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Comparison of cyclic fatigue resistance of four pediatric rotary file systems at body temperature: an in vitro study

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Abstract

Background The aim of this study was to compare the cyclic fatigue resistance (CFR) of the newly developed pediatric nickel-titanium (NiTi) rotary file systems for root canal preparation of primary teeth.

Methods Eighty pediatric NiTi rotary file systems files were used in this study, including 20 EasyInSmile X-Baby (25/0.04), 20 Scope miniScope (25/0.04), 20 EndoArt Pedo Gold (25/0.04), and 20 EndoArt Pedo Blue (25/0.04) files. Static CFR tests; performed on a custom-made stainless steel block with an inner diameter of 1.5 mm, an angle of curvature of 60° and a curved artificial canal with a radius of curvature of 5 mm. The test system was filled with distilled water and the temperature was kept constant at 35 ± 1 °C. The files were rotated in the simulated canal until fracture occurred. The number of cycles to failure (NCF) data was recorded, and all the fracture surfaces of the files were evaluated using scanning electron microscopy (SEM). One-way ANOVA and Tukey tests were used for statistical analysis of the data, and the significance level was set at $p < 0.05$.

Results EndoArt Pedo Blue showed the highest NCF values (2668.10 ± 755.26), while the miniScope showed the lowest NCF values (453.65 ± 72.51), with a statistically significant difference between all the tested file systems ($p < 0.05$). There was no statistical difference in terms of fractured fragment lengths among all tested files ($p > 0.05$).

Conclusion The EndoArt Pedo Blue file system showed the best CFR performance among the four file systems specifically designed for primary teeth.

Keywords Cyclic fatigue resistance, Pediatric rotary systems, NiTi files

Background

Dental caries remains a prevalent chronic disease in childhood. Since the enamel and dentin tissues are thinner and the pulp cavity is wider, caries affects the pulp tissue more quickly in primary teeth than in permanent teeth [1]. One of the most critical responsibilities of pediatric dentistry is to maintain the health and function of primary teeth until the time of exfoliation [2]. Malocclusion, aesthetic, phonation and functional problems may occur with the early loss of primary teeth [3, 4].

Pulpectomy is performed to remove necrotic residues, debris, and microorganisms from the root canal system

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of teeth exhibiting evidence of irreversible pulpitis or pulp necrosis, allowing primary teeth to function for a longer period of time [5]. Following the completion of biomechanical preparation and disinfection procedures for the root canal system, the canal is uniformly shaped and filled with a biocompatible filling material [6]. Due to the complex anatomy, curved canal course, dynamic changes observed in the apical region, proximity of the permanent tooth germ, and behavioral management difficulties, pulpectomy in primary teeth is regarded as a challenging procedure [7]. Hand files are traditionally used for the biomechanical preparation of primary teeth, but this method is time-consuming and can result in iatrogenic errors such as lateral perforations, canal transportation, and zipping [8].

Nickel-Titanium (NiTi) rotary files have become routine due to their high flexibility and good cutting efficiency [9]. NiTi rotary files have been reported to provide a smooth surface, conical canal shape and minimal risk of canal transportation [10, 11]. Barr et al. first used NiTi rotary files in pediatric endodontics in 2000 to minimize working time, improve patient cooperation, and reduce application errors [12]. Until 2006, root canal treatment (RCT) in the primary dentition was performed using specifically designed rotary instruments for permanent teeth. Due to the differences in morphology between primary and permanent teeth, pediatric rotary file systems specially developed for primary teeth are available for use [13].

Although the performance of NiTi endodontic files has improved over time, fracture due to cyclic fatigue or torsional failure during use remains a problem [14]. Continuous bending of the files in inclined canals causes deformation and tension within the files, leading to cyclic fatigue fracture [15]. Although there are numerous studies evaluating the cyclic fatigue resistance (CFR) of files produced for permanent teeth, there is a limited study evaluating the CFR of files specially designed for primary teeth. The aim of this study was to evaluate the CFR of EasyInSmile X-Baby (EasyInSmile International Corp., Changsha, China), Scope miniScope (Gtech Dizayn Dental Medikal, Yozgat, Turkiye), EndoArt Pedo Gold (İnci Dental, Istanbul, Turkiye) and EndoArt Pedo Blue (İnci Dental, Istanbul, Turkiye) pediatric rotary-systems with similar taper and apical diameter in simulated 60° curved canals.

Materials and methods

Power analysis was calculated with G*Power version 3.1.5.1 software (Universitat Kiel, Kiel, Germany). It was found that the total sample size of 80 files provided more than 80% power (actual power = 0.8453) to detect significant differences, with an effect size of 0.40 at the significance level of $\alpha = 0.05$.

80 pediatric rotary NiTi files were used in this study, including 20 EasyInSmile X-Baby (25/0.04), 20 Scope miniScope (25/0.04), 20 EndoArt Pedo Gold (25/0.04), and 20 EndoArt Pedo Blue (25/0.04) rotary files. All instruments tested have a constant 0.04 taper. Before being employed in the test files, each file was checked using a stereomicroscope (Zumax OMS2380, Suzhou, China) under x10 magnification to examine for deformation and fabrication defects.

The study involved conducting a static test model for cyclic fatigue investigations on a custom-made stainless steel block that had specific dimensions, including an inner diameter of 1.5 mm, a 60° angle of curvature, and a 5 mm radius of curvature. Using a holder arm to stabilize the system, the files were operated at the manufacturer's recommended speed (350 rpm and a torque of 2.6 N/cm) with a torque-controlled electric motor handpiece (X-Smart Plus; Dentsply Sirona, Ballaigues, Switzerland). It was reported that the lengths of primary and secondary molars varied between 14.5 and 17.3 mm [16]. Therefore, the working length was determined to be 16 mm in all file groups. To simulate the temperature in the canal, a heating system was prepared, which is filled with distilled water and can keep the experimental setup at a temperature of 35 ± 1 °C. The front of the stainless steel block was covered with glass to keep the files from coming out of the artificial canals and to observe the moment the files were broken.

Files rotated inside the artificial canal until a fracture developed. A quartz timer capable of measuring with a 1/100 of a second (TS-1809, Taksun, China) was used to record the length of time till breakage for each file. The video was recorded simultaneously to eliminate human error, and the recordings were watched to double-check when the files were separated. The determination of the number of cycles to failure (NCF) for each file was achieved through the multiplication of the time to fracture by the number of rotations per minute (rpm). The length of each fragment was also evaluated by means of an electronic digital caliper. A scanning electron microscope (SEM) (Zeiss LEO 1430 SEM, Oberkochen, Germany) was used to inspect the fractured fragments and identify the different forms of fracture. Two of the broken files from each system were analyzed with an SEM, and various magnifications of photomicrographs of the fractured areas were taken. Flow chart summarizing the experimental groups were presented in Fig. 1.

Statistical analysis of the data obtained in the study was performed using the SPSS 24 (IBM, Chicago, IL, USA) package program. The Shapiro-Wilk test and the Levene test were employed to assess the data's normality and homogeneity of variance, respectively. Statistical analysis of the normally distributed NCFs of the files was performed by one-way ANOVA due to the presence of 3

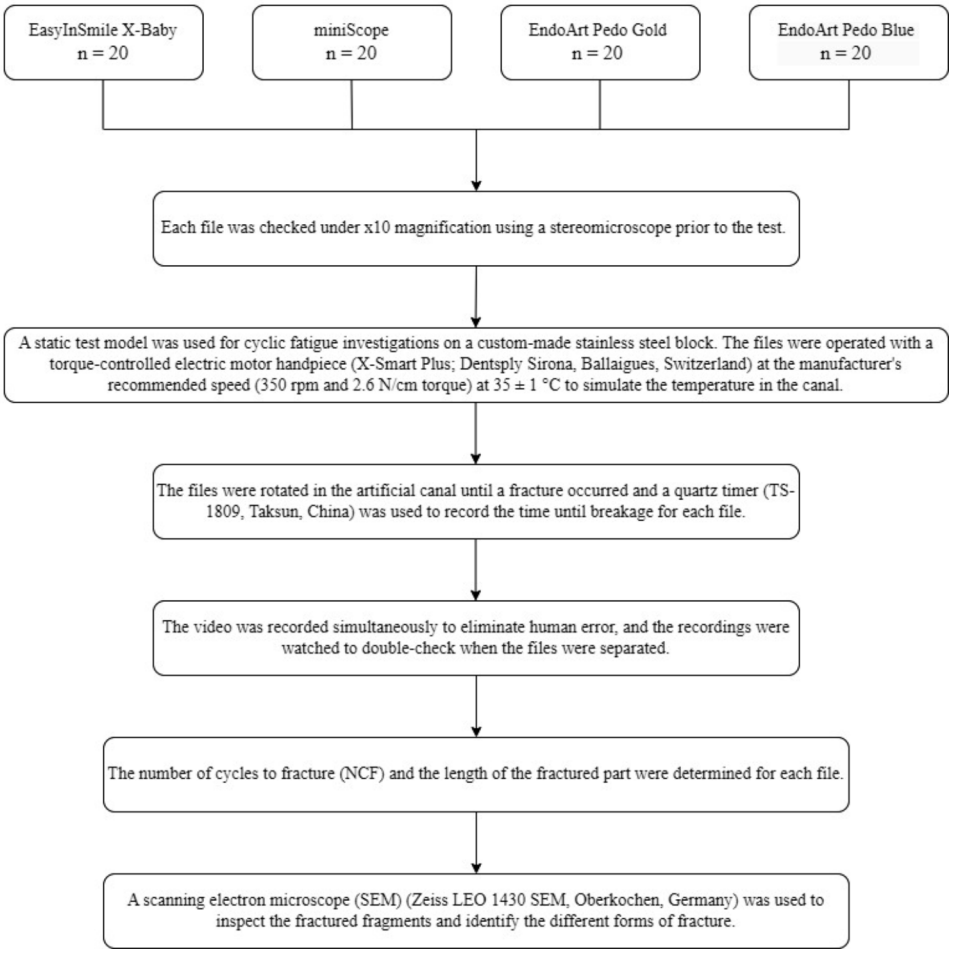

Fig. 1 Flow chart summarizing the experimental groups

Table 1 Means and standard deviations (SD) of number of cycles to failure (NCF) and fragment lengths (mm) for pediatric NiTi files

Instruments	*N*	NCF Mean ± SD	Fragment length (mm) Mean ± SD
EasyInSmile X-Baby	20	$1964.50^{c} \pm 406.14$	$3.58^{a} \pm 0.34$
MiniScope	20	$453.65^{a} \pm 72.51$	$3.43^{a} \pm 0.29$
EndoArt Pedo Gold	20	$1346.25^{b} \pm 365.35$	$3.63^{a} \pm 0.53$
EndoArt Pedo Blue	20	$2668.10^{d} \pm 755.26$	$3.65^{a} \pm 0.40$

$^{a, b, c, d}$ – different superscript letters indicate statistically significant differences within the same column ($p < 0.05$)

or more groups, followed by the post hoc Tukey test to determine the significance between groups. The data on fractured fragment length was assessed using a one-way ANOVA, and $p<0.05$ indicated statistical significance.

Results

Table 1 displays the mean values and standard deviations of the NCF for the EasyInSmile X-Baby, Scope miniScope, EndoArt Pedo Gold, and EndoArt Pedo Blue NiTi files. Higher resistance of the tested files to cyclic fatigue leads to an increased NCF. EndoArt Pedo Blue showed the highest values of NCF (2668.10±755.26), while significant differences were detected between the CFRs of all the tested files ($p<0.05$). EasyInSmile X-Baby's resistance to cycle fatigue was higher than EndoArt Pedo Gold and Scope miniScope ($p<0.05$). MiniScope showed the lowest values of NCF (453.65±72.51), with a statistically significant difference among the file systems tested ($p<0.05$).

There was no statistical difference in terms of fractured fragment lengths among the EasyInSmile X-Baby, miniScope, EndoArt Pedo Blue, and EndoArt Pedo Gold files in tested conditions ($p>0.05$). SEM photomicrographs showed the formation of striation patterns and fracture regions, which are typical signs of cyclic fatigue failure in the images of the fracture planes of the files. Representative SEM photomicrographs of the coronal and apical parts of the tested instruments were shown in Fig. 2. SEM photomicrographs of the fractured instrument surface at 300 and 1500 magnification were shown in Fig. 3. SEM photomicrographs of all instruments at 300 magnification showed marks from the manufacturing process.

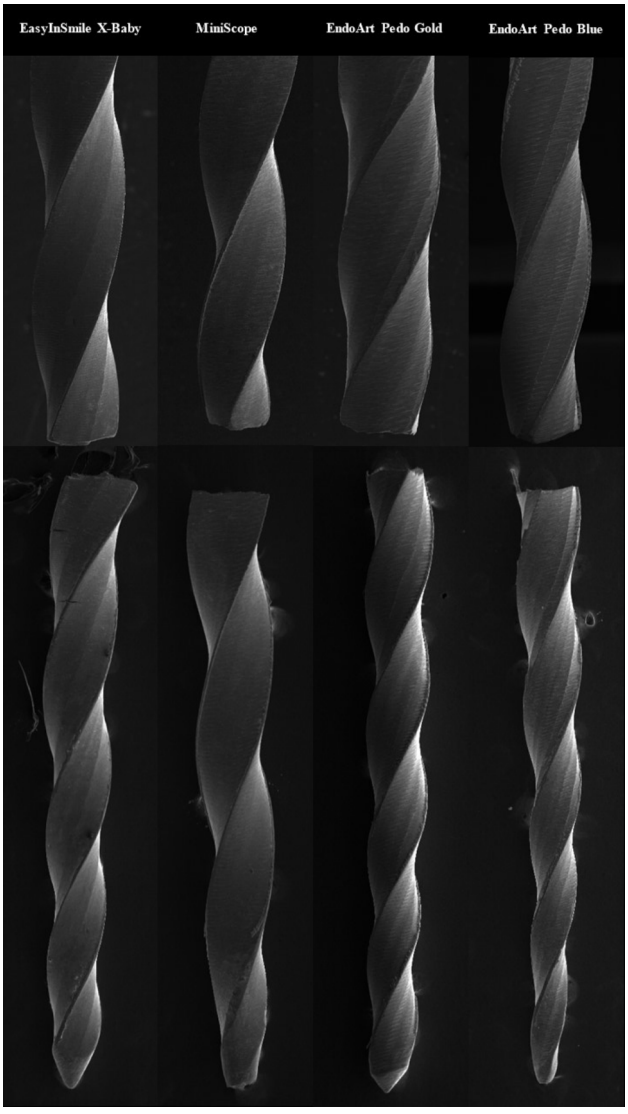

Fig. 2 Representative SEM images showing (from top to bottom) the coronal and apical portions of the instruments tested

SEM microphotographs of the fracture surface of the analyzed instruments revealed overload areas and fracture initiation zones.

Discussion

The retaining of primary teeth in children until the period of physiologic exfoliation is essential for maintaining arch length and guiding the eruption of the successor teeth [2]. For this reason, pulpectomy treatment is applied to infected primary teeth. The purpose of RCT in children is to eliminate the infected tissue, disinfect the root canals, and fill the canals with a biocompatible material [17]. Traditionally, RCT was performed with manual files; however, NiTi rotary endodontic files are currently used. The use of Ni-Ti rotary files for the instrumentation of the root canals of primary teeth is preferred since it shortens the duration of the procedure time and provides more uniform shaping [12, 18]. NiTi rotary systems have disadvantages compared to manual mechanical preparation, such as decreased tactile sensitivity during preparation, and high cost [19]. It has been reported that training to acquire the technique is useful [19] but even beginners could easily learn how to use NiTi rotary instruments and be able to instrument curved canals, although the possibility of instrument fracture during clinical use is still present [20]. It is important to be cautious about the working length when using a rotary instrument because of the reduction in tactile sensitivity [19]. Instrumentation with both manual and rotary techniques appears to be safe for deciduous teeth and the underlying permanent tooth germs if all steps and precautions carefully followed [21]. Although more residual dentin thickness has been reported with rotary instruments than with manual instruments in the instrumentation of deciduous molars [22], there have also been studies reporting less residual dentin thickness with instrumentation using rotary instruments than with manual instruments at different levels of the root canals [23, 24]. The difference might depend on the type and taper of the instruments used [22].

Primary teeth differ from permanent teeth in terms of their morphology in that they have short, thin, curved roots and may contain undetectable root resorptions [17]. Particularly in primary molars with apical curvature canals [25], lateral perforation of the inner root surface may occur when large taper NiTi rotary file systems designed for permanent teeth are used to instrument root canals [26]. Rotary files specially designed for primary teeth have been developed to prevent such complications and to use them more comfortably in children due to their short length [17]. For this purpose, the Kedo-S file system was first produced specifically for primary teeth. Using this variable taper file system, the dentin is abraded, allowing for effective three-dimensional obturation by removing a thin layer of dentin from the whole perimeter of the root canal [27]. Later, different brands produced NiTi rotary files for primary teeth. NiTi rotary file systems for permanent teeth have a higher rate of file fracture rate when used on primary teeth [28].

In previous studies, various file systems for permanent teeth have been tested for cyclic fatigue [29]. In the literature, there is a study evaluating the clinical fracture incidence of Kedo S, one of the pediatric file systems, and a study evaluating the effect of irrigation solutions on the CFR of Pro AF Baby Gold and Kedo SG blue file systems [27, 30]. To our knowledge, no studies have been conducted comparing the CFR of new generation pediatric rotary endodontic files such as EasyInSmile X-Baby, Scope miniScope, EndoArt Pedo Gold, and EndoArt Pedo Blue.

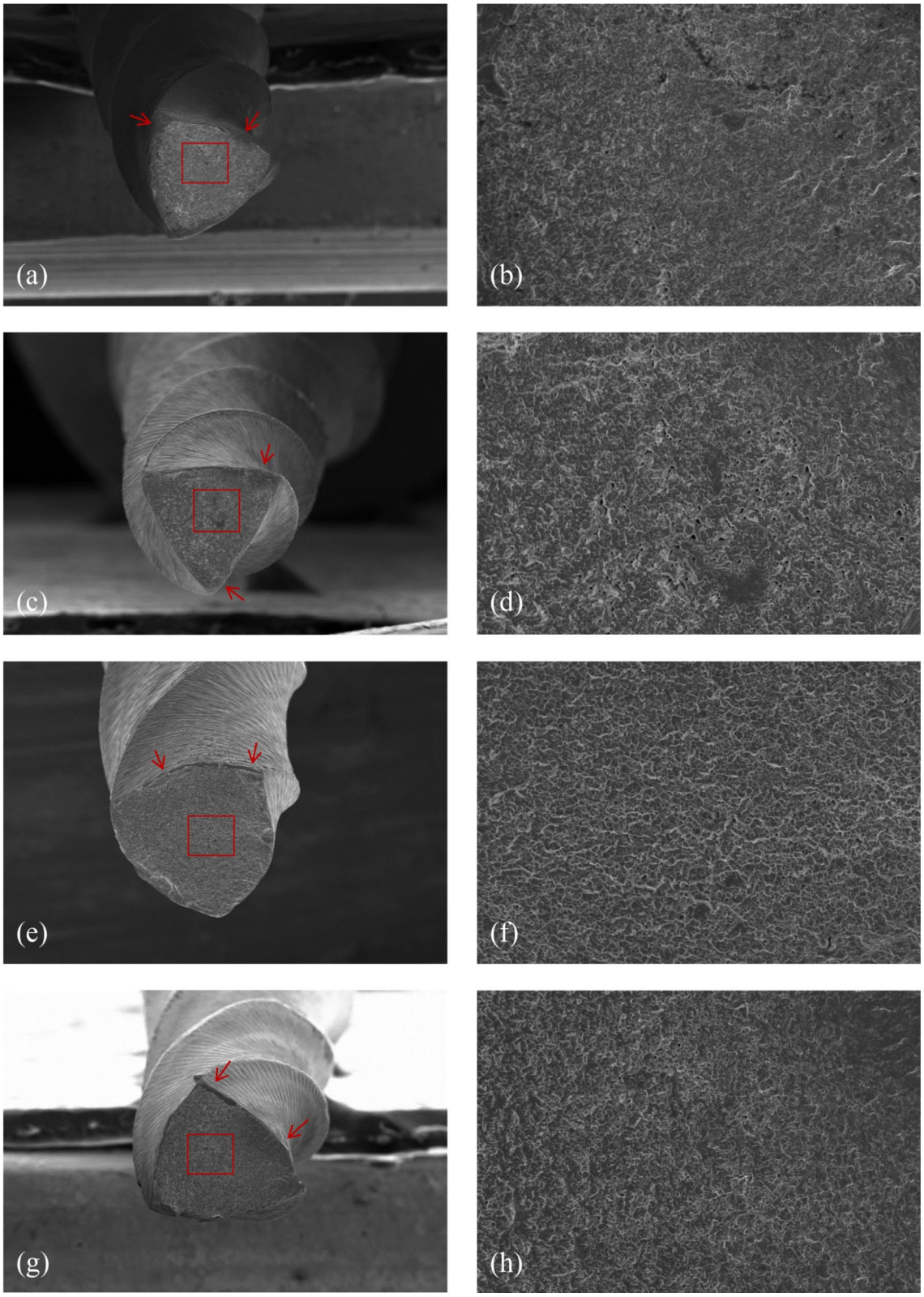

Fig. 3 Scanning electron microscope images of the fracture surfaces of EasyInSmile X-Baby (**a** and **b**), Scope miniScope (**c** and **d**), EndoArt Pedo Gold (**e** and **f**) and EndoArt Pedo Blue (**g** and **h**) instruments at 300 and 1500 magnification, respectively. The arrows identify the origins of the fracture and the rectangles indicate the area of magnification

Fractures in files usually develop due to cyclic fatigue and torsional stress. Manufacturers have made various attempts to prevent breakage in NiTi files, such as different surface treatments, heat treatment, geometric design and changes in production techniques [29, 31]. The EasyInSmile X-Baby file used in this study has high flexibility due to the crystallographic phase in its alloy and has an 'AF-H' type wire. The cross-section of this file is in the shape of a convex triangle and has an inactive tip, thus avoiding the risk of step formation in the root canals. EndoArt Pedo Gold and EndoArt Pedo Blue file systems have control memory and are produced with gold and blue heat treatment techniques, respectively. Their cross sections are convex triangular. The MiniScope file system has non-sharp rounded safe tips and produced with heat treatment techniques. The cross-section is in the shape of an equilateral triangle.

Heat treatment of NiTi alloys has significant effects on the martensitic/austenitic transformation behavior [32]. Systems using blue heat-treated wire allow the instrument to reach the martensitic phase during root canal treatment, which improves the cyclic fatigue resistance substantially [33]. The mechanical properties of NiTi tools vary widely according to their phase transformation behavior and can be easily modified by chemical composition, heat treatment and manufacturing processes [34]. EndoArt Blue files are more flexible and have better cyclic fatigue values because they are produced at a temperature of approximately 500–600 °C, higher than EndoArt Gold files, which are produced at 300–350 °C [35]. A proprietary heat-treated alloy named AF-H wire used in EasyInSmile X-Baby files provides high flexural and torsional resistance, according to internal studies [36]. The MiniScope instrument is manufactured using gold heat treatment with a thermal post-grinding process [33]. Detailed information on the manufacturing process of the MiniScope and EasyInSmile X-Baby files are not available.

In this study, the cyclic fatigue test was carried out with a certain level of standardization using a specially fabricated stainless steel block, as described by Pruett et al. [37]. In vivo, it has been estimated that the in-canal temperature is around 35 °C, and irrigation solutions reach at body temperature 30 to 60 s after being initiated into the canal [38]. To simulate body temperature in this study, the experimental setup was filled with distilled water and a heater was used to stabilize the ambient temperature at 35 ± 1 °C. It has been reported that the CFR of files generally decreases with increasing ambient temperature [39]. The artificial canal on the block had a constant 1.5 mm internal diameter. The block could have been designed to mimic the shape of the instrument, but since the purpose of this study was to compare the cyclic fatigue resistance of materials, the study was carried out with a standard test setup that has been used many times before for this purpose [31, 40, 41]. Since the instruments had the same taper and the same block was used, the test setup was standardized for all files.

According to the results of the current study, the files most resistant to cyclic fatigue were EndoArt Pedo Blue, EasyInSmile, EndoArt Pedo Gold and miniScope, respectively. There is currently no information in the literature about the CFR of these NiTi rotary canal files designed for primary teeth. The file with the lowest CFR was the miniScope. This may have been due to its different cross-sectional shape from the other files. While the cross-section of the other three files was convex triangular, the miniScope had an equilateral triangular cross-section. Consistent with this, increasing cross-sectional surface area was reported to increase the CFR of the file [40]. The EndoArt Pedo Blue file had the highest CFR. Although the EndoArt Pedo Blue with control memory wire had a similar cross-section to the EasyInSmile produced using AF-H type wire, its higher CFR might be due to differences in the alloy used, the type of wire, and the heat treatment process. Control memory wire alloys subjected to different heat treatment procedures have different amounts of titanium oxide layers, and the colors can be blue or gold. The difference between the CFRs of EndoArt Pedo Blue and EndoArt Pedo Gold could be due to the difference in the heat treatment process. Cyclic fatigue resistance is influenced by many factors [42].

The differences in the CFR of the files may be due to the differences in the production technologies, alloys, and geometry of the files. Manufacturers have devised new production methods to enhance the physical and mechanical properties of their files. Modifications in file geometry and heat treatment are utilized to improve NiTi alloy production due to the influence of cross-sectional design and longitudinal shape on mechanical properties [43]. Although each file has a triangular cross-section, there are geometrical differences between different brands. Since the manufacturer of EndoArt Pedo Gold and EndoArt Pedo Blue files is the same, their geometries are similar; however, there are differences between the production technologies because the heat treatments to which these two files are subjected are different. Scanning electron microscopy observations of the fracture cross-sections of all instruments showed comparable surface features with overload areas and fracture initiation zones.

Blue and gold heat treatments are used to improve the mechanical properties of files. In a study comparing WaveOne Gold and Reciproc Blue files, it was reported that Reciproc Blue had lower bending load and higher CFR compared to WaveOne Gold [41]. Consistent with this study, the CFR of the blue heat-treated EndoArt

Pedo Blue file was observed to be higher than that of the EndoArt Pedo Gold file.

Standardization of the root canal system in teeth and reproducibility of the test conditions for each instrument is not possible. Therefore, the researchers use a standardized experimental setup instead of testing cyclic fatigue in clinical conditions [44]. It is argued that this type of standardized experimental setup is useful for clinical relevance in determining failure due to cyclic fatigue under the same conditions [45]. As in this study, all CFR comparison studies performed on an artificial canal cannot completely replicate in vivo conditions. Due to this limitation of the studies, an extrapolation is made using a standardized experimental setup. Another limitation is that files with different taper and apical diameters were not included in the study.

Conclusion

Within the limitations of this study, the EndoArt Pedo Blue file, produced by blue heat treatment with a control memory wire, showed the best CFR performance on the artificial canal in a stainless steel block at body temperature among the four file systems specifically designed for primary teeth. The other files, in descending CFR order, were as follows: EasyInSmile, EndoArt Pedo Gold, and miniScope. Differences such as cross-sectional design, material alloy, and heat treatment technology have an effect on the CFR. The clinical use of instruments with a high CFR in curved root canals is beneficial to avoid instrument fracture.

Abbreviations

CFR	Cyclic fatigue resistance
NiTi	Nickel-titanium
NCF	Number of cycles to failure
RCT	Root canal treatment
RPM	Rotations per minute
SEM	Scanning electron microscope

Author contributions

KE conceptualized and designed the study. KS, HA and HBO were involved in data analysis. KS and HA wrote the main manuscript text. All authors read and approved the final manuscript.

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Data availability

The data presented in this study are available on reasonable request from the corresponding author.

Declarations

Ethics approval and consent to participate

The study did not include any human or animal information, tissue, or material. Thus, no ethical approval was required.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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