International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Review - Rotary File Systems Used in Endodontics

Hacer Gündüz

Corresponding author Email: *hacergndz12[at]gmail.com*
Tel: +32456544529

Abstract: ***Rotary file systems used during root canal treatment in endodontics have been used for a long time. With the development of technology and especially with the discovery of nickel - titanium alloys, file systems have developed much faster with the beginning of their use in endodontics. Thanks to the superelasticity and shape memory feature of the file systems, much better motion and control is provided in the canal and the treatment efficiency is increased. In addition, the use of increasingly complex combinations in the rotational motion also increases the treatment efficiency and tool resistance against rotational fatigue. In this review, the current rotary instrument systems that endodontists will choose in root canal treatment are discussed.***

Keywords: Endodontics, rotary file systems, alloy, root canal treatment.

1. Introduction

Mechanical shaping of root canals in root canal treatment is one of the factors that directly affect the success of the treatment. In this way, vital and necrotic tissues and infected dentin are removed from the canal (1, 2). With this shaping, the canal is filled by giving the canal a conical form that gradually expands from the apical to the coronal. When this process is done in the best way, an area is obtained that allows the bacterial biofilm to be removed and then antimicrobials to disinfect the root canals (1 - 3).

Various instruments and materials have been used for the preparation of canals in root canal treatment. For this purpose, after the use of stainless steel files and reamers for a long time, nickel titanium alloys were developed and started to be used in endodontics. Nickel - titanium alloys can remain in the center of the canal during the remaining preparation, and due to its flexible structure, it leads to the formation of much less steps (1 - 3). In this way, the shaping of the canals becomes faster and easier, and issues such as elbow step formation, transportation, perforation, canal obstruction, canal flattening and instrument breakage have begun to be seen less (2 - 5).

After the first use of nickel - titanium alloy rotary instruments, file systems with different physical and chemical properties and different mechanical designs were produced and released to the market over time. In this way, both the efficacy of treatment has been increased and possible complications have been reduced. In addition, the risk of tool breakage has been tried to be reduced with designs that try to reduce the resistance against files (2 - 6). In this review, it is aimed to examine the development of nickel titanium alloy rotary file systems used in endodontics and the properties of current rotary instruments.

Properties of Nickel - Titanium Alloys

Nickel - titanium alloys consist of 55% nickel and 45% titanium. They show high resistance to cyclic fatigue and have superelasticity. Its elastic structure allows easy motion in narrow and curved channels (7, 8).

Nickel titanium alloys show recoverable strain. The thermomechanical mechanisms of these alloys are simple and have a high power to weight ratio. Biocompatibility levels are high. They show high electrical and corrosion resistance. However, in addition to these features, it has shape memory, that is, the ability to return to its predetermined shape and/or size when exposed to appropriate heat treatment (9, 10). Phase transformations of the alloy provide shape memory properties. According to this, it can be deformed by showing elastic elongation up to 10% in the phase called martensite, and can return to its former shape and/or size after heat treatment in the austensite phase, or vice versa, it can be taken to the martensite phase after the austenite phase and its previous shape can be obtained with elastic elongation. In a short temperature interval between cooling and heating, the intermediate form R - phase is formed (9 - 11).

Nickel - Titanium Alloys Used in Endodontis

The superelasticity and shape memory properties of nickel - titanium alloy and its high resistance to cyclic fatigue have led to the use of this alloy in root canal treatment in endodontics. Different designs have been developed and released to the market in order to increase the efficacy and ease of application in treatment and to reduce the risk of fracture (12).

Endodontic instruments produced from conventional nickel titanium alloy are produced by machine cutting of nickel titanium wire and irregularities may occur on the instrument surface during cutting. Therefore, the fracture resistance and cutting efficiency of the file decrease (13).

There is 55.8% nickel in the M - Wire alloy, which is produced by thermomechanical processing of the metal by subjecting it to heat treatments at various temperatures before processing. Although the alloy obtained by this method is mostly in the austenite phase at body temperature, some of it is also found in the martensite and R - phase, thus maintaining its superelasticity (12, 14).

In R - phase alloys, when the alloy is in R - phase, rotary tools were produced by bending the nickel titanium wire, and then the rotary tools were brought to the austenite phase

by applying additional heat treatment. Because less stress is required to deform in the R - phase, the material can be shaped by wire bending in the R - phase. R - phase alloys have higher rotational fatigue resistance and elasticity than conventional nickel titanium alloys. In this way, a more central canal preparation can be made and the risk of transportation decreases (15 - 17).

Controlled Memory (CM - Wire) alloy does not show superelasticity at room temperature and body temperature. Since they are in the martensite phase at room temperature, they are easily deformed, but because they are in the martensite phase, they are more flexible and have higher rotational fatigue resistance. They do not show shape memory because of their phase ratio (18).

Tools produced with Gold and Blue heat treatment alloys are machine cut and then subjected to thermal treatment, which includes heating and cooling. For this reason, their surfaces are covered with a layer of titanium oxide, which causes them to appear in different colors (19).

Maxwire alloy is the first endodontic nickel titanium alloy with shape memory and super elasticity. These alloys are relatively flat at room temperature in the martensite phase and show austenite phase transformation within the channel during application. In this way, they take a more curved shape and show shape memory and super elasticity properties (20).

Tools made from T - Wire alloys are much more resistant to fracture than untreated alloys. Shape memory can be controlled in tools produced from C - Wire alloy and subjected to special heat treatment (13, 19).

Firewire alloys are thermomechanically processed by a series of heating and cooling processes and are more flexible, but their shape memory is reduced (13, 19).

In Electrical Discharge Machining (EDM) alloys, spark - erosion technology is used and melting areas are formed in the alloy and some parts are evaporated by means of a conductive liquid and a controlled electric current. The cyclic fatigue resistance of the alloy obtained by subsequent heat and mechanical treatments is high (21.22)

Design Features of Endodontic Instruments

The designs of endodontic nickel titanium rotary instruments vary depending on their helix angle, helical structure, radial area, tip size, taper angle, cross - section, and (2 - 6).

The helix angle is the angle between the long axis and the cutting edge of the rotary tool. A constant helix angle causes debris to accumulate coronally. Files with a fixed helix angle offer less resistance to the screwing force. On the other hand, instruments with variable helix angle can remove debris more effectively and screwing effect can be reduced (2, 3, 9).
The helical structure (pitch) is the number of grooves in a fixed length of the rotary tool and this structure varies with the distance between the grooves. Fixed helical instruments can become trapped in the canal, so many rotary instruments are variable helical (3, 4, 9).

The radial area is the flat surface between two grooves in the rotary tool. The radial area is the most important factor in keeping the file centered in the canal and supports the file. The radial areas contact the canal walls peripherally and reduce the penetration into the canal. However, they also cause a decrease in cutting efficiency. The full radial area keeps the file in the center of the canal, while the discontinuous radial area reduces friction (5, 6, 14).

Rake angle in files is the angle made by the cutting edge with the section perpendicular to the long axis of the tool. This angle affects the cutting efficiency of the file. Tools with a positive rake angle cut more effectively, but can cause dentin snagging and cracks. Tools with a negative rake angle create a scraping effect. Most rotary instruments have negative or neutral rake angles (2, 3, 9).

In rotary instruments, the tip design can be active or passive. Active inserts cut and can enter narrow and calcified channels, but have a higher risk of channel transport due to the inserts. Therefore, the use of passive tips is recommended (2 - 6)

Kinematics of Motion in Rotary Systems

Motion kinematics in rotary systems have been designed in different ways over time to increase treatment efficiency and resistance to fracture.

Continuous rotation is the first designed motion kinematics in endodontic rotary instrument systems. In this system, the file works by rotating 360 degrees in the canal. This creates high stress on the tool. Most rotary tools on the market still have this kinematics (7, 9). Rotation motions are divided into symmetrical (centric) and asymmetrical (eccentric). Tools with asymmetrical motion can perform better cleaning in canal structures with irregular cross - sections and provide more surface contact on canal walls (23, 24).

In reciprocating motion kinematics, which was developed after the rotation motion, continuous motions are made clockwise and counterclockwise. With this motion kinematics, it is possible to use a single rotary tool instead of multiple rotary tools. With this motion, the tensile and compressive stresses in the rotary tool are lowered and fatigue resistance increases (9, 25).

In vertical vibratory motion kinematics, erosion of the dentin canals and continuous irrigation are provided. It causes less stress and less cracks on the canal walls compared to rotation (26).

In Adaptive (Rotation and Reciprocation) motion kinematics, rotation and reciprocation coexist and the advantages of both kinematics are used. When the tension force increases as a result of a series of rotations, the instrument returns to the reciprocating motion. It rotates again when the torque drops. With various combinations like this, both the efficiency of the cutting process and the fatigue resistance are increased (23, 24, 27).

First Generation Files

First generation nickel titanium files came into use at the beginning of the 90s with a taper angle of 0.2. Later, ProFile files were released with a taper angle of 0.4. First generation files have a negative rake angle. The error rate is low in the use of first generation files, but a large number of files are required. There is only rotational motion in the first three generations of files (28 - 33).

ProFile files were first produced with a taper angle of 0.02 in 1994, and then released as 0.04 and 0.06. These files have been developed with U - shaped grooves evenly spaced around the nickel titanium wire and untreated radial areas between these grooves that prevent locking into the dentin (30).

LightSpeed files were developed in 1993. They have an unsharp long body and a short front cutting edge and are flexible. It is used between 750 - 2000 Rpm. Available up to 60 numbers with intermediate numbers. It is recommended not to skip numbers while using (31).

Quantec files were introduced in 1996. It consists of ten files of different sizes, diameters and taper angles with standard tips size 25, 40 and 45. With a positive cutting angle, it cuts through the dentin and the helix angle removes debris from the canal quickly and effectively. The cutter mass reduces the risk of file breakage (32, 33).

Second Generation Files

Second generation files were introduced to the market in 2001. was released in. Second generation files have active cutters that do not have a radial area, which helps to reduce the number of files needed during canal preparation. These files have a positive rake angle (34). It is also aimed to improve the instrument surfaces and increase the cutting efficiency by using techniques such as ion implantation and electropolishing in these files (28, 35 - 42).

In Protaper files, the cross - section is in the form of a modified K - file with sharp cutting edges and no radial area. It features increased taper angles and improved thread designs. It consists of a total of six files, three shapers and three finishers. There are variable helix angles in different regions as a factor that reduces the screwing effect (28, 35).

K3 files have a cross - sectional area with positive rake angle, large radial areas, peripheral relief areas. The third radial area and non - cutting tips of the K3 files enabled them to have higher cutting efficiency and to reduce friction thanks to the relief areas (36).

MTWO files have four sizes of tools from 10 - 25 with conical angles between 0.04 - 0.06. This file system has four types of tip size files ranging from 10 - 25. The helix angles are greater in large diameter tools and differ in a single saddle. This design improves cutting efficiency on large diameter tools and facilitates channel feed on small diameter tools. Later, the MTWO - R version was released (37).

HERO 642/HERO Shaper has high elasticity in rotation and six files in the system, 20, 25 and 30 files with conical angles of and 0.06. In these files, the distance between the blades increases gradually and has a blunt tip. The short metallic handles of these files make it easier to work on posterior teeth (38, 39).

EndoSequence files have a length of 16 mm and taper angles of 0.04, 0.06. The cutting surfaces alternately contact the dentin walls, and this reduces the need for high torque, keeping it in the middle of the canal during operation (40).

RaCe, reamer with alternating cutting edges, has an electropolished surface. The ends are rounded and not sharp. Changes in the cutting edge reduce the operating torque and, accordingly, the effect of embedding in the canal (41, 42).

Third Generation Files

Third generation files, which are more resistant to breakage and splitting, were introduced in 2007. These files, which are produced by applying various heating and cooling processes and electroerosion processes, have advanced shape memory and this is especially advantageous in curved canals. In these files, resistance to rotational fatigue has been increased with M - phase and intermediate phase R - phase technologies (43 - 49).

ProFile Vortex files have no radial area. On the other hand, they are made of M - Wire with a helix angle in order to prevent the screwing effect of the channel. The later produced Vortex Blue files have a hard titanium oxide layer, which has increased cutting efficiency, resistance to abrasion and chipping, and flexibility (44, 45).

Hyflex CM files are made from CM Wire. The cross - sections of these files are triangular. The nickel ratio is lower (46). Twisted File (SybronEndo, Orange CA, USA) files were produced by bending with R - phase of Nickel titanium alloy and introduced to the market in 2008 (47).

ProFile GT Series X (Dentsply) files were produced and released with M - Wire in 2007. Thanks to the design of the chip cavity in these files, the need for filing is reduced and this enables more efficient cutting of dentin. In this way, the files can stay in the middle of the canal during cutting (48).

K3XF files (SybronEndo) were launched in 2011, unlike the K3 files, produced with R - phase instead of the traditional Nickel titanium alloy. The horizontal cross - sections are U - shaped and the same as the K3 files. It has similarities with Twisted File produced by the same company (49).

Fourth Generation Files

Along with the fourth generation files, reciprocating motion were introduced to the market. With this belt, cleaning and shaping can be done using only one tool. In the first files produced, the reciprocating motion was used with equal angles, 90° clockwise and 90° counterclockwise, but later on, files that work symmetrically with smaller angles and asymmetrically working systems developed by Yared in 2008 came into use (13, 50 - 53).

WaveOne files are designed to rotate three times 30° clockwise and 150° counterclockwise, making cutting more efficient and easier and better removing debris from the canal. The WaveOne system consists of a single file and is a disposable system. Three WaveOne files are available in different sizes to work with different root canal anatomies (50).

Reciproc files are a reciprocating system with different clockwise and counterclockwise rotation angles. These files, which have an S - shaped cross - section, are attached to the dentin wall while rotating at a large angle. Afterwards, it rotates in the opposite direction with a smaller angle and can easily move forward in the canal without the effect of screwing by separating from the dentin (13, 51).

Self - Adjusting File files (SAF; ReDent - Nova, Raanana, Israel) are produced in a very different way in terms of design and working method. This system has hollow files allow irrigation during mechanical preparation. In this system, when the file is inserted into the canal, it adapts itself to the dimensions of the canal in three dimensions and works with a back - and - forth motion by making 3000 - 5000 vibrations per minute (13, 52).

The Endo - EZE file system consists of four files and was developed to shape the middle of the canal and was designed and launched to be used with the gyromatic angledruva. In this system, the use of a stainless steel file is recommended for shaping the apical third of the canal (53).

Fifth Generation Files

Asymmetric design has been applied in the fifth generation file systems. In these files, there is an asymmetry in the cross - section of the centers of rotation and mass on the files. The asymmetrical design allows a mechanical wave to form along the long axis of the file during use. In this way, both the screwing effect is reduced and the cutting process and the removal of debris are performed more effectively than files that rotate around the center of mass (13, 55 - 58).

One Shape (Micro - Mega) files consist of a single file with number 25 and taper angle of 0.06. However, a single file has different cross - sectional areas. One Shape files work with a continuous rotation motion (55).

Revo - S files work with a continuous rotation motion. These files are manufactured from a conventional nickel titanium alloy and have a triangular cross - sectional area and a fixed taper angle. It advances in the channel with its asymmetrical cross - sectional area and provides easy adaptation to the channels. This file system includes two files for apical preparation and one file for recapitulation (56).

In the ProTaper Next file system, taper angles are designed as increasing and decreasing and rotation angles are designed asymmetrically. With this design, only two points of the file touch the canal walls at the same time, thus reducing the screwing and taper lock effect. With this design, the risk of debris accumulating in the lateral side of the canal and blocking the canal is also reduced. Unlike other file systems, the taper angles are fixed at the tip of the file, while they are not fixed at the other parts of the file (57.58).

Other New File Systems

With the advancement of technology, file systems that do not fall into the generation categories, adapt to the canal anatomy rather than shaping the canal, and can perform minimally invasive shaping have been introduced to the market (59 - 62).

XP - Endo Shaper (FKG Dentaire, La Chaux - de - Fonds, Switzerland) is a single file system with a continuous rotation motion like the first three generations. It is designed in the shape of a snake with MaxWire technology and has a triangular cross - sectional area. These files have superelasticity and shape memory properties. In this way, the taper angle increases with the transformation from the martensite phase to the austenite phase at body temperature. These files have higher rotational fatigue resistance than other files (59, 60).

Edge Coil (EdgeEndo, Albuquerque, New Mexico, USA) file system is manufactured with FireWire. It is a single file system and works with reverse reciprocating motion. It is designed in the shape of a snake and flexible, so it can be used in channels with a slope of up to 90 degrees (61).

TruShape (Dentsply/Tulsa Dental Specialties) file system has an asymmetrical, triangular cross - sectional design. It has an S - shaped horizontal section. While working, it contacts the channel at two points (61).

TruNatomy (Dentsply Sirona Endodontics, Ballaigues, Switzerland) file system has an asymmetrical design, high elasticity and a regressive taper angle. The taper angles are not constant and gradually decrease along the instrument (62).

2. Conclusion

Rotary file systems used during root canal treatment in endodontics during root canal preparation have been used and developed for a long time. The materials of these rotary instruments, their elasticity, structure, motion kinetics and resistance to rotational fatigue directly affect the treatment effectiveness and usability of these instruments. With the development of technology, more and more complex rotary file systems have been used in root canal preparation and much more effective treatment results have been obtained.

References

[1] León - López M, Cabanillas - Balsera D, Martín - González J, Montero - Miralles P, Saúco - Márquez JJ, Segura - Egea JJ. Prevalence of root canal treatment worldwide: A systematic review and meta - analysis. Int Endod J.2022; 55 (11): 1105 - 1127. doi: 10.1111/iej.13822.
[2] Dablanca - Blanco AB, Castelo - Baz P, Miguéns - Vila R, Álvarez - Novoa P, Martín - Biedma B. Endodontic Rotary Files, What Should an Endodontist

Know? Medicina (Kaunas).2022; 58 (6): 719. doi: 10.3390/medicina58060719.
[3] Tabassum S, Zafar K, Umer F. Nickel - Titanium Rotary File Systems: What's New? Eur Endod J.2019; 4 (3): 111 - 117. doi: 10.14744/eej.2019.80664.
[4] Gavini G, Santos MD, Caldeira CL, Machado MEL, Freire LG, Iglecias EF, Peters OA, Candeiro GTM. Nickel - titanium instruments in endodontics: a concise review of the state of the art. Braz Oral Res.2018; 32 (suppl 1): e67. doi: 10.1590/1807 - 3107bor - 2018. vol32.0067.
[5] Lima Neto JC, Fernandes LM, Magno MB, Rocha Lima TF, de Almeida LFD, Santiago BM, Cavalcanti YW. The Effect of Reciprocating and Rotary Systems on Postoperative Endodontic Pain: A Systematic Review and Meta - analysis. Iran Endod J.2020; 15 (4): 198 - 210. doi: 10.22037/iej. v15i4.23778.
[6] Kuzekanani M. Nickel - Titanium Rotary Instruments: Development of the Single - File Systems. J Int Soc Prev Community Dent.2018; 8 (5): 386 - 390. doi: 10.4103/jispcd. JISPCD_225_18.
[7] Zanza A, D'Angelo M, Reda R, Gambarini G, Testarelli L, Di Nardo D. An Update on Ni - ckel - Titanium Rotary Instruments in Endodontics: Mechanical Characteristics, Testing and Future Perspective—An Overview. Bioengineering; 2021; 8 (12): 218.
[8] Cheung GS, Shen Y, Darvell BW. Does electropolishing improve the low - cycle fatigue be - havior of a nickel - titanium rotary instrument in hypochlorite? Journal of Endodontics.2007; 33 (10): 1217 - 1221.
[9] Gavini G, Santos MD, Caldeira CL, Machado MEL, Freire LG, Iglecias EF, Peters OA, Candeiro GTM. Nickel - titanium instruments in endodontics: a concise review of the state of the art. Braz Oral Res.2018; 32 (suppl 1): e67. doi: 10.1590/1807 - 3107bor - 2018. vol32.0067.
[10] Dablanca - Blanco AB, Castelo - Baz P, Miguéns - Vila R, Álvarez - Novoa P, Martín - Biedma B. Endodontic Rotary Files, What Should an Endodontist Know? Medicina (Kaunas).2022; 58 (6): 719. doi: 10.3390/medicina58060719.
[11] Guillory M DVM, Vall P DVM, DAVDC. Past, Present, and Future Trends of Nickel Titanium Rotary Instrumentation. J Vet Dent.2022; 39 (3): 257 - 268. doi: 10.1177/08987564221098566.
[12] Zupanc J, Vahdat - Pajouh N, Schäfer E. New thermomechanically treated NiTi alloys - a review. Int Endod J.2018; 51 (10): 1088 - 1103. doi: 10.1111/iej.12924.
[13] Işık V. Nikel titanyum döner aletlerin metalürjik gelişimi, Küçükay ES, editör. Endodontide Döner Alet Sistemleri - Hangi Sistem, Nerede, Neden? 1. Baskı, Ankara, Türkiye Klinikleri, 2020: 13 - 20.
[14] Pereira ES, Gomes RO, Leroy AM, Singh R, Peters OA, Bahia MG, Buono VT. Mechanical behavior of M - Wire and conventional NiTi wire used to manufacture rotary endodontic instruments. Dent Mater.2013; 29 (12): e318 - 24. doi: 10.1016/j. dental.2013.10.004.
[15] Hou X, Yahata Y, Hayashi Y, Ebihara A, Hanawa T, Suda H. Phase transformation behaviour and bending property of twisted nickel - titanium endodontic instruments. Int Endod J.2011; 44 (3): 253 - 8. doi: 10.1111/j.1365 - 2591.2010.01818. x.
[16] Pedullà E, Grande NM, Plotino G, Pappalardo A, Rapisarda E. Cyclic fatigue resistance of three different nickel - titanium instruments after immersion in sodium hypochlorite. J Endod.2011; 37 (8): 1139 - 42. doi: 10.1016/j. joen.2011.04.008.
[17] El Batouty KM, Elmallah WE. Comparison of canal transportation and changes in canal curvature of two nickel - titanium rotary instruments. J Endod.2011; 37 (9): 1290 - 2. doi: 10.1016/j. joen.2011.05.024.
[18] Zhou HM, Shen Y, Zheng W, Li L, Zheng YF, Haapasalo M. Mechanical properties of controlled memory and superelastic nickel - titanium wires used in the manufacture of rotary endodontic instruments. J Endod.2012; 38 (11): 1535 - 40. doi: 10.1016/j. joen.2012.07.006.
[19] Uygun AD, Kol E, Topcu MK, Seckin F, Ersoy I, Tanriver M. Variations in cyclic fatigue resis - tance among ProTaper Gold, ProTaper Next and ProTaper Universal instruments at different levels. International Endodontic Journal; 2016; 49: 494 - 499.
[20] Zupanc J, Vahdat - Pajouh N, Schäfer E. New thermomechanically treated NiTi alloys—A re - view. International Endodontic Journal.2018; 51: 1088–1103.
[21] Daneshmand S, Kahrizi EF, Abedi E, Abdolhosseini MM. Influence of machining parameters on electro discharge machining of NiTi shape memory alloys. Int J Electrochem Sci.2013; 8: 3095–104.
[22] Singh S, Maheshwari S, Pandey PC. Some investigati - ons into the electric discharge machining of hardened tool steel using different electrode materials. J Mater Process Technol.2004; 149: 272–7.
[23] 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 microcomputed tomography. International Endodontic Journal; 2015; 48 (2): 162 - 70.
[24] Zuolo ML, Zaia AA, Belladonna FG, Silva EJ, Souza EM, Versiani MA et al. Micro - CT assess - ment of the shaping ability of four root canal instrumentation systems in ovalshaped canals. International Endodontic Journal; 2018; 51 (5): 564 - 571.
[25] Adıgüzel M, Capar ID. Comparison of cyclic fatigue resistance of waveone and waveone gold small, primary, and large instruments. Journal of Endodontics; 2017; 43 (4): 623 - 627.
[26] Capar ID, Ozcan E, Arslan H, Ertas H, Aydinbelge HA. Effect of different final irrigation methods on the removal of calcium hydroxide from an artificial standardized groove in the apical third of root canals. J Endod.2014; 40 (3): 451 - 4. doi: 10.1016/j. joen.2013.10.019.
[27] Hayashi Y, Yoneyama T, Yahata Y, Miyai K, Doi H, Hanawa T, Ebihara A, Suda H. Phase transformation behaviour and bending properties of hybrid nickel - titanium rotary endodontic instruments. Int Endod - 2007; 40: 247 - 253.
[28] Haapasalo M, Shen Y. Evolution of nickel - titanium instruments: From past to future. Endod Topics.2013; 29: 3–17.

[29] Hata G, Uemura M, Kato AS, Imura N, Novo NF, Toda T, et al. A comparison of shaping ability using ProFile, GT file, and flex - R endodontic instruments in simulated canals. J Endod.2002; 28: 316–21.
[30] Ankrum MT, Hartwell GR, Truitt JE. K3 Endo, ProTaper, and ProFile systems: breakage and distortion in severely curved roots of molars. J Endod.2004; 30 (4): 234 - 7.
[31] Barbakow F. The LightSpeed system. Dent Clin North Am.2004; 48 (1): 113 - 35. doi: 10.1016/j. cden.2003.10.003.
[32] Hülsmann M, Herbst U, Schäfers F. Comparative study of root - canal preparation using Lightspeed and Quantec SC rotary NiTi instruments. Int Endod J.2003; 36 (11): 748 - 56. doi: 10.1046/j.1365 - 2591.2003.00725. x.
[33] Hülsmann M, Schade M, Schäfers F. A comparative study of root canal preparation with HERO 642 and Quantec SC rotary Ni - Ti instruments. Int Endod J.2001; 34 (7): 538 - 46. doi: 10.1046/j.1365 - 2591.2001.00431. x.
[34] Kuzekanani M. Nickel - Titanium Rotary Instruments: Development of the Single - File Systems. J Int Soc Prev Community Dent.2018; 8 (5): 386 - 390. doi: 10.4103/jispcd. JISPCD_225_18.
[35] Fariniuk LF, Azevedo MAD, Carneiro E, Westphalen VPD, Piasecki L, da Silva Neto UX. Efficacy of protaper instruments during endodontic retreatment. Indian J Dent Res.2017; 28 (4): 400 - 405. doi: 10.4103/ijdr. IJDR_89_16.
[36] Mounce RE. The K3 rotary nickel - titanium file system. Dent Clin North Am.2004; 48 (1): 137 - 57.
[37] Kuzekanani M, Walsh LJ, Yousefi MA. Cleaning and shaping curved root canals: Mtwo vs ProTaper instruments, a lab comparison. Indian J Dent Res.2009; 20 (3): 268 - 70. doi: 10.4103/0970 - 9290.57355.
[38] Pentelescu C, Colceriu L, Pastrav O, Culic C, Chisnoiu R. In vitro evaluation of root canal preparation with two rotary instrument systems - Pro Taper and Hero Shaper. Clujul Med.2015; 88 (3): 395 - 402. doi: 10.15386/cjmed - 454.
[39] Pentelescu C, Colceriu L, Pastrav O, Culic C, Chisnoiu R. In vitro evaluation of root canal preparation with two rotary instrument systems - Pro Taper and Hero Shaper. Clujul Med.2015; 88 (3): 395 - 402. doi: 10.15386/cjmed - 454.
[40] Kurtzman GM. Simplifying endodontics with endosequence rotary instrumentation. J Calif Dent Assoc.2007; 35 (9): 625 - 8.
[41] Nabavizadeh M, Shokouhi MM, Kheirandish M, Sahebi S, Sadatshojaee N, Abbaszadegan A. A Comparison of the Apical Extrusion of Debris during the Preparation of Root Canal with Medin, RaCe, and ProTaper Rotary Systems. J Dent (Shiraz).2021; 22 (3): 193 - 197. doi: 10.30476/DENTJODS.2020.84776.1100.
[42] Tofangchiha M, Ebrahimi A, Adel M, Kermani F, Mohammadi N, Reda R, Testarelli L. In vitro evaluation of Kedo - S and RaCe rotary files compared to hand files in preparing the root canals of primary molar teeth. Front Biosci (Elite Ed).2022; 14 (2): 14. doi: 10.31083/j. fbe1402014.
[43] Hou X, Yahata Y, Hayashi Y, Ebihara A, Hanawa T, Suda H. Phase transformation behaviour and bending property of twisted nickel - titanium endodontic instruments. Int Endod J.2011; 44 (3): 253 - 8. doi: 10.1111/j.1365 - 2591.2010.01818. x.
[44] Zhou HM, Shen Y, Zheng W, Li L, Zheng YF, Haapasalo M. Mechanical properties of controlled memory and superelastic nickel - titanium wires used in the manufacture of rotary endodontic instruments. J Endod.2012; 38 (11): 1535 - 40. doi: 10.1016/j. joen.2012.07.006.
[45] Shen Y, Zhou H, Coil JM, Aljazaeri B, Buttar R, Wang Z, Zheng YF, Haapasalo M. ProFile Vortex and Vortex Blue Nickel - Titanium Rotary Instruments after Clinical Use. J Endod.2015; 41 (6): 937 - 42. doi: 10.1016/j. joen.2015.02.003.
[46] Bürklein S, Börjes L, Schäfer E. Comparison of preparation of curved root canals with Hyflex CM and Revo - S rotary nickel - titanium instruments. Int Endod J.2014; 47 (5): 470 - 6. doi: 10.1111/iej.12171.
[47] Altunbas D, Kutuk B, Toyoglu M, Kutlu G, Kustarci A, Er K. Reciproc versus Twisted file for root canal filling removal: assessment of apically extruded debris. J Istanb Univ Fac Dent.2016; 50 (2): 31 - 37. doi: 10.17096/jiufd.96734.
[48] Kramkowski TR, Bahcall J. An in vitro comparison of torsional stress and cyclic fatigue resistance of ProFile GT and ProFile GT Series X rotary nickel - titanium files. J Endod.2009; 35 (3): 404 - 7. doi: 10.1016/j. joen.2008.12.003.
[49] Keskin C, Inan U, Guler DH, Kalyoncuoğlu E. Cyclic Fatigue Resistance of XP - Endo Shaper, K3XF, and ProTaper Gold Nickel - titanium Instruments. J Endod.2018; 44 (7): 1164 - 1167. doi: 10.1016/j. joen.2018.04.005.
[50] Alsilani R, Jadu F, Bogari DF, Jan AM, Alhazzazi TY. Single file reciprocating systems: A systematic review and meta - analysis of the literature: Comparison of reciproc and WaveOne. J Int Soc Prev Community Dent.2016; 6 (5): 402 - 409. doi: 10.4103/2231 - 0762.192945.
[51] Siddique R, Nivedhitha MS. Effectiveness of rotary and reciprocating systems on microbial reduction: A systematic review. J Conserv Dent.2019; 22 (2): 114 - 122. doi: 10.4103/JCD. JCD_523_18.
[52] Metzger Z. The self - adjusting file (SAF) system: An evidence - based update. J Conserv Dent.2014; 17 (5): 401 - 19. doi: 10.4103/0972 - 0707.139820.
[53] Nordmeyer S, Schnell V, Hülsmann M. Comparison of root canal preparation using Flex Master Ni - Ti and Endo - Eze AET stainless steel instruments. Oral Surg Oral Med Oral Pathol Oral Radiol Endod.2011; 111 (2): 251 - 9. doi: 10.1016/j. tripleo.2010.08.022.
[54] Liang Y, Yue L. Evolution and development: engine - driven endodontic rotary nickel - titanium instruments. Int J Oral Sci.2022; 14 (1): 12. doi: 10.1038/s41368 - 021 - 00154 - 0.
[55] Prabhakar AR, Yavagal C, Dixit K, Naik SV. Reciprocating vs Rotary Instrumentation in Pediatric Endodontics: Cone Beam Computed Tomographic Analysis of Deciduous Root Canals using Two Single - file Systems. Int J Clin Pediatr Dent.2016; 9 (1): 45 - 9. doi: 10.5005/jp - journals - 10005 - 1332.
[56] Ahmetoglu F, Keles A, Simsek N, Ocak MS, Yologlu

S. Comparative evaluation of root canal preparations of maxillary first molars with self - adjusting file, reciproc single file, and revo - s rotary file: A micro - computed tomography study. Scanning.2015; 37 (3): 218 - 25. doi: 10.1002/sca.21202.

[57] Nishad SV, Shivamurthy GB. Comparative Analysis of Apical Root Crack Propagation after Root Canal Preparation at Different Instrumentation Lengths Using ProTaper Universal, ProTaper Next and ProTaper Gold Rotary Files: An In vitro Study. Contemp Clin Dent.2018; 9 (Suppl 1): S34 - S38. doi: 10.4103/ccd. ccd_830_17.

[58] Eliasz W, Kubiak K, Poncyljusz W, Surdacka A. Root Canal Transportation after Root Canal Preparation with ProTaper Next, WaveOne Gold, and Twisted Files. J Clin Med.2020; 9 (11): 3661. doi: 10.3390/jcm9113661.

[59] Bayram HM, Bayram E, Ocak M, Uygun AD, Celik HH. Effect of ProTaper Gold, Self - Adjusting File, and XP - endo Shaper Instruments on Dentinal Microcrack Formation: A Micro - computed Tomographic Study. J Endod.2017; 43 (7): 1166 - 1169. doi: 10.1016/j. joen.2017.02.005.

[60] Emara RS, Gawdat SI, El - Far HMM. Effect of XP - endo Shaper versus conventional rotary files on postoperative pain and bacterial reduction in oval canals with necrotic pulps: a randomized clinical study. Int Endod J.2021; 54 (7): 1026 - 1036. doi: 10.1111/iej.13494.

[61] Thomas JP, Lynch M, Paurazas S, Askar M. Micro - computed Tomographic Evaluation of the Shaping Ability of WaveOne Gold, TRUShape, EdgeCoil, and XP - 3D Shaper Endodontic Files in Single, Oval - shaped Canals: An In Vitro Study. J Endod.2020; 46 (2): 244 - 251. e1. doi: 10.1016/j. joen.2019.11.001.

[62] Lee YJ, Kim S, Shin SJ. Volume Percentage of Filling Voids in Root Canals Prepared by a Novel Nickel - Titanium Rotary System (TruNatomy) Using Two Different Obturation Techniques. Materials (Basel).2021; 14 (14): 3846. doi: 10.3390/ma14143846.