



Shaping performance of local nickel-titanium rotary file systems on resin blocks

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Purpose: The increasing development and clinical adoption of nickel-titanium (NiTi) rotary systems in Türkiye highlights the need for performance comparisons with widely used reference instruments. This study aimed to evaluate the shaping ability of locally manufactured files (EndoPlus Universal Gold-EPUG and EndoArt Action Gold-EAG vs. ProTaper Gold-PTG) in terms of canal transportation, weight loss, and changes in prepared canal area using standardized resin blocks with 30° curvature and 16 mm length.

Methods: Twenty-four blocks with known initial weights were photographed under a stereomicroscope at 4× magnification, randomly divided into three groups, and prepared with rotary files up to size F2 following each system's sequence. Irrigation with 2 mL saline was performed after each instrument. Post-instrumentation weights were recorded using a precision balance, while canal transportation at apical, middle, and coronal levels and canal area changes were calculated by superimposing pre- and post-instrumentation images with ImageJ software. Data were analyzed using one-way and two-way ANOVA with Bonferroni post-hoc testing at a 0.05 significance level.

Results: Instrument fractures occurred in one sample from PTG (S2), four from EPUG (three S2, one S1), and two from EAG (S2). No statistically significant differences were found among the groups regarding canal transportation and shaped area changes ($p=0.43$ and 0.06 , respectively). The greatest transportation was observed coronally in all groups ($p=0.001$). Coronal transportation was significantly higher than apical transportation in the PTG and EAG systems ($p=0.001$ and $p=0.048$, respectively). Weight loss was significantly different among all groups (PTG: 3.16 ± 0.45 mg; EPUG: 4.63 ± 0.26 mg; EAG: 5.90 ± 0.63 mg; $p=0.001$).

Conclusion: Within the limitations of this study, the shaping performance of locally manufactured systems appeared comparable, though further research in extracted human teeth is recommended.

Keywords: Alloys; nickel titanium; root canal preparation.

Introduction

One of the fundamental requirements for the success of root canal treatment is the mechanical preparation of the canal system in a way that enables thorough cleaning and three-dimensional obturation.(1) The instrumentation of

the root canal is a key stage in endodontic treatment and is considered a predictive factor for the long-term success of therapy when properly performed. Ideally, the mechanical preparation should provide the canal with a continuously tapered shape from the coronal portion to the apical third while preserving the original anatomy, respecting multi-

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planar curvatures, and maintaining the apical foramen as small as possible.(2) The success of root canal shaping is not only evaluated by the enlargement of the canal but also by the ability to maintain the original canal path without deviation. Such deviations, known as transportation, particularly in the apical region, may compromise the adaptation and sealing of the root filling, thereby jeopardizing the treatment outcome.(3,4)

Recently, rotary nickel–titanium (NiTi) instruments have become an integral part of the endodontic armamentarium.(5) In addition to greater flexibility and shorter preparation time, their super elasticity has been associated with fewer procedural errors, such as zipping, ledge formation, or transportation, compared with stainless steel files.(6,7) NiTi rotary instruments have evolved considerably over the years and are now widely used in clinical practice. Both manufacturing processes and thermal treatments significantly influence their mechanical properties and overall performance.(8) Currently, a wide variety of NiTi systems with different cross-sectional designs and heat-treatment technologies are available in the international market.(5,9) ProTaper Gold (PTG, Dentsply Tulsa Dental Specialties, Tulsa, OK, USA) is a multi-file system composed of three shaping files (SX, S1, S2) and five finishing files (F1–F5) used in continuous rotation. PTG maintains the same design as its predecessor, ProTaper Universal (Dentsply Maillefer), featuring multiple progressive tapers, a convex triangular cross-section, and a modified guiding tip.(10) However, the high cost and limited accessibility of international brands have driven the development of locally manufactured NiTi rotary systems as alternative solutions for clinical practice. EndoArt Action Gold (EAG, Inci Dental, Istanbul, Türkiye) is a NiTi rotary system designed for efficient endodontic preparation, with a convex triangular cross-section, manufactured from CM (controlled memory)-wire and coated with gold plating, which enhances cyclic fatigue resistance and flexibility. EAG files have variable taper like PTG files and similar numbers of shaping and finishing files as the PTG system. There is also a blue alternative to this file system with 21-, 25- and 31-mm options.(11) Another system produced in Türkiye, EndoPlus Universal Gold (EPUG, Turkuaz Sağlık Hizmetleri, Denizli, Türkiye), is a heat-treated NiTi rotary system with a concave triangular cross-section. There are also silver and blue types of files with 19-, 21-, 25- and 31-mm length alternatives. EndoPlus files have an MDR (medical device regulations) certificate. This certificate governs the production and distribution of medical devices in the European Union.(12) Like PTG and EAG, EPUG includes 3 shaping files (Sx-19/.04, S1-18/.02, S2-20/.04) and 5 finishing files (F1-20/.07, F2-

25/.08, F3-30/.09, F4, F5); however, data on the mechanical properties or shaping performance of this locally manufactured file system remain limited.(13,14) A recent study reported that scanning electron microscopy analysis of fractured types of EndoPlus files' (EndoPlus Flex Plus Gold X2) tips displayed classic cyclic-fatigue features, and energy dispersive X-ray spectroscopy confirmed a NiTi composition.(14) While internationally recognized systems such as PTG have been extensively studied in terms of both mechanical features and shaping ability(10,15), there is a significant lack of evidence concerning locally manufactured systems such as EAG and EPUG. Clinicians, both nationally and internationally, may widely use these NiTi files if studies yield positive results. Therefore, shaping performance of these files has to be further evaluated. Furthermore, assessing transportation alone is not sufficient, since canal area changes and weight loss are also clinically relevant parameters. Only a limited number of studies in the literature have simultaneously evaluated these three parameters.(16) While canal area change reflects the extent of canal enlargement and morphological transformation, weight loss directly demonstrates the amount of dentin removed; excessive removal weakens the canal wall and may negatively influence prognosis.(17,18) Hence, the combined evaluation of transportation, area change, and weight loss provides a multidimensional assessment of rotary systems in terms of both centering ability and dentin preservation. Specifically, no study to date has evaluated the effects of the aforementioned local systems on transportation, area change, and dentin removal. Therefore, the present study aimed to compare the shaping outcomes of PTG, EAG, and EPUG rotary systems in terms of canal transportation, area change, and weight loss. The null hypothesis was that PTG, EPUG, and EAG would not differ in (i) transportation at apical/middle/coronal levels, (ii) canal area change, and (iii) weight loss.

Materials and Methods

Sample Selection

The sample size was determined by power analysis using the G*Power program (Version 3.1.9.4, Kiel University). Based on previous studies(19,20), with an effect size of 0.7, an alpha error probability of 0.05, and a power of 80%, a total of 24 samples (n=8 per group) were included. Twenty-four resin block canals (Endo Training-Block, Dentsply Maillefer, Ballaigues, Switzerland) with a single 30° curvature and known initial weights were photographed under a stereomicroscope (SZ61; Olympus Corporation, Taichung, Taiwan) at 4× magnification (Fig. 1). The blocks were randomly assigned to three groups according to the shaping system to be used: ProTaper Gold (PTG, Dentsply

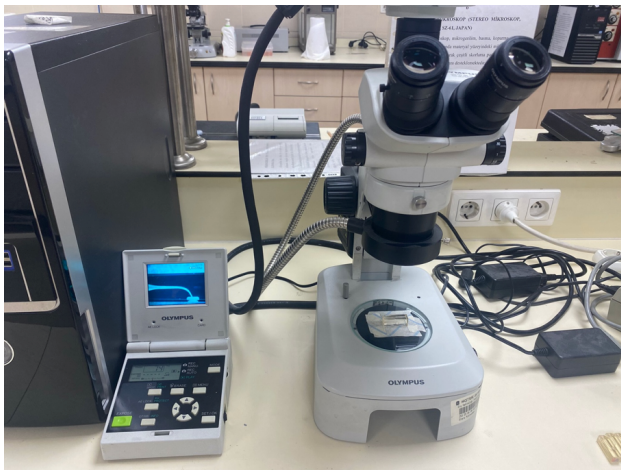


Fig. 1. A mechanism made of glass lamellae that allows stereomicroscope images of resin blocks to be taken from the same angle at all time.

Maillefer, Ballaigues, Switzerland), EndoPlus Universal Gold (EPUG, Turkuaz Sağlık Hizmetleri, Denizli, Türkiye) and EndoArt Action Gold (EAG, İnci Dental, İstanbul, Türkiye).

Sample Preparation

All shaping procedures were performed by a single experienced operator, and a new file was used for each specimen. Prior to shaping, a glide path was prepared in all samples with #10 and #15 stainless steel K-files (D-perfect, Shenzhen Guangdong, China) at the working length (WL). Each group was shaped according to the manufacturer's recommended sequence, speed, and torque, using an X-Smart endodontic motor (Dentsply Maillefer, Ballaigues, Switzerland):

PTG group: SX [to half of the canal length 300 rpm; 5.1 Ncm-19 (tip diameter)/.045(taper)], S1 (300 rpm; 5.1 Ncm-18/.02), S2 (300 rpm; 1.5 Ncm-20/.04), F1 (300 rpm; 1.5 Ncm-20/.07), and F2(25/.08) files were used at 300 rpm and 3.1 Ncm torque at WL, respectively.

EAG group: SX (300 rpm-3Ncm), S1, S2, F1, and F2 files at 300 rpm and 2.6 Ncm torque was used during preparation of simulated canals, respectively.

EPUG group: Sx-19/.04, S1-18/.02, S2-20/.04, F1-20/.07, F2-25/.08 were used during preparation of simulated canals, respectively.

After each shaping step, apical patency was confirmed with an ISO #10 K-file (D-perfect) advanced 1 mm beyond the WL. The canals were irrigated with 2 mL sterile distilled water as in a previous study(8) using a 30-G side-vented needle (Scope Endo FX, JECT, Türkiye) after every step. At the end of shaping after the final irrigation step, simulated canals were dried with paper points, re-weighed, and

photographed again under the stereomicroscope.

Stereomicroscope Analysis and Transportation Measurement

All resin blocks were examined under a stereomicroscope under the same conditions, both before and after shaping. Images were obtained at 4× magnification using a colored stereomicroscope (SZ61) equipped with an integrated digital camera. All images were exported in PNG format and recorded for analysis. Pre- and post-shaping images were superimposed on the same plane using ImageJ software (v1.54c, NIH, USA) (Fig. 2A-C). During the superimposition process, only horizontal and vertical shifts were corrected using the “Align image by translation” command, while magnification and rotation were kept constant. The superimposed images enabled direct visualization of changes in canal morphology. Transportation analysis was performed separately in three regions of the canal (coronal, middle, and apical) as in previous studies.(21,22) In each region, the positions of the canal walls before and after shaping were manually identified on the superimposed images, and the differences in distance between the inner (concave) and outer (convex) walls were measured. The transportation value was calculated using the following formula: Transportation = inner wall distance – outer wall distance.

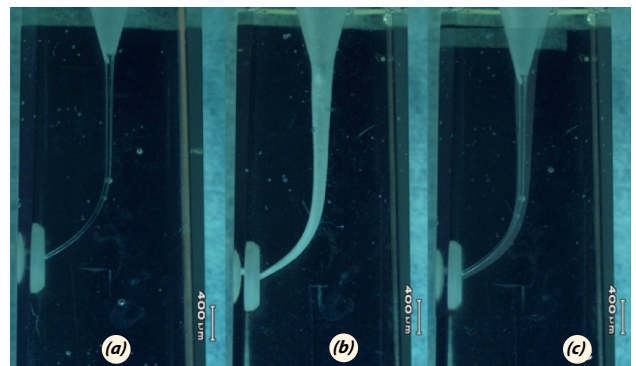


Fig. 2. Stereomicroscopic images of resin blocks showing the initial view (a), the post-instrumentation view (b), and the superimposed images (c).

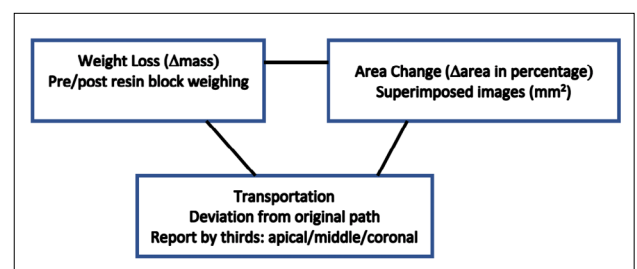


Fig. 3. Schematic representation of experimental setup.

Positive values indicated transportation toward the convex (outer) direction, whereas negative values indicated transportation toward the concave (inner) direction. All measurements were performed by the same investigator and at the same screen magnification to ensure standardization. The absolute values of transportation were used for statistical analysis.

Weight Change

Each resin block was weighed before and after shaping using an analytical balance with a precision of 0.0001 g (Radwag, Radom, Poland). All measurements were performed under a dry surface and stable environmental conditions. Three separate measurements were obtained for each sample, and their mean values were used for analysis. The weight difference between the post-preparation and the pre-preparation represented the amount of resin material removed during canal preparation and was recorded as weight loss in milligrams.

Area Change

For each resin block, canal areas before and after shaping were calculated using stereomicroscopic images. The images were analyzed with ImageJ software (v1.54c, National Institutes of Health, USA). The images were first converted to 8-bit grayscale format, and the canal lumen boundaries were manually delineated. The canal area was

then measured in mm² using the “Analyze → Set Measurements → Area” command. The difference between the post-shaping and pre-shaping area values was considered as the increase in canal area. This value provided quantitative data regarding the canal enlargement effect of the file systems. All measurements were performed under identical magnification and contrast conditions by the same operator. Schematic representation of the experimental setup takes place at Figure 3.

Complications during experiments

During shaping, instrument fractures occurred in one sample of the PTG group (S2), four samples of the EPUG group (3-S2 and 1-S1) and two samples of the EAG group (2-S2). Acrylic resin blocks were eliminated, and new blocks were further included in the experiments.

Statistical Analysis

The transportation data were analyzed using two-way ANOVA with the Bonferroni post-hoc test, whereas weight and area changes were evaluated using one-way ANOVA with the Bonferroni post-hoc test. The significance level was set at $p < 0.05$. SPSS software (v23, IBM Corp., Armonk, New York, USA) was used for statistical analysis.

Results

The results of the study are presented in Table 1. No

Table 1. Results of evaluated parameters

File systems	Parameters	Mean	SD	Min	Max
PTG Sx-F2	Transportation in m				
	Apical Third	54.94 ^a	22.51	31.62	90.10
	Middle Third	80.26 ^{ab}	35.03	48.00	141.65
	Coronal Third	117.19 ^b	47.07	55.36	197.35
	Weight Difference in mg	3.16 [*]	0.45	2.50	3.60
	Area Difference in percentage (%)	147.77	19.15	125.17	176.99
EPUG Sx-F2	Transportation				
	Apical Third	65.47 ^a	21.11	44.18	113.35
	Middle Third	69.30 ^a	25.19	42.80	114.53
	Coronal Third	90.99 ^a	31.41	43.9	137.10
	Weight Difference	4.63 ^μ	0.26	4.30	5.10
	Area Difference	130.52	10.60	120.79	147.88
EAG Gold Sx-F2	Transportation				
	Apical Third	54.82 ^a	20.47	31.49	94.41
	Middle Third	75.89 ^{ab}	19.18	45.18	106.51
	Coronal Third	90.72 ^b	31.30	58.54	156.76
	Weight Difference	5.90 [^]	0.63	5.10	7.00
	Area Difference	131.49	14.25	114.49	152.75

a, b: reveal statistical difference between root thirds of same file system (for PTG group $p=0.001$, for EAG group $p=0.048$, for EPUG group $p=0.182$). ^{*}, [^]: reveal statistical difference between weight loss of different file systems ($p=0.001$, for all comparisons). PTG: ProTaper Gold; EPUG: EndoPlus Universal Gold; EAG: EndoArt Action Gold; m: micron; mg: milligram.

statistically significant differences were observed among the file systems in terms of transportation values or area changes of simulated canals ($p=0.43$ and 0.06 , respectively). In all groups, the highest transportation occurred in the coronal region ($p=0.001$). In the PTG and EAG systems, coronal transportation was significantly higher than the apical transportation ($p=0.001$ and $p=0.048$, respectively). Weight loss was significantly different among all groups (PTG: 3.16 ± 0.45 mg; EPUG: 4.63 ± 0.26 mg; EAG: 5.90 ± 0.63 mg; $p=0.001$).

Discussion

In this study, the shaping performances of the locally manufactured EPUG and EAG rotary NiTi systems were evaluated in resin blocks in comparison with the internationally well-established PTG system. This study found no between-system differences in transportation or canal area change. The greatest transportation occurred coronally in all groups. Weight loss differed among systems (PTG<EPUG<EAG). Accordingly, the null hypothesis was accepted for transportation and area change but rejected for weight loss.

Root canal transportation was defined as any measurable deviation of the prepared canal from its original center-line/curvature, assessed by pre- and post-instrumentation image superimposition (e.g., micro-CT or standardized radiographs), indicating nonconcentric dentin removal and canal relocation.(23) A comprehensive recent review categorizes apical transportation, as an intra-operative error that can adversely influence periapical healing after root canal treatment.(24) Therefore, evaluating the transportation potential of file systems is important. Transportation could be calculated either with superimposed 2-dimensional images obtained via stereomicroscope(25,26) or cone-beam computed tomography.(27) Both methods have advantages and disadvantages. Superimposing images obtained with a stereomicroscope is a nondestructive, quick and low-cost method that allows fine sampling along the canal and is excellent for transparent or dyed resin blocks.(26) In the present study, the mean transportation value in the coronal region for the PTG, EPUG, and EAG groups was 0.12 mm, 0.09 mm and 0.09 mm, respectively. Several resin block studies that evaluated transportation and shaped area quantitatively through pre/post image superimposition have reported findings consistent with the present study.(10,15,25-27) Comparisons of PTG with different file systems such as WaveOne Gold (Dentsply Maillefer, Ballaigues, Switzerland), TruNatomy (Dentsply Sirona, Maillefer, Ballaigues, Switzerland), Reciproc Blue (VDW, Munich, Germany) revealed no substantial differences in overall transporta-

tion, with the greatest deviations occurring coronally or in the middle/coronal regions.(15,25,26) Previous studies using one of these transportation evaluation methods reported for PTG 0.10-0.16 mm, 0.07-0.13 mm and 0.07-0.11 mm transportation at coronal (7 mm from apex), middle (5 mm from apex) and apical thirds (3mm from apex), respectively.(21,22,26) In the literature, studies evaluating shaping characteristics of locally manufactured EAG and EPUG are limited.(28) Mainly their cyclic fatigue characteristics are evaluated.(13,14) A recent study reported a mean apical transportation of 0.23 mm for another heat-treated EndoArt file, using CBCT cross-sections of extracted primary molars.(28) The differences in apical transportation may be attributed to factors such as the use of extracted teeth, the method of calculating transportation from cross-sections, or the specific type of EndoArt file used; in the current study, the mean apical transportation was 0.054 mm. Transportation tends to concentrate around the curved mid-coronal region, while apical deviation is usually smaller and kept below clinically critical thresholds. Mechanistically, curvature and taper drive this pattern: Larger coronal tapers and straightening forces produce asymmetric dentin removal coronally, whereas heat-treated NiTi better maintains apical curvature and typically keeps apical transportation <0.3 mm—the level beyond which sealing may be compromised.(4) None of the file systems exceeds this value in any of the evaluated thirds. These data support the present finding of higher coronal vs. apical transportation and align with guidance that canal curvature and taper selection are primary intraoperative risk factors for transportation.(29)

Change in the area of the simulated root canal was one of the parameters that was evaluated in the present study. The amount and pattern of canal enlargement produced during instrumentation are known to be dependent on the endodontic file system used. In the present study, no significant differences were observed among PTG, EPUG, and EAG with respect to changes in the shaped canal area. This outcome may be explained by the fact that EPUG and EAG were manufactured with taper values and geometric features closely resembling those of PTG. Previous investigations have highlighted that canal enlargement is strongly influenced by the design and kinematic properties of the instrument(30), and that geometric characteristics such as taper play a crucial role in the amount of dentin removed from canal walls.(10) Therefore, the absence of significant differences among the tested systems appears consistent with their comparable design philosophy and taper configuration.

Several studies that quantitatively assessed resin removal or weight loss have reported system-dependent differences

in the amount of removed material, even when transportation values were similar.(8,25) This parameter quantitatively demonstrated the extent of material removal from the resin block in each system. Results of the current study indicate that cutting efficiency (and consequently weight change) may vary independently of shaping accuracy. In the present study, the weight-loss gradient observed (PTG<EPUG<EAG) is consistent with these findings, suggesting meaningful differences in cutting aggressiveness among systems that may not necessarily translate into clinically relevant variations in shaping accuracy. Similarly, Cecchin et al.(25) evaluated the cutting efficiency of different rotary NiTi instruments based on weight-loss analysis and reported significant differences among systems. Nevertheless, because resin blocks have lower microhardness compared with dentin and may soften due to heat generation during instrumentation(25,31), weight loss results may not fully represent clinical conditions. Therefore, findings from resin block studies should be corroborated by investigations in extracted human teeth to ensure their clinical applicability.(31)

Fracture of NiTi instruments has long been discussed as one of the major complications in endodontic treatment. The main mechanisms reported in the literature are cyclic fatigue and torsional loading, while in clinical conditions both factors often play a role simultaneously.(26) In the present study, the distribution of fractured instruments (PTG: 1, EPUG: 4, EAG: 2) reveals the need for further studies regarding local file systems. Mainly S2 (20/.04) (total 6 times) files were fractured in the simulated canals. Reported instrument fractures in simulated canals are generally low—several resin-block studies document no separations at all—yet incidence is system- and setup-dependent, as earlier standardized-block work with ProFile showed measurable fracture rates under severe curvature and highlighted operator effects.(32) Furthermore, it has been reported that the ProTaper Universal S2 exhibits the lowest cyclic-fatigue life among the new S1, S2, F1, F2 files.(33)

Simulated canals are widely accepted and considered a reliable model for investigating shaping efficiency because they provide anatomical standardization.(10,34) On the other hand, there are several limitations of the current study, such as the assessment of only one curvature angle, the two-dimensional limitation of ImageJ and stereomicroscopic analysis, and the sensitivity of weight measurements.

Conclusion

In resin-block models, weight loss, area/width change, and transportation provide complementary views of shaping

behavior. Weight loss reflects overall cutting and, by proxy, dentin sacrifice; area change indicates the magnitude and distribution of enlargement relevant to irrigant exchange and obturation; transportation quantifies curvature maintenance, with apical deviation being most prognostically relevant. While these metrics are not direct surrogates for clinical outcomes, their comparative patterns help identify file systems that balance debridement with dentin preservation. Accordingly, the current finding of similar area changes and small transportation across PTG, EPUG, and EAG suggests broadly comparable shaping philosophies; clinically, this supports selecting among these systems based on handling, taper strategy, and case anatomy, while adhering to minimally invasive enlargement to preserve dentin.

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