



Evaluation of Centering Ability in Artificially Curved Canals with Three Thermomechanically Treated NiTi Instruments: Blue, Pink and Gold

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Abstract

Introduction: The present study aimed to evaluate the instrumentation time and transportation ability of three file sequences sharing the same physical properties (diameter, tip design, cross-sectional shape, and taper), each manufactured entirely of one single alloy type (Pink, Blue, or Gold). **Materials and Methods:** One hundred and eighty simulated curved resin canals were instrumented using the BlueShaper system, with full Z1-Z4 sequences, each made entirely of a single alloy type (Pink, Blue, or Gold). Images before and after instrumentation of each specimen were overlaid with Photoshop software to evaluate centering ability in the coronal, middle, and apical thirds. Data were analyzed using one-way analysis of variance (ANOVA) with post hoc multiple comparisons or the non-parametric Kruskal-Wallis test for intergroup analysis. **Results:** No significant differences were found between the different alloys in the centering ability of the simulated canals in the coronal third ($P>0.05$). The Blue alloy of the BlueShaper system showed significantly less transport ability in the middle third than Pink and Gold alloys ($P<0.05$). A significantly lower centering ability ($P<0.001$) was observed in the apical third between the Blue and Pink alloys than the Gold alloy. **Conclusions:** It was concluded that the Blue alloy performed better than the Pink and Gold alloys in the middle and apical thirds. The pink alloy performed better than the Gold alloy in the apical third.

Keywords: Alloys; Endodontics; Endodontic File; Nitinol; Root Canal therapy

Introduction

One of the most important steps in root canal treatment is the preparation of the root canal system [1]. Instrumentation of the root canal is a critical step in endodontic treatment and is considered a predictive factor for the long-term success of endodontic therapy if performed correctly. Ideally, the mechanical preparation of the endodontic space should give the root canal a continuous tapered shape from the coronal level to the apical third, respecting the anatomical shape and multiplanar curves of the canal and keeping the size of the foramen as small as possible [2].

Achieving a continuous tapered shape and respecting the original morphology in narrow and curved root canals is still a significant challenge in today's practice. Traditional mechanical canal instrumentation with stainless steel hand files is time-consuming, and it is not easy to fulfill the above-mentioned criteria when preparing narrow and curved canals [3].

The introduction of nickel-titanium (NiTi) as a material for endodontic instruments around 34 years ago opened up many new perspectives [4]. Many dentists and scientists see an advantage in the use of NiTi file [5]. Initial problems such as frequent fractures and the uncertainty of the best way to use them have been improved [6]. Other challenges, such as enhancing the cutting ability or optimizing speed, torque, and fatigue are currently being addressed.

Since their introduction, NiTi alloys have continued to revolutionize the endodontics field. They have significant advantages over conventional stainless-steel files regarding mechanical properties [7]. However, despite their superior mechanical properties, NiTi alloys still pose a particular risk of fracture [8]. Therefore, extensive research has been conducted to investigate the mechanisms behind the occurrence of these procedural errors [9-11]. Since the last decade, various proprietary processing techniques have been introduced to further improve the mechanical properties of NiTi alloys, each serving a specific purpose [12]. For instance, thermal treatments are used to modify

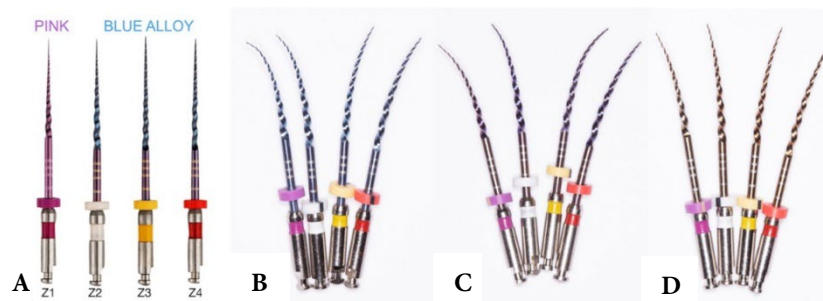


Figure 1. A) Original BlueShaper sequence and alloy (Z1 Pink, Z2-Z4 Blue); B) Same sequence in Blue alloy; C) in Pink D) in Gold

the alloy's microstructure and enhance its mechanical performance; electrical discharge machining is employed primarily for cutting and shaping the wire; and electropolishing is applied to smooth and refine the instrument's surface [12].

NiTi alloys used for endodontic instruments can be divided into those containing mainly the austenite phase (austenitic: conventional NiTi, M-wire, R-phase) and those primarily containing the martensite phase (martensitic: CM-wire, Gold and Blue heat-treated) [12].

Thermomechanically treated NiTi alloys are reported to be more flexible and exhibit higher cyclic fatigue resistance and a greater deflection angle at fracture than conventional NiTi [13, 14]. These improved properties can be attributed to a changed phase composition with different proportions of R-phase and martensite [12]. Endodontic instruments made of austenitic alloys have superelastic properties due to the stress-induced martensite transformation and, therefore, tend to return to their original shape after deformation [15]. In contrast, martensitic instruments can be easily deformed due to the reorientation of the martensite variants and show a controlled memory effect when heated [16]. Using a martensitic alloy leads to more flexible instruments with a higher cyclic fatigue resistance than an austenitic alloy [17].

Fracture of endodontic instruments is a procedural problem that represents a significant obstacle to routine therapy [18]. With the advent of NiTi instruments, this problem has become a substantial barrier to adopting this essential technical advance. Extensive research has been conducted to understand the NiTi alloy's failure mechanisms and minimize their occurrence [19, 20]. This has led to changes in instrument design, instrumentation protocols, and manufacturing methods [20-22]. In addition, factors such as clinician experience [23], technique [24], and competence [25] are influential.

Manufacturers have developed various heat treatments for NiTi alloys to modify the fatigue resistance of the instruments [21, 26, 27]. A new and innovative system, the BlueShaper rotary files (Zarc4endo, Gijón, Asturias, Spain), has been launched. This is the first system that contains two alloys, Pink and Blue alloys, in its instrument sequence.

It is a system consisting of four instruments from Z1 to Z4 (Fig. 1). The Z1 file is used for the glide path; it has a diameter of 14 and a taper of 2% at the tip and up to 10% in the coronal part, a maximal flute diameter (MFD) of 0.9 mm, and a Pink alloy. This alloy is obtained by a heat treatment between Gold and Blue, which ensures a balance between torsional resistance and flexibility.

An interesting proposal is that the Pink alloy is an intermediate treatment between Gold and Blue. This allows the instrument to combine cutting capacity and flexibility in the same instrument, and as it is the first instrument to be used, the other instruments in the system have a Blue treatment to have greater flexibility during the chemomechanical preparation phase.

The instruments Z2 15/0.02, Z3 19/0.06, Z4 25/0.07 are then used for chemomechanical preparation. Depending on the anatomy of the root canal, it is possible to use an additional instrument, Z5 29/0.08. These instrument files have a convex triangular cross-section, a 16 mm long active part, and a Blue alloy that gives them flexibility without reducing their cutting performance.

According to the manufacturer, a speed of 500 rpm/4 Ncm is recommended for the AI rotary system.

It is important to note that there are no studies investigating the behavior of this novel Pink alloy during chemomechanical preparation.

This study evaluated the Blue system's instrumentation time and centering ability using different thermal treatments, such as Pink, Gold, and Blue alloys, in simulated curved canals.

Materials and Methods

One hundred and eighty transparent epoxy resin blocks (Endo Training Blocks; Dentsply/Maillefer, Ballaigues, Switzerland) with ISO size No. 15, 0.02-taper, 40° angle, single curvature, and 10 mm length simulated canals were used.

Specimens were randomly divided into three groups ($n=60$). A size 10 K-type hand file (Dentsply Tulsa Dental, Charlotte, USA) was inserted into the canal until the tip was visible through the apical foramen. Then, 1 mm was subtracted from this length

to determine the working length (WL). Instrumentation was performed by a single operator, a master's postgraduate student trained with the instrumentation system, who used a dental operating microscope (Carl Zeiss, Berlin, Germany). Each canal was prepared with the full sequence of files recommended by the manufacturer (Z1, Z2, Z3, and Z4), driven by an endodontic motor (Eighteeth, Jiangsu, China). Files were used in an in-and-out motion with an amplitude of 3 to 4 mm until WL was reached without brushing. Each set of files was used for a single canal and discarded afterward, in accordance with the manufacturer's recommendations. After use, all instruments were cleaned with sterile gauze and alcohol to remove debris.

Instrumentation groups

Each sequence from Z1 (14/0.02-10), Z2 (17/0.02-10), Z3 (19/0.05-06), and Z4 (25/0.05-06) was fabricated in Pink, Blue, and Gold alloys. Then, the chemomechanical preparation was performed with the same system but changing the alloy (Pink, Gold, and Blue).

After rinsing with 1 mL of 5.25% NaOCl, a size 10 K-type file (Zarc4endo, Madrid, Spain) was used to explore the resin block canal up to 10 mm, and then instrumentation was performed as follows:

The Z1 instrument was operated under continuous rotation in the E-connect S motor at 500 rpm and 4 Ncm with in and out movements up to 10 mm. The instrument was withdrawn and cleaned, and the canal was irrigated with 1 mL 5.25% NaOCl. The patency of the apical foramen was checked after using Z1. The same procedure was then repeated sequentially with instruments Z2, Z3, and Z4 until the working length was reached for each file. A final irrigation with 1 mL of 5.25% NaOCl was then performed on all acrylic blocks.

Resin blocks analysis

In order to capture the initial canal images, each block was attached to a stable support in a camera device (Canon, Tokyo, Japan) with a macro lens (Canon EF 100mm f/2.8L IS USM). A digital image of each specimen was taken before and after instrumentation. After obtaining the images from the initial and final photographs, the Slicer 5.0.3 software was used for the co-registration of the models with a custom combination of a rigid registration module based on image intensity similarities, to keep the images in the same position. Then, pre- and post-instrumentation Images were superimposed using Adobe Photoshop software (CS6, version 13.0; Adobe Systems, San Jose, CA, USA). The image dimensions were standardized to 900×2352 pixels. The areas of the canals before and after instrumentation were then calculated in pixels and converted to millimeters for the final analysis.

Centering deviations were analyzed in two-dimensional images using ImageJ software (National Institutes of Health,

Bethesda, MD, USA). In our images, the canal was oriented horizontally, with the coronal portion on the left and the apical portion on the right. Hence, the X-axis (ranging from 0 to 2352 pixels) represents the canal's length from coronal to apical. We selected three X-axis positions (784, 1568, and 2352 pixels) to examine the coronal, middle, and apical thirds, respectively. At each of these positions, the corresponding Y-axis value was recorded to quantify centering or deviation. Superimposed images were then assessed independently by two calibrated endodontists, who were blinded to the groups.

During the chemomechanical preparation with the different alloys (Blue, Gold, Pink), the instruments were used sequentially from Z1 to Z4. For each instrument (Z1, Z2, Z3, and Z4), the instrumentation time was recorded from its introduction until it reached the working length. The instrumentation times recorded for each instrument were then averaged to determine the overall instrumentation time for each alloy.

Statistical analysis

The normality of the quantitative variables was verified through the Kolmogorov-Smirnov test. One-way analysis of variance (ANOVA) with post hoc multiple comparisons or the Kruskal-Wallis non-parametric test was used for the three groups' intergroup analysis regarding centering ability and time. SPSS software (Statistical Package for Social Sciences version 21.0; IBM Corp, Armonk, NY, USA) analyzed data with the significance level set at 5%.

Results

All acrylic blocks were successfully instrumented using the full sequence (Z1, Z2, Z3, and Z4). No procedural errors, such as ledges, zips, lateral perforations, or instrument fractures, were observed during chemomechanical preparation.

Table 1 shows the data on centring abilities and instrumentation times for the three alloy groups (Blue, Pink, and Gold).

Regarding centering abilities, no significant differences in canal transportation were found between the different alloys in the coronal third ($P>0.05$). Similarly, in the middle third, no significant differences were observed between the Pink and Gold alloys ($P>0.05$). The Blue alloy showed significantly less transportation compared to both the Pink and Gold alloys ($P<0.05$). When analyzing the centering ability in the apical third, the Blue alloy showed a mean value of 4.12 mm, the Pink alloy 6.61 mm, and the Gold 13.98 mm. A highly significant difference ($P<0.001$) was observed between the Gold alloy and the two other groups. In addition, the Blue alloy performed significantly better than the Pink alloy ($P<0.001$) (Fig. 2).

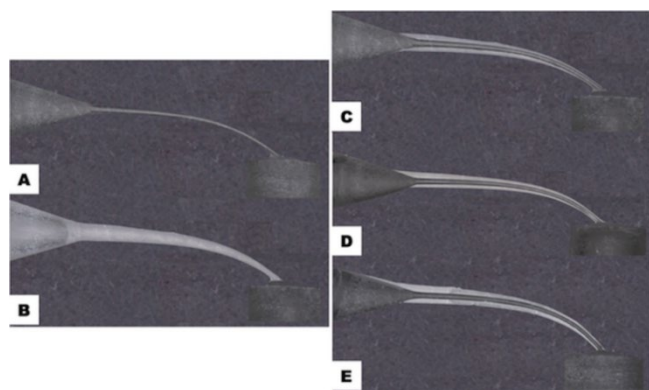


Figure 2. Representative figures of simulated canals: A) Before preparation; B) After preparation. Superimposed images of three alloys after instrumentation: C) Pink; D) Blue; and E) Gold

Regarding the instrumentation time, the mean values recorded were 127.26 sec (2.12 min) for the Blue alloy, 119.11 sec (1.99 min) for the Pink alloy, and 116.85 sec (1.95 min) for the Gold alloy. A statistically significant difference ($P < 0.05$) was observed between the Blue alloy and the other groups.

Discussion

In this study, three sequences of endodontic instruments (Z1, Z2, Z3, and Z4) were compared. Each sequence shares identical physical properties (diameter, tip design, cross-sectional shape, and taper), with the only variable being the type of alloy used (Blue, Pink, or Gold). This design allowed for isolating the influence of alloy composition on centering ability and instrumentation time.

The study findings demonstrated that, regarding centering ability, the Blue alloy sequence performed significantly better than Pink and Gold alloys, particularly in the middle and apical thirds. This superior performance can be explained by the advanced thermomechanical treatment employed in the Blue alloy, which produces an oxide layer [27] that enhances flexibility, thus a better ability to maintain the original trajectory of the canal [28]. These results are consistent with previous studies that showed improved canal centralization for Reciproc Blue compared to Protaper Gold [29] and WaveOne Gold [30].

Similarly, the Pink alloy significantly maintained the original shape of the canal in the apical third compared to the Gold alloy. The Pink alloy is obtained with an intermediate heat treatment between Gold and Blue to balance torsional resistance and

flexibility. Probably because it contains parts of both alloys, the centralized behavior of this alloy is lower than Blue but higher than Gold. This new alloy is part of a new system (BlueShaper) that combines two different alloys in one instrument set. Although its performance does not match that of the Blue alloy, the Pink alloy may offer a beneficial compromise, especially as a glide path instrument (BlueShaper Z1). Future studies on natural teeth should be conducted to evaluate the glidepath efficiency of the Pink alloy instrument. Differences in instrument design, torque, and speed of rotation can influence the centering ability [31]. However, the use of the same sequence of instruments, only differing in the type of alloy, allows us to exclude these confounding variables and evaluate the pure influence of the alloy on the outcome.

From a clinical point of view, these findings have several practical implications. First, an initial instrument (Z1) in the sequence that offers high cutting efficiency and superior flexibility can facilitate the subsequent advancement of the other instruments in the system to reach the working length more quickly, therefore reducing overall instrumentation time. The other files in the system (Z2-Z4) have a Blue treatment, which, due to its great flexibility, enables the instruments to be highly effective in a short time once the working length has been reached with the first instrument (Z1). In other words, the Pink alloy has a higher cutting and penetration capacity but a lower flexibility than the Blue one. However, as it is a 14/0.02-10 taper instrument, it is important to maintain the cutting capacity, in particular, in order to achieve an effective glide path during instrumentation.

Several parameters, such as cross-section design, helix, and rake angles, angle of incidence between instrument and specimen, hardness of the alloy or heat treatments, and the movement of the instrument, influence the cutting efficiency of NiTi instruments [32, 33]. The instrumentation time in this study was 1.95, 1.99, and 2.12 minutes, respectively. Nowadays, the improvement in the alloys of the instruments [34] has allowed greater flexibility and a remarkable cutting ability, so that the system reaches the working length faster; as a result, the time for instrumentation has shortened [35, 36]. In other words, instruments are now more effective but not necessarily more efficient. They can reach working length in a relatively shorter time, but this can also result in less retention time, replacement, and volume of the irrigant. This situation is common, mainly when single-use instruments are used. For this reason, it is essential to use

Table 1. Centering ability analysis after preparation and the instrumentation time with the three alloys; data for the coronal, middle, and apical third, expressed in μm as mean (range) and in seconds (minutes), respectively

Level	Blue	Gold	Pink
Coronal	9.68 (0.01-18.5)	11.44 (3.01-24.02)	9.77 (1.5-26.5)
Middle	3.45 (0.01-11.01)	14.10 (6.01-22.03)	13.84 (0.5-25.02)
Apical	4.12 (0.01-14.01)	13.98 (0.01-32.02)	6.61 (0.01-21.03)
Time second (minutes)	127.26 (2.12)	116.85 (1.95)	119.11 (1.99)

high volumes of irrigation, even when the preparation is completed in a short period, to maintain the effectiveness of the irrigation and, consequently, the intracanal disinfection.

In the present study, a series of instruments were used (Z1-Z4), so although it is possible to reach the working length, using multiple instruments quickly allows us to try to optimize canal disinfection by using higher volume and retention time of irrigant, and consequently greater intracanal disinfection [35].

In addition, it is important to mention that the shape of the instrument, its taper, and its tip may have helped to achieve rapid penetration in each sequence with the three alloys in the present study. No procedural errors, such as perforations, ledges, transportation, or instrument fractures, were observed during chemomechanical preparation, indicating that all alloys can safely perform root canal instrumentation. However, future studies should compare the safety of the BlueShaper instrument in natural teeth.

The model used in the present study simulates a severely curved root canal. These findings could translate into improved clinical outcomes, especially in patients with such challenging root canal morphologies. Conversely, in simpler canal configurations, the differences between the alloys might have a less pronounced impact, allowing clinicians more freedom in instrument selection. Additionally, in cases where anatomical complexities are present, instruments that minimize procedural errors and enhance safety during root canal preparation could offer additional clinical benefits.

The use of acrylic blocks could be a limitation in the study. Although the use of acrylic blocks allows for the standardization of the anatomy of the root canals, thus eliminating variables that may affect the final result when different instruments are compared [37], a part of the real clinical situation is lost in this method. Indeed, the hardness and abrasion behavior of acrylic resin and root dentin differ [37-39], and the root canal can be evaluated only in two dimensions. Although micro-computed tomography is the most accurate method to evaluate the transportation of NiTi files [39, 40], using extracted teeth or simulated root canals, are widely accepted methods to assess the shaping effects of instrumentation [41-43]. Furthermore, other factors, such as operator experience and specific clinical techniques, also play an important role in determining centering ability and should be considered when interpreting these findings.

Conclusion

Under the conditions of the present study, it can be concluded that Blue alloy showed less transportation than Pink and Gold alloys in the middle and apical thirds. The Pink alloy was better than the Gold alloy in the apical third. The three alloys safely reached the

apical third without causing procedural errors. From a clinical point of view, these results suggest that for severely curved canals, instruments made from the Blue alloy may be the best choice to maximize canal centering ability and minimize procedural errors, while the Pink alloy could be optimal for an effective glide path.

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Conflict of interest

None.

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Authors' contributions

Conceptualization: AF/NN/JA; Methodology: AF/JA/NN/AP; Formal Analysis and investigation: AF/JA/NN/AP; Writing-Original draft preparation: NN/AP; Writing-review and editing: JA/NN/AP; Supervision: JA/NN. All authors read and approved the final manuscript.

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