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Influence of endodontic motors on the behaviour of root canal shaping instruments: an in vitro comparative study

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AIMS: The endodontic literature reports a lot of comparative study on endodontic instruments, concerning as well their geometry, instrumental dynamics, material, mechanical behavior or heat treatment. However, to our knowledge, no study has focused on the influence of endodontic motors on the shaping abilities of endodontic instruments. Thus, the aim of this study was to analyze the influence of the endodontic motors on root canal shaping instruments.

METHOD: Dual Move (MICRO-MEGA, Besançon, France), Canal Pro CL2i (COLTENE, Alstätten, Suisse), Canal Pro Jeni Motor (COLTENE, Alstätten, Suisse), Ai Motor (WOODPECKER, Guilin, China), Wave One motor (VDW, Postfach, Munich) and Smart A (WOODPECKER, Guilin, China) were pre-clinically compared in continuous rotation and reciprocating motion on a traction/compression bench using resin blocks. Canal shaping in continuous rotation and reciprocating motion were performed with One Curve and One RECI instruments (MICRO-MEGA, Besançon, France), respectively. The penetration/removal forces, making it possible to objectify the cutting effect and screwing effect of the instruments during root canal shaping, were analyzed.

RESULTS: The results showed (i) that endodontic motors influence the mechanical behavior of endodontic instruments, (ii) that the influence of the motors is essentially felt during reciprocating motion and (iii) that the reciprocating angles influence the mechanical behavior of endodontic instruments.

CONCLUSION: Only endodontic instruments are widely studied in literature while endodontic motors have a direct influence on root canal treatment. This study analyzes the influence of the endodontic motors on root canal shaping instruments. This study tends to demonstrate that Jeni Motor could optimize the mechanical behavior of endodontic instruments.

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INTRODUCTION

Since the advent of nickel titanium and the democratization of mechanized endodontic instruments, the endodontic market has continuously developed to offer safer and more efficient solutions [1–3]. In this context, instrumental developments in terms of materials [4–6], geometries [7–12], kinematics [13–22], surface [5, 23–27] and thermal treatments [28–33] have gradually allowed to offer more reproducible endodontic treatments. By taking these different parameters one by one as variable, several mechanical and pre-clinical studies have made it possible to compare these instruments in terms of flexibility [10, 28, 34–46], cyclic fatigue [19, 36–38, 42, 47–57], resistance to torsion [43–45, 58, 59] and separation incidence. [10, 60–64] The aim of these endodontic developments is to limit therapeutic errors as much as possible, especially instrument breakage [65].

In parallel with these instrumental developments, endodontic motors and kinematics have also been widely developed [66–70]. Historically on the dental unit, these motors had only one mode of continuous rotation without any torque control. Then came the first dedicated endodontic motors with torque control, then the first non-wired motors. Subsequently, different instrumental dynamics

were implemented, among which we can cite the reciprocating motion. More recently, manufacturers have offered “intelligent endodontic motors”, as such as the Canal Pro Jeni (COLTENE, Alstätten, Germany), the TriAuto ZX2+ (MORITA, Osaka, Japan) or the EndoPilot (KOMET, Lemgo, Germany), allowing to adapt its movement by analyzing the torsion constraints in real time.

Today, all endodontic manufacturers propose endodontic motors in addition to their range of instruments. However, the scientific literature has not extensively investigated endodontic motors and the studies generally highlight the non-reproducibility between kinematics settings and manufacturers’ declared values [70–74], torque analysis [68, 75–78] or integrated apex locator [79–84]. To our knowledge, no study has been properly carried out on the impact of the endodontic motor on root canal shaping. Similarly, no study has made it possible to highlight an equivalence or not between these motors, their different modes or instrumental dynamics.

Therefore, by taking endodontic instruments as a fixed parameter, this paper proposes to study endodontic motors as a variable by pre-clinically comparing them by penetration/removal preclinical tests.

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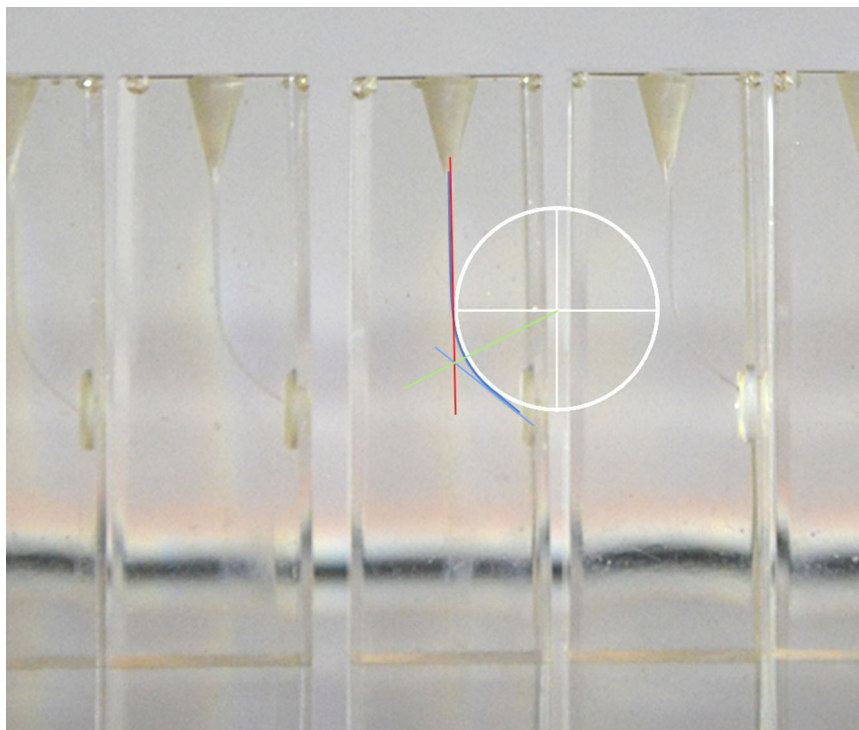


Fig. 1 DENTSPY MAILLEFER endodontic resin block. The blue and red lines are the tangents of the white circle. The intersection of the green line and the blue curve marks the point where the bending is maximum. The radius of the white circle represents the radius of curvature.

MATERIALS AND METHODS

Fixed parameters

Resin blocks. 120 resin blocks (DENTSPLY SIRONA, Ballaigues, Switzerland) were used for the performance and security tests on traction / compression bench.

The DENTSPLY SIRONA resin blocks have an average length of 18 mm with an apical permeability, an average radius of curvature of 4.5 to 5 mm and an average curvature of 30 to 50° (Fig. 1). According to the AAE Endodontic Case Difficulty Assessment Form and Guidelines, these endodontic blocks simulate complex endodontic cases.

For each tested endodontic motor, 10 blocks were shaped in continuous rotation and 10 blocks in reciprocating motion.

Root canal shaping instruments. Concerning the continuous rotation tests, all the resin blocks were shaped using the following protocol:

- permeabilization using a K.10 file (MICRO-MEGA, Besançon, France);
- shaping using the One Curve instrument (MICRO-MEGA, Besançon, France).

Concerning the reciprocating motion, all the resin blocks were shaped using the following protocol:

- permeabilization using a K.10 file (MICRO-MEGA, Besançon, France);
- shaping using the One RECI instrument (MICRO-MEGA, Besançon, France).

Variable parameters

The tested endodontic motors are DualMove (MICRO-MEGA, Besançon, France), Canal Pro CL2i (COLTENE, Langenau, Germany), Jeni Motor (COLTENE, Langenau, Germany), Ai Motor (WOODPECKER, Guilin, China), Wave One motor (VDW, Postfach, Munich) and Smart A (WOODPECKER, Guilin, China).

For the continuous rotation tests, all the motors were set at a speed of 350 rpm and a maximum torque of 2.5 N.cm, in accordance with the One Curve manufacturer recommendations. Contrary to the other motors, the Jeni Motor presents a specific program for One Curve with an assistance system that control the variable instrument movements.

For the reciprocating motion tests, all the motors could not be configured according to the One RECI manufacturer recommendations

due to non-present reciprocating angle ranges. In addition, all motors could not associate a speed or a maximum torque during reciprocating motion mode. The reciprocity parameters were:

- Dual Move: 60 °CW/170 °CCW (the manufacturer does not offer the possibility to change rotation speed and maximum torque);
- Canal Pro CL2i: 30 °CW/150 °CCW, rotation speed 350 rpm and maximum torque 4 N.cm (the manufacturer does not offer the possibility to set the One RECI angle parameters);
- Jeni Motor: equivalent of 60 °CW/170 °CCW set in milliseconds, rotation speed 350 rpm and maximum torque 4 N.cm (the Jeni Motor doesn't present a specific assistance system for One Reci; it was used with the "Doctor's choice" mode);
- Ai Motor: 60 °CW/170 °CCW, rotation speed 350 rpm and maximum torque 4 N.cm;
- Wave One Motor: 30 °CW/150 °CCW (the manufacturer does not offer the possibility to change rotation speed, maximum torque none to set the One RECI angle parameters);
- Smart A: 60 °CW/170 °CCW, rotation speed 400 rpm, maximum torque 4 N.cm (the manufacturer offers a non-editable One RECI program with a 400 rpm rotation speed).

Penetration/removal preclinical tests

The development of an endodontic penetration/removal (P/R) protocol was carried out on a traction machine (Zwick/Roell-50 N force cell, Ulm, Germany) controlled by the testXpert II software (Zwick/Roell) in the LEM3 laboratory (PolyTech, Nancy, France) [85]. This protocol corresponds to a free P/R test involving 25 successive charge/discharge cycles, divided into 9 groups of cycles, allowing the descent and the work of the tested endodontic instrument in a resin block having a radius of curvature about 4.5 mm (DENTSPLY SIRONA, Ballaigues, Switzerland). Complete instrumental removal is performed between each cycle allowing (i) a canal irrigation to remove debris and (ii) a verification of the maintenance of apical patency. The vertical components of the force and displacement are measured. At the end of each test, the maximum penetration and removal forces are recorded for each group of cycles by testXpert II software (Zwick/Roell). Only the max torque was defined. No real-time measures of torque has been made. This protocol was established in order to respect

Table 1. P/R protocol in continuous rotation: penetration from 10 to 14 mm.

			Penetration [mm]	Speed [mm/s]	Stop [s]
Group 1	Cycle 1	Charge	11	5	
		Discharge	10.5	5	
	Cycle 2	Charge	11.5	5	
		Discharge	11	5	
	Cycle 3	Charge	12	5	
		Discharge	11.5	5	
	Irrigation		-51	15	5
Group 2	Cycle 4	Charge	12.5	5	
		Discharge	12	5	
	Cycle 5	Charge	13	5	
		Discharge	12.5	5	
	Cycle 6	Charge	13.5	5	
		Discharge	13	5	
	Irrigation		-51	15	5
Group 3	Cycle 7	Charge	14	5	
		Discharge	13.5	5	
	Cycle 8	Charge	14.5	5	
		Discharge	14	5	
	Cycle 9	Charge	15	5	
		Discharge	14.5	5	
	Irrigation		-51	15	5

The protocol considers the 1 mm wedge positioned between the instrument and the resin block.

Table 2. P/R protocol in continuous rotation: penetration from 14 to 16 mm.

			Penetration [mm]	Speed [mm/s]	Stop [s]
Group 4	Cycle 10	Charge	15.25	2	
		Discharge	15	2	
	Cycle 11	Charge	15.5	2	
		Discharge	15.25	2	
	Cycle 12	Charge	15.75	2	
		Discharge	15.5	2	
Cycle 13	Charge	16	2		
	Discharge	15.75	2		
	Irrigation		-51	15	5
Group 5	Cycle 14	Charge	16.25	2	
		Discharge	16	2	
	Cycle 15	Charge	16.5	2	
		Discharge	16.25	2	
	Cycle 16	Charge	16.75	2	
		Discharge	16.5	2	
Cycle 17	Charge	17	2		
	Discharge	16.75	2		
	Irrigation		-51	15	5

The protocol considers the 1 mm wedge positioned between the instrument and the resin block.

the clinical reality and to be reproducible. It shows three groups of parameters appropriate to the work of the associated canal section:

- Canal penetration from 10 to 14 mm, before the curvature (Table 1),
- Canal penetration from 14 to 16 mm, in the most coronal part of the curvature (Table 2),

- Canal penetration from 16 to 18 mm, in the most apical part of the curvature (Table 3).

The endodontic instrument is mounted on an endodontic contra-angle connected to the programmable endodontic motor tested. The instrument

Table 3. P/R protocol in continuous rotation: penetration from 16 to 18 mm.

			Penetration [mm]	Speed [mm/s]	Stop [s]
Group 6	Cycle 18	Charge	17.25	2	
		Discharge	17	2	
	Cycle 19	Charge	17,5	2	
		Discharge	17.25	2	
	Irrigation		-51	15	5
Group 7	Cycle 20	Charge	17.75	2	
		Discharge	17.5	2	
	Cycle 21	Charge	18	2	
		Discharge	17.75	2	
	Irrigation		-51	15	5
Group 8	Cycle 22	Charge	18.25	2	
		Discharge	18	2	
	Cycle 23	Charge	18.5	2	
		Discharge	18.25	2	
	Irrigation		-51	15	5
Group 9	Cycle 24	Charge	18.75	2	
		Discharge	18,5	2	
	Cycle 25	Charge	19	2	
		Discharge	18.75	2	
	Irrigation		-51	15	5

The protocol considers the 1 mm wedge positioned between the instrument and the resin block.

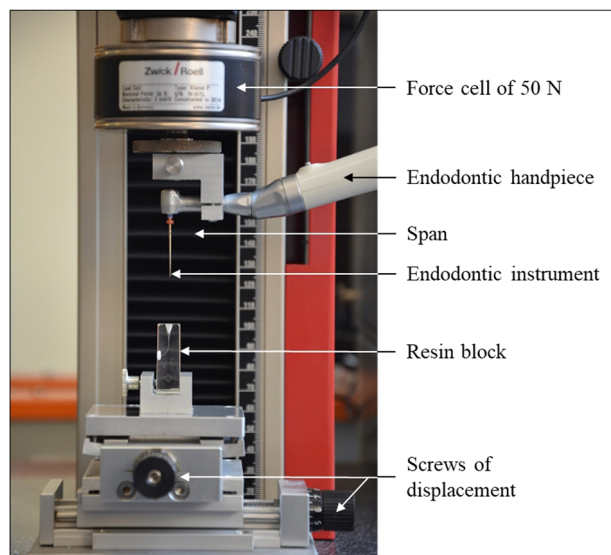


Fig. 2 P/R bench used for this study. The black arrows show the different elements of the bench.

under test is positioned to 1 mm from the occlusal edge of the resin block using a wedge.

The irrigation protocol was not standardized. Between each group of cycles, a first irrigation was made by the same operator with water until complete elimination of the coronal two-thirds debris. Then, the apical patency was verified with a K.10 file. Finally, a last irrigation was made to eliminate the debris from the apical third placed in suspension after the apical patency verification.

The penetration/removal bench is shown in Fig. 2.

Statistics

Numerical data were analyzed using non-parametric Kruskal-Wallis-type statistical tests. A Dunns correction with $\alpha = 0.05$ was performed for the

two-by-two multiple comparisons. The results were considered statistically significant for a P value < 0.05 . All statistical analyzes were performed using GraphPad Prism® 6 software (San Diego, California, US).

RESULTS

In our work, two types of forces are recorded by the force cell.

-Positive compressive forces which correspond to the penetration forces. Low penetration forces mean an effective cutting effect of the instruments.

-Negative traction forces which correspond to the removal forces. High removal forces mean high screwing forces driving the instruments in the apical direction.

These two types of forces are directly linked to the profile of the endodontic instrument. Therefore, instrument with cutting efficiency will tend to have higher screwing sensations.

Continuous rotation

During continuous rotation kinetics, the influence of the endodontic motors on the mechanical behaviour of the instruments is low. Few significant differences are found for the Jeni Motor and the Dual Move. Concerning the Jeni Motor, the differences appear during all the steps of canal shaping. However, Dual Move differences only appear on the apical part during removal steps.

All the results in continuous rotation are reported in the Fig. 3 and Tables 4, 5.

Reciprocating motion

During reciprocating motion, several significant differences are found bringing to light the complexity of this kinetic. Its main findings that the Canal Pro CL2i motor had the worst influence on the mechanical behaviour of the instruments. Wave One Motor, Ai Motor and Jeni Motor seems better respecting the reciprocating requirements.

All the results in reciprocating motion are reported in the Fig. 4 and Tables 6, 7.

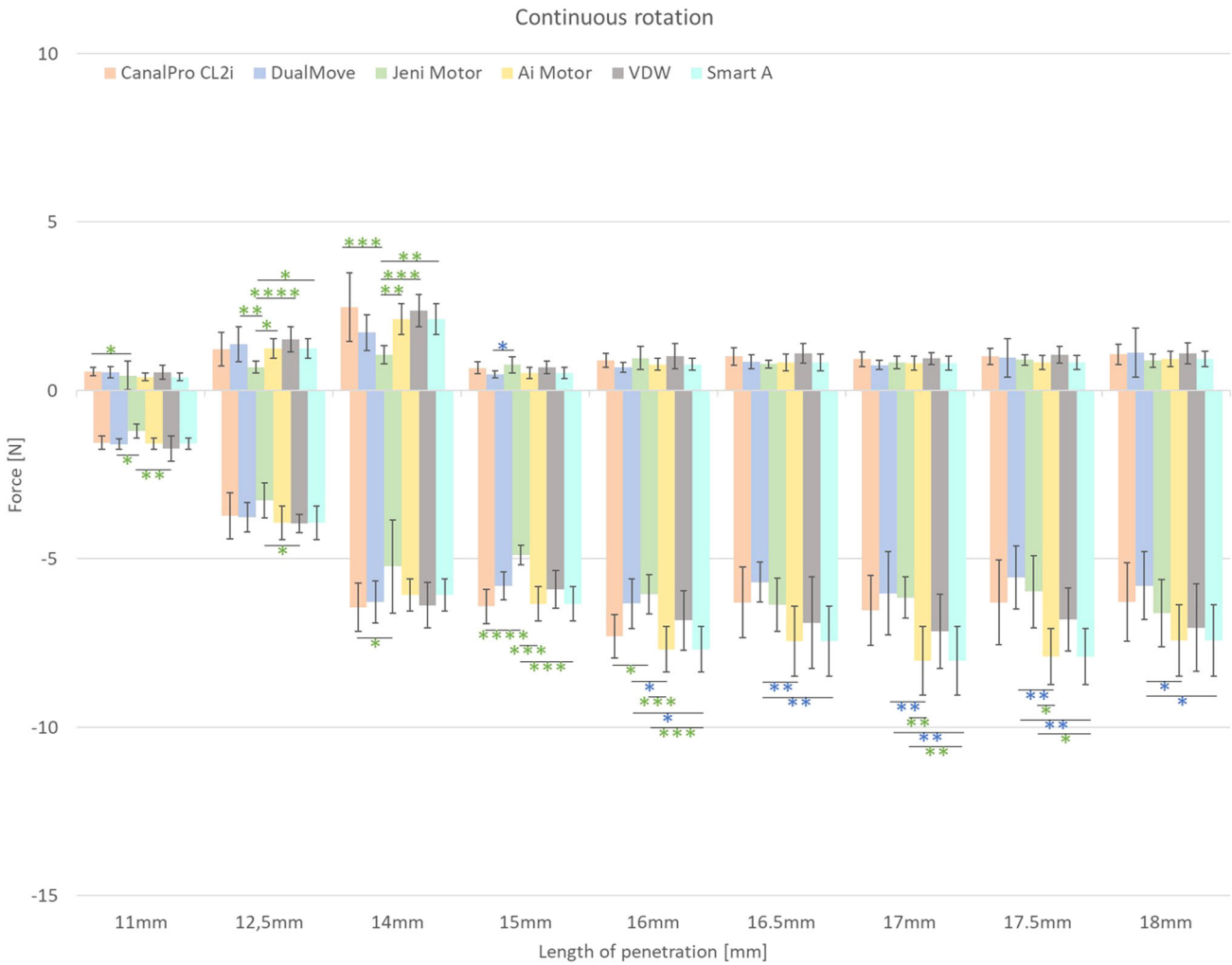


Fig. 3 P/R results after shaping of the resin blocks with One Curve instruments drove by different endodontic motors (* $P > 0.05$; ** $P > 0.01$; *** $P > 0.001$; **** $P > 0.0001$). The positive and negative forces represent the penetration and removal forces, respectively. When statistical significance is present, the statistical significance marks have the color of the best endodontic motor.

Table 4. Statistically significant differences obtained in penetration during continuous rotation tests (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; **** $P < 0.0001$).

Continuous Rotation	Dual Move	Canal Pro CL2i	Jeni Motor	Ai Motor	Wave One motor	Smart A
Dual Move		15 mm*				
Jeni Motor	12.5 mm**	11 mm* 14 mm***		12.5 mm* 14 mm**	12.5 mm**** 14 mm***	12.5 mm* 14 mm**

Table 5. Statistically significant differences obtained in removal during continuous rotation tests (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; **** $P < 0.0001$).

Reciprocating Motion	Dual Move	Canal Pro CL2i	Jeni Motor	Ai Motor	Wave One motor	Smart A
Dual Move				16 mm* 16.5 mm** 17 mm** 17.5 mm** 18 mm*		16 mm* 16.5 mm** 17 mm** 17.5 mm** 18 mm*
Jeni Motor	11 mm*	14 mm* 15 mm**** 16 mm*		15 mm*** 16 mm*** 17 mm** 17.5 mm*	11 mm** 12.5 mm*	15 mm*** 16 mm*** 17 mm** 17.5 mm*



Fig. 4 P/R results after shaping of the resin blocks with One RECI instruments drove by different endodontic motors (* $P > 0.05$; ** $P > 0.01$; *** $P > 0.001$; **** $P > 0.0001$). The positive and negative forces represent the penetration and removal forces, respectively. When statistical significance is present, the statistical significance marks have the color of the best endodontic motor.

DISCUSSION

Concerning the reciprocating motion, Fidler showed that is a complex kinematic to apprehend, presenting more critical parameters than only angles and rotational speed [74]. He concluded that actual kinematics values differ from manufacturers' declared values. In the same way, Irmak and Orhan (2017) showed that the actual kinematics of reciprocating endodontic motors differ from the manufacturers' set values [73]. Braambati et al. studied the CCW angle, CW angle, speed at both directions, and standstill time at each change of directions and confirmed that none of the motors were able to reproduce faithfully the set movements [71]. Regarding the continuous rotation motion, Monteiro-Netto et al. studied the rotational speed parameters of three endodontic motors. They demonstrated that endodontic motors presented different behaviors between them [72].

In conclusion, there is a difference between the values recommended by the manufacturer and the values that the motors achieve. Taking this fact into consideration, our study looked at the potential clinical impact of using one motor more than another.

It is important to note that the One RECI instruments have the same cross-section as the One Curve instruments. The only difference is the One RECI step inversion allowing the practitioner to conventionally keep the main reciprocity angle in a counter-

clockwise way. Therefore, the choice of these instruments was made to fix the geometry parameter, which has a very strong impact on the analysis of the penetration/removal forces.

In the first hand, endodontic motors obtain good results in terms of reproducibility during continuous rotation movements. The differences are most often of the order of 1 N, therefore considered not perceptible from a clinical point of view. Continuous rotation is limited to a rotational speed and a maximum torque setting. These easy-to-manage parameters could explain why all the endodontic motors obtain very close results to each other. However, we can note that the Jeni Motor obtains the best results in penetration and removal, followed by the Dual Move motor. This first conclusion underlines the interest of intelligent endodontic motors. Effectively, due to its specific assistance system that control the variable instrument movements, the Jeni Motor is the only tested motor in our work which can adapt the One Curve kinematics movements according to torsional stresses. This particularity is certainly the reason why the Jeni Motor achieves the best results during continuous rotation movements. The Canal Pro CL2i motor is the only motor that has reached the maximum torque limits during canal shaping, mainly in the medial and apical parts of the canals.

In the other hand, the results obtained during reciprocating motion are much difficult to analyze than those obtained during

Table 6. Statistically significant differences obtained in penetration during reciprocating tests (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; **** $P < 0.0001$).

Continuous Rotation	Dual Move	Canal Pro CL2i	Jeni Motor	Ai Motor	Wave One motor	Smart A
Jeni Motor	15 mm** 16 mm** 16.5 mm* 17.5 mm*	11 mm** 14 mm*** 15 mm**** 16 mm**** 16.5 mm*** 17 mm*** 17.5 mm**** 18 mm***				
Ai motor	12.5 mm** 14 mm** 15 mm** 16 mm** 16.5 mm** 17 mm** 17.5 mm** 18 mm*	11 mm**** 12.5 mm**** 14 mm**** 15 mm**** 16 mm**** 16.5 mm**** 17 mm**** 17.5 mm**** 18 mm****				16.5 mm** 17 mm** 17.5 mm* 18 mm*
Wave One motor	12.5 mm* 14 mm* 15 mm* 16 mm** 16.5 mm** 17 mm* 17.5 mm* 18 mm***	11 mm**** 12.5 mm**** 14 mm**** 15 mm**** 16 mm**** 16.5 mm**** 17 mm**** 17.5 mm**** 18 mm****				16.5 mm* 17 mm** 18 mm*

Table 7. Statistically significant differences obtained in removal during reciprocating tests (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; **** $P < 0.0001$).

Reciprocating Motion	Dual Move	Canal Pro CL2i	Jeni Motor	Ai Motor	Wave One motor	Smart A
Dual Move		11 mm**** 12.5 mm**** 14 mm** 15 mm**** 16 mm**** 16.5 mm**** 17 mm**** 17.5 mm**** 18 mm****		11 mm*		12.5 mm* 16 mm* 18 mm*
Jeni Motor		11 mm* 12.5 mm* 14 mm* 15 mm* 16 mm** 16.5 mm** 17.5 mm** 18 mm*				
Ai motor		12.5 mm* 14 mm**** 15 mm*** 16 mm* 16.5 mm** 17 mm** 17.5 mm* 18 mm*				
Wave One motor		11 mm** 12.5 mm**** 14 mm**** 15 mm**** 16 mm**** 16.5 mm**** 17 mm**** 17.5 mm**** 18 mm****				12.5 mm* 18 mm*
Smart A		11 mm** 17 mm*				

continuous rotation movements. Reciprocating settings are more complex and include (i) clockwise and anti-clockwise angle, (ii) overall speed of rotation, (iii) clockwise acceleration, (iv) counter-clockwise acceleration (v) maximum torque and (vi) standstill time during the direction changes. All motors are not programmable in the same way. For example, some motors do not present all the ranges of reciprocity angles, others do not allow to program the speed or the maximum torque in reciprocating mode. The differences inherent to each motor were important to consider and highlight the disparity in motor parameters. However, no contraindication to the use of endodontic instruments on these motors is mentioned, both on the instrument and motor instructions. In reciprocity, only the angles of rotation are systematically communicated. Therefore, a practitioner could use a motor with a non-recommended speed or torque due to the impossibility to program the motor. In our study, these parameters were deliberately not changed in order to reproduce clinical reality. Therefore, it is important to know the indications of each motor/instrument couple if some motor parameters are not programmable. At equivalent engine parameters, our results show very different penetration and withdrawal force values. In accordance with literature, this observation confirms that the declared manufacturers' values are different from the really obtained ones [71–74].

The Jeni Motor angles are set by the combination of rotation speed and duration in milliseconds in clockwise/counter-clockwise directions. Therefore, the Jeni Motor is the only fully reciprocally programmable motor. Our study showed that the Jeni Motor reach one of the best results in reciprocating motion despite the lack of specific assistance for the One Reci. The Wave One motor is the oldest tested motor and is one of the first technologies on the market to have offered reciprocating motion. The good mastery of this movement could therefore explain its good results.

The Ai Motor obtained the best results for the 60°/170° angles, followed by the Jeni Motor. The Wave One motor obtained the best results for 30°/150° angles. In addition, it is interesting to note that the One RECI instruments (manufacturers recommendations 60 °CW/170 °CCW) showed better mechanical behavior at 30 °CW/150 °CCW with the Wave One Motor than at 60 °CW/170 °CCW with Dual Move, Ai Motor and Smart A motors.

The Ai Motor obtained excellent results in reciprocating motion, both during penetration and removal movements. The Dual Move also presented good results, mainly during removal movements. The Canal Pro CL2i obtained the worst results. This could be explained by a higher difference between the entered and obtained values of the Canal Pro CL2i motor than those of the other tested motors. Accordingly with this hypothesis, the root canal instruments were used in unfavorable conditions which could increase the stresses suffered.

CONCLUSION

Within the limits of this study, we can highlight (i) that endodontic motors influence the mechanical behavior of endodontic instruments, (ii) that the influence of the motors is essentially objectified during reciprocating motion and (iii) that the reciprocating angles influence the mechanical behavior of endodontic instruments.

For continuous rotation and within the limits of our results, we obtained:

Jeni Motor > Dual Move > [Ai Motor–Wave One–Smart A] > CL2i

For reciprocating motion results, taking account the correct or not correct parameter settings and within the limits of our results, we obtained:

[Wave One Motor–Ai Motor–Jeni Motor] > Dual Move > Smart A > Canal Pro CL2i

DATA AVAILABILITY

The datasets supporting the conclusions of this article are included within the article and its additional files.

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AUTHOR CONTRIBUTIONS

Corresponding author: MV; Conceptualization: MV; methodology: MV ; formal analysis: CR; MV; Investigation: CR; RG; Data curation: RB; Writing—original draft preparation: EM; MV; Writing—review and editing: CR; RG; JD; J-MM; EM; RB; MV; Visualization: CR; MV; Supervision: RB; Project administration: MV. All authors have read and agreed to the published version of the manuscript. GIESS Renaud is co-first author and BALTHAZARD Rémy is co-last author.

COMPETING INTERESTS

The authors declare no competing interests.

ETHICS DECLARATION

None to declare. Ethical approval was not required for this study on dental instruments.

ADDITIONAL INFORMATION

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