ATATÜRK ÜNİVERSİTESİ YAYINLARI
ATATURK UNIVERSITY PUBLICATIONS

Research Article *Araştırma Makalesi* DOI: 10.17567/currresdentsci.1618988

Comparison of Edgefile X3-One Curve File Systems and Cold Lateral Condensation-Single Cone Filling Techniques in Monoblocks With Simulated Curved Root Canals

Tasarlanmış Eğimli Kök Kanallarına Sahip Monobloklarda Edgefile X3-One Curve Eğe Sistemleri ve Soğuk Lateral Kondensasyon-Tek Kon Dolum Tekniklerinin Karşılaştırılması

Deniz KARAOSMANOĞLU AKIN[1]
[1] Department of Endodontics, Hakkari Oral and Dental Health Center, Hakkari, Türkiye

Murat MADEN[2]
[2] Department of Endodontics, Süleyman Demirel University, Faculty of Dentistry, Isparta, Türkiye

ABSTRACT

Objective: The present study aimed to compare the effects of EdgeFile X3 and One Curve files on the angle of curvature and the effectiveness of cold lateral condensation and single-cone filling techniques in monoblocks with curved root canals.

Methods: One hundred and eight monoblocks were divided into three main groups according to the curvature angle**.** Main group I had curvature angle of 5° at a distance of 6 mm from the root apex; main group II had curvature angle of 20° at the same distance from the root apex; and main group III had curvature angle of 20° at the same distance and curvature angle of 30° at a distance of 12 mm from the root apex. The main groups were divided into sub and end groups according to the use of Edgefile X3, One Curve, cold lateral condensation and single-cone techniques.

Results: With the One Curve, more straightening was observed in the curvature angle of the root canals in main group III. In main group III, there was a significant negative correlation between the change in apical and coronal curvature angles and the gutta-percha ratio and a significant positive correlation with the canal sealer ratio for both techniques.

Conclusions: With the Edgefile X3 file system, the shaping process took less time and the angular change was less. It was concluded that the main determinant of higher gutta-percha ratio was the filling technique used and the single-cone filling technique was more successful.

Keywords: Transportation, Resin block, EdgeFile X3, One Curve, Single-cone, Cold lateral condensation

ÖZ

Amaç: Bu çalışmanın amacı, eğimli kök kanallarına sahip monobloklarda EdgeFile X3 ve One Curve eğe sistemlerinin eğim açısı üzerindeki etkileri ile soğuk lateral kondensasyon ve tek kon dolum tekniklerinin etkinliğini karşılaştırmaktır.

Yöntemler: Yüz sekiz monoblok eğim açısına göre üç ana gruba ayrıldı. Ana grup I, kök apeksinden 6 mm uzaklıkta 5° eğim açısına sahipti; ana grup II, kök apeksinden aynı uzaklıkta 20° eğim açısına sahipti; ve ana grup III,aynı uzaklıkta 20° eğim açısına, kök apeksinden 12 mm uzaklıkta ise 30° eğim açısına sahipti. Ana gruplar Edgefile X3, One Curve, soğuk lateral kondensasyon ve tek kon tekniklerinin kullanımına göre alt ve uç gruplara ayrıldı.

Bulgular: One Curve ile ana grup III'teki kök kanallarının eğim açılarında daha fazla düzleşme gözlendi. Ana grup III'te her iki teknik için de apikal ve koronal eğim açılarındaki değişim ile guta-perka oranı arasında anlamlı negatif korelasyon ve kanal dolgu patı oranı arasında ise anlamlı pozitif korelasyon mevcuttu.

Sonuç: Edgefile X3 eğe sistemi ile şekillendirme işlemi daha az zaman aldı ve açısal değişim daha azdı. Guta-perka oranının yüksek olmasının temel belirleyicisinin kullanılan dolum tekniği olduğu ve tek kon dolum tekniğinin daha başarılı olduğu sonucuna varıldı.

Anahtar Kelimeler: Transportasyon, Rezin blok, EdgeFile X3, One Curve, Tek kon, Soğuk lateral kondensasyon

Geliş Tarihi/Received	14.04.2023
Revizyon Talebi/Revision Requested	24.04.2023
Son Revizyon/Last Revision	26.01.2024
Kabul Tarihi/Accepted	26.01.2024
Yayın Tarihi/Publication Date	20.01.2025

Sorumlu Yazar/Corresponding author:
Deniz Karaosmanoğlu Akın
E-mail: denizkaraosmanoglu@hotmail.com

Cite this article: Karaosmanoğlu Akın D, Maden M. Comparison of Edgefile X3-One Curve File Systems and Cold Lateral Condensation-Single Cone Filling Techniques in Monoblocks With Simulated Curved Root Canals. *Curr Res Dent Sci* 2025;35(1): 25-31.

INTRODUCTION

Curved root canals are frequently encountered in clinical practice. It is well established that root canals curve in almost all directions and canals that appear radiographically straight contain curvatures and irregularities in the apical third.[1] The aforementioned curvatures may not be detected on periapical radiographs and frequently lead to incorrect shaping and difficulties in root canal obturation.[1] As the curvature angle in the root canal increases, root canal treatment becomes more difficult and the risk of complications increases. Some of these complications are loss of root canal working length, step formation in the root canal, apical zip and elbow formation in the root canal, root canal transportation, perforation in the root canal and instrument breakage.[2]

The various root canal morphologies of extracted human teeth complicate efforts to standardise relevant studies.[3] Transparent resin blocks with simulated root canals that can be produced with preset diameter, shape and curvature can be used for standardisation when comparing the effectiveness of filling techniques and shaping capabilities of nickel–titanium (Ni-Ti) rotary file systems.[4] Furthermore, resin blocks with simulated root canals are important for research on S-shaped canals, especially since it is almost impossible to obtain natural teeth containing S-shaped canals along with a sufficient number of standard features.[5,6]

One Curve (OC) and EdgeFile X3 (EF) file systems are made of heat-treated Ni–Ti alloy. The OC file system consists of a single file, whereas the EF is a complete line of rotary file systems.[7,8] The EF file system is manufactured using a proprietary heat treatment process called FireWire. This heat treatment method was reported to provide the files with greater flexibility, increased resistance to cyclic fatigue, and higher torque endurance compared to the conventional Ni–Ti files, as well as better canal tracking and centring ability.[8] The OC file system is manufactured using the C-Wire technology. C-Wire technology provides the file with greater blade flexibility and fracture resistance.[9]

The aims of this study about curved root canals are to determine which file system causes greater angular change, to determine which filling technique provides more effective filling and to show the effect of angular changes on filling success. Resin blocks containing root canals designed with different degrees of curvatures were used with the aim of comparing the duration of shaping with the EF and OC file systems and the resulting changes in curvature angles. The degree of improvement of the effectiveness of the cold lateral condensation (CLC) and single-cone (SC) techniques were also compared when used in appropriately-shaped root canals.

METHODS

This article does not contain any studies with human or animal participants. Therefore, ethics committee approval and informed consent were not required.

Design of Resin Blocks and Setting the Experimental Groups

In the present study, 108 transparent resin blocks were divided into three main groups (n = 36) based on their curvature angles. The curvature angles of the root canals in the blocks were set as follows: main group I had curvature angle of 5° and radius of curvature of 3.5 mm at a distance of 6 mm from the root apex; main group II had curvature angle of 20° and radius of curvature of 4.5 mm at a distance of 6 mm from the root apex; and main group III had curvature angle of 20° and radius of curvature of 4.5 mm at a distance of 6 mm and curvature angle of 30° and radius of curvature of 5 mm at a distance of 12 mm from the root apex. Subsequently, the resin blocks were produced with apical diameter of 0.15 mm and taper of 0.02 (ARG Medikal, Isparta, Türkiye). The blocks were divided into two sub-groups based on the angle of curvature and shaped with either the EF (Edge Endo, Albuquerque, United States of America) (n = 18) or the OC (Micro-Mega SA, Besançon, France) file system (n = 18). The above sub-groups were further subdivided into end groups for obturation with the CLC (n = 9) or SC filling techniques (n = 9).

Shaping Resin Blocks

All the blocks used in the study were shaped by the same researcher. During the shaping procedure, the blocks were covered with aluminium foil and held in place by a setup mechanism. For both file systems, the resin residues inside the grooves left during shaping were cleaned with gauze dampened with distilled water. Recapitulation was performed with a 0.02 tapered #10 Ni–Ti K-type file by turning a quarter turn counterclockwise at the working length after each use. The above-mentioned procedures were repeated until the coronal–apical working length was achieved. Four different root canals were shaped with each file. During root canal preparation, a chronometer was used to determine the duration of shaping for each block. In order to comply with clinical practice, the irrigation time, recapitulation, removal of resin residues on the rotary file and file replacement times were all included in the study duration.

Shaping the resin blocks in the EF groups: Files C1 (20/0.06) and C2 (25/0.06) were used with the X-Smart Plus (Dentsply, Maillefer, Ballaigues, Switzerland) endodontic motor at 350 rpm speed and 3 Ncm torque as recommended by the manufacturer, with movements in the apicocoronal direction at a working length of 1 mm from the apical foramen.

In the OC groups: The 25/0.06 OC files were used with the X-Smart Plus endodontic motor at 300 rpm speed and 2.5 Ncm torque as recommended by the manufacturer, with movements in the apicocoronal direction at a working length of 1 mm from the apical foramen.

Detection of Angular Changes in the Shaped Root Canal

The images of all the shaped resin blocks were recorded using a surgical microscope (Leica, Vienna, Austria) in a fixed position. The root canal curvature angle measurements were performed on the basis of the long-axis technique using the angle function in ImageJ 1.53c software (National Institutes of Health and the Laboratory for Optical and Computational Instrumentation [LOCI, University of Wisconsin], United States of America) (Figure 1). In this technique, a line is drawn parallel to the long axis of the tooth. Then, another line is drawn between the root apex and the point where the slope ends. The acute angle at the intersection of two lines gives the root canal curvature angle.[10] Measurements were made blindly by three independent observers. Accordingly, angles prior to shaping and angular changes after filing were calculated. The final result was determined by taking the average of the measurements.

Obturation of Root Canals

AH Plus Root Canal Sealer (CS; Dentsply, Konstanz, Germany) was used for both filling techniques. In the end groups filled with the SC and CLC techniques, the 0.06 taper #25 gutta-percha (GP) cones (PearlEndo, Ho Chi Minh, Vietnam) and 0.02 taper #25 main GP cones (PearlEndo, Ho Chi Minh, Vietnam) were used, respectively. The condensation procedure was applied using the #25 Ni–Ti finger spreader in the CLC technique. In the resultant cavity, GP cones (0.02 taper) covered with root CS and one size smaller than the spreader were emplaced.

Figure 1. Determination of angular change after shaping

Sectioning the Resin Blocks and Analysis of Sections

The resin blocks were kept in an oven with constant humidity and temperature for 7 days to allow the CS to harden sufficiently. The blocks were cut at 3-, 6-, and 12-mm intervals from the root apex using a precision cutting device (Brillant 220, QATM, Mammelzen, Germany), which was a 0.3 mm thick cutting disc rotating at 2500 rpm under water cooling. The coronal faces of the parts were examined using a stereo microscope (50× magnification) (Zeiss Stemi 508, Jena, Germany). The sectional images were analysed using ImageJ 1.53c software to determine the percentages of GP, CS and empty spaces in the root canal lumen. The area percentages were calculated using the pixel-counting method. First, the number of pixels in the entire root canal lumen was determined (Figure 2). Then, the number of pixels for GP, CS and empty spaces were determined, and their respective percentages were calculated (Figure 3). The measurements were made blindly by three different observers. The final result was the average of the measurements.

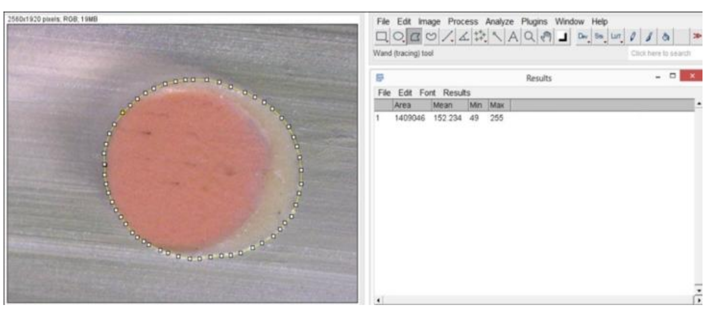

Figure 2. Determination of the number of pixels in the entire root canal lumen

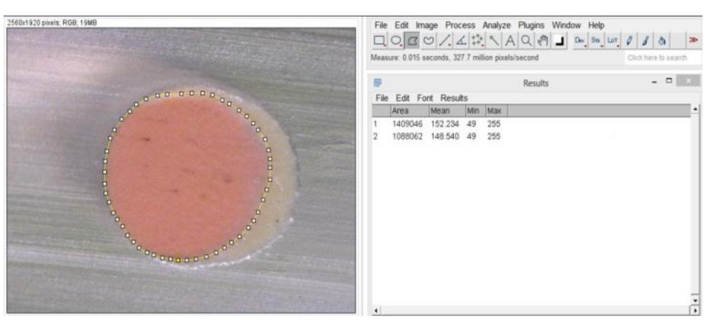

Figure 3. Determination of the number of pixels in the area filled with gutta-percha

Statistical Analysis

The Statistical Package for the Social Sciences Version 23 software (IBM SPSS Corp.; Armonk, NY, USA) was used for statistical analyses. Prior to statistical analyses, necessary controls were established to avoid data entry errors and to ensure that the parameters were within the expected ranges. The normal distribution hypothesis for continuous variables was tested using the Kolmogorov–Smirnov test, while variance homogeneity was tested using Levene's test. Mean and standard deviation values were used to present the descriptive statistics for continuous variables. The *t*-test and one-way analysis of variance were used to compare two groups and three or more groups, respectively, if the data met the normal distribution hypothesis, whereas the Mann–Whitney U test and Kruskal-Wallis test were used for comparing two groups and three or more groups, respectively, if the data did not have normal distribution. Pearson and Spearman (Spearman's Rho) correlation analyses were used to test the relationships between continuous variables. A *p* value of <.05 was considered statistically significant for all analyses.

RESULTS

In all three groups, shaping with the EF file system took significantly less time compared to shaping with the OC file system (Table 1).

Following the shaping procedure, there was an angular decrease in the curvature of all blocks. In terms of the angle of curvature of the blocks in main group III at a distance of 12 mm from the root apex, those shaped with the OC file system had statistically significantly higher angular change than those shaped with the EF file system (*P* <.05) (Table 2).

Table 1. Descriptive statistics about the duration of root canal shaping procedures

	EdgeFile X3			One Curve			*P*
	n	**Mean±SD**	**Min-Max**	**n**	**Mean±SD**	**Min-Max**	
Main Group I	18	171.94±7.19	162-189	18	196.67±19.89	164-225	***<.05****
Main Group II	18	172.17±8.87	159-190	18	197.22±15.45	172-221	***<.05****
Main Group III	18	278.89±16.26	252-306	18	295.78±9.02	280-311	***<.05****
All Blocks	54	207.67±52.07	159-306	54	229.89±49.41	164-311	

*****: Statistically significant *p* values
n, number of blocks in each group; SD, standard deviation; Min, minimum; Max, maximum

Table 2. Angular changes at curvature points after shaping

		EdgeFile X3			One Curve			*P*
		n	**Mean±SD**	**Min-Max**	**n**	**Mean±SD**	**Min-Max**	
Main Group I	**6 mm**	18	0.66±0.5	0.0-1.78	18	0.71±0.45	0.0-1.60	*>.05*
Main Group II	**6 mm**	18	1.37±0.54	0.7-2.35	18	1.41±0.50	0.80-2.40	*>.05*
Main Group III	**6 mm**	18	1.43±0.63	0.38-2.40	18	1.82±0.76	0.6-2.83	*>.05*
	12 mm	18	4.03±0.87	3.15-5.73	18	4.89±1.31	3.10-7.15	***<.05****

*: Statistically significant *p* values
n, number of blocks in each group; SD, standard deviation; Min, minimum; Max, maximum

Based on the comparison for only the filling technique used, regardless of the shaping system, there were statistically significantly higher GP rates and lower CS rates for the SC technique than for the CLC technique in all sections, except those taken 3 mm from the root apex in the blocks from main group I (Table 3).

Table 3. Comparison of filling techniques used, regardless of the file system, in terms of canal filling material ratios in sections taken at 3 mm, 6 mm and 12 mm distances from the root apex

			Cold Lateral Condensation			Single-Cone			P
			Mean±SD	Min	Max	Mean±SD	Min	Max	
Main Group I	3 mm	GP	75.98±6.34	69.20	91.33	76.43±4.79	67.21	84.18	>.05
		CS	21.90±6.81	8.67	29.82	21.86±4.43	15.45	29.61	>.05
		Emp	2.12±2.95	0.00	12.99	1.71±1.13	0.00	3.20	>.05
	6 mm	GP	50.22±9.13	37.73	69.27	76.79±6.35	66.59	88.18	<.05*
		CS	47.35±9.21	28.31	60.67	21.24±6.23	10.72	33.41	<.05*
		Emp	2.44±1.19	0.00	4.22	1.97±1.66	0.00	4.56	>.05
	12 mm	GP	75.53±5.91	67.20	86.07	80.54±3.74	72.70	87.91	<.05*
		CS	24.42±6.45	8.45	30.77	17.63±3.43	11.07	24.68	<.05*
		Emp	2.06±1.33	0.00	5.48	1.83±1.54	0.00	4.30	>.05
Main Group II	3 mm	GP	72.90±7.52	64.73	97.92	77.72±4.86	69.25	87.93	<.05*
		CS	25.08±7.16	1.34	33.93	19.82±4.75	9.84	28.65	<.05*
		Emp	2.02±0.70	0.74	3.12	2.46±3.01	0.00	12.70	>.05
	6 mm	GP	50.78±12.91	36.20	81.84	76.45±6.69	67.94	89.12	<.05*
		CS	46.15±12.07	17.12	61.40	21.50±6.38	8.84	30.72	<.05*
		Emp	3.06±1.64	1.04	6.20	2.06±1.15	0.00	4.12	>.05
	12 mm	GP	73.52±5.79	64.18	86.07	79.92±5.07	69.24	87.16	<.05*
		CS	24.33±5.69	8.45	31.47	18.26±4.30	11.58	28.35	<.05*
		Emp	2.15±1.64	0.00	5.62	1.83±1.59	0.00	4.75	>.05
Main Group III	3 mm	GP	57.52±6.12	45.42	68.54	64.20±7.04	50.18	78.28	<.05*
		CS	37.27±6.20	20.33	49.70	31.75±7.87	11.25	46.02	<.05*
		Emp	5.22±4.58	0.00	18.26	4.05±3.41	0.00	14.08	>.05
	6 mm	GP	50.33±4.43	42.05	56.47	64.40±5.11	56.72	75.40	<.05*
		CS	45.04±6.82	24.87	55.64	31.40±5.50	21.65	40.95	<.05*
		Emp	4.63±4.23	1.25	18.73	4.20±3.93	0.94	15.95	>.05
	12 mm	GP	64.46±6.15	57.15	83.12	70.63±6.90	53.83	82.26	<.05*
		CS	31.29±6.10	16.88	38.55	26.74±6.30	17.74	44.55	<.05*
		Emp	4.25±4.26	0.00	17.75	2.63±1.52	0.00	4.63	>.05

*: Statistically significant *p* values
SD, standard deviation; Min, minimum; Max, maximum; GP, gutta-percha; CS, canal sealer; Emp, empty

In the comparison based on both shaping system and filling technique combined, the mean GP ratios were significantly higher and mean CS ratios were significantly lower in the combinations using the SC technique compared to combinations using the CLC technique for block sections at a distance of 6 mm and 12 mm from the root apex in main groups I and II and for block sections at a distance of 6 mm from the root apex in main group III (Table 4).

The correlation analyses, which sought to investigate the relationship between the angular change in curvature at 6 mm distance from the root apex and the filling ratios of the section at the same level, revealed a statistically significant, positive and moderate correlation between the change in curvature angle and the ratio of empty spaces in the blocks in main group II filled using the CLC technique. For both filling techniques, there was a statistically significant, negative and very high correlation between the angular change in curvature and the GP ratios in blocks from the main group III; however, there was a statistically significant, positive and high correlation between the angular change in curvature and CS rates (Table 5).

There was a statistically significant, positive and moderate correlation between the angular change in curvature 12 mm from the root apex and CS in main group III blocks filled using the CLC technique. There was a statistically significant, negative, and high correlation between the angular changes in curvature at the same level in the blocks included in the same group and filled using the SC technique and the GP ratio; however, there was a statistically significant, positive and high correlation between the angular change in curvature and CS (Table 6).

Table 4. Comparison of file system and filling technique combinations in terms of canal filling material ratios in sections taken at 3 mm, 6 mm and 12 mm distances from the root apex

			Mean±SD				P
			EF+CLC	EF+SC	OC+CLC	OC+SC	
Main Group I	3 mm	GP	75.53±6.82	76.75±4.03	76.44±6.20	76.11±5.67	>.05
		CS	22.00±7.65	21.46±4.13	21.80±6.34	22.26±4.94	>.05
		Emp	2.47±4.08	1.78±1.17	1.77±1.24	1.64±1.15	>.05
	6 mm	GP	49.87±8.60	77.11±6.96	50.57±10.13	76.47±6.07	<.05*
		CS	47.67±8.65	20.93±7.61	47.02±10.25	21.55±4.93	<.05*
		Emp	2.47±1.24	1.96±1.66	2.41±1.22	1.98±1.76	>.05
	12 mm	GP	73.04±6.37	81.10±3.96	74.00±5.76	79.98±3.65	<.05*
		CS	24.93±7.20	17.08±3.64	23.90±6.01	18.18±3.34	<.05*
		Emp	2.02±1.65	1.81±1.59	2.10±1.01	1.84±1.59	>.05
Main Group II	3 mm	GP	73.39±9.82	77.57±6.15	72.42±4.84	77.87±3.51	>.05
		CS	24.71±9.43	19.75±6.02	25.44±4.42	19.90±3.42	>.05
		Emp	1.90±0.65	2.68±3.94	2.14±0.77	2.23±1.90	>.05
	6 mm	GP	51.14±12.87	77.21±7.18	50.43±13.72	75.69±6.49	<.05*
		CS	45.84±11.97	20.80±7.27	46.46±12.89	22.21±5.71	<.05*
		Emp	3.01±1.83	2.01±1.12	3.11±1.55	2.10±1.23	>.05
	12 mm	GP	73.50±5.37	80.01±4.08	73.54±6.52	79.82±6.17	<.05*
		CS	24.35±6.36	18.17±3.79	24.32±5.32	18.34±5.01	<.05*
		Emp	2.15±1.67	1.82±1.70	2.14±1.71	1.84±1.58	>.05
Main Group III	3 mm	GP	57.54±7.54	64.87±8.20	57.50±4.75	63.54±6.08	<.05
		CS	37.23±8.04	31.06±9.79	37.31±4.15	32.43±5.90	>.05
		Emp	5.23±5.97	4.07±4.04	5.20±2.99	4.03±2.90	>.05
	6 mm	GP	51.19±5.05	64.03±5.09	49.47±4.94	64.77±5.40	<.05*
		CS	44.07±8.50	31.83±5.99	46.01±4.94	30.97±5.30	<.05*
		Emp	4.74±5.33	4.13±4.63	4.52±3.09	4.26±3.37	>.05
	12 mm	GP	64.40±4.84	70.40±7.13	64.51±7.55	70.85±7.09	>.05
		CS	31.44±4.68	26.96±7.01	31.14±7.56	26.53±5.93	>.05
		Emp	4.15±3.30	2.64±1.71	4.35±5.26	2.62±1.40	>.05

*: Statistically significant *p* values
SD, standard deviation; Min, minimum; Max, maximum; GP, gutta-percha; CS, canal sealer; Emp, empty; EF, EdgeFile X3; OC, One Curve; CLC, cold lateral condensation; SC, single-cone

Table 5. Relationship between the change in curvature angle during shaping and the gutta-percha, canal sealer and empty spaces ratios in the sections taken at a distance of 6 mm from the root apex

				Filling Technique	
				Cold Lateral Condensation	Single-Cone
Sections taken from 6 mm distance from root apex	Main Group I	GP	R	0.032	-0.040
			P	>.05	>.05
		CS	R	0.005	-0.007
			P	>.05	>.05
		Emp	R	-0.279	0.179
			P	>.05	>.05
	Main Group II	GP	R	-0.441	0.029
			P	>.05	>.05
		CS	R	0.406	-0.005
			P	>.05	>.05
		Emp	R	0.482	-0.143
			P	<.05*	>.05
	Main Group III	GP	R	-0.852	-0.812
			P	<.05*	<.05*
		CS	R	0.625	0.671
			P	<.05*	<.05*
		Emp	R	-0.115	0.116
			P	>.05	>.05

*: Statistically significant *p* values
GP, gutta-percha; CS, canal sealer; Emp, empty

Table 6. Relationship between the change in curvature angle during shaping and the gutta-percha, canal sealer and empty spaces ratios in a section taken at a distance of 12 mm from the root apex in main group III blocks

			Filling Technique	
			Cold Lateral Condensation	Single-Cone
Sections taken from 12 mm distance from root apex	GP	R	-0.445	-0.696
		P	>.05	<.05*
	CS	R	0.504	0.684
		P	<.05*	<.05*
	Emp	R	-0.079	0.327
		P	>.05	>.05

*: Statistically significant *p* values
GP, gutta-percha; CS, canal sealer; Emp, empty

DISCUSSION

The duration of the root canal shaping procedure is determined by the root canal shaping technique used, the number of files used, and the operator's experience. Certain factors, including the operator's experience and technique, complicate standardisation efforts. Therefore, even in studies using the same file systems, extremely different results may be obtained.[3,5] The results of the present study suggest that the shaping procedure with the EF file system takes a statistically significantly shorter time than the OC file system for all three main groups. In both file systems, the S-shaped root canals in main group III took a significantly longer time to be shaped. Despite double files being used in the EF file system, the file system's production characteristics and cross-sectional design, as well as speed and torque values recommended by the manufacturer, may have accounted for the completion of the shaping procedure in a comparatively shorter period of time. According to a study, the EF file system was more flexible and more resistant to cyclic fatigue compared to the OC file system.[11] The above-mentioned flexibility might have contributed to shortening the shaping procedure duration in curved root canals. Furthermore, starting the shaping procedure with a smaller-sized C1 file may have facilitated the movement of canal tools in curved canals, resulting in a faster shaping procedure with the EF file system, which includes the C1 and C2 files. Furthermore, the manufacturer-recommended speed and torque values were higher for the EF file system. The high speed and torque might have accelerated the shaping procedure. Because the OC file system recommends a lower maximum torque value, the likelihood of more frequent bounce backs in the root canal, especially at the curvature points, may have prolonged the procedure.

Based on a comprehensive literature review, there is no study that examined the OC and EF file systems in combination, the angular change in the root canals after shaping; and the associated transportation. The results of studies that compared different file systems could have been affected by certain factors, including the file system, the use of tooth or resin block, and the degree of curvature of the root canal. The angular changes in the present study favoured root canal straightening. In the present study, the OC file system produced significantly greater angular changes in the curvature 12 mm from the root apex of the S-shaped, double-curved blocks in main group III during the shaping procedure than the EF file system. A previous study suggested that the EF file system was more flexible compared to the OC file system, which may account for less angular change in EF cases. The file's flexibility enabled it to more successfully adapt to curvature points.[11] The respective manufacturers report that the OC file system has triangular cross-sections at the tip and S-shaped cross-sections on the body, while the EF file system has a parabolic cross-section design. It was further claimed that the variable cross-sectional structure, which is unique to the OC file system, also preserved the original anatomy of the root canal and provided a centring ability in the apical third. Moreover, the variable cross-sectional structure provided higher cutting efficiency in the middle and coronal thirds.[5] The differences in production technology and design between the two file systems might explain why the OC file system induced a higher rate of angular change than the EF system. Previous studies on different file systems reported that metallurgical properties and production techniques were effective on transportation.[12,13] Furthermore, higher straightening of the coronal curvature caused by the OC file system in main group III, where there was a significant difference in angular change, could be because of higher cutting efficiency in the middle and coronal thirds due to the variable cross-sectional structure.[5] It is well established that increased cutting efficiency of the files paves the way for transportation.[14] The difference in angular change could also be explained by the fact that the shaping procedure was performed with a single file in the OC file system and with two files in the EF file system. According to relevant studies that tested different file systems, the use of less conical and more flexible files in multi-file systems reduced the amount of transportation.[13,15] Because of the lack of a pre-widening step, the grooves on single-file systems could become clogged more easily, resulting in more torque and pressure on the file. This would increase canal transportation.[16]

The mean angular change in main group III was greater than in main group II, and the mean angular change in main group II was greater than in main group I. Accordingly, increased angular change may be associated with increased difficulty of root canal anatomy. A previous study supports the above conclusion.[12] The coronal curvature of the blocks in main group III showed the highest mean angular change. The blocks in main group III with the highest curvature angle in the study may have caused this. Furthermore, similar to the results of the present study, previous studies using different file systems reported that transportation occurred more frequently in the coronal section.[5,6] It was suggested that the cause of this could be the tapering of Ni–Ti systems.[5] We believe that the same reason leads to higher rates of coronal transportation.

Root canal filling is affected by the degree of root canal curvature.[17] To ensure standardisation and to avoid the likelihood of angled GP cones specifically produced for the EF and OC file systems interfering with the comparison of filling techniques in blocks filed with different file systems, 0.06 taper #25 GP cones were used instead of angled SC GPs. This has been the preferred method in a number of studies.[17,18] The percentage of GP in root canal cross-sections is a frequently used method for investigating the success of obturation.[19-21] While GPs are stable in size, they may shrink and dissolve as the sealant hardens, and thus their sizes may change over time.[22,23] Higher GP and lower CS rates should be targeted to ensure successful outcomes from the root canal obturation procedure.[18,20,21] It is well established that filling the root canals without gaps is associated with higher rate of success in root canal treatment.[24]

Alim et al.[17] reported that the most successful technique for 2 and 5 mm distances was CLC in their study, in which they filled the mandibular first molars with a root canal curvature degree of >25° using CLC, SC, continuous-wave obturation and core carrier techniques. They investigated the filling success using micro-computed tomography on sections at 2, 5 and 8 mm distances. Furthermore, the SC technique had the lowest GP percentage of all the filling techniques in that study. The coronal part of all teeth included in the study had the most successful filling, while the apical part had the least successful. A number of factors might have caused the discrepancy with the present study's findings. The main differences in the study by Alim et al.[17] were the use of extracted teeth, the fact that the curvature points and angles in those teeth were not constant, the shaping size was not the same between the groups, the CS ratio was not included in the assessment, and the use of micro-computed tomography. Schafer et al.[19] used SC, CLC and warm vertical condensation techniques to fill extracted teeth with root canal curvatures ranging from 25° to 35°. They took sections at 2, 3, 4, 6 and 8 mm distances from the root apex and investigated the GP, CS and empty space ratios under a stereo microscope. Accordingly, similar to our study, there was no significant difference between the techniques in terms of empty space ratio. Simultaneously, teeth filled with the SC technique had a higher rate of CS and a lower rate of GP than other techniques at all levels.[19] The extracted teeth in the above-mentioned study were similar to those of Alim et al.[19] and no information about the location of the curvature points was provided. We believe that such differences might have affected the results of the study. Romania et al.[25] used the CLC and SC techniques to fill mandibular premolar teeth with straight canals and examined the sections under a stereo microscope. They found that GP and CS percentages were similar. Tasdemir et al.[26] filled mandibular premolar teeth using SC and CLC techniques and reported a significantly higher rate of GP with the SC filling technique, which is similar to our study. Gordon et al.[27] filled resin blocks with curvature angles of 30° and 58° and the mesiobuccal canals of maxillary first molars with curvature angles of 25.6° ± 19.7° using the SC and CLC techniques and investigated sections taken at certain distances from the apical foramen for GP, CS and empty space ratios under a stereo microscope. Accordingly, the SC technique had higher area covered with GP in the apical part of resin blocks compared to the CLC technique. In the same study, there was no difference between the methods in terms of the curved mesiobuccal canals of the maxillary first molars.[27] This study suggests that the success of filling techniques may differ between extracted teeth and standard resin blocks. We believe that the differences in results between the present study and other studies of extracted teeth are because of the variable root canal anatomy of extracted teeth. A different study found that anatomical variations and oval or round shape of the canals might affect the success of the filling technique.[20] The canal must be circularly enlarged with a sufficient taper for GP to fit into the root canals when using the SC technique, which uses GPs compatible with rotary Ni–Ti canal instruments. This method will be more effective for the mesial and distal roots of the upper molars, as well as the mesial roots of the lower molars. A number of studies reported that the SC technique was more suitable for round-shaped canals.[24,27,28] In contrast, it was suggested that the GP cone was not suitable for root canals with oval and large diameters because of the inability to adapt to the root canal.[27] We believe that the higher GP rates with the SC technique compared to the CLC technique in the present study were because of the use of resin blocks with round root canals.

GP ratios in S-shaped canals in main group III were lower in both techniques when compared to the other main groups. The correlation between the angular change in the curvature of the blocks in main group III and the GP and CS ratios in the sections taken from the curvature points was also remarkable. The curvature points of the root canal are sections taken at 6 mm and 12 mm distances from the root apex, and at these points, the root canal loses its rounded structure owing to transportation and becomes oval, and the curvature angle changes in favour of straightening. As reported in other studies, this causes the GP used in the SC technique to be unable to effectively fill the root canal at those distances, increasing the percentages of empty space and CS.[17,27] In the CLC technique, this may be due to the spreader used to attach the auxiliary cones not being able to be placed within 1–2 mm of the apical working length.[29] Furthermore, even if the spreader is placed at the desired distance, there may be areas without GP owing to the inability to place the auxiliary cones in the space created by the spreader.[4] Previous studies reported that when using the CLC method, spreaders and endodontic pluggers might not reach all the way apical in excessively-curved root canals and may become stuck at the beginning of the curvature.[4,17] Moreover, a different study suggested that transportation negatively affected the success and impermeability of root canal filling.[30] We believe that the difficult anatomy of the S-shaped canals in main group III resulted in lower GP ratios with both techniques, especially at the curvature points, as a result of the mechanisms discussed above.

The most important limitation of our study is the use of resin blocks instead of extracted teeth. Other limitations are that only sectioned areas were evaluated and no radiological examination was performed. Extracted teeth with the same curvature angle are difficult to obtain. Similarly, it is almost impossible to obtain bi-curved teeth with a standard angle of curvature. This challenge was overcome by using resin blocks. This is the most important factor supporting the strength of our study. These results obtained with resin blocks should be supported by further studies on extracted teeth.

In conclusion, when compared to the OC, the shaping procedure with EF took significantly less time. In double-curved S-shaped canals, the sub-group shaped with OC had significantly more straightening at the angle of curvature in the coronal curvature compared to the sub-group shaped with EF. It was concluded that the main determinant of higher GP ratios was the filling technique used and that the SC filling technique was more successful. It was observed that as the extent of straightening upon shaping increased in main group III, so did the extent of CS in the sections corresponding to the curvature point.

Etik Komite Onayı: Bu makale, insan veya hayvan katılımcılar ile yapılan herhangi bir araştırma içermemektedir.
Hasta Onamı: Bu makale, insan katılımcılar ile yapılan herhangi bir araştırma içermemektedir.
Hakem Değerlendirmesi: Dış bağımsız.
Yazar Katkıları: Fikir – DKA, MM; Tasarım- DKA, MM; Denetim- DKA, MM; Kaynaklar - DKA, MM; Malzemeler - DKA, MM; Veri Toplama ve/veya İşleme - DKA, MM; Analiz ve/veya Yorum - DKA, MM; Literatür Taraması - DKA, MM; Yazma - DKA, MM; Eleştirel İnceleme - DKA, MM.
Çıkar Çatışması: Yazarlar, çıkar çatışması olmadığını beyan etmiştir.
Finansal Destek: Yazarlar bu çalışmanın herhangi bir finansal destek almadığını beyan etmişlerdir.

Ethics Committee Approval: This article does not contain any studies with human or animal participants.
Informed Consent:: This article does not contain any studies with human participants.
Peer-review: Externally peer-reviewed
Author Contributions: Concept – DKA, MM; Design- DKA, MM; Supervision - DKA, MM; Resources - DKA, MM; Materials - DKA, MM; Data Collection and/or Processing - DKA, MM; Analysis and/or Interpretation - DKA, MM; Literature Search - DKA, MM; Writing Manuscript - DKA, MM; Critical Review - DKA, MM.
Conflict of Interest: The authors have no conflicts of interest to declare.
Financial Disclosure: The authors declared that this study received no financial support.

REFERENCES

1. Sakkir N, Thaha KA, Nair MG, Joseph S, Christalin R. Management of Dilacerated and S-shaped Root Canals - An Endodontist's Challenge. *J Clin Diagn Res.* 2014;8:22-24.
2. Alaçam T. Kök kanallarının mekanik preperasyonu. In: Alaçam T ed. *Endodonti. 1st Ed.*, Ankara: Özyurt Matbaacılık;2012:405-514.
3. Hülsmann M, Peters OA, Dummer PMH. Mechanical preparation of root canals: shaping goals, techniques and means. *Endod Top.* 2005;10:30-76.

4. Aminsobhani M, Ghorbanzadeh A, Sharifian MR, Namjou S, Kharazifard MJ. Comparison of Obturation Quality in Modified Continuous Wave Compaction, Continuous Wave Compaction, Lateral Compaction and Warm Vertical Compaction Techniques. *J Dent (Tehran).* 2015;12:99-108.
5. Saleh AM, Gilani PV, Tavanafar S, Schafer E. Shaping ability of 4 different single-file systems in simulated S-shaped canals. *J Endod.* 2015;41:548–552.
6. Topçuoğlu HS, Topçuoğlu G, Akti A, Düzgün S. In Vitro Comparison of Cyclic Fatigue Resistance of ProTaper Next, HyFlex CM, OneShape, and ProTaper Universal Instruments in a Canal with a Double Curvature. *J Endod.* 2016;42:969-971.
7. Jamleh A, Alfadley A, Alghofaili N, Jamleh H, Al Fouzan K. Analysis of Force and Torque with XP Shaper and OneCurve Systems During Shaping of Narrow Canals. *Eur Endod J.* 2020;5:123-127.
8. Versiani MA, Carvalho KKT, Mazzi-Chaves JF, Sousa-Neto MD. Micro-computed Tomographic Evaluation of the Shaping Ability of XP-endo Shaper, iRaCe, and EdgeFile Systems in Long Oval-shaped Canals. *J Endod.* 2018;44:489-495.
9. Khalil WA. Effect of heat treatment on cyclic fatigue, flexibility and phase transformation of two controlled memory niti rotary instruments. *Egypt Dent J.* 2019;65:1463-1468.
10. Hankins PJ, ElDeeb ME. An evaluation of the Canal Master, balanced force, and step-back techniques. *J Endod* 1996;22:123-130.
11. Staffoli S, Grande NM, Plotino G, et al. Influence of environmental temperature, heat-treatment and design on the cyclic fatigue resistance of three generations of a single-file nickel-titanium rotary instrument. *Odontology.* 2019;107:301-307.
12. Zhao D, Shen Y, Peng B, Haapasalo M. Micro-computed tomography evaluation of the preparation of mesiobuccal root canals in maxillary first molars with Hyflex CM, Twisted Files, and K3 instruments. *J Endod.* 2013;39:385-388.
13. Gergi R, Osta N, Bourbouze G, Zgheib C, Arbab-Chirani R, Naaman A. Effects of three nickel titanium instrument systems on root canal geometry assessed by micro-computed tomography. *Int Endod J.* 2015;48:162-170.
14. Lam TV, Lewis DJ, Atkins DR, et al. Changes in root canal morphology in simulated curved canals over-instrumented with a variety of stainless steel and nickel titanium files. *Aust Dent J.* 1999;44:12–19.
15. Gergi R, Rjeily JA, Sader J, Naaman A. Comparison of canal transportation and centering ability of twisted files, Pathfile-ProTaper system, and stainless steel hand K-files by using computed tomography. *J Endod.* 2010;36:904–907.
16. Pak JG, White SN. Pain prevalence and severity before, during and after root canal treatment: a systematic review. *J Endod.* 2011;37:427–438.
17. Alim BA, Garip Berker Y. Evaluation of different root canal filling techniques in severely curved canals by micro-computed tomography. *Saudi Dent J.* 2020;32:200-205.
18. Obeidat RS, Abdallah H. Radiographic evaluation of the quality of root canal obturation of single-matched cone Gutta-percha root canal filling versus hot lateral technique. *Saudi Endod J.* 2014;4:58.
19. Schäfer E, Nelius B, Bürklein S. A comparative evaluation of gutta-percha filled areas in curved root canals obturated with different techniques. *Clin Oral Investig.* 2012;16:225-230.
20. Jarrett IS, Marx D, Covey D, Karmazin M, Lavin M, Gound T. Percentage of canals filled in apical cross sections—an in vitro study of seven obturated techniques. *Int Endod J.* 2004;37:392–398.
21. Yilmaz A, Karagoz-Kucukay I. In vitro comparison of gutta-percha-filled area percentages in root canals instrumented and obturated with different techniques. *J Istanb Univ Fac Dent.* 2017;51:37-42.
22. Wu MK, Özok AR, Wesselink PR. Sealer distribution in root canals obturated by three techniques. *Int Endod J.* 2000;33:340–345.
23. Schäfer E, Zandbiglari T. Solubility of root canal sealers in water and artificial saliva. *Int Endod J.* 2003;36:660–669.
24. Motamedi MRK, Mortaheb A, Zare Jahromi M, Gilbert BE. Micro-CT Evaluation of Four Root Canal Obturation Techniques. *Scanning.* 2021;2021:6632822.
25. Romania C, Beltes P, Boutsioukis C, Dandakis C. Ex-vivo area-metric analysis of root canal obturation using gutta-percha cones of different taper. *Int Endod J.* 2009;42:491–498.
26. Tasdemir T, Yesilyurt C, Ceyhanli KT, Celik D, Er K. Evaluation of apical filling after root canal filling by 2 different techniques. *J Can Dent Assoc.* 2009;75:201.
27. Gordon MPJ, Love RM, Chandler NP. An Evaluation of .06 Tapered Gutta Percha Cones for Filling of .06 Taper Prepared Curved Rooot Canals. *Int Endod J.* 2005;38:87-96.
28. Somma F, Cretella G, Carotenuto M, et al. Quality of thermoplasticized and single point root fillings assessed by micro-computed tomography. *Int Endod J.* 2011;44:362-369.
29. Bal AS, Hicks ML, Barnett F. Comparison of laterally condensed .06 and .02 tapered gutta-perchaand sealer in vitro. *J Endod.* 2001;27:786–788.
30. Wu MK, Fan B, Wessellink PR. Leakage along Apical Root Fillings in Curved Root Canals. *J Endod.* 2000;26:210-216.