International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Continuous Rotation versus Reciprocity: A Systematic Literature Review

Soukaina El Kharroubi[1], Hasnaa Sakour[2], Malika Karami[3]

[1]Specialist, Department of Conservative Dentistry and Endodontics, Faculty of Dentistry, Hassan II University of Casablanca, Morocco
[2]General Dentist
[3]University Professor, Department of Conservative Dentistry and Endodontics, Faculty of Dentistry, Hassan II University of Casablanca, Morocco

ABSTRACT

The aim of this systematic review was to compare the continuous motion with the reciprocating motion in root canal preparation.

The research was conducted using electronic databases. We collected randomized controlled trials, in vitro comparative studies, simulation studies (fatigue-fracture parameter only), published between 2007 and 2017, and comparing different parameters of root canal preparation. The writing of this systematic review followed the guidelines of the PRISMA Statement (Preferred Reporting Items for Systematic reviews and Meta Analyzes).

43 articles were included in our systematic review. The results showed that rotary single file systems are the fastest in root canal preparation, and the use of multi-file rotary systems showed better results in root canal disinfection.

The reciprocating motion provided better resistance to instrumental fatigue and fracture and reduced dentinal microcracks. In addition, the M-Wire® combined with a low number of instruments makes it possible to respect the canal trajectory and reduce the apical projection of debris.

Keywords: continuous motion, reciprocating motion, nickel-titanium files, root canal preparation, single file technique.

INTRODUCTION

Root canal shaping techniques are subject to numerous evolutions, and several systems have emerged on the market to simplify the protocol. However, the biological and mechanical imperatives of endodontic treatment have clearly been established for several years and remain unchanged. The duration of endodontic treatment, the complexity of sequences, and the fear of failure are factors that lead practitioners to continually search for ways to facilitate their practice. Consequently, the introduction of Nickel-Titanium (NiTi) instruments in 1992 marked a true revolution in endodontic practice. Furthermore, the advent of mechanized instrumentation or continuous rotation (CR) has brought several advantages over manual preparation. In an effort to reduce time, a new instrumental dynamic was proposed by Yared in 2008, based on unequal clockwise and counterclockwise movements, known as reciprocity or asymmetric transverse alternating motion (MATA). Through this review, we will compare the two types of instrumental dynamics (continuous rotation and reciprocity) during root canal preparation in order to determine the advantages and disadvantages of each dynamic and assess the quality of the resulting endodontic treatments.

MATERIALS AND METHODS

Data collection for this systematic review was primarily conducted using two databases: "PubMed" and "Science Direct". Subsequently, other sources were consulted to optimize the search, such as "Wiley Online Library" and "Google Scholar". The search strategy relied on Boolean equations using Anglo-Saxon keywords: Root Canal Preparation - Nickel Titanium – Nitinol – Endodontics - Rotary motion - Reciprocating motion - Continuous Rotary Files - Reciprocating files - Continuous rotary technique - Reciprocating technique - Single file technique.

For studies to be included, they had to meet the following inclusion criteria:

- Randomized controlled clinical trials.
- In vitro and in situ comparative studies of the two instrumental dynamics: continuous rotation (CR) and asymmetric transverse alternating motion (MATA).

- Simulator studies (exceptionally for the instrument fatigue-fracture parameter).
- Published between 2007 and 2017.

Initially, over 400 articles were identified through our literature search, of which 77 were deemed potentially relevant to the topic under investigation. Using the criteria listed above, 43 articles were included. The selected articles are presented in a flow diagram suggested by the "PRISMA Statement" (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Figure 1).

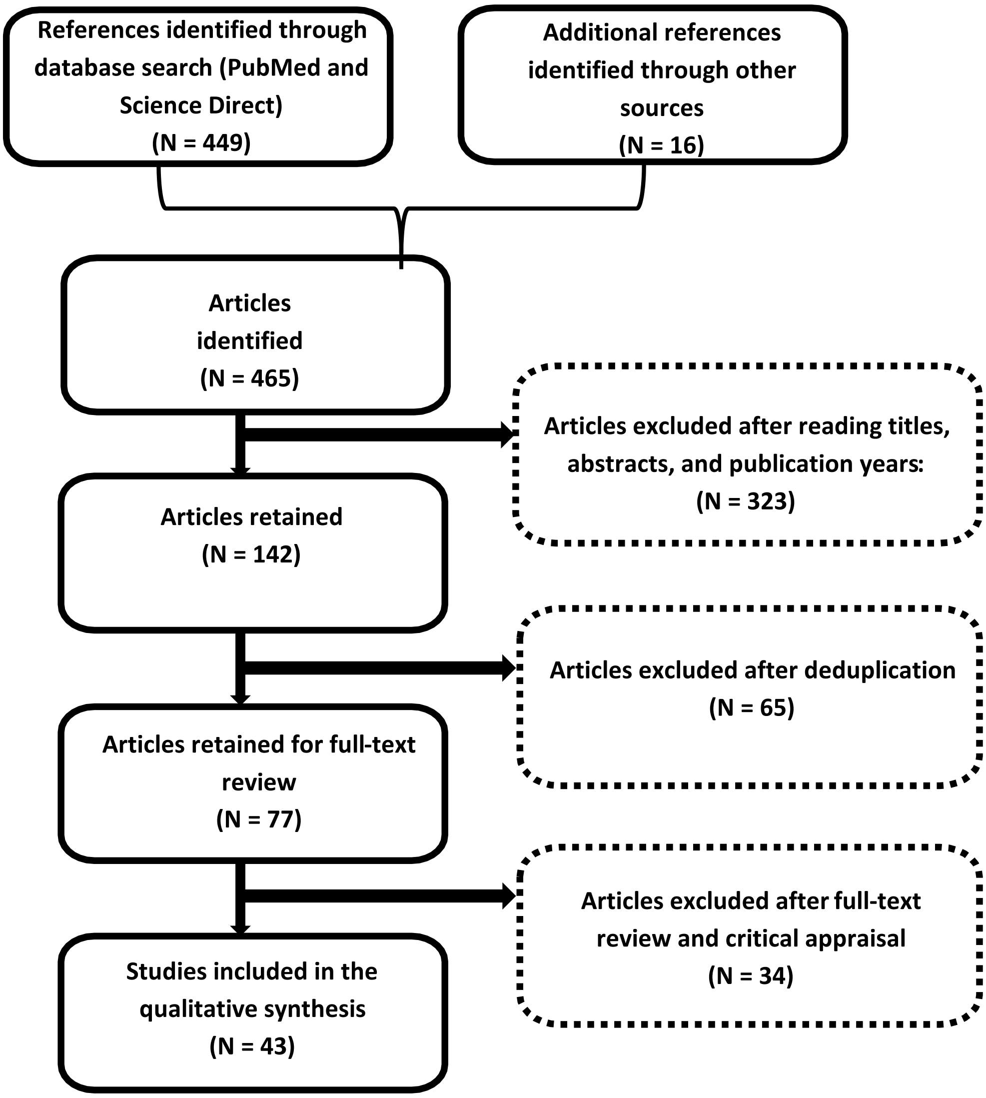

Figure 1: Flow diagram of the article selection and identification process

RESULTS

The studies' results are summarized in the following tables. The distribution of samples (teeth or patients) is randomized for most parameters of root canal preparation, except for instrument fatigue, which is evaluated on platforms. The working length (WL) is set at 1 or 0.5 mm from the apex, and canal patency is confirmed using files #8, #10, or #15. Irrigation is primarily performed with sodium hypochlorite, with varying concentrations and volumes across studies, except in two studies that use distilled water [2,3]. Comparisons are typically made between one or two groups with similar participant characteristics.

Table 1: Preparation time

Articles	Instruments in MATA	Instruments in CR	Outcomes
You S.Y and coll, 2010 [4]	- F2 ProTaper®.	- ProTaper® Universal-(PTU).	Total time for root canal preparation in the continuous rotation group was longer than in the reciprocity

			(MATA) group (46.42 ± 18.12 seconds (s) vs. 21.15 ± 6.70 s).
Paqué F and coll, 2011 [5]	- F2 PTU.	- PTU.	- Total time for root canal preparation in the continuous rotation (CR) group was longer than in the MATA group. MATA = 37.7 ± 13.8 s, CR = 55.5 ± 12.4 s.
Stern S andcoll, 2012 [6]	- F2 PTU.	- PTU. - Twisted Files™ (TF).	- No significant difference in preparation time between the different techniques (TF: 62.5 ± 5.4 s, RC PTU 60.6 ± 3.9 s, and F2 MATA PTU 51.0 ± 3.3 s).
Zhao D and coll, 2014 [7]	- WaveOne® (WO).	- PTU. - ProTaper® Next (PTN).	- Total preparation time (including instrument changes and irrigation) with WO was shorter than with the other two instruments.
Saber S.E.D.M and coll, 2014 [8]	- WO Primary File. - Reciproc® R25 (Rec).	- OneShape® n° 25/.06 (OS).	- Preparation with OS is faster than with WO and Rec, while Rec is significantly faster than WO.

Preparation time is the same when using a single-file system, whether in reciprocity or continuous rotation, and may even be shorter for continuous rotation. Obviously, as the number of instruments increases, the preparation time also increases.

Table 2: Canal disinfection and bacterial elimination

Articles	MATA	RC	Outcomes
Alves F.R.F et coll, 2012 [9]	- Rec R40.	- BioRace®.	- With both systems, the average reduction in bacterial populations exceeded 99.9%. - Comparison of the samples after preparation between the two groups showed no significant difference
Robinson J.P et coll, 2013 [10]	- WO Primary File.	- PTU.	- WO left additional debris of 8.9% in the canals. - Debris accumulated at an average density of 1.60 g/m³ for WO compared to 1.55 g/m³ for PTU (not significant). - The majority of debris was detected in the non-instrumented regions: the protrusions in the canal walls and the isthmuses
Siqueira J.F et coll, 2013 [11]	*- Rec R25.*	*- TF.*	*- Chemomechanical preparation with both systems favored a highly significant bacterial reduction.* *- No significant difference was observed between the groups.*
Martinho F.C et coll, 2014 [12]	*- Rec R40.* *- WO Primary File.*	*- PTU.* *- Mtwo®.*	*- No significant difference was found in the average endotoxin reduction percentages between the MATA systems and the RC systems.* *- Culture analysis revealed no difference in the average bacterial reduction percentages found in the MATA and RC groups.*
Poggio C et coll, 2014 [13]	*- Rec R25.*	*- Mtwo®.*	*-The Mtwo group exhibited significantly lower dentin debris scores than the Rec group in the middle and apical thirds of the canal, but no significant difference was observed in the coronal third.*

Canal disinfection is highly significant for both instrumental dynamics. However, continuous rotation appears to further optimize the cleaning of the canal walls.

Table 3: Adherence to Canal Path and Canal Transportation

Articles	MATA	RC	Outcomes
You S-Y et coll, 2011 [14]	- F2 PTU.	- PTU.	- Canal preparation resulted in a decrease in curvature and an increase in the degree of canal enlargement in both groups. - No statistically significant difference was observed between the two groups regarding the straightening of the canal path. - No significant difference was found between RC and MATA regarding canal transportation.
Paqué F et coll, 2011 [5]	- F2 PTU.	- PTU.	-No significant difference between the groups regarding: ○ Removal of circumferential pulp dentin and the degree of canal enlargement. ○ Transport is in the middle third and apical third of the canal. -Transport in the coronal third (towards the furcation): MATA > RC.
Stern S et coll, 2012 [6]	- F2 PTU.	- PTU. - TF.	- The degree of canal enlargement achieved with the different instrumentation techniques is not significant. - No significant difference regarding canal transportation. - No significant difference in the centering ratio between MATA and RC.
Marzouk A.M et coll, 2013 [15]	- WO Primary File.	- TF.	- WO resulted in a significantly higher average transportation than TF at the apical, middle, and coronal levels. - No significant difference between the two systems regarding changes in curvature and the degree of canal enlargement.
Versiani M.O et coll, 2013 [16]	- WO Large n° 40.08. - Rec R40.	- PTU.	- A significant increase in all parameters tested was observed in all groups: perimeter, surface area, degree of enlargement, major diameter, and minor diameter. -WO and PTU exhibited the greatest increase.
Zhao D et coll, 2014 [7]	- WO.	- PTU. - PTN.	- For all groups, preparation increased the degree of enlargement and the canal surface area. -Mesial canals: Less apical transportation was measured after the use of PTN. -Distal canals: No significant difference in apical transportation between MATA and RC. -No significant differences between the groups for non-instrumented areas.
Saber S.E.D.M et coll, 2014 [8]	- WO Primary File. - Rec R25.	- OS n°25/06.	- The use of OS in RC resulted in a significantly greater canal straightening and apical transportation compared to WO and Rec in MATA. -RC was responsible for twice the canal transportation compared to MATA.

McRay B et coll, 2014 [17]	- WO Primary File.	- PTU.	- No statistically significant difference in the centering ratio between WO in MATA and PTU in RC at 1, 3, 5, and 7 mm from the apex -No statistically significant difference in canal transportation between MATA and RC at 1, 3, 5, and 7 mm from the apex.
Junior A.S.A et coll, 2014 [18]	- Rec R25 then with R40.	- Mtwo n° 10, 15, 20, 25/ Mtwo n° 30,35 et 40.	- Preparation with #40 instruments significantly increased the degree of canal enlargement compared to #25 instruments for both dynamics. -Canal enlargement and residual dentin thickness: no significant difference between RC and MATA.
Baek J.Y et coll, 2014 [19]	- WO Primary File.	- Profile® (PF). - TF.	- For all groups, preparation increased the degree of enlargement and the canal surface area. 0No significant difference between the 3 groups for: Degree of enlargement., Surface area, Canal transportation, Centering ratio, except at 5 mm from the apex where MATA < RC.
uimara es L.S et coll, 2017 [20]	- Rec R40.	- TRUShape® (Dentsply) n° 20 à n° 40.	- Increase in the degree of enlargement and canal surface area in both groups with no significant difference. - At 10 mm from the apex: MATA showed a larger percentage of non-prepared surfaces (30%) compared to RC (24%). - At 4 mm from the apex: no significant difference

The results reveals that the canal path is better maintained with reciprocating motion compared to continuous rotation. However, when using the latter with an improved alloy such as M-Wire®, the results are similar.

Table 4: Fatigue and Fracture Resistance of Instruments

Articles	**MATA**	**RC**	**Outcomes**
Gavini G et coll, 2012 [21]	- Rec R25.	- Rec R25	-Instruments in MATA exhibited a greater number of cycles to fracture compared to instruments in RC
Pedullà E et coll, 2013 [22]	- Rec R25. - WO Primary file /Mtwo® n° 25/06 - TF n° 25/06.	- Rec R25. - WO Primary file.	-Cyclic fatigue resistance was higher in MATA than in RC.
Pérez-Higueras J.J et coll, 2013 [23]	- K3™. - K3XF™. - TF.	- K3™. - K3XF™. - TF.	-The average lifespan was significantly longer for all instruments used in MATA compared to RC. -The probability that instruments used in MATA lasted longer than those used in RC was 100% for K3, 87% for K3XF, and 99% for TF.
Frota M et coll, 2014 [24]	- Rec R25. - WO Primary File.	- F2 PTU. - Mtwo® n° 25/06.	-The number of cycles to fracture was significantly higher for instruments in MATA compared to instruments in RC, regardless of the axial movement.

Vadhana S et coll, 2014 [25]	- Mtwo® n° 25/06. - Race® n° 25/06.	- Mtwo® n° 25/06. - Race® n° 25/06.	-The cyclic fatigue resistance of Race® and Mtwo® significantly increased when used in MATA compared to RC. -No significant difference between the groups for the average length of fractured segments observed at 5 and 6 mm from the tip of the file.
Arslan H et coll, 2016 [26]	- Rec R25.	- Rec R25.	-Cyclic fatigue resistance was higher in MATA than in RC.
Gundogar M et coll, 2017 [27]	- Reciproc® Blue R25. - WaveOne® Gold Primary.	- HyFlex® EDM n° 25. - OS n° 25/06.	- Cyclic fatigue resistance: HyFlex® EDM > Rec Blue > WO Gold > OS. -No significant difference in the average length of fractured segments between the different groups.

Fatigue and fractured resistance are significantly higher in reciprocation. However, the use of instruments made from improved alloys such as CM-Wire® enhances resistance in continuous rotation.

Table 5: Debris Projection Towards the Apical Direction

Articles	MATA	RC	Outcomes
Koçak S et coll, 2013 [28]	- Rec R25.	- PTU. - Revo S®.	- There is no statistically significant difference between the groups.
Tinoco J.M et coll, 2014 [29]	- Rec R25. - WO Medium File.	- BioRace®.	- The RC group was associated with a significantly higher CFU count compared to the two MATA groups. - There is no significant difference in CFU count between the two MATA groups.
Lu Y et coll, 2015 [30]	- Rec R25. - WO Primary File.	- PTU. - BLX®.	-The Rec and WO instruments produced fewer apical debris than the BLX and PTU instruments. -No significant difference was observed between the two MATA systems: Rec and WO, or between the two RC systems: BLX and PTU.
Aydin U et coll, 2016 [31]	- Rec R25.	- OS n° 25/06.	- No significant difference between Rec and OS in the amount of apically extruded bacteria.
Borges A.H et coll, 2016 [32]	- Rec R40. - WO Large File.	- PTU. - PTN. - PF.	- No significant difference was observed when comparing RC systems and MATA systems.
Silva E.J.N.L et coll, [33]	- Rec R40. - WO Large File.	- PTU. - PTN.	-The amount of apically extruded debris was significantly higher with the PTU system compared to the other systems. -No significant difference was observed between the PTN, WO, and Rec systems.

Table 6: Root Cracks and Fracture

Articles	MATA	RC	Outcomes
Burklein S et coll, 2013 [34]	- Rec R40. - WO Large File.	- PTU. - Mtwo®.	- Instrumentation with MATA was associated with significantly more complete cracks compared to RC. -MATA produced significantly more incomplete cracks than RC in the apical 3 mm.

Liu R et coll, 2013 [35]	- Rec n° 25/08.	- PTU. - OS n° 25/06.	-No cracks were observed in the control group. -The Rec instruments caused fewer cracks than the PTU and OS instruments.
De-Deus G et coll, 2014 [36]	- Rec R25 et R40. - WO Primary et Large File.	- BioRaCe®.	-Before preparation, dentinal microcracks were observed in: • 8.72% in the Rec group. • 11.01% in the WO group. • 7.91% in the BioRace® group. -After preparation: no new microcracks were observed.
Li S et coll, 2015 [37]	- WO n° 25/08.	- PTU. - PTN.	-PTU produced more complete cracks than the WO and PTN systems. -PTU and WO produced much more incomplete cracks compared to the PTN system.
Pedullà E et coll, 2016 [38]	- WO n° 25. - Rec R25. - WO Gold n° 25.	- OS n° 25. - F6 SkyTaper® n° 25. - HyFlex® EDM (HEDM) n° 25.	- No microcracks were found in the control group. -All single instruments tested caused dentinal defects, primarily in the apical section. -HEDM in RC and WO Gold in MATA showed fewer microcracks than the other groups, with no significant difference between the two.
Bahrami B et coll, 2017 [39]	- WO Gold n° 25/07.	- TRUShape® n° 25/06.	- No significant difference was observed between WO Gold, TRUShape, and the control group in the frequency of microcracks at 3, 6, and 9 mm from the apex. -No significant difference in the extension, direction, or location of microcracks between MATA and RC.

Reciprocation or MATA seems to reduce the incidence of dentin defects compared to continuous rotation.

Table 7: Retreatment of Root Canal Treatment

Articles	MATA	RC	Outcomes
Rios M.D.A et coll, 2014 [40]	- Rec R25. - WO Primary File.	- PTU Retreatment.	- All teeth examined contained residual filling material in the canals. - No significant difference between the dynamics regarding the amount of residual filling material.
Capar I.D et coll, 2015 [41]	- séquence [PTU-Retreatment + F3 PTU].	- séquence [PTU Retreatment + F3 PTU].	- The average percentage of residual filling material was similar: 11.6% for the RC group and 11.5% for the MATA group. - No significant difference was observed across the different root thirds.

Alves F.R.F et coll, 2016 [42]	- Rec R40.	- Mtwo®.	-RC favored a greater removal of filling material compared to MATA. -The additional use of the XP-Endo Finisher instrument in 17 canals with residual material (12 MATA canals and 5 RC canals) resulted in an average reduction of 69% in the remaining filling material volume; this was statistically significant.

Continuous rotation enhances the removal of previous root canal fillings compared to reciprocation.

Table 8: Postoperative Pain

Articles	MATA	RC	Outcomes
Nekoofar M.H et coll, 2015 [43]	- WO.	- PTU.	-Postoperative pain experienced after preparation with MATA was greater than that experienced in the RC group
Pasqualini D et coll, 2015 [44]	- WO.	- PTU.	-No significant difference in pain scores between MATA and RC. -Difficulty in eating, sleeping, performing daily activities, and managing social relationships was more pronounced in the MATA group.
Shokraneh A et coll, 2016 [45]	- WO.	- PTU.	-Patients in the MATA group reported significantly lower levels of postoperative pain at 6, 12, and 18 hours compared to patients in the RC group. -No significant differences in postoperative pain between the two groups at other time intervals.
Comparin D et coll, 2017 [46]	- Rec.	- Mtwo® Retreatment.	-Retreatment of root canal treatment: No significant difference was observed between the two dynamics for postoperative pain or the use of analgesic medication.

The incidence of postoperative pain does not appear to be influenced by the instrumental dynamics used, whether it is an initial endodontic treatment or a retreatment

DISCUSSION

Preparation Time

Studies by You et al. (4) and Paqué et al. (5), comparing the F2 of ProTaper® (PTU) in reciprocation with the full PTU sequence in continuous rotation, showed that preparation is faster using only the F2 in reciprocation. Similarly, Zhao et al. (7) found the same result when comparing the single-instrument WaveOne® (reciprocation) system with the multi-instrument PTU sequence in continuous rotation. In contrast, Stern et al. (6) observed no significant difference between the F2 PTU used in reciprocation and the PTU sequence in continuous rotation. These studies compared single instruments with a full sequence of four to five instruments, making it unclear whether the time gain was due to the instrumental dynamics or the reduced number of instruments. To eliminate the bias of the number of instruments, Saber et al. (8) compared WO (WaveOne®) and Rec (Reciproc®) with a single-instrument continuous rotation system, OS (OneShape®). The results showed that preparation time with OS was significantly shorter than with the two reciprocating instruments. This study also demonstrated that Rec was faster than WO. The significant difference between WO and the other two instruments could be attributed to their different profiles and cross-sections. OS and Rec had a significantly smaller core diameter compared to WO. WO features a different cross-section along its active part, with a modified triangular tip section and radiant flats, leading to less cutting efficiency due to reduced chip space, which required more time for canal preparation. The difference between OS and Rec could be explained by the different dynamics and rotation speeds. OS was used at a speed of 400 rpm, while Reciproc instruments operate at about 300 rpm with a 150-158° counterclockwise rotation followed by a 30-34° clockwise rotation.

In conclusion, while reciprocating motion generally offered faster preparation time with a single instrument, results varied depending on the number of instruments and their design characteristics. The comparison between reciprocating and continuous rotation systems depended on several factors, including cutting efficiency and instrument configuration.

Canal Disinfection

Studies by Alves et al. (9), Martinho et al. (12), and Siqueira et al. (11), comparing the reciprocation systems Rec/WO with continuous rotation systems PTU, Bio-Race®, TF (Twisted Files®), or Mtwo®, showed that for both instrumental dynamics, the chemo-mechanical preparation was comparable and promoted a highly significant bacterial reduction, based on cultures and/or quantitative PCR analysis (polymerase chain reaction). In Alves et all's study (9), disinfection was highly effective for both dynamics; however, many samples remained positive for bacterial presence after instrumentation. It is important to note that the reciprocation preparation technique (Rec group) did not follow the manufacturer's recommendations; it was adjusted to ensure the same irrigant volume and preparation time as the conventional continuous rotation instrumentation. Similarly, in the studies by Martinho et al. (12) and Siqueira et al. (11), disinfection was very effective for both dynamics, but several samples still presented detectable bacteria after instrumentation. The remaining bacteria were located in non-instrumented areas, canal recesses, isthmuses, and other irregularities of the canal system. It was therefore more reasonable to assume that the difference between Rec/WO and Mtwo®/PTU regarding the apical preparation diameter, including their design features, did not significantly affect the bacterial and endotoxin disinfection outcome. Additionally, Robinson et al. (10) and Poggio et al. (13), who compared WO with PTU and Rec with Mtwo® respectively, using microtomography (microCT) (10) and scanning electron microscopy (SEM) (13), showed that reciprocation systems left significantly more debris compared to continuous rotation systems, especially in the apical and middle thirds of the canal. The continuous rotation instrument movement allowed for a constant expulsion of debris along the file, whereas the reciprocation movement might allow debris to accumulate in protrusions and isthmus areas. Furthermore, the alternating motion of the file might not allow for proper dentin cutting, resulting in a burnishing effect that pushed debris into grooves and isthmuses.

In summary, both reciprocating and continuous rotation systems effectively reduced bacteria during canal disinfection, though some bacteria remained in irregular areas. Reciprocating systems might leave more debris, particularly in the apical and middle thirds of the canal, due to less efficient debris removal caused by the alternating motion.

Canal Pathway and Apical Transportation

Studies by You et al. (14), Stern et al. (6), Marzouk et al. (15), Versiani et al. (16), McRay et al. (17), Junior et al. (18), Baek et al. (19), and Guimaraes et al. (20) agreed that both continuous rotation and reciprocation movements caused straightening and widening of the canal. These studies, comparing WO, Rec, or F2 PTU in reciprocation with PTU, TF, Mtwo®, PF, or TRUShape® sequences in CR, showed no significant difference between the two dynamics based on pre- and postoperative microCT analysis, even in oval canals. Regarding apical transportation, most studies showed no significant difference between Rec and CR, except for three studies: Marzouk et al. (15) found that WO caused more apical transportation than TF, possibly due to the alternating motion and different manufacturing methods. TF with an 8% taper caused minimal apical aberrations, contradicting other studies suggested tapers over 4% should not be used for apical widening. The minimal apical transportation caused by TF compared to WO might be due to the use of low taper instruments before the 8% taper. Paqué et al. (5) observed greater transportation coronally and towards the furcation with reciprocation compared to continuous rotation, likely due to the brushing effect of S1 and S2 along the wall opposite the furcation during continuous rotation. Zhao et al. (7) found no significant difference in distal canals but noted that mesial canals had significantly less apical transportation with PTN compared to WO and PTU, likely due to the smaller apical taper of PTN (X2, 25/6%) compared to F2 PTU and WO Primary (both 25/8%). Saber et al. (8) compared WO, Rec, and OS in curved canals, showed that OS caused more straightening and apical transportation than WO and Rec. WO and Rec, made from M-wire alloy, have superior flexibility compared to OS, made from conventional NiTi, which might explain these differences. Instrument design characteristics also contributed. WO instruments had variable cross-sections and radiant flats, helping them stay centered during apical advancement. (7)

In conclusion, both reciprocating and continuous rotation systems could cause canal straightening and apical transportation, but most studies found no significant difference. Differences observed are mainly linked to instrument design, alloy type, and taper, with reciprocating systems like WO and Rec showing better flexibility and canal centering in curved canals.

Fatigue and Fracture Resistance of Instruments

In Frota and al's study (24), reciprocating instruments (Rec and WO) exhibited high resistance to cyclic fatigue compared to continuous rotation instruments like Mtwo® and F2 PTU. This enhanced resistance is attributed to the M-Wire® alloy, which improved flexibility and fatigue resistance due to its martensitic crystalline microstructure (52). Several studies compared the same systems in both continuous rotation and reciprocation to isolate factors like profile and alloy. For example, Gavini et al. (21) and Arslan et al. (26) compared fracture resistance of Reciproc® in both dynamics, while Pérez-Higueras et al. (23), Vadhana et al. (25), and others studied K3™, K3XF™, TF, Mtwo®, and Race® in both dynamics. In reciprocation, the counterclockwise motion engaged the file, creating a screwing effect, while the clockwise motion disengaged it, reducing compression forces and fracture risks. Pedullà et al. (22) found that reciprocation improved fracture resistance, though WO showed lower fatigue resistance compared to other systems, likely due to the unique cross-sectional design and movement. Gundogar et al. (27) found HEDM (HyFlex® EDM) to have superior cyclic fatigue resistance over Rec Blue, WO Gold, and OS, due to its CM-Wire alloy and electroerosion machining. Rec Blue exhibited higher fatigue resistance than WO Gold, likely due to its titanium-oxidized blue surface and S-shaped cross-section. Almeida-Gomes et al. (54) compared multiple systems, showing that PTN, Rec, WO, and UO had superior cyclic fatigue resistance compared to OS, K3XF™, Mtwo®, PTU, and BioRace®. PTN, made from the same alloy as WO and Rec, demonstrated the best resistance, likely due to its small cross-section enhancing flexibility. Otherwise, Gizem and al. (65) showed that While the TruNatomy system had the highest number of cycles until fracture occurred, no statistically significant difference was found between the Reciproc and WaveOne Gold systems. The ProTaper Next system showed the lowest cyclic fatigue resistance.

In conclusion, reciprocating systems (Rec, WO) generally showed higher cyclic fatigue resistance than continuous rotation systems, mainly due to M-Wire® alloy and motion dynamics that reduced stress. Performance also depended on instrument design and alloy type, with some systems like HEDM and PTN showing superior resistance.

Apical Debris Extrusion

Studies by Koçak et al. (28) and Borges et al. (32) found no significant difference between continuous rotation and reciprocation systems regarding apical debris extrusion. Similarly, Aydin et al. (31) concluded that neither instrument dynamics nor canal morphology significantly affected debris extrusion. Their study emphasized that effective chemo mechanical preparation was more important than the instrument used or canal morphology in reducing bacterial extrusion. However, other studies (29, 33, 30) indicated that continuous rotation systems expelled more debris apically. The superior performance of WO and Rec systems suggested that the reciprocating motion, which mimicked balanced forces (Roane, 1985) without exerting pressure, provided better control over apical debris extrusion (55). Tinoco et al. (29) found that BioRace® expelled more debris than WO and Rec, likely due to the system's design, where the BR1 file rotated freely in the canal, creating a vortex effect that increased apical bacterial extrusion. Silva et al. (33) demonstrated that PTU produced more debris than other systems when comparing PTU, PTN, WO, and Rec. PTU instruments (F2, F3, F4) had larger tapers (8%, 9%, 6%) in the apical 3 mm compared to PTN's smaller tapers (6%, 7%, 6%), resulting in a more aggressive canal preparation and greater debris extrusion. No significant differences were found between PTN and the alternative systems. PTN's superior performance was attributed to its improved alloy and motion, which minimized dentine-file contact, expelling debris coronally. Additionally, PTN required fewer instruments (four files) compared to PTU (six files), further enhancing its performance.

In summary, Reciprocating systems (WO, Rec) generally caused less apical debris extrusion than continuous rotation systems, though results varied. Differences were mainly due to instrument design, taper size, and motion, with more aggressive systems like PTU and BioRace® expelling more debris.

Radicular Cracks and Fractures

The results of the studies showed significant discordance. Burklein et al. (34) demonstrated that dentinal defects occured independently of the type of instrument used. However, in the apical portion of the canals, alternative instruments (WO and Rec) produced much less complete cracks compared to rotary instruments (PTU and Mtwo®). In contrast, Liu et al. (35) found that PTU caused more cracks on the apical root surface and canal wall than single-instrument systems OS and Rec. In this study, Rec, with an 8% apical taper, caused fewer cracks than OS, with a 6% taper, indicating that reciprocity resulted in fewer dentinal defects. Furthermore, the alternative motion showed significantly higher resistance to cyclic fatigue. This movement, combined with M-Wire® alloy, minimized torsional and flexural stresses (56) and reduced canal transport (57). Li et al. (37) concluded that multiple factors caused dentinal cracks during canal preparation, including increased canal curvature, which placed higher stress on the instrument, potentially leading to apical cracks. The taper of the instruments used also influences crack formation, with larger tapers removing more dentine and increasing the risk of root fractures (58). Pedullà et al. (38) revealed that the patient's age could play a significant role in the presence of dentinal cracks, as microstructural changes in dentine due to aging might increase the incidence of defects, which raised with age (59). Instruments with different geometric characteristics did not significantly affect the incidence of microcracks during preparation using either dynamic instrumentation. Moreover, microcrack incidence could be influenced by factors such as NiTi alloy and instrument dynamics. Studies have showed that CM-Wire® instruments (e.g., HEDM) were more flexible than conventional NiTi or M-Wire® instruments. The greater flexibility of WO Gold and HEDM contributed to fewer cracks compared to WO, Rec, OS, and F6 SkyTaper®. Bahrami et al. (39) found no significant difference in the frequency of microcracks between the control (non-prepared) and instrumented groups. Similarly, De-deus et al. (36) observed that the microcracks seen in postoperative images were already present in preoperative images. This study used microCT, a more reliable non-invasive technique, whereas most studies used transverse root sectioning and stereomicroscopic observation. Micro-CT offered several advantages over direct vision techniques:

- It allowed evaluation of samples before experimental procedures, detecting pre-existing defects.
- Three-dimensional localization of defects was possible with or without contrast agents.
- The same sample could be evaluated at different stages of treatment and used for self-monitoring.

Therefore, cleaning and shaping procedures with either continuous rotary or reciprocating systems were not associated with the formation of microcracks.

In summary, Studies on radicular cracks showed mixed results. Reciprocating systems (WO, Rec) might cause fewer cracks than rotary systems, but factors like instrument taper, canal curvature, patient age, and pre-existing defects also played a role. MicroCT studies suggested many cracks existed before instrumentation, indicating that neither motion type directly caused them.

Root Canal Retreatment

Rios et al. (40) found that none of the canals subjected to retreatment were completely free of residual gutta-percha and cement. This was consistent with the findings of Xu et al. (60) and Bramante et al. (61), who reported that 100% removal of residual gutta-percha and cement from canal walls was impossible, regardless of the retreatment technique. Additionally, the Rec and WO systems were not initially designed for retreatment, but their specialized design and alternative motion have been shown to be effective in removing obturation materials. No significant differences were observed between alternative systems and PTU Retreatment sequences. In line with these findings, Capar et al. (41) found no significant difference in retreatment capacity when comparing PTU Retreatment in reciprocity and continuous rotation. Alves et al. (42) showed that Mtwo® Retreatment outperformed Reciproc® due to the continuous rotation movement, which generated a consistent flow of debris coronally. Mtwo® R was also faster in canal de-obturation. An additional approach with the XP-Endo® Finisher instrument significantly improved the removal of residual obturation material.

In conclusion, Complete removal of filling material during retreatment was impossible with any system. Rec and WO, though not designed for retreatment, performed similarly to traditional systems. Mtwo® Retreatment, using continuous rotation, was faster and more effective, and the XP-Endo® Finisher further improved cleaning.

Postoperative Pain

Nekoofar and al. (43) found that postoperative pain was significantly higher in the WO group compared to the PTU group, although pain intensity did not influence analgesic choice. Caviedes-Bucheli and al. (62) showed higher neuropeptide expression in teeth prepared with WO, while Pasqualini et al. (44) found no significant pain difference between continuous rotation (PTU) and reciprocity (WO) groups. Four days post-treatment, pain prevalence was low, regardless of technique or medication (63). Standardizing pain reports was difficult due to individual variability and different measurement methods. Caviedes-Bucheli and al. (62) also noted that instrument design has a larger impact on neuropeptide expression than the number of instruments used. Apical extrusion of debris, shown to influence neuropeptide expression, was observed in both rotary and alternative systems. Shokraneh and al. (45) found less pain in the WO group due to lower apical extrusion. Tinoco and al. (29), Lu and al. (30), and Silva and al. (33) linked continuous rotary preparation to higher apical extrusion and pain, though no significant pain difference was observed 18 hours post-treatment. Comparin and al. (46) found no significant difference in pain between Reciproc® and Mtwo® Retreatment groups, suggesting preoperative factors might influence pain more than the instruments used. Prior studies (64, 65) confirmed higher pain incidence when pre-existing pain was present.

In summary, postoperative pain varied between systems, with some studies showing higher pain in the WO group compared to PTU, while others found no significant difference. Factors like apical extrusion, neuropeptide expression, and pre-existing pain influenced pain levels more than the instrument type.

CONCLUSION

Nickel-titanium (NiTi) instruments with continuous rotary motion offer several advantages over traditional stainless-steel files, including greater flexibility, enhanced cutting efficiency, and improved long-term performance. However, continuous rotation has limitations, and some authors have explored asymmetric reciprocal motion, which allowed for effective canal shaping with a single instrument. The time savings observed with reciprocal motion are primarily due to the reduced number of instruments rather than the instrumental dynamics, as single-instrument continuous rotary systems are the fastest for canal preparation. Since endodontic treatment involves mechanical preparation combined with chemical disinfection, time savings with single-instrument techniques should ideally allow more time for irrigation, while still adhering to the unchanged biomechanical principles of endodontic therapy. Additionally, asymmetric reciprocal motion offers better resistance to fatigue and fracture, and causes fewer dental defects due to disengagement action, which significantly reduces stress on the instrument. Furthermore, the M-Wire® alloy, when combined with a reduced number of instruments, helps maintain the canal trajectory and reduces apical extrusion of debris due to its high flexibility. Each motion type has its advantages, and while reciprocal motion has demonstrated clear benefits, a solid understanding and control of the instrumental dynamics remain key to successful endodontic treatment.

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