

## Original Research Article

# Comparison of Canal Shaping and Transportation Between the Protaper Next and Protaper Ultimate in Simulated Double-curved Canals

Seher Pelda Bicer<sup>1</sup>, Betül Aycañ Uysal<sup>2</sup>

<sup>1</sup>DDS, Postgraduate student, Health Science University, Faculty of Hamidiye Dentistry, Department of Endodontics, Istanbul, Türkiye

<sup>2</sup>DDS, Associate Professor, Health Science University, Faculty of Hamidiye Dentistry, Department of Endodontics, Istanbul, Türkiye

**Copyright:** ©2026 Bicer & Uysal. This work is licensed under a [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/). Unrestricted use, distribution and reproduction in any medium is permitted provided the original author and source are credited.

## ABSTRACT

**Aim:** To compare the canal shaping and transportation caused by the Protaper Next (PTN) and Protaper Ultimate (PTU) file systems in artificially created double-curved canals.

**Material and Method:** Thirty double-curved canals in clear resin blocks were prepared up to an apical size of #25 using PTN and PTU instruments. Resin blocks were filled with ink and photographed before and after instrumentation to develop composite images by superimposition. Shaping ability and transportation of the canals were evaluated. Student's t-test and Mann Whitney U test was used ( $p < 0.05$ ).

**Results:** Compared with the PTU system, PTN demonstrated significantly greater shaping at the 7–10 mm levels, corresponding to the coronal third of the canals ( $p < 0.05$ ). At the 4 mm level, representing the apical curvature, transportation was significantly higher in the PTU group ( $p = 0.006$ ). No statistically significant differences were observed at the other levels ( $p > 0.05$ ).

**Conclusion:** The PTU group, compared to the PTN group, demonstrated more conservative shaping in the coronal and middle thirds, preserving pericervical dentin more effectively. The PTU group may lead to transportation in the apical curvature.

**Keywords:** Root canal preparation; Root canal therapy; Root canal transportation

**Citation:** Bicer SP, Uysal BA. Comparison of canal shaping and transportation between the Protaper Next and Protaper Ultimate in simulated double-curved canals *ADO Klinik Bilimler Dergisi* 2026;15(1):47-54

**Editor:** Prof. Dr. Sibel Elif Gültekin, Gazi University, Faculty of Dentistry, Department of Oral Pathology, Ankara, Türkiye.

## INTRODUCTION

Root canal morphology is complex and significantly influences the success of endodontic treatment. Effective root canal treatment depends on preserving the tooth structure while maintaining the original canal shape during instrumentation, cleaning, shaping, and hermetic sealing.<sup>1</sup> However, complex root canal anatomy can cause difficulties in shaping the canal. Root canal shaping should preserve the original structure of the apical foramen and avoid root canal transportation.<sup>2</sup> The amount of root canal transportation depends both on the anatomy of the root canal and the cross-sectional design, taper, and flexibility of the files. Thanks to the improved mechanical properties of nickel-titanium (Ni-Ti) instruments, the shaping process can be performed more effectively and with fewer errors, especially in curved root canals.<sup>3,4</sup> Ni-Ti rotary file systems were developed to reduce iatrogenic errors by increasing flexibility through different alloys, tapers, cross-sectional designs, and heat treatments. Heat-treated Ni-Ti alloys contain the more ductile R-phase or martensitic phase, while conventional Ni-Ti alloys consist primarily of austenite. This provides heat-treated Ni-Ti files with higher flexibility and cyclic fatigue resistance than traditional Ni-Ti files.<sup>5</sup> Meanwhile, efforts have been made to improve the preservation of remaining pericervical dentin, which contributes to the fracture resistance of teeth and directly impacts long-term prognosis.<sup>6</sup> This has led to the continual evolution of innovative filing systems whose aim is to protect the tooth structure. Protaper Next (PTN; Dentsply, Maillefer, Ballaigues, Switzerland) is among the file systems developed for this purpose.<sup>7</sup>

Received: 08.03.2025; Accepted: 11.11.2025

Corresponding author: Dr. Betül Aycañ Uysal, Health Science University, Faculty of Hamidiye Dentistry, Department of Endodontics, Istanbul, Türkiye.

E-mail: [dr.betulaycanuysal@gmail.com](mailto:dr.betulaycanuysal@gmail.com)

PTN is an M-Wire file system composed of heat-treated Ni-Ti alloy, containing austenite, martensitic, and R-phases for improved cyclic fatigue resistance and flexibility.<sup>7,8</sup> The PTN has an off-center rectangular design and progressive tapers. Through the inclusion of both ascending and descending tapered designs on a single file, it minimizes the contact between dentin and file, reducing the unwanted screw effect.<sup>9</sup> In the PTN file system, only two points of the rectangular cross-section contact the canal wall at any one time.<sup>10</sup>

The ProTaper Ultimate (PTU; Dentsply Maillefer, Ballaigues, Switzerland) is a multi-file system comprising shaping and finishing files with different crystallographic structures; the different mechanical properties of the files complement each other.<sup>11</sup> The newest generation of the Protaper group, this file group has a parallelogram cross-section with pronounced acute angles, partially off-center, and a maximum groove diameter of 1.0 mm. This allows for the conservative removal of dentin in important areas such as the cemento-enamel junction, while at the same time offering larger apical dimensions for preparation. The finisher files of the PTU system include varied tip sizes and tapers (#20/0.07, #25/0.08, and #30/0.09), which allow for more effective shaping in the apical triangular region.<sup>11,12</sup>

The main advantage of this system is the separate shaper files, for working on the coronal two-thirds of the canal, and finisher files, for increasing the taper of the apical third without unnecessary widening of the coronal portion. The five main files of the set represent the most commonly used types: a slider to identify the canals, a shaper to prepare the coronal and middle thirds of the canal, and three different sizes of finisher files.<sup>13</sup> As with the PTN, heat treatment technology increases flexibility and resistance to cyclic fatigue, and optimizes performance. The PTU set consists of three different heat-treated alloys: including M-Wire for the slider, Gold-Wire for shapers and finishers, and Blue-Wire for finishers.<sup>13</sup> This study aimed to compare the shaping ability and amount of transport of the PTN and PTU file systems in artificial double-curved canals. The null hypothesis of this study was that there would be no significant differences between the PTN and PTU systems in terms of canal shaping ability (the ability of the file system to enlarge and

shape the canal while maintaining its original curvature) and transportation in simulated double-curved canals.

## MATERIALS AND METHODS

This study was conducted at Health Science University, Faculty of Hamidiye Dentistry, Department of Endodontics. Simulated double-curved resin blocks were used to compare the shaping efficiency of different Ni-Ti file systems in difficult canals and measure the amount of transportation. G\*Power software (version 3.1.9.7; Heinrich Heine Universität, Düsseldorf, Germany) was used to determine the required sample size. A priori analysis of variance (ANOVA; fixed effects, omnibus, one-way) was selected from the F-test family. The effect size was set at 0.6 based on data from a previous study.<sup>14</sup> The calculations were performed by setting the alpha error at 0.05 and the power ( $\beta$  value) at 0.85. A total of 30 resin blocks (Endo Training-Bloc-S, 0.02 Taper; Dentsply Maillefer, Ballaigues, Switzerland) with double-curvature canals were used, with  $n=15$  per group.

**Sample Preparation:** Simulated canals in the resin blocks were prepared with a taper of 0.02, an apical diameter of 0.15 mm, a length of 18 mm, an apical curvature of 20° (3.5 mm radius), and a coronal curvature of 30° (5 mm radius). These blocks were randomly divided into two groups according to the file system used, PTN ( $n=15$ ) and PTU ( $n=15$ ).

**Canal Shaping Procedures:** The resin blocks were numbered from 1 to 30 and randomly divided into two groups according to the Ni-Ti file system used. Before instrumentation, all canals were injected with black ink (Pelikan 4000, Germany). To ensure the homogeneity of the photographs for each sample, a specialized setup was used to consistently position the transparent resin blocks. The setup was maintained with the same position and settings, and photographs were taken using a microscope-calibrated camera (Nikon D3500, Nikon, Japan).

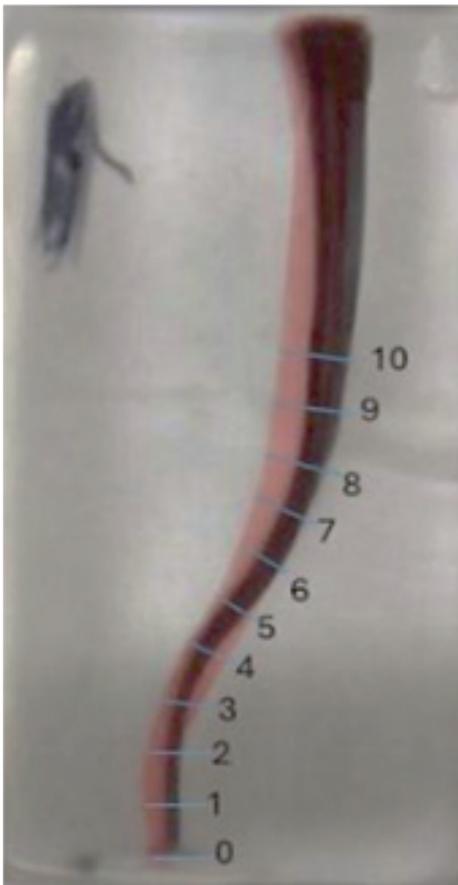
Canal patency was confirmed using an ISO standard size #10K file (Dentsply Maillefer, Ballaigues, Switzerland). Root canal shaping was performed using the Ai-Endomotor (Woodpecker, China), with torque and speed at the manufacturer's recommended settings. All procedures were carried

out by a second-year endodontic resident. Each file was used for a single canal only. The working length was set to 18 mm, and a glide path was established using a #15K file. Distilled water was used instead of clinical irrigation solutions to prevent chemical interactions with the transparent blocks.

Following instrumentation, red ink (Pelikan 4001, Germany) was injected into the canal to enhance the color contrast of the photographs, and the images were captured again under the same conditions as before. To minimize the margin of error, all photographs were taken by the same individual.

### Analysis of Transportation and Shaping Efficiency

The images obtained before and after instrumentation were transferred to Adobe Photoshop CC 2023 (Adobe Systems, San Jose, CA, USA) for further analysis. The photographed surfaces were optimally aligned by superimposing the created openings (Figure 1).



**Figure 1.** The images obtained before and after instrumentation were transferred to Adobe Photoshop CC 2023 (Adobe Systems, San Jose, CA, USA) and aligned using the overlay method.

To evaluate the shaping efficiency of the Ni-Ti rotary file systems used in this study, changes in the original shape of the canal were determined based on the following criteria:

- a – Amount of enlargement on the outer side of the curvature (O)
- b – Amount of enlargement on the inner side of the curvature (I)
- c – Total amount of enlargement (S):  $O + I$
- d – Direction and amount of transportation (T):  $I - O$

The difference between the amount of material removed from the outer side of the curvature and the amount removed from the inner side determines the transportation value (T). According to this formula:

$T = 0$  indicates that no transportation has occurred in the canal.

$T > 0$  signifies that the transportation direction is inward.

$T < 0$  signifies that the transportation direction is outward.

### Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics v.22. Student's t-test was used for comparisons between the two groups for normally distributed parameters, and the Mann-Whitney U test was used for comparisons between the two groups when the normality assumption was not met. The p value  $< 0.05$  was considered statistically significant.

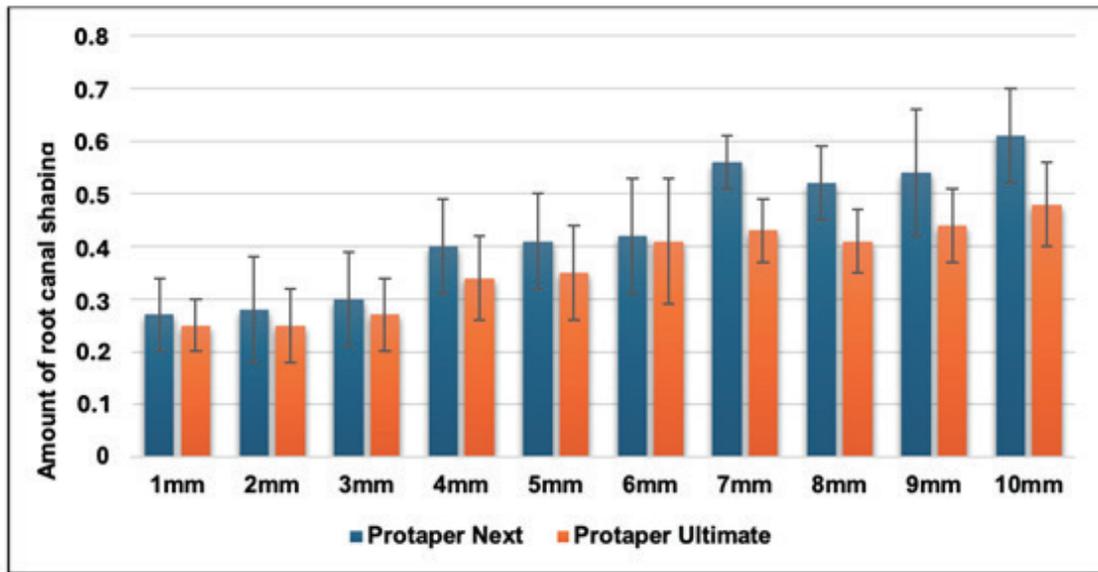
## RESULTS

**Evaluation of Canal Shaping Amount:** Table 1 presents the root canal shaping measurements for each group. No statistically significant differences were found between the groups at the 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, and 6 mm levels, corresponding to the apical and middle thirds of the canal ( $p > 0.05$ ). However, the extent of root canal shaping at the 7 mm, 8 mm, 9 mm, and 10 mm levels, representing the coronal third of the canal, was significantly higher in the PTN group compared to the PTU group ( $p < 0.05$ ). Furthermore, the shaping measurements increased progressively from 1 mm to 10 mm within both file systems (Figure 2).

**Table 1.** The amounts of root canal shaping of Protaper Next and Protaper Ultimate groups

Amounts of root canal shaping	Protaper Next	Protaper Ultimate	p
	Mean±SD	Mean±SD	
1 mm	0.27±0.07	0.25±0.05	0.380
2 mm	0.28±0.10	0.25±0.07	0.533
3 mm	0.30±0.09	0.27±0.07	0.437
4 mm	0.40±0.09	0.34±0.08	0.141
5 mm	0.41±0.09	0.35±0.09	0.192
6 mm	0.42±0.11	0.41±0.12	0.891
7 mm	0.56±0.05	0.43±0.06	0.001*
8 mm	0.52±0.07	0.41±0.06	0.001*
9 mm	0.54±0.12	0.44±0.07	0.046*
10 mm	0.61±0.09	0.48±0.08	0.002*

Student's t-test \*p<0.05



**Figure 2.** The amount of root canal shaping of Protaper Next and Protaper Ultimate

**Table 2.** The amounts of root canal transportation of Protaper Next and Protaper Ultimate groups

Amounts of root canal transportation	Protaper Next	Protaper Ultimate	p
	Mean±SD	Mean±SD	
1 mm	0.09±0.04 (0.08)	0.06±0.03 (0.06)	0.057
2 mm	0.14±0.08 (0.13)	0.11±0.10 (0.08)	0.269
3 mm	0.12±0.11 (0.09)	0.20±0.14 (0.15)	0.223
4 mm	0.05±0.03 (0.04)	0.16±0.13 (0.10)	0.006*
5 mm	0.16±0.04 (0.16)	0.14±0.06 (0.15)	0.704
6 mm	0.15±0.06 (0.19)	0.13±0.10 (0.11)	0.411
7 mm	0.12±0.09 (0.10)	0.11±0.08 (0.08)	0.731
8 mm	0.04±0.03 (0.04)	0.07±0.05 (0.07)	0.359
9 mm	0.08±0.04 (0.08)	0.07±0.03 (0.08)	0.939
10 mm	0.09±0.03 (0.09)	0.07±0.04 (0.07)	0.137

Student's t-test \*p<0.05

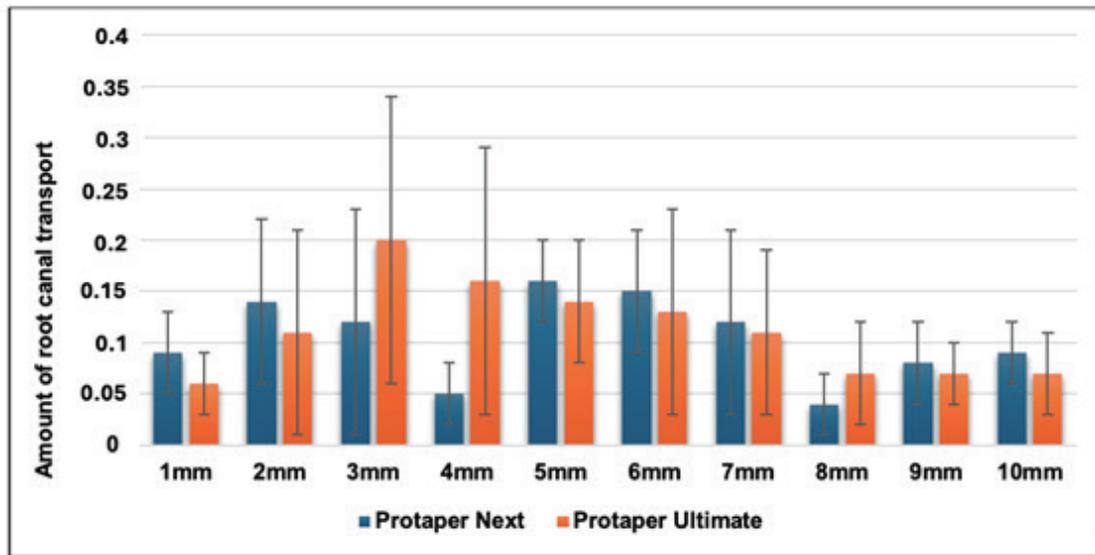


Figure 3. The amount of root canal transportation of Protaper Next and Protaper Ultimate

**Evaluation of Root Canal Transportation:** The extent of root canal transportation at the 4 mm level was found to be significantly higher in the PTU group compared to the PTN group ( $p=0.006$ ).

However, no statistically significant differences were observed between the groups at 1 mm, 2 mm, 3 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, and 10 mm ( $p>0.05$ ) (Table 2). A significant difference between the two groups was detected only at the 4 mm level, corresponding to the apical curvature of the canal (Figure 3).

## DISCUSSION

Regardless of the instrumentation technique used, cleaning and shaping procedures inevitably result in the removal of a certain amount of dentin from the canal walls. If dentin is not removed uniformly in all directions along the main axis of the tooth, but instead excessively in a single direction, it leads to a phenomenon known as canal transportation.<sup>15,16</sup> According to Goldberg *et al.*<sup>17</sup>, apical transportation occurring during root canal treatment increases the risk of treatment failure.

Root canal transportation up to 0.15 mm is considered an acceptable amount; transportation exceeding 0.30 mm can impede apical sealing after canal obturation, potentially leading to failed treatment.<sup>2</sup> Older file systems were generally indicated for shaping straight or slightly curved canals. However,

with ongoing advances in modern file systems, instruments with a higher martensitic phase have been developed. These newer instruments offer greater flexibility and shape memory control, making them more suitable for use in severely curved or double-curvature root canals.<sup>18,19</sup>

Consistent with our results, a previous study comparing the shaping efficiency of different Ni-Ti files in double-curvature root canals concluded that files with a lower taper more effectively preserved the original canal shape. In other words, as the taper angle decreases, the amount of transportation is also reduced.<sup>20</sup> When comparing the shaping ability of canal instruments, the instruments must have a similar apical diameter.<sup>21</sup> It was stated that an apical diameter of at least #35 size is necessary for optimal root canal cleaning.<sup>22</sup> However, Akhlaghi *et al.*<sup>23</sup> reported that, in terms of the ability to reduce bacterial load, an apical size of #25 was not significantly different from larger diameters. Additionally, as the apical size increases, the flexibility of the file decreases, leading to a higher risk of transportation.<sup>23</sup> Similarly, López *et al.*<sup>24</sup> reported an increased tendency for canal transportation as the file diameter increases. In the present study, the PTN system caused less transportation than the PTU files. This is believed to be due to the smaller taper angle of the PTN. Consistent with this, Sheno *et al.*<sup>25</sup> previously reported that PTN did not cause significant transportation in the apical region. Although both PTU and PTN files were

used according to the manufacturers' instructions, differences in torque and continuous rotation settings may have influenced the results. Variations in these parameters can affect cutting efficiency, flexibility, and the tendency for canal transportation, particularly in curved canals. Therefore, while the present findings provide valuable insights into the shaping behavior of these systems, the potential influence of mechanical settings should be considered when interpreting and applying the results clinically.

In this study, PTN demonstrated significantly greater dentin removal in the coronal third (7–10 mm levels), whereas PTU caused more transportation in the apical third (4 mm level). These outcomes can be attributed to differences in taper and cross-sectional design. The progressive and variable taper of the PTN system likely enhanced flexibility in the apical region, thereby reducing transportation. In contrast, the larger taper of the PTU files may have increased stiffness within the apical curvature, resulting in higher transportation values.

Clinically, these findings suggest that PTN may be preferable in curved canals to minimize apical transportation, while PTU may be more suitable for preserving pericervical dentin in straighter canals. Based on our results, the null hypothesis stating that there would be no significant difference between the PTN and PTU systems was rejected.

Wu *et al.*<sup>26</sup> compared the PTU, WaveOne, and PTN systems and found that PTN caused the least apical transportation in severely curved canals, while also providing better shaping efficiency. This outcome was attributed to the PTN's progressive taper design, providing more flexibility in the apical section, and to the microstructure of its Ni-Ti alloy, which consists predominantly of the flexible martensitic phase.<sup>26</sup>

In a study comparing PTU with WaveOne Gold (Dentsply-Maillefer, Tulsa, OK) files, PTU demonstrated superior performance in preserving pericervical dentin.<sup>27</sup> Several studies have examined the resistance to cyclic fatigue of PTN and PTU files.<sup>28-31</sup> In one study comparing cyclic fatigue resistance, PTN demonstrated significantly better results than PTU.<sup>30</sup>

A larger taper in the file design has been shown to increase canal transportation. Kunert *et al.*<sup>32</sup> suggest

that the taper is a primary factor responsible for canal transportation. In our study, when comparing the amount of transportation between groups, a statistically significant difference was observed only at the 4 mm level ( $p=0.006$ ). This may be attributed to the fact that in the double-curvature resin blocks, the apical curvature transition occurs at 4 mm, leading to a higher degree of transportation at this specific level.

Many studies conducted on simulated resin blocks have suggested that differences in hardness between extracted tooth dentin and resin blocks may influence clinical outcomes.<sup>33</sup> However, Khalilak *et al.*<sup>34</sup> have argued that the amount of apical transportation observed in extracted teeth and high-hardness resin blocks is similar, and that results obtained from resin blocks can be considered valid if interpreted carefully. In our study, the use of simulated canals in resin blocks ensured standardization in factors such as canal size, curvature, and taper angle, eliminating parameters that vary according to root canal anatomy. This approach provided a controlled environment for a more reliable comparison of shaping and transportation effects. Additionally, the transparency of the simulated canals in resin blocks allowed for a direct comparison of pre- and post-instrumentation images, enabling a more precise evaluation of the shaping and transportation.

This study has several limitations. Although resin blocks provided standardization, they do not fully replicate the mechanical and histological properties of natural dentin. Micro-computed tomography (micro-CT), considered the gold standard for assessing canal shaping and transportation, was not employed; instead, two-dimensional image superimposition was used, which may not adequately represent three-dimensional changes. Distilled water was used for irrigation to ensure standardization, but this does not simulate the chemical and biological interactions occurring with clinical irrigants. Additionally, instrumentation time, file fatigue, and debris extrusion were not evaluated, limiting the clinical applicability of the findings. Finally, inter- and intra-observer reliability was not assessed, which may have introduced measurement bias. It is recommended that these limitations be excluded in future studies.

## CONCLUSION

The PTU group, compared to the PTN group, demonstrated more conservative shaping in the coronal and middle thirds, preserving pericervical dentin more effectively. However, it was also found that PTU may lead to more extensive transportation in the apical curvature. Therefore, the use of PTU file systems is recommended in teeth without curvature and in those with weakened pericervical dentin.

## FUNDING

This study was self-funded by the authors.

## CONFLICT OF INTEREST

The authors report no conflict of interest.

## ETHICAL APPROVAL

Not applicable

## INFORMED CONSENT

Not applicable

# Simüle Edilmiş Çift Kurvatürlü Kanallarda Protaper Next ve Protaper Ultimate Eğeleri Arasındaki Kanal Şekillendirme ve Transportasyonunun Karşılaştırması

## ÖZET

**Amaç:** Yapay olarak oluşturulan çift kurvatürlü kanallarda Protaper Next (PTN) ve Protaper Ultimate (PTU) eğe sistemlerinin neden olduğu kanal şekillendirme ve transportasyonu karşılaştırmak.

**Gereç ve Yöntem:** Şeffaf rezin bloklarda otuz adet çift kurvatürlü kanal, PTN ve PTU eğeleri kullanılarak #25 apikal boyuta kadar hazırlandı. Resin bloklar mürekkeple dolduruldu ve preparasyon öncesi ve sonra fotoğraflanarak görüntüler karşılaştırıldı. Kanalların şekillendirme ve transportasyon miktarları değerlendirildi. Student t testi ve Mann Whitney U testi kullanıldı ( $p<0.05$ ).

**Bulgular:** PTU'ya kıyasla, kanalların koronal üçte birine denk gelen 7-10 mm seviyelerinde kök kanal şekillendirme miktarı, PTN'de önemli ölçüde daha yüksekti ( $p<0.05$ ). Apikal kurvatüre

karşılık gelen 4 mm seviyesinde ise, transportasyon miktarı PTU grubunda PTN'ye kıyasla anlamlı derecede daha fazlaydı ( $p = 0.006$ ). Diğer mesafelerde kök kanal transportasyon miktarları açısından gruplar arasında istatistiksel olarak anlamlı bir fark bulunmadı ( $p>0.05$ ).

**Sonuç:** PTU grubu, PTN grubuna kıyasla, koronal ve orta üçüde daha konservatif bir şekillendirme yaparak periservikal dentini daha etkili bir şekilde koruyabilir. PTU grubu apikal üçüde transportasyona yol açabilir.

**Anahtar Kelimeler:** Kök kanal preparasyonu; Kök kanal tedavisi; Kök kanal transportasyonu

## REFERENCES

- Shakouie S, Mokhtari H, Ghasemi N, Gholizadeh S. Two-rooted maxillary first molars with two canals: a case series. *Iran Endod J* 2013;8:29-32.
- Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. *J Endod* 2004;30:559-67.
- Işık V, Ersev H. Farklı Teknolojiler Kullanılarak Üretilmiş Güncel Nikel-Titanyum Esaslı Döner Alet Sistemlerinin Şekillendirme Etkinliklerinin İncelenmesi. *Yeditepe J Dent* 2024;20:4-11.
- Hülsmann M, Peters OA, Dummer PMH. Mechanical preparation of root canals: Shaping goals, techniques, and means. *Endod Topics* 2005;10:30-76.
- Abdellatif D, Iandolo A, Scorziello M, Sangiovanni G, Pisano M. Cyclic fatigue of different Ni-Ti endodontic rotary file alloys: A comprehensive review. *Bioengineering (Basel)* 2024;11:499.
- Brasil SC, Marceliano-Alves MF, Marques ML, Grillo JP, Lacerda MFLS, Alves FRF, *et al.* Canal Transportation, Unprepared Areas, and Dentin Removal after Preparation with BT-RaCe and ProTaper Next Systems. *J Endod* 2017;43:1683-7.
- Elnaghy AM. Cyclic fatigue resistance of ProTaper Next nickel-titanium rotary files. *Int Endod J* 2014; 47:1034-9.
- Zupanc J, Vahdat-Pajouh N, Schäfer E. New thermomechanically treated NiTi alloy – A review. *Int Endod J* 2018;51:1088-103.
- Ruddle CJ. The ProTaper endodontic system: Geometries, features, and guidelines for use. *Dent Today* 2001;20:60-7.
- Elnaghy AM, Elsaka SE. Assessment of the mechanical properties of ProTaper Next nickel-titanium rotary files. *J Endod* 2014;40:1830-4.
- Martins JNR, Silva EJNL, Marques D, Ajuz N, Rito Pereira M, Pereira da Costa R, *et al.* Characterization of the file-specific heat-treated ProTaper Ultimate rotary system. *Int Endod J* 2023;56:530-42.
- Mustafa M, Attur K, Bagda KK, Singh S, Oak A, Kathiria N. An Appraisal on Newer Endodontic File Systems: A Narrative Review. *J Contemp Dent Pract* 2022;23:944-52.
- Dentsply Sirona. ProTaper Ultimate Endodontic Files. 2023. Available from <https://www.dentsplysirona.com/en-gb/categories/endodontics/protaper-ultimate-files.html>

14. Unno H, Ebihara A, Hirano K, Kasuga Y, Omori S, Nakatsukasa T, *et al.* Mechanical Properties and Root Canal Shaping Ability of a Nickel-Titanium Rotary System for Minimally Invasive Endodontic Treatment: A Comparative *In Vitro* Study. *Materials (Basel)* 2022;15:7929.
15. Kim H, Jeon SJ, Seo MS. Comparison of the canal transportation of ProTaper GOLD, WaveOne GOLD, and TruNatomy in simulated double-curved canals. *BMC Oral Health* 2021;21:533.
16. Nagaraja S, Sreenivasa Murthy BV. CT evaluation of canal preparation using rotary and hand Ni-Ti instruments: An *in vitro* study. *J Conserv Dent* 2010;13:16-22.
17. Goldberg F, Araujo JA. Comparison of three instruments in the preparation of curved root canals. *Endod Dent Traumatol* 1997;13:265-8.
18. Bueno CRE, Cury MTS, Vasques AMV, Sivieri-Araújo G, Jacinto RC, Gomes-Filho JE, *et al.* Cyclic fatigue resistance of novel Genius and Edgefile nickel-titanium reciprocating instruments. *Braz Oral Res* 2019;33:e028.
19. Gambarini G, Grande NM, Plotino G, Somma F, Garala M, De Luca M, *et al.* Fatigue resistance of engine-driven rotary nickel-titanium instruments produced by new manufacturing methods. *J Endod* 2008;34:1003-5.
20. Bürklein S, Poschmann T, Schäfer E. Shaping ability of different nickel-titanium systems in simulated S-shaped canals with and without glide path. *J Endod* 2014;40:1231-4.
21. Bergmans L, Van Cleynenbreugel J, Beullens M, Wevers M, Van Meerbeek B, Lambrechts P. Progressive versus constant tapered shaft design using NiTi rotary instruments. *Int Endod J* 2003;36:288-95.
22. Tan BT, Messer HH. The quality of apical canal preparation using hand and rotary instruments with specific criteria for enlargement based on initial apical file size. *J Endod* 2002;28:658-64.
23. Mohammadzadeh Akhlaghi N, Rahimifard N, Moshari A, Vatanpour M, Darmiani S. The Effect of Size and Taper of Apical Preparation in Reducing Intra-Canal Bacteria: A Quantitative SEM Study. *Iran Endod J* 2014;9:61-5.
24. López FU, Fachin EV, Camargo Fontanella VR, Barletta FB, Só MV, Grecca FS. Apical transportation: a comparative evaluation of three root canal instrumentation techniques with three different apical diameters. *J Endod* 2008;34:1545-8.
25. Sheno PR, Luniya DA, Badole GP, Makade CS, Kubde R, Khode RT. Comparative evaluation of shaping ability of V-Taper 2H, ProTaper Next, and HyFlex CM in curved canals using cone-beam computed tomography: An *in vitro* Study. *Indian J Dent Res* 2017;28:181-6.
26. Wu H, Peng C, Bai Y, Hu X, Wang L, Li C. Shaping ability of ProTaper Universal, WaveOne and ProTaper Next in simulated L-shaped and S-shaped root canals. *BMC Oral Health* 2015;15:27.
27. Ribeiro G, Martin V, Rodrigues C, Gomes P. Comparative Evaluation of the Canal Shaping Ability, Pericervical Dentin Preservation, and Smear Layer Removal of TruNatomy, WaveOne Gold, and ProTaper Ultimate-An *Ex Vivo* Study in Human Teeth. *J Endod* 2023;49:1733-8.
28. Diaconu CT, Diaconu AE, Tuculina MJ, Mihai LL, Gheorghită M, Gheorghită LM, *et al.* Assessment of the Cyclic Fatigue Performance of the Novel Protaper Ultimate File System Used in Different Kinematics: An *In Vitro* Study. *J Funct Biomater* 2024;15:85.
29. Riyahi AM, Bashiri A, Alshahrani K, Alshahrani S, Alamri HM, Al-Sudani D. Cyclic Fatigue Comparison of TruNatomy, Twisted File, and ProTaper Next Rotary Systems. *Int J Dent* 2020;3190938.
30. Gouédard C, Pino L, Arbab-Chirani R, Arbab-Chirani S, Chevalier V. Comparison of the cyclic fatigue resistance of One Curve, F6 Skytaper, Protaper Next, and Hyflex CM endodontic files. *Restor Dent Endod* 2022;47:e16.
31. Rubio J, Zarzosa JI, Aranda S, Casino A, Pallarés A. A comparative study of cyclic fatigue of 6 endodontic systems. An *in vitro* study. *J Clin Exp Dent* 2022;14:560-5.
32. Kunert GG, Camargo Fontanella VR, de Moura AA, Barletta FB. Analysis of apical root transportation associated with ProTaper Universal F3 and F4 instruments by using digital subtraction radiography. *J Endod* 2010;36:1052-5.
33. Yang GB, Zhou XD, Zhang H, Wu HK. Shaping ability of progressive versus constant taper instruments in simulated root canals. *Int Endod J* 2006;39:791-9.
34. Khalilak Z, Fallahdoost A, Dadresanfar B, Rezvani G. Comparison of extracted teeth and simulated resin blocks on apical canal transportation. *Iran Endod J* 2008;3:109-12.