, 10 gf. However, when the same instruments had their tips inserted in the 3 mm and 6 mm deep canals, the instrument lengths were equal to 22 mm and 19 mm, respectively. Under these conditions, the buckling resistance of PathFile was 68 gf for the 3 mm deep canal and 167 gf for the 6 mm deep canal. With regard to the ScoutRace instruments, their buckling resistance was 51 gf for the 3 mm deep canal and 115 gf for the 6 mm deep canal.

The greater buckling resistance of PathFile and ScoutRace when the instrument tips were inside the 3 mm and 6 mm deep canals may be explained by the equation: \( P_{CR} = \pi^2EI/L^2 \), where \( P_{CR} \) = Maximum axial load, \( E \) = Modulus of elasticity of the alloy, \( I \) = Moment of inertia of the instrument, and \( L^2 \) = the squared length of the instrument.6,18 In this equation, it is possible to observe that the buckling resistance (maximum axial load) increases as the instrument length decreases. The results from the present study revealed that the buckling resistance of PathFile showed an increase of 109% and 413% when these instruments were inserted in 3 mm and 6 mm deep canals, respectively. As for the ScoutRace, an increase of 155% for the 3 mm deep canals and of 475% for the 6 mm deep canals was observed. The increase of 30% in PathFile metal mass is a factor that impacts on its mechanical properties. In all analyses this file presented equal to or greater resistance than the instrument made of SS (C-Pilot file), even though it is manufactured with NiTi alloy. The instrument design (13/.02) compensates the superelasticity of the NiTi alloy giving greater bulk resistance to the file. The ScoutRace instrument had
the lowest buckling resistance of the studied instruments, because its properties are provided by the design (10/02) and the NiTi alloy.

For SS files, the greater buckling resistance represents a clinical advantage for initial exploration of the cervical portion of calcified canals, rendering these instruments the first choice for this procedure. However, SS files also show higher stiffness (lower flexibility), which increases the probability of ledge formation or canal transportation during initial exploration of calcified and curved canals. On the other hand, PathFile and ScoutRace have lower resistance to buckling, which may cause difficulties during the initial exploration of calcified canals. Nonetheless, these files may be used after the initial exploration (coronal portion) is accomplished with C-Pilot files.

As demonstrated by the results, the buckling resistance is inversely proportional to the length of the instrument tested. Therefore, the combined use of SS files in the coronal portion and NiTi instruments in the middle and apical portions of the canal results in greater effectiveness and safety in the initial exploration of calcified and curved root canals.

### Conclusions

Under the experimental conditions of the present study, it is possible to conclude that the C-Pilot file has the greatest resistance to buckling among the instruments tested, and that the resistance to buckling was inversely proportional to the length of the instrument on the flat surface.

At a depth of 3 mm within a simulated calcified root canal, NiTi rotary instruments show the same resistance to buckling as SS hand files on the flat surface. The differences in buckling resistance among the instruments tested support the recommendation for combined use of SS hand files and NiTi rotary instruments during the initial exploration of calcified and curved canals: SS hand files should be used in the coronal portion and NiTi rotary instruments in the middle and apical portions of the root canal.

### Acknowledgements

The authors deny any conflicts of interest related to this study.

### References