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A Comparative Study of Two Martensitic Alloy Systems in Endodontic Files Carried out by Unskilled Hands

Juan Algar [1], Alejandra Loring-Castillo [1], Ruth Pérez-Alfayate [1], Carmen Martín Carreras-Presas [2] and Ana Suárez [2,*]

[1] Department of Clinical Dentistry, School of Biomedical Sciences, Universidad Europea de Madrid, 28005 Madrid, Spain; juan.algar2@universidadeuropea.es (J.A.); alejandra.loring@universidadeuropea.es (A.L.-C.); ruth.perez@universidadeuropea.es (R.P.-A.)
[2] Department of Preclinical Dentistry, School of Biomedical Sciences, Universidad Europea de Madrid, Villaviciosa de Odón, 28670 Madrid, Spain; carmen.martin2@universidadeuropea.es
* Correspondence: ana.suarez@universidadeuropea.es

Abstract: The aim of this study was to compare the behavior of two heat-treated file systems on resin blocks in unskilled hands. For this purpose, an in vitro, randomized, cross-sectional study was conducted to compare ProTaper Gold (PTG) with BlueShaper (BS) files. A total of 81 resin blocks were used and analyzed photographically to assess the amount of material removed during instrumentation. PTG removed more material on the outside of the curve in the coronal and apical third, while BS removed more material on the inner part of the curve in the middle third. The procedural errors observed in the total sample were apical transportation (33.8%), blockages (4.9%), ledges (3.7%), and canal perforation. PTG produced more apical transportation, and there were no statistically significant differences between the groups in the formation of ledges, canal perforations, or blockages. No file fractures were recorded during the study. Within the limitations of this study, we can affirm that neither file excessively deformed the artificial canals, and the PTG file produced more apical transportation.

Keywords: dental students; undergraduate students; endodontic training; root canal treatments; NiTi; rotary instrumentation; apical transportation

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1. Introduction

There is currently an increased worldwide awareness of the importance of the preservation of natural teeth, resulting in a global increase in the number of root canal treatments (RCT) [1–4]. However, this conservative demand clashes with the perception of many general dentists who consider endodontic practice to be complex, difficult to master, and a major source of stress [5], and this could be associated with an increase in RCTs with often less-than-ideal quality [6–8]. It is also suggested that aptitude takes on an important role in this regard, given that a high percentage of dentists also consider their endodontic training to be inadequate [9].

If this same issue is transferred to dental students, they also report that endodontics is challenging, difficult, and stressful, resulting in a lack of confidence in approaching these treatments [10,11]. These perceptions should be treated with special importance, and teachers should be put on notice since the quality and quantity of endodontic teaching in dental undergraduates may have an impact on future RCTs [12].

In addressing the quality of endodontic teaching, dental schools have undergone changes to improve the teaching–learning process for students [13], specifically pre-clinical instrumentation practices. There are universities that continue to instruct in the step-back technique using steel files (K-files) [4,14] which, being more rigid, can lead to errors during the procedure [15,16]; on the contrary, other universities have chosen to teach undergraduate students to use rotary instrumentation with nickel–titanium (NiTi) instruments [8,17–19] because they allow the performance of RCTs to be achieved in a fast and predictable way [3,11,16,20,21], presenting lower complication rates [10,22] due to the fact that these rotary instruments cause fewer errors in the root canal preparation compared to manual files [23] because they are more flexible [24]. With NiTi instruments, it is possible to improve the student's experience in their preclinical training [10] because, by performing these treatments more quickly, the number of practice attempts is increased, and an increase in the repetition of a procedure has proven to be very useful in preparing students in the acquisition of acceptable preclinical skills that will translate into better preparation and the optimization of their future professional practices [4,11,22,25,26].

When it comes to selecting an ideal rotary instrument for inexperienced hands, there is a wide range available on the market today [24]. In the design of this type of files, there is great variability in terms of alloys, cross-sectional design, cutting edges, tapering, etc., in addition to the thermo-mechanical treatment of the NiTi alloy itself, which is carried out to optimize its microstructure and therefore its mechanical performance, giving it greater flexibility and resistance to fracture [23,27,28]. Since the release of the first conventional NiTi instruments, thermomechanical treatments have been developed that could induce changes in their behavior through stability in the martensitic phase, increasing their flexibility and resistance to cyclic fatigue under clinical conditions, thus creating a new generation of instruments and alloys [29]. Thus, up to the present date, NiTi alloy instruments with thermomechanical treatments have been launched on the market: M-Wire, R-Phase, CM-Wire, Blue, Gold, and Max Wire [23], and more recently, the Pink alloy in the year 2020. The effects of heat treatment depend on time, temperature (T), processing sequence, and the amount of previous cold working. These treatments aim to change the transitional T of the alloy (i.e., the T at which the crystalline arrangement of NiTi atoms changes from an austenitic, cubic phase to a martensitic, tetragonal molecular arrangement [30]. New generations of NiTi rotary systems include ProTaper Gold files (Dentsply Sirona, Ballaigues, Switzerland), a system made of a NiTi alloy called "Gold," which, according to the manufacturer, confers greater flexibility and which presents a convex, triangular-shaped section, as well as BlueShaper files (Zarc4Endo Gijón, Asturias, Spain). BlueShaper is a system made of a double NiTi alloy, called "Pink wire" and "Blue wire" which, according to the manufacturer, gives it resistance to torsion and cyclic fatigue. Like ProTaper Gold, it has a convex, triangular cross-section.

The objective of this study was to determine which rotary system causes less deformation in the instrumentation of standardized canals with medium difficulty in students with no previous training in rotary endodontics by comparing two systems with the same section but with different alloys: the ProTaper Gold (PTG) system versus the BlueShaper (BS) system.

2. Materials and Methods

A randomized, cross-sectional, in vitro study was carried out on resin blocks (Endo-Training-Bloc, Dentsply Maillefer, Ballaigues, Switzerland) with a degree of curvature of 40°, which were worked on by fourth-year dental students at the Universidad Europea de Madrid (UEM) in 2022. This study was approved by the UEM research ethics committee (CIPI/213006103). Informed consent was required to be signed by all participants, indicating that the outcome of the practice would not affect their final grades. The eligibility criteria included students who had never performed endodontics with rotary files and who agreed to take part in the study.

A total of 84 resin blocks were used and marked on their undersides with a handpiece and a milling cutter. The blocks for the PTG system were marked with the letter "P", followed by the corresponding numbering (1–42). Those for the BS system were marked with a "B", followed by the corresponding number (1–42). Subsequently, preoperative photographic records of each of the blocks were taken with a camera (Canon MKII, Ōta, Tokyo, Japan) and a 60 mm macro lens (Canon, Ōta, Tokyo, Japan). To ensure that the photographs were taken at the same distance and positioned in the same place without the possibility of moving the camera or specimens, a stable, wooden platform was fabricated. Once these preoperative recordings were made, the blocks were placed in individual blank, opaque envelopes, along with a fresh set of files, and distributed by an independent investigator to ensure randomization.

Once the students opened their envelopes and checked which group they were in, they were distributed and received a specific, 45-min training on the objective of the study and the characteristics of the system they had to work with: the alloy, design, and work sequence, according to the manufacturer's instructions. In addition, they were given a step-by-step sheet detailing the procedure, indicating that they had no time limits in which to perform the artificial canal instrumentation.

The 42 students in the PTG group started working by preflaring the coronal third using K-file #10 and K-Flexofile #15–25 hand files. They proceeded to determine the working length with a K-file #10 hand file. They then performed the glidepath with the K-Flexofile #15 hand file. They went on to use rotary instrumentation, for which they used a 16:1 reduction handpiece with an X-Smart electric motor (Dentsply Sirona, Ballaigues, Switzerland), adjusting the speed to 350 rpm. They used shaping files (S1 and S2) with a planing action during the withdrawal movement. The torque for the S1 was 4 N/cm and 1.5 N/cm for the S2. Subsequently, the finishing files (F1 and F2) were used. The latter files were used with a pecking motion, passively up to the working length. All files were removed immediately after reaching the working length (without remaining more than 1 s). The torque for the F1 was 1.5 N/cm and 3 N/cm for the F2.

The 42 students in the BlueShaper group started working by performing a coronal manual preflaring of the canal using a K-file #10, and then performing a rotary preflaring with the Z1 file (500 rpm, torque 4 N/cm) mounted on an X-Smart motor, up to the place reached by the K #10 file or until a slight resistance was felt. After determining the working length with the K #10 file, a manual glide path was performed with the K-Flexofile #15. Then, a Z1 file (500 rpm) was passed to the working length with a planing action. The instrumentation was finished with Z2 (500 rpm, torque 4 N/cm), Z3 (500 rpm, torque 4 N/cm), and Z4 (350 rpm, torque 4 N/cm) files in a pecking motion, passively up to the working length, removing the file immediately (without remaining more than 1 s).

Both groups had to clean the file coils frequently with gauze during instrumentation, checking for signs of distortion or wear, irrigate after using each file (2 mL distilled water), and perform patency with a K #10 file. After instrumentation, a final wash was performed with distilled water for 1 min.

At the end of the instrumentation, the students returned the blocks, and, after drying the blocks, postoperative photographic recordings were taken using the positioner. All of the images were taken by the same researcher.

The images were then stored in a computer and prepared using Adobe Photoshop version 22.0.0 (Adobe, San Jose, CA, USA). In order to compare both images easily, a yellow filter was applied to eliminate the chromatic aberrations of the postoperative image, which could produce halos. Subsequently, the initial image was superimposed on the second image, to which an opacity reduction of 45% was applied. Once the images were assembled, they were converted to grayscale (Figure 1).

In order to measure the amount of tissue removed during instrumentation, a scale in millimeters was superimposed that was adapted to the curvature of the canal, so that all of the measurements taken were perpendicular to the major axis of the original canal (Figure 2). Both internal and external loss were measured.

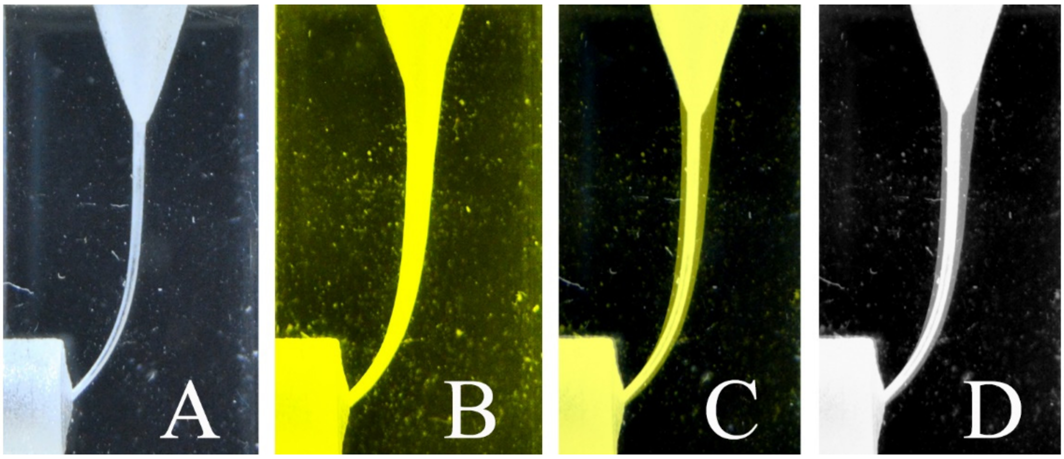

Figure 1. (**A**) preoperative image; (**B**) postoperative image with color-shifted image processing; (**C**) preoperative–postoperative composite image; and (**D**) grayscale image.

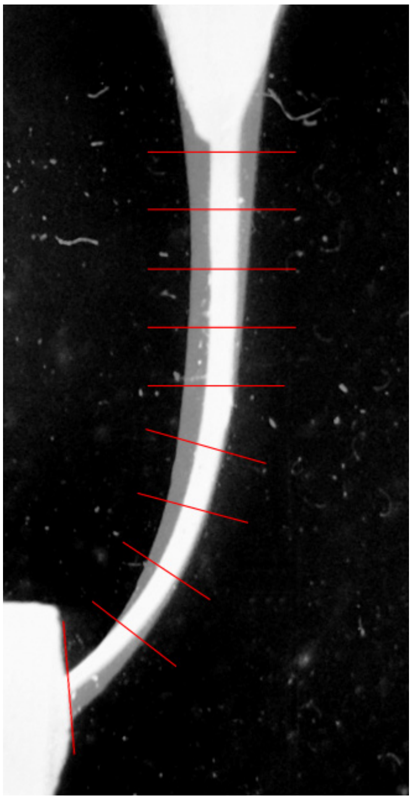

Figure 2. Illustration of the measurement points, measured every 1 mm, perpendicular to the axis of the duct.

All measurements were made using the ImageJ version 1.52 (National Institutes of Health, Bethesda, MD, USA) program, which was previously calibrated using a photograph of a millimeter ruler in order to make the measurements in millimeters (mm).

Finally, the presence of instrumentation errors was evaluated, classifying them as: steps, false passages, blockages, or apical transport if in D0 there was a loss of tissue greater than 0.3 mm [31]. In relation to accidents, it was evaluated whether instrument fractures occurred.

The records obtained were recorded in an Excel spreadsheet (Microsoft, Redmond, WA, USA).

The measurements obtained were analyzed with SPSS version 25 software (IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY, USA, IBM Corp.). First, the Kolmogorov–Smirnov test was performed. Subsequently, the variables were compared between groups with the Mann–Whitney U test and the Chi-Square test. The level of statistical significance was set at $p < 0.05$.

3. Results

Of the 84 plastic cups, 3 were not returned by the students, leaving 41 samples in the PTG group and 40 in the BS group (See Tables 1 and 2, and Figure 3).

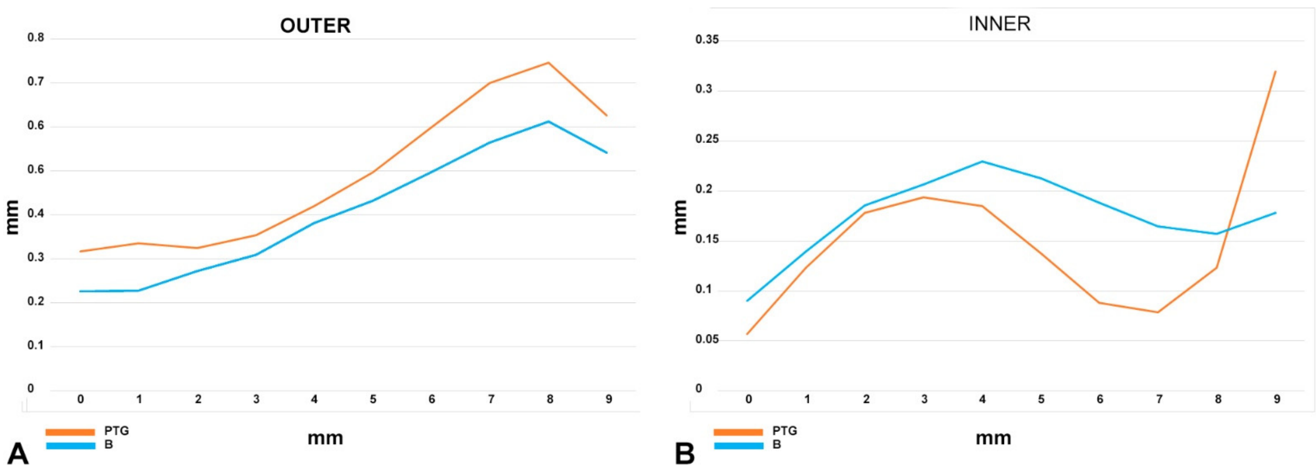

Figure 3. Behavior of the systems outside (**A**) and inside (**B**) of the curve.

Table 1. Descriptive statistics by instrumentation system and mm.

	System			
	PTG		BS	
	Mean	**SD**	**Mean**	**SD**
0 mm inner	0.05698	0.059503	0.09053	0.091237
0 mm outer	0.31690	0.172002	0.22639	0.153350
1 mm inner	0.12359	0.098513	0.13985	0.112815
1 mm outer	0.33622	0.194072	0.22795	0.096084
2 mm inner	0.17834	0.132551	0.18575	0.132526
2 mm outer	0.32505	0.081248	0.27328	0.072562
3 mm inner	0.19376	0.128035	0.20680	0.126781
3 mm outer	0.35393	0.058098	0.30895	0.080819
4 mm inner	0.18490	0.125404	0.22963	0.137130
4 mm outer	0.41976	0.073131	0.38133	0.082588
5 mm inner	0.13729	0.113589	0.21283	0.130169
5 mm outer	0.49729	0.077243	0.43280	0.092329
6 mm inner	0.08844	0.099885	0.18863	0.116763
6 mm outer	0.59871	0.086054	0.49703	0.091950
7 mm inner	0.07839	0.086767	0.16435	0.115822
7 mm outer	0.70022	0.106444	0.56443	0.092332
8 mm inner	0.12368	0.135149	0.15695	0.102327
8 mm outer	0.74661	0.160313	0.61225	0.136036
9 mm inner	0.31934	0.241814	0.17793	0.156473
9 mm outer	0.62651	0.292731	0.54153	0.223379

SD: Standard Deviation.

Table 2. Amounts of resin removed per system.

	Mann–Whitney U	Wilcoxon W	Z	Sig.
0 mm inner	589.000	1450.000	−1.555	0.120
0 mm outer	489.000	1155.000	−2.542	0.011 *P
1 mm inner	760.500	1621.500	−0.378	0.705
1 mm outer	441.500	1221.500	−3.446	0.001 *P
2 mm inner	807.500	1668.500	−0.118	0.906
2 mm outer	490.500	1310.500	−3.114	0.002 *P
3 mm inner	786.000	1647.000	−0.321	0.748
3 mm outer	495.500	1315.500	−3.066	0.002 *P
4 mm inner	650.000	1511.000	−1.607	0.108
4 mm outer	541.500	1361.500	−2.632	0.008 *P
5 mm inner	506.500	1367.500	−2.966	0.003 *B
5 mm outer	436.000	1256.000	−3.631	0.000 **P
6 mm inner	396.000	1257.000	−4.041	0.000 **B
6 mm outer	296.000	1116.000	−4.954	0.000 **P
7 mm inner	438.500	1299.500	−3.652	0.000 **B
7 mm outer	263.500	1083.500	−5.260	0.000 **P
8 mm inner	631.000	1492.000	−1.796	0.073
8 mm outer	407.500	1227.500	−3.898	0.000 **P
9 mm inner	550.500	1370.500	−2.553	0.011 *P
9 mm outer	648.500	1468.500	−1.621	0.105

* *p*-value < 0.05—statistically significant, ** *p*-value < 0.001—highly statistically significant. P = PTG > BS, B = BS > PTG.

The procedural errors observed in the total sample were apical transportation (33.8%), blockage (4.9%), ledge (3.7%), and canal perforation (3.7%).

The result of the Chi-Square test on apical transportation production was statistically significant ($\chi^2 = 8.839$, df = 1, $p = 0.03$), with PTG being the system that created the most transportation. The formation of ledges, canal perforations, and blockages did not show statistically significant differences.

No file fractures were recorded during the experiment.

4. Discussion

The instrumentation phase of root canals is considered to be one of the most important steps in endodontics [32] because it facilitates the passage of irrigants along its entire length and geometrically configures the canal for a correct, three-dimensional obturation [33].

In recent decades, to perform instrumentation, numerous rotary systems have emerged, which advocate simplifying the task for clinicians, minimizing errors during instrumentation [23] and preserving root-canal anatomy during preparation [34]. The alloys and geometry of the instruments have evolved over the years to give them more flexibility, cutting ability, and resistance to fracture [35]. The incorporation of rotary instrumentation leads to faster treatment times and lower complication rates [36,37]. Previous studies have shown that the introduction of rotary endodontics provides students with greater confidence and safety when performing treatments [38]. With the aim of better preparing students to perform endodontic treatments on real patients, the Universidad Europea de Madrid advocates the introduction of rotary instrumentation in preclinical practice in order to minimize procedural errors on the one hand, and on the other hand, to allow for a greater number of canals to be performed in the same preclinical practice time, thus reducing the learning-curve time [39]. The starting point was those students who had never prepared canals with rotary instrumentation. These inexperienced students were chosen because they had no acquired vices from previous rotary endodontic training, so they could strictly follow the manufacturer's instructions. It was assumed that procedural errors could occur (ledges, apical transportations, blockages, etc.). The objective was to test the files in an unfavorable situation and to verify if they were able to instrument the canals in an adequate way. Therefore, we wanted to evaluate whether improvements in alloys would enable any practitioner with no experience in rotary endodontics to perform the instrumentation of simulated canals without altering the anatomy of the artificial canal. Thus, this study was carried out with files of the same section but manufactured with different alloys.

The most frequent procedural error found in this study was apical transportation, followed by blockage, ledge, and canal perforation. Other studies found the most frequent complication to be the presence of ledges [17,40] although, in our case, we did not find statistically significant differences, as did the study by Alghamdi [41].

In view of the results, it can be affirmed that PTG removed more resin than BS in the coronal and apical third (especially on the external face of the curvature), while BS removed more in the middle third, on the internal face. These results could be due to several causes. At the coronal level, PTG has a higher value for the maximum flute diameter (1.22 mm), so it could remove more material in the coronal third and would be less conservative with the pericervical dentin. Several studies have reported the importance of preserving this dentin and the ways that the greater conicity of files would produce a greater loss of dentin, with a consequent decrease in the resistance of the tooth, and an increase in the appearance of fractures [42–45].

The higher resin removal produced by BS in the middle third could be due to the fact that this system is better adapted to the canal curvature. The blue alloy, together with the glide path achieved by Z1, coupled with a smaller jump between the diameter of the posterior files, could result in hardly any deformation of the outer part of the curvature and thus avoid the straightening of the canal.

The correct shaping and cleaning of the apical third has a direct relationship with the success of the treatment [46]. Apical transport compromises the cleanliness and correct sealing of the canals allowing tissue debris as well as microorganisms to remain [31]. In this study, a reference was taken to affirm the presence of apical transport if there were an apical deformation >0.30 mm [31].

The apical transport was mainly towards the external part of the curve. This is in agreement with other studies [47,48]. The higher incidence of the apical transport of ProTaper Gold could be due to the fact that, although the F2 file has the same cross-section as the Z4 (0.25 mm), its taper is 2% greater (8% vs. 6%). This greater taper could provide greater rigidity to the instrument and, therefore, less efficiency in adapting to the curvature with greater possibility of straightening [49] since bending is inversely proportional to the size of the file section [50] as well as to the taper of the file [51]. This greater deformation could also be explained by the type of alloy used. The Blue alloy has a higher amount of martensite and R-phase in clinical conditions than does the Gold alloy [52], and this would cause it to better adapt to the curvature, producing less deformation at this level. The fact that PTG produces more apical transport than BS could be explained not only in terms of geometry and alloy, but also in terms of the clinical sequence during the instrumentation process. The diameter jump between files in the PTG system is greater than that in the BS system, and, as the passage from a smaller file to a larger one is less progressive, it could lead to the production of greater deformation in the canals due to a greater contact area, which, by generating greater torque force, would lead to the operator having to tighten more for the file to advance to the working length [53]. It is possible that BS, by having less of a diameter jump between files, makes it possible for these inexperienced students to instrument the canals with greater respect for their anatomy. The BS system starts with a gauge of 0.14 mm (Z1), followed by 0.17 mm (Z2), 0.19 mm (Z3), and finally 0.25 mm (Z4). PTG starts with 0.17 mm (S1), followed by 0.20 mm (S2 and F1), and finally 0.25 mm (F2). We believe that the passage of Z1 as the first file creates a gliding path that facilitates the action of the following files, making the jump from one diameter to a higher one less abrupt, and, as the instrumentation process is more fluid, makes the student more capable of respecting the original anatomy of the canal.

In this study there were no fractured files. This result is in agreement with previous studies that state that martensitic phase alloys are more resistant to fractures in curved ducts [23,24,28].

One of the main limitations of this study is that it was performed on methacrylate blocks. Therefore, the results of this study should be taken with caution because the study was not carried out on natural teeth. This form of evaluation was chosen because methacrylate blocks had already been validated previously as a model for the study of the conformability of rotary endodontic systems [54]. In addition, we used them because standardized conditions of root canal anatomy could be created [55]. However, it is true that the characteristics of this material differ from those of natural tooth dentin in terms of the reproduction of anatomical variations, having less hardness [56,57], and the generation of heat during instrumentation, which can soften this material [58,59].

5. Conclusions

Under the conditions of this study, the files studied did not produce a great change in canal anatomy. ProTaper Gold produced greater apical transport in students with no previous rotary endodontic experience.

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