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Nickel Titanium Instruments with Reciprocal Motion: A Review

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Abstract
Background Nickel-titanium (NiTi) alloy was improved in endodontic treatments in the last ten years. Many processing techniques were developed to increase the mechanical features of NiTi endodontic instruments. A single-file approach was used in the reciprocating system that shapes and cleans the canal in less time while using a less antimicrobial solution with low apical pressure. **Objectives** to describe the reciprocating NiTi instruments with an overview of the comparison studies of these instruments in different subjects including; root canal cleaning and shaping, debris compaction and apical extrusion, dentin defects, and cyclic fatigue resistance. **Materials and Methods** the data was collected from 160 papers from the PubMed, Google Scholar, and Science Direct databases in the English language, without date restriction. Following the inclusion and exclusion criteria application, topic papers were critically appraised using the Critical Appraisal Skills Program to identify the most relevant papers. This review of 82 papers included the related studies after excluding 78 unrelated papers. Results the reciprocating motion was shown to have fewer tendencies to canal transportation. It was discovered that the reciprocating instruments had decreased apical debris extrusion. The reciprocating instruments produced a lower risk of fracture during the preparation. **Conclusion** the reciprocation motion maintained the anatomical canal pathway and enhanced an instrument›s fracture resistance with less apical debris extrusion.

Keywords: Continuous rotation; nickel-titanium; reciprocating motion.

Introduction

The major goal of root canal therapy is to clean and reshape the intracanal space to remove necrotic debris, bacteria, and canal abnormalities while preserving the original shape, and preventing iatrogenic errors such as ledge, instrument fracture, external transportation, or perforation, as well as to making permanent root filling placement easier (Schilder, 1974; Adigüzel and Özkan, 2011). Traditional stainless steel (S.S.) instruments typically failed to develop the root canal shapes needed for effective end filling especially when utilized in highly curved canals (Schäfer et al, 2004). In 1988, Nickel-titanium (NiTi) instruments were introduced by manufacturers to improve the shape of

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root canals and control the most iatrogenic instrumentation issues that came with S.S. (Walia et al, 1988). These new instruments have been established by using superelastic materials and new engineering ideas; it also has been a remarkable transformation from the international standardization organization (ISO) instruments (Gaddalay et al, 2018). Over the last decade, NiTi rotary files have seen significant advancements. Manufacturers used a variety of treatments on NiTi instruments to improve their elasticity and breakage resistance, including electro-polishing of the surface. Thermo - mechanical processes have recently been performed on NiTi alloy to optimize transformation performance and file structure, which have an impact on the physical features and the mechanical properties improvement of rotary files, as well as the addition of a new alloy to NiTi metal or the creation of cross-sectional new designs for the same purpose (Park et al, 2010; Pirani et al, 2016). Endodontic engines had improved, torque regulation and kinematic motions that were changeable in multiple directions in conjunction with technological improvements in metallurgy and an attempt to produce instruments with higher functionality. The majority of mechanical preparation systems still use the rotary movement that was first developed in the 1980s with a full continuous rotation of 360° (Gavini et al, 2018). Yared conducted a study in which a single F2 ProTaper file was used for complete canal preparation in the clockwise and counterclockwise directions, the instrument can be advanced with low apical pressure by using different angles of rotation (Yared, 2008). According to kinematic movements, endodontic machine-assisted instrumentation can be divided into five groups: rotary motion, rotary motion + rotational reciprocating motion (adaptive), rotational reciprocating motion, vertical vibration + rotational reciprocating motion, and vertical vibration (Çapar et al, 2015). The reciprocating method employed a single-file system that shapes and cleans the canal in less time with fewer antimicrobial agents (Siddique & Nivedhitha, 2019).

Aims

This article aims to describe the reciprocating NiTi instruments with an overview comparison of studies related to these instruments in different subjects including; root canal cleaning and shaping, debris compaction and apical extrusion, dentin defects, and cyclic fatigue resistance.

Materials and Methods

Data were collected from 160 papers in English without date restrictions from the PubMed, Science Direct, and Google Scholar databases. After the application of inclusion and exclusion criteria, topic papers were critically appraised using the Critical Appraisal Skills Program to identify the most relevant papers. This review of 82 papers included the related studies of all sections after excluding 78 unrelated papers as shown in Figure1. After that, this article described the main characteristic features of different reciprocating NiTi instruments with an overview of comparison studies for these instruments in different subjects including; 12 articles for comparison of the cleaning and shaping abilities, 18 articles were analyzed for debris› compaction, and apical extrusion, 12 articles for evaluation of dentin defect, and 19 studies were assessed for cyclic fatigue resistance.

Nickel-titanium reciprocating systems

The reciprocating NiTi instruments include; Reciproc, WaveOne, Twisted File Adaptive, ProDesign R, WaveOne Gold, Edge One File, Reciproc Blue files, R-Motion, and One RECI file. These systems were introduced

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in this review according to the year of manufacturing from the oldest to the new one. Some of these files are no longer in use and have been discontinued, but it was mentioned here because this review included a narrative comparison of old to modern file types. More information and details related to these instruments were shown in Table 1.

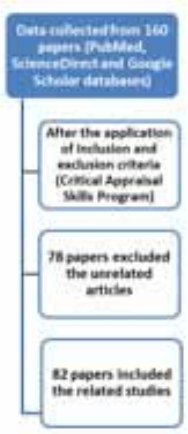

Figure (1): Flow chart represented the method of data collection in the article review.

Table (1): Features of NiTi reciprocating instruments.

Files	Manufacture	Year	Sizes	Cross section	Motor	Angle
Reciproc	VDW, Munich, Germany	2011	R25/08, R40/06 and R50/05	S- shape cross section	VDM, Gold Reciproc motor	CCW150° CW30° at 300rpm
WaveOne	Dentsply Tulsa Dental Specialties and Dentsply Maillefer	2011	Small, 21/06 yellow, primary 25/08 red, and large, 40/08 black	Modified convex triangular (apically), Convex triangular (coronally)	X-Smart Plus engine device	CCW150° CW 30° at 300rpm
Twisted File Adaptive	Axis/SybronEndo, Orange, CA, USA	2013	25/04, 25/06, 30/06, 35/06, 40/04 and 50/04	Triangular cross-section	ElementsTM Motor	CW600-0° or 370°CW CCW 50°
ProDesign R	MG, Brazil Belo Horizonte Odontológica Equipamentos	2014	25/0.06 and 35/0.05	Double Helix	I Root Apex Motor	CCW150° CW 30° at 300rpm
WaveOne Gold	Dentsply Maillefer, Ballaigues, Switzerland	2015	Small, yellow 20/07, Primary, red 25/07, Medium, green 35/06 and Large, white 45/05	Parallelogram with an 85- degree active cutting edge with alternate one and two-point contact	X-Smart Plus device	CCW150° CW 30° at 300rpm
EdgeOne Fire	Edge Endo, Albuquerque, New Mexico, USA	2015	Small 20, primary 25, Medium 35 and large 45	parallelogram cross-section	ENDOMAX ® BRITE Hand Piece	CCW150° CW 30° at 300rpm
Reciproc Blue	VDW, Munich, Germany	2016	25/08, 40/06, 50/05 within the first 3 mm	S-shaped-cross section	VDM,Gold motor with integrated apex locator	CCW150° CW 30° at 300rpm
R motion	FKG, Dentaire, Switzerland	2020	0.4 and 0.6 (size 25), 0.06 (size 30), 0.04 (size 40), 0.04 (size 50)	rounded triangular cross-section with sharp cutting edge	Root r X300 0 motor	(CCW >> CW)
One Reci	MicroMega, Besançon, France	2021	20.04, 25.04, 25.06, 35.04, and 45.04	triple helix and progressively changing to an S-shape toward the shank	MicroMega One Reci motor	170° CCW, 60° CW

Reciproc file

In 2011, the Reciproc file was the first reciprocating NiTi file introduced (VDW, Munich, Germany). These files were created by using a modern metallurgy and heat treatment of the M-Wire patented thermal treatment process. At canal temperature, Reciproc files were in the austenite phase; the material was quite tough and durable. Only one Reciproc instrument was required for canal instrumentation to preserve the canal›s original size without a glide path. It›s safe and effective in being used in curved canals, especially in retreatment cases (Saber et al, 2015).

WaveOne file

In the same year of Reciprocal File production, Wave One (WO, DENTSPLY Maillefer, Ballaigues, Switzerland), a single file manufactured from M-wire was introduced. In most circumstances, only one file was necessary for entirely shaping a canal. Technological advances in NiTi metallurgy had resulted in the creation of a unique super metal file. Engineers determined the ideal phase transitional stage between the austenite and martensite, resulting in a metal that was more clinically suitable than standard NiTi files (Ruddle, 2012).

Twisted file adaptive

Twisted File Adaptive (TFA; Axis/ SybronEndo, Orange, CA, USA) system was introduced in 2013 which rotated and reciprocated in response to the amount of pressure applied (Çitak & Özyürek, 2017). In general, a completely different manufacturing process was developed by SybronEndo from a NiTi wire in the austenite crystallized phase and electropolishing it to a new crystallized R-phase (Gambarini et al, 2008). Instead of grinding, these files were twisted because grinding could result in microcrack locations throughout

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the manufacturing process. Because there were no surface microfractures that needed to be polished away, they kept their excellent cutting performance with an extended lifespan (Elsaka et al, 2017).

ProDesign R file

In 2014, ProDesign R files (MG, Brazil Belo Horizonte Odontológica Equipment) were introduced with a special reciprocating action that allowed canal preparation with just one instrument. It was manufactured by heat treatment of CM wire. The screw-in effect was reduced by using the ProDesign R file in centric motion. ProDesign R was also created with reciprocating motion having angulation comparable to the WaveOne system (Menezes et al, 2017). This instrument was made from NiTi wire that had undergone patented Thermo-mechanical treatment to raise the austenite temperature to more than 37 °C, at working temperature, keeping the NiTi file in the twinned martensitic phase compared to the CM method. In general, this thermal treatment was known to improve the crystal structure arrangement, thus leading to flexibility raising (Shen et al, 2011).

WaveOne gold file

The simplicity of the WaveOne system was enhanced in 2015 with advanced metallurgy from M-wire, resulting in the WaveOne Gold system (WOG, DENTSPLY Maillefer, Ballaigues, Switzerland). The gold procedure was the post-production phase that involved heating and cooling ground NiTi files. From a technical standpoint, the thermal treatment altered the properties of the instrument by changing the transition temperatures between the austenite start and austenite finish temperatures (Webber et al, 2015).

EdgeOne fire system

In 2015, a new file was developed to be utilized with reciprocating motion (Edge Endo, Albuquerque, New Mexico, USA). FireWire, a proprietary heat process that gave outstanding flexibility, and minimal restoring force were utilized to coat these endodontic instruments. This NiTi file had more elasticity and no shape memory or «bounce back» allowing it to achieve incredible canal geometry with dentin preservation in the apical third (EdgeEndo, 2015; Gambarini et al, 2019).

Reciproc blue file

In 2016, an enhanced variant of the traditional Reciproc file named the Reciproc blue file was introduced (VDW, Munich, Germany). Reciproc blue file was a thermally treated NiTi instrument that was produced from M-wire undergoing a complicated heating-cooling patented process, leaving the instrument›s surface with a visible layer of titanium oxide. The Reciproc blue instruments were used to prepare canals without using a glide path. Regardless of the canal›s size and the curve›s extent or the calcified canal, just one file was required to enlarge and taper the majority of canals (De-Deus et al, 2017).

R-Motion file

In 2020 the R-Motion system (RM, FKG, Dentaire, Switzerland) was composed of heat-treated (M wire) NiTi alloy instruments. A technique for electrochemical polishing has been used on this system. Based on the anatomy of the root canal that needs to be treated, the appropriate instrument is chosen. R-Motion instruments have lowered core diameters than comparable competitors› files, which reduces the chance of excessive dentin removal and lessens the impact on non-infected areas. High cutting efficiency is achieved down

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to the apex while maintaining dentin. The rounded triangular cross-strong section›s cutting edges and a newly developed file tip (De Deus et al, 2021).

One RECI file

A new reciprocating single-file system called One Reci (OR; MicroMega, Besançon, France) was recently introduced on the market in 2021. The heat treatment (C-wire) used in OR files is designed to increase the flexibility and centering ability of the instrument. With a deep flute and a changeable off-centered cross-section that begins as a triple helix and gradually transforms into an S-shape toward the shank, it should have excellent cutting efficiency and provide greater room for the evacuation of debris in the coronal direction (Kharouf et al, 2022).

Results and discussion

The reciprocating motion preserved the canal shape (with fewer tendencies to canal transportation) and typically had good cutting efficiency. The reciprocating instruments were found to have reduced apical debris extrusion because the reciprocating instrument was a modified type of balanced force technique that diminished the debris extrusion with little variation in the amount between these instruments. It was identified a controversy about which motion was better concerning the dentinal defects or cracks. The reciprocating instruments created a lower risk of fracture during the preparation since these systems had been demonstrated to travel a shorter circular distance than rotary instruments. Finally, modern studies showed the reciprocating files that were recently introduced have the most reliable characteristics involved; maintaining the canal shape and enhancing an instrument›s fracture resistance with less apical debris extrusion.

Cleaning and shaping

The shaping ability gained from a preparation strategy may impact the succeeding procedures of root canal therapy whether under rotary or reciprocating movement. Endodontic instrumentation may alter root anatomy, particularly in curved canals. However, ledges, zipping and other issues may be developed making it difficult to remove contaminated tissue leading to a failure (Hülsmann et al, 2005). Compared to instruments with continuous rotational motion, instruments with reciprocating motion appeared to have fewer tendencies to canal transportation (You et al, 2011). In general, centering ability varied among different systems. At all canal thirds, the Twisted File system observed markedly decreased canal transportation in comparison to the WaveOne group, but at the apical third, these two groups recorded the least quantity of transportation (Marzouk et al, 2013). In another study, the Reciproc system was proven to be more efficient in terms of cutting properties than the WaveOne system (Plotino et al, 2014). Also, Reciproc and WaveOne instruments are better at preserving the original canal curvature than the OneShape file (Saber et al, 2015). When comparing the reciprocating (Reciproc and WaveOne) systems to continuous rotation (ProTaper and Mtwo) systems, preparation with Reciproc was quicker and more efficient cleaning followed by WaveOne, Mtwo, and ProTaper systems. In the apical portion of the canals, the Reciproc and Mtwo instruments performed much better cleaning and shaping ability than the other instruments. But, in the middle and coronal portions, ProTaper showed a substantial amount of remaining debris (Palatino et al, 2015). Minimal transportation was observed in the apical region with the Reciproc Blue system, followed by WaveOne Gold and ProTaper Next systems,

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so Reciproc Blue demonstrated higher values of centralization in this region (Silva et al, 2018). The most transportation of the canal during preparation was achieved with rotary ProTaper Next files, whereas the most conservative canal preparation was achieved with WaveOne Gold files (Wojciech et al, 2020). In other research, EdgeOne Fire and WaveOne Gold systems caused slight changes in canal curvature; however, EdgeOne performed a reduction in the canal's curvature angle more than WaveOne Gold (Sanguanwongthong & Sakdee, 2020). Orel et al. showed that the ProTaper Gold had greater coronal third centering than WaveOne Gold and Reciproc Blue, whereas Reciproc Blue had better middle third centering than the other files. While WaveOne Gold has a somewhat higher centering ability in the apical third (Orel et al, 2022). Compared to PTG rotary systems and manual instrumentation, R-Motion and RaceEvo rotary systems could be utilized as reliable replacements without having negative mechanical impacts and keeping the original root canal morphology of curved root canal systems (Islam et al., 2021). One RECI demonstrated fewer canal transportation and improved dentin surface contact. Consequently, it may be recommended for use in therapeutic endodontic applications (Mann et al, 2022).

Debris compaction and apical extrusion

Balanced force techniques diminished apical debris extrusion when compared to linear and continuous movements (Al-Omari et al, 1995). Additionally, some authors believed that a single reciprocating file was a modified type from the balanced force technique (Yoo et al, 2012; Bürklein and Schäfer, 2012). When triggered by extruded debris and irrigant, C-type nerve fibers found in the periapical tissues can release neuropeptides, which act as inflammatory process mediators (Caviedes-Bucheli et al, 2008). According to the fact of the previous study, the levels of neuropeptides after canal preparation with Reciproc were slightly equal to those seen in the negative control group (no canal preparation) and lower than those after using the WaveOne system (Caviedes-Bucheli et al, 2013). In another comparison, the Reciproc system generated less apical debris than the ProTaper, Revo-S, and Self-Adjusting systems (Koçak et al, 2013). All these systems (WaveOne, Reciproc, and BioRase) extruded debris beyond the foramen. However, both reciprocating systems apically extruded fewer bacteria than the conventional multi-files BioRase rotary system (Tinoco et al, 2014). When just one instrument was employed for both kinematics (rotary and reciprocating) in two types of research that showed contrasting findings, when using the Reciproc file; Arslan et al, reached the conclusion that reciprocating motion produced less debris than continuous rotation (Arslan et al, 2016). On the other hand, Karatas et al, who employed the Twisted File, concluded that reciprocating motion extruded more debris (Karataş et al, 2016). In another study, all these systems (ProTaper Universal, ProTaper Next, WaveOne, and Reciproc) were associated with apical extrusion of debris when canals were prepared to a large apical size, whereas, the ProTaper Universal system was associated with more debris extrusion than other (Silva et al, 2016). Although the variation in debris extrusion between the WaveOne Gold and Twisted File Adaptive systems was not clearly defined, the WaveOne Gold showed less debris extrusion in curved canals (Boijink et al, 2018). When two reciprocating systems ProDesign and Reciproc Blue were compared, both generated nearly similar

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amounts of apically extruded debris (Amaral et al, 2019). When compared to HyFlex EDM, WaveOne Gold extruded the least amount of apical debris (Elashiry et al, 2020). In another study, the teeth with simulated apical root resorption produced more apically extruded debris than teeth without apical root resorption (Topçuoğlu et al, 2020). The Mtwo rotary system extruded most debris, followed by WaveOne Gold and self-adjusting files (Singh et al, 2021). Ates et al, showed that the EdgeOne Fire system had less apical debris extrusion than the WaveOne Gold system (Ates et al, 2021). Compared to the other subgroups (WaveOne Gold and ProTaper Next), One RECI and One Curve subgroups produced fewer apical extrusion debris (Kharouf et al, 2022). In another study, R-motion displayed reduced apical debris extrusion when compared to Reciproc blue, Hyflex EDM, and Race EVO (Abi Saad et al, 2022).

Dentin defects

Dentin suffered from transitory stress concentrations as a result of the instruments› contact with the canal wall during the preparation of the canal. Dentinal cracks caused by such stress concentrations may result in vertical root fracture (Adorno et al, 2011). It's still controversial which motion was better concerning dentinal defects or cracks. The discrepancies in the instrument designs may be the cause of this controversy. According to reports, taper, size, cross-section, manufacturing process, or alloys utilized in instruments, as well as the preparation method, all have an impact on the likelihood of developing dentinal flaws (Kim et al, 2010; Gao et al, 2012). Liu et al, showed that Reciproc and the Self Adjusting File caused fewer dentinal cracks compared to ProTaper and OneShape rotary instruments (Liu et al, 2013). Dentinal flaws were examined after using the rotary Mtwo and ProTaper to compare with Reciproc and WaveOne systems, all approaches enabled dentin defects to form, but reciprocating instruments caused defects more than rotary near the apex (Abou El Nasr et al, 2014). On the other hand, when comparing ProTaper in rotation with WaveOne in reciprocation at oval canals, the fewest defects were established with the WaveOne system. ProTaper was more aggressive in creating microcracks than WaveOne systems (Ashwinkumar et al, 2014). In the apical portion, when compared to the ProTaper Universal and WaveOne systems, the ProTaper Next and Twisted File Adaptive systems produced fewer cracks (Karataş et al, 2015). Jalali et al, showed that the group prepared with the Reciproc instrument had fewer defects than Mtwo and ProTaper Universal (Jalali et al, 2015). In other investigations, the reciprocating motion of the WaveOne and Reciproc files caused much fewer dentinal cracks than the ProTaper instruments (Wei et al, 2016). Regardless of alloy type, taper, or cross-section, the WaveOne Gold and Reciproc systems performed slightly similar dentinal defects (Tsenova et al, 2018). Martins et al, showed that the Reciproc Blue and HyFlex EDM systems did not produce microcracks in extracted teeth when evaluated with micro-CT (Martins et al, 2021). Another study represented that the Reciproc Blue and Twisted Adaptive instruments caused fewer micro-cracks than ProTaper Gold and ProTaper Universal systems (Aggarwal et al, 2021).

Cyclic fatigue resistance

De-Deus et al., noticed that kinematics motion was an important influential factor on the resistance to cyclic fracture of rotary NiTi files; reciprocation movement promoted a longer resistance to cyclic fatigue of the

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F2 ProTaper instrument when compared to continuous rotation with the same file (De-Deus et al, 2010). Reciprocating files (Reciproc and WavOne) caused a less likelihood of fracture during preparation because these systems had been shown to travel a shorter circular distance than rotary instruments (Mtwo and Twisted File) (Pedulla et al, 2013; Vadhana et al, 2014). However, there was a difference in cyclic fatigue resistance between Reciproc and WaveOne reciprocating systems. The Reciproc file has a higher resistance compared to the WaveOne system (Arias et al, 2012; Pedulla et al, 2014). Once using the Reciproc file, it must be discarded when the case was finished, because the file began to suffer from cyclic fatigue. When an instrument is autoclaved, the plastic band around the handle deformed, this safety feature prevented fatigue fracture due to repeated use (Yared et al, 2013). Indeed, raising the angle of reciprocation and as a result, increasing the angle of progression for each reciprocation cycle leads to lower resistance to cyclic fatigue (Gambarini et al, 2012; Saber et al, 2013). Other researchers also found that the resistance to cyclic fatigue of Reciproc was higher than the other NiTi single-file systems examined, such as OneShape and WaveOne (Dagna et al, 2012; Dagna et al, 2014). In many cases, the reciprocating file systems on the market now have a longer cycle fatigue life than rotary full-sequence systems (Pirani et al., 2014; Kiefner et al, 2014). Other investigations showed that Reciproc R25 had a higher resistance to cyclic fatigue than WaveOne (Higuera et al, 2015). WaveOne Gold and Reciproc R25 instruments showed substantially lower cyclic fatigue resistance than Reciproc Blue R25 instruments (Keskin et al, 2017; Topçuoğlu et al, 2018). Gambarini et al, showed that the EdgeOne Fire system was more resistant than the WaveOne Gold instrument when subjected to cyclic fatigue tests (Gambarini et al, 2019). Reciproc Blue tends to be more resistant to fracture in canals with gentle and acute curvatures than WaveOne Gold (Lall et al, 2021). The innovative R-Motion and RACE EVO instruments are less rigid and more flexible than RaCe instruments due to their higher cyclic fatigue resistance and lower torsional and bending resistance (Basturk et al, 2022). In comparison to WaveOne Gold, One Curve, and ProTaper Next files, one RECI displayed adequate mechanical qualities with the highest cyclic fatigue resistance and angle of rotation (Pedulla et al, 2022).

Conclusion

According to the included studies, the reciprocation improved safety treatment while maintaining the anatomical canal pathway. The reciprocating movement enhanced the instrument›s fracture resistance and less apical debris extrusion. Additionally, there is still controversy in the available studies about which motion was better concerning dentin defects or cracks.

Conflict of interest

We the authors (Ahmed A. Malik, BDS, and Iman M. Al Zaka, MSc) state that the manuscript for this paper is original, and it has not been published previously (or part of MSc. dissertation or PhD thesis) and is not under consideration for publication elsewhere, and that the final version has been seen and approved by all authors.

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