Agreement and Reliability of An Endodontic Motor with Integrated Electronic Apex Locators During Gutta-Percha Retrieval: An Ex Vivo Comparative Study

Pamornauckakate Saikaew[1] Suwit Wimonchit[1*]

Abstract

Objective: This ex vivo study evaluated the agreement and reliability of two endodontic motors with integrated electronic apex locators, Tri Auto ZX2® and VDW.GOLD® RECIPROC®, for canal length measurement during gutta-percha retrieval.

Materials and Methods: Thirty extracted maxillary premolars were prepared with occlusal reduction to create a flat reference surface, and standard endodontic procedures were performed. Before obturation, canal length was determined by inserting a file to 0.5 mm short of the apical foramen, defined as the "actual length" (AL). The specimens were embedded in an experimental acrylic model using alginate. After obturation, canal length was remeasured during gutta-percha retrieval using the two tested devices at the 1.0 and 0.5 marks. Differences between measurements were compared using the Mann–Whitney U test, while agreement and reliability were assessed using the intraclass correlation coefficient (ICC) and Bland–Altman analysis.

Results: For both endodontic motors, measurements at the 1.0 mark were closer to the AL and showed a statistically significant difference compared with those at the 0.5 mark. The ICC indicated good reliability for measurements at the 1.0 mark in both devices, with values around 0.87. Bland–Altman analysis demonstrated that the measurements were within acceptable limits of agreement, with minimal dispersion at the 1.0 mark.

Conclusions: The 1.0 mark setting of both Tri Auto ZX2® and VDW.GOLD® RECIPROC® provided better agreement in canal length measurements during gutta-percha retrieval and may help reduce the risk of overinstrumentation.

Keywords: Electronic apex locator, Retreatment, Tri Auto ZX2®, VDW.GOLD® RECIPROC®, Working length determination

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Introduction

Root canal retreatment is the treatment of choice for recurrent or reinfected endodontically treated teeth (1, 2). This procedure involves several steps, including retrieval of old root canal filling, re-instrumentation, canal debridement, and re-obturation of the root canal (3). Successful retreatment relies on precise determination of working length, as underfilling — resulting from under instrumentation — can lead to persistent microbial contamination within the canal, whereas overfilling — caused by over instrumentation — may injure periapical tissues, push debris beyond the apex, and ultimately infect the periapical area. Sjögren et al. reported that the success rate of retreatment is lower than that of primary root canal treatment, particularly when underfilling or overfilling occurs (4). These findings highlight that proper agreement between measured and actual working length is a key factor for the success of root canal retreatment.

Electronic apex locators (EALs) are widely used in clinical practice to determine working length with high precision. Previous studies have reported that EALs achieve accuracy exceeding 95% in primary root canal treatment (5, 6), with measurements at the 0.5 mark corresponding to file tip positions within ±0.5 mm of the apical foramen (7). Consistently, Alothmani and Siddiqui (8) demonstrated that readings taken at the apex mark were associated with a higher risk of overextension beyond the apex compared with measurements at the 0.5 mark.

Previous studies indicate that EAL accuracy is lower in root canal retreatment than in primary treatment. Reported accuracy ranges from 31% to 92%, varying by device (9). Similar findings were reported by Aggrawal et al. (10) and Tufenkci and Kalayci (11), with a higher likelihood of readings extending beyond the apex. This reduction in accuracy has been attributed to changes in canal contents affecting impedance-based measurements (12). During retreatment, overinstrumentation and overfilling at the apex are common (13), and post-instrumentation changes in canal length may further compromise treatment outcomes, contributing to reduced periapical healing (14).

Nowadays, several endodontic motors integrated with EALs have been developed to instrument root canals and simultaneously measure working length (13, 15–21). Tri Auto ZX2® (J. Morita Mfg. Corp., Kyoto, Japan), a new version of the previous Tri Auto ZX®, and VDW.GOLD® RECIPROC® (VDW GmbH, Munich, Germany) are examples of such devices. These motors can operate in apex locator mode or perform mechanical instrumentation while measuring working length concurrently (18–21). In primary root canal treatment, both the Tri Auto ZX2® and VDW.GOLD® RECIPROC® have been shown to provide high accuracy, comparable to conventional EALs, while minimizing the risk of overpreparation (18–21).

In root canal retreatment, Uzun et al. (13) reported that 60% of roots showed file tips extending beyond the apical foramen at the 0.5 mark using the Tri Auto ZX® with auto-reverse. However, data on the accuracy and agreement of the Tri Auto ZX2® in retreatment are lacking. Measurements at the 0.5 mark often exceed the apical constriction, and post-instrumentation changes may further increase overextension risk. It remains unclear whether the 1.0 mark with the apical stop function can consistently maintain working length within an acceptable range.

Therefore, the purpose of this study was to compare the agreement and reliability of the Tri Auto ZX2® and VDW.GOLD® RECIPROC® motors during gutta-percha retrieval at the 1.0 and 0.5 marks.

Materials and Methods

This study was approved by the Ethics Committee of Srinakharinwirot University (No. SWUEC-671050) and conducted in accordance with the Declaration of Helsinki. Sample size was calculated using G*Power (v3.1.9.4) based on Jung et al. (6), with a power of 0.80 and a significance level of 0.05, yielding a minimum of 29 teeth per group. To improve measurement reliability, 30 teeth per group were included.

Sample selection

Thirty extracted maxillary premolars were collected. Teeth with straight canals, two separate roots, and minimally damaged coronal structures were selected based on buccolingual and mesiodistal radiographs and stored in 0.1% thymol solution until the study commenced. Specimens with aberrant canal morphology, such as calcified canals or resorption, were excluded.

Sample preparation

All roots were cleaned of soft tissue and calculus using 2.5% NaOCl (M-Dent, Mahidol University, Bangkok, Thailand) with ultrasonic cleaning, then stored in 0.7% saline for up to 1 week. Access cavities were prepared and irrigated with 5 mL 2.5% NaOCl.

Primary working length (WL) was determined in buccal and lingual canals with a #15 K-file (K-file: Dentsply Sirona, North Carolina, USA) until the tip was visible at the coronal border of the apical foramen under an operating microscope (EXTARO 300, Carl Zeiss Meditec AG, Jena, Germany). Teeth with apical diameters larger than a #15 K-file or where the file could not reach the apex were excluded. Incisal edges were flattened to create a reference point (15–18 mm teeth). Rubber stops were fixed with flowable resin (Filtek™ Supreme Flowable, 3M ESPE, St. Paul, MN, USA). Files were photographed on a 10 mm grid using a Nikon D5300 (Nikon, Tokyo, Japan) mounted perpendicular on a tripod, and lengths measured with ImageJ software (v1.54p, NIH, Bethesda, Maryland, USA). Primary WL was defined as measured file length minus 0.5 mm.

Initial canal preparation was performed using a crown-down technique with Protaper Next rotary files (PROTAPER NEXT 21 mm, Dentsply Sirona Maillefer, Ballaigues, Switzerland) until X2 reached the estimated WL, with 10 mL of 2.5% NaOCl irrigation after each file. #25 K-files were then inserted to determine actual canal length (AL) using the same procedure as primary WL. Canals were finally rinsed with 3 mL of 17% EDTA (M-Dent, Mahidol University, Bangkok, Thailand) for 1 minute, followed by 5 mL of 2.5% NaOCl, dried with paper points, and obturated with matched gutta-percha (size 25/.06, Dentsply Sirona, Charlotte, NC, USA) using vertical condensation with an epoxy resin–based sealer (AH Plus®, Dentsply DE Trey, Konstanz, Germany). Buccolingual and mesiodistal radiographs confirmed obturation; teeth with short extensions or voids were excluded. Access cavities were sealed with Caviton™ (GC Corporation, Tokyo, Japan), and specimens were stored at 37°C in 100% humidity for 7 days.

Experimental models were prepared by mixing alginate with water per manufacturer instructions and pouring into plastic blocks with a central cavity and attached metal loop. Teeth were centered and stabilized with self-cure acrylic (UNIFAST™ Trad, GC America Inc., Alsip, IL, USA) to ensure stability during gutta-percha retrieval and working length measurement. Specimens were embedded before alginate setting, and all procedures were completed within 2 hours of mixing (Fig. 1).

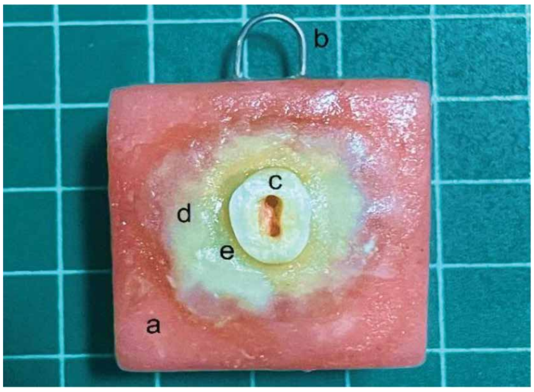


Fig. 1. Components of the experimental model: (a) cylindrical acrylic resin block, (b) metal wire loop, (c) tooth specimen, (d) freshly mixed alginate, and (e) self-cure acrylic resin.

Retreatment procedure and retreatment length measurement

Both root-filled canals from each tooth were randomly assigned to one of two endodontic motors with integrated EALs: Tri Auto ZX2® and VDW.GOLD® RECIPROC®. When the buccal canal was assigned to the Tri Auto ZX2®, the corresponding palatal canal was assigned to the VDW.GOLD® RECIPROC®, and vice versa. This allocation was continued until all 30 teeth were included, resulting in Group I (Tri Auto ZX2®, n = 30) and Group II (VDW.GOLD® RECIPROC®, n = 30) (Fig. 2).

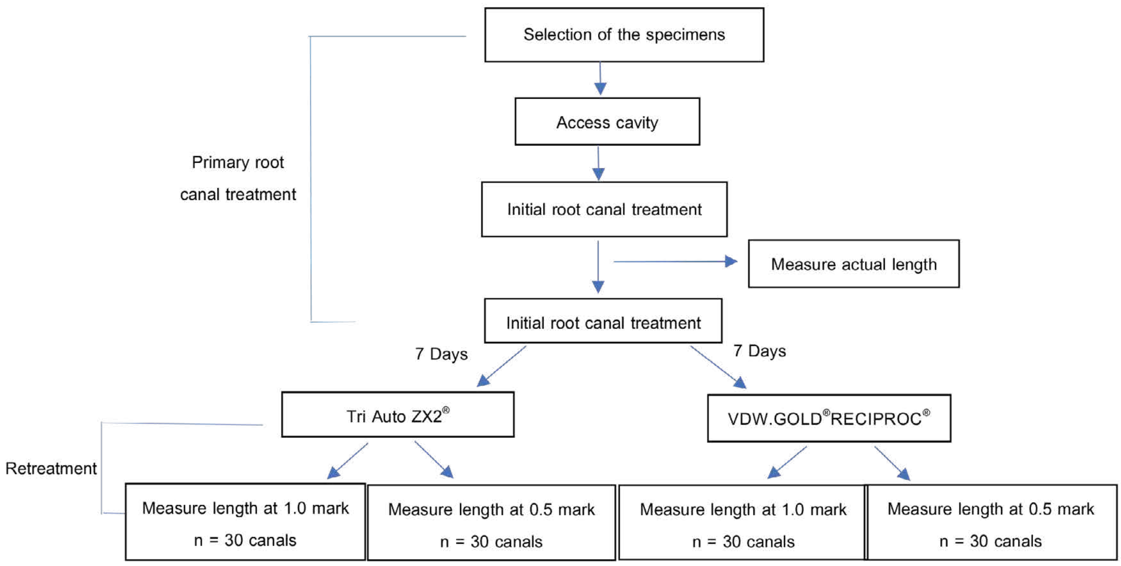


Fig. 2. Flow diagram of the experimental procedures, including primary root canal treatment, retreatment, AL measurement, and retreatment length measurement at the 1.0 and 0.5 marks.

Retreatment with Tri Auto ZX2®

After removal of the temporary restoration, the coronal 3 mm of gutta-percha was removed with a #2 Gates–Glidden drill (Dentsply Sirona Inc., Ballaigues, Switzerland). Retreatment was performed using Tri Auto ZX2® at 300 rpm and maximum torque with #R2 (25/.05) Mtwo retreatment files (VDW GmbH, Munich, Germany) in continuous rotation with the optimal apical stop (OAS) function. Files were advanced with gentle in-and-out motions, cleaned after each stroke, and the canal irrigated with 5 mL 2.5% NaOCl. Upon OAS activation, the rubber stop was adjusted to the coronal reference, secured with flowable resin, and the file photographed. The distance from the rubber stop to the tip was measured with ImageJ as the retreatment working length at the 1.0 mark (RWL-T-1) and repeated at the 0.5 mark (RWL-T-0.5) (Fig. 3A).

Retreatment with VDW.GOLD® RECIPROC®

The remaining canals underwent gutta-percha retrieval using the VDW.GOLD® RECIPROC® with #R2 (25/.05) Mtwo retreatment files in continuous rotation. The device was set at 300 rpm with maximum torque and equipped with the auto apical stop (AAS) function, and operated via a foot pedal. File tip position was indicated by the torque meter, displaying three green bars at the 1.0 mark and one green bar at the 0.5 mark; the pedal was released to stop the device at each level. Working length was measured as described for the Tri Auto ZX2®, and values at the 1.0 and 0.5 marks were recorded as (RWL-V-1) and (RWL-V-0.5), respectively (Fig. 3B).

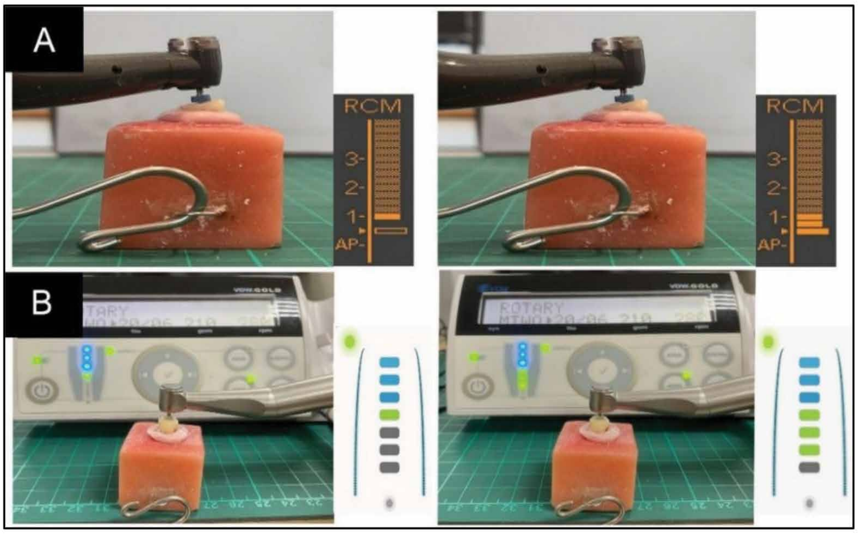


Fig. 3. Experimental setup: (A) The Tri Auto ZX2® attached to the file during measurements of retreatment working length at the 1.0 (RWL-T-1) and 0.5 (RWL-T-0.5) marks. (B) The VDW.GOLD® RECIPROC® attached to the file during measurements of retreatment working length at the 1.0 (RWL-V-1) and 0.5 (RWL-V-0.5) marks.

Statistical analysis

All measurements were performed by an experienced endodontist blinded to the AL. Descriptive statistics summarized the distribution of file tip positions relative to the AL, expressed as the difference between retreatment working length and AL (RWL–AL); negative values indicated a short position, and positive values indicated extension beyond the AL. Distances within -0.5 to 0.5 mm were considered acceptable. As data were not normally distributed, group comparisons were performed using the Mann–Whitney U test. Agreement between AL and RWL at both marks was assessed using the intraclass correlation coefficient (ICC), with reliability further evaluated by Bland–Altman plots. All analyses were conducted using IBM SPSS Statistics 20 (SPSS Inc, Chicago, IL, USA), with statistical significance set at 5%.

Results

Distribution of file tip positions relative to the AL, categorized as short, within, or beyond the acceptable range (-0.5 to 0.5 mm). At the 1.0 mark, all measurements with Tri Auto ZX2® and 96.7% with VDW.GOLD® RECIPROC® were within the acceptable range, decreasing to 23.3% and 16.7% at the 0.5 mark. Overinstrumentation was minimal at the 1.0 mark (3.3% for VDW.GOLD® RECIPROC®) but increased markedly at the 0.5 mark (76.7% for Tri Auto ZX2® and 83.3% for VDW.GOLD® RECIPROC®) (Fig. 4).

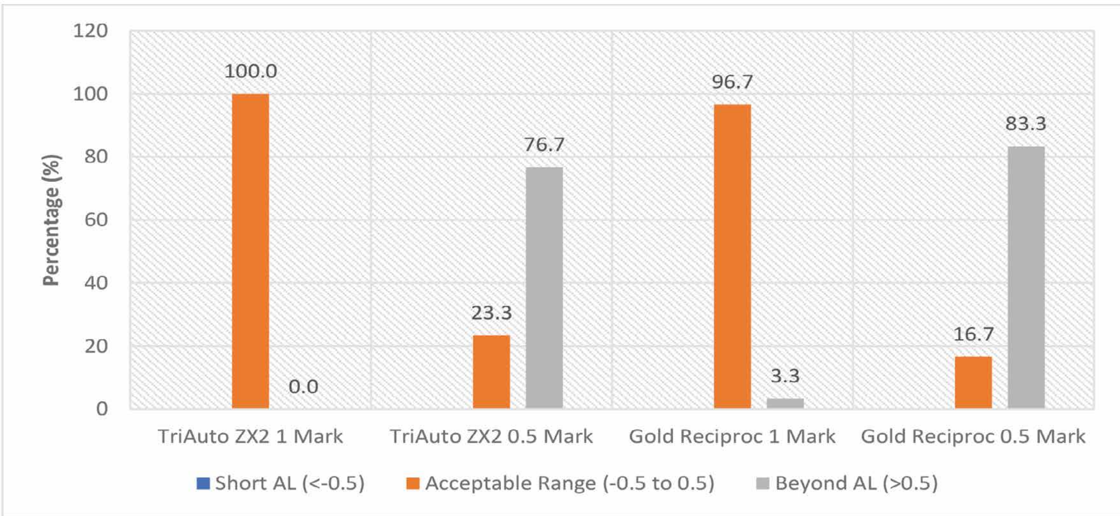


Fig. 4. Percentage of measurements short of, within, or beyond the acceptable range for Tri Auto ZX2®and VDW.GOLD® RECIPROC® at the 1.0 and 0.5 marks.

Distribution of file tip positions relative to the apical foramen. At the 1.0 mark, all Tri Auto ZX2® and 96.7% of VDW.GOLD® RECIPROC® measurements remained within the canal, decreasing to 23.3% and 16.7% at the 0.5 mark. Overextension beyond the foramen increased from 3.3% at 1.0 mark to 76.7% and 83.3% at 0.5 mark for Tri Auto ZX2® and VDW.GOLD® RECIPROC®, respectively (Fig. 5).

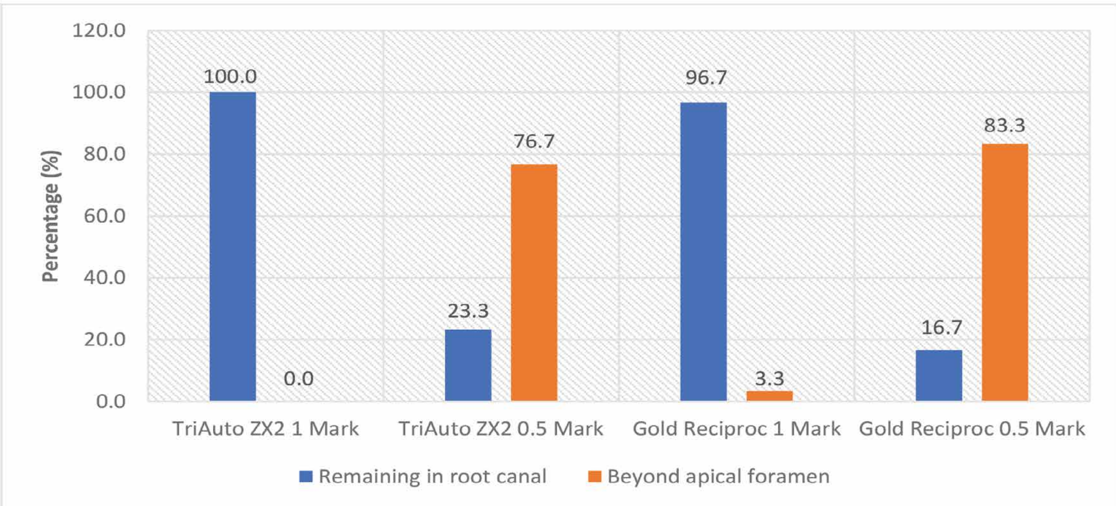


Fig. 5. Percentage of file tip positions classified as within the canal or beyond the apical foramen for Tri Auto ZX2® and VDW.GOLD® RECIPROC® at the 1.0 and 0.5 marks.

The mean difference in length for the Tri Auto ZX2® and VDW.GOLD® RECIPROC® was 0.29 ± 0.16 mm and 0.29 ± 0.18 mm at the 1.0 mark, and 0.59 ± 0.15 mm and 0.66 ± 0.14 mm at the 0.5 mark, respectively. Mann-Whitney U test showed that the differences at the 1.0 mark were significantly smaller than those at the 0.5 mark ($p < 0.05$) (Table 1).

Table 1. Descriptive values of difference length measurement from AL.

	Mean ± SD	median	p-value
Tri Auto ZX2® at 1.0 mark	0.29 ± 0.16	0.31	<0.001
Tri Auto ZX2® at 0.5 mark	0.59 ± 0.15	0.59	
VDW. GOLD® RECIPROC® at 1.0 mark	0.29 ± 0.18	0.35	<0.001
VDW. GOLD® RECIPROC® at 0.5 mark	0.66 ± 0.14	0.68	

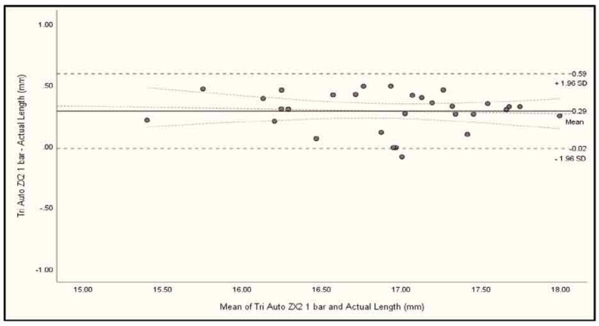
Both endodontic motors demonstrated agreement with AL, as indicated by ICC shown in Table 2. For the Tri Auto ZX2®, ICC were 0.876 at the 1.0 mark and 0.670 at the 0.5 mark, while for the VDW.GOLD® RECIPROC®, ICC were 0.897 and 0.692 at the 1.0 and 0.5 marks, respectively. Agreement between RWL and AL was statistically significant at both marks ($p < 0.001$), with higher ICCs observed at the 1.0 mark for both devices.

Table 2. ICC and RC between the AL and position of the file tip at 1.0 and 0.5 mark.

	Tri Auto ZX2®		VDW.GOLD® RECIPROC®	
Marker	ICC	p-value	ICC	p-value
1.0 mark	0.876	p <0.001	0.897	p <0.001
0.5 mark	0.670	p <0.001	0.692	p <0.001

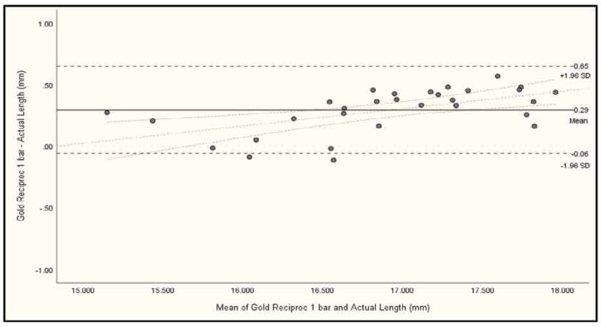
ICC, intraclass correlation coefficient; AL, actual length.

Bland—Altman analysis evaluated agreement between AL and RWL at the 1.0 and 0.5 marks for both motors. At the 1.0 mark, mean differences were 0.29 mm (95% CI: 0.228–0.345) for Tri Auto ZX2® and 0.29 mm (95% CI: 0.227–0.361) for VDW.GOLD® RECIPROC® (Fig. 6A and 6B). At the 0.5 mark, differences increased to 0.594 mm (95% CI: 0.538–0.650) and 0.656 mm (95% CI: 0.602–0.709), respectively (Fig. 6C and 6D).



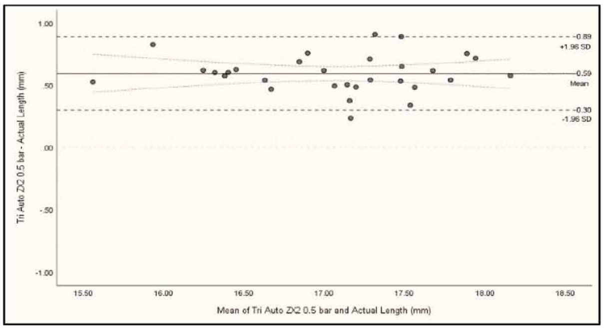
A: RWL-T-1 to AL

Mean and 95% CI	0.2864		0.2279 to 0.3449	
P (H_0 Mean = 0)	< 0.0001			
Lower limit and 95% CI	-0.0207		-0.0767 to 0.0354	
Upper limit and 95% CI	0.5935		0.5374 to 0.6495	
Regression Equation	y = 0.637 – 0.021x			
	SE	t	P	95% CI
Intercept	0.811	0.785	0.439	-1.024 to 2.298
Slope	0.048	-0.432	0.669	-0.119 to 0.077



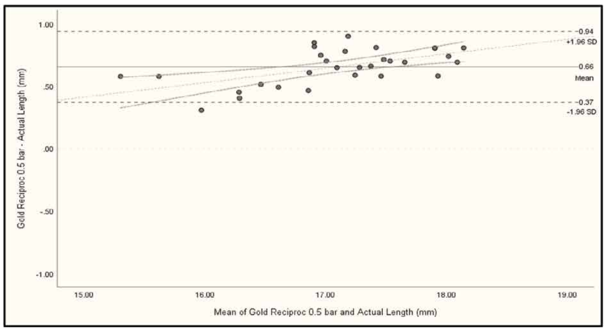
B: RWL-V-1 to AL

Mean and 95% CI	0.2940		0.2265 to 0.3614	
P (H_0 Mean = 0)	< 0.0001			
Lower limit and 95% CI	-0.0600		-0.1247 to 0.0046	
Upper limit and 95% CI	0.6480		0.5833 to 0.7126	
Regression Equation	y = -2.090 + 0.141x			
	SE	t	P	95% CI
Intercept	0.661	-3.160	0.004	-3.444 to -0.735
Slope	0.039	3.608	0.001	0.061 to 0.221



C: RWL-T-0.5 to AL

Mean and 95% CI	0.5940		0.5378 to 0.6501	
P (H_0 Mean = 0)	< 0.0001			
Lower limit and 95% CI	0.2991		0.2453 to 0.3530	
Upper limit and 95% CI	0.8888		0.8350 to 0.9426	
Regression Equation	y = 0.624 – 0.002x			
	SE	t	P	95% CI
Intercept	0.780	0.800	0.430	-0.974 to 2.223
Slope	0.046	-0.039	0.969	-0.095 to 0.092



D: RWL-V-0.5 to AL

Mean and 95% CI	0.6555		0.6020 to 0.7090	
P (H_0 Mean = 0)	< 0.0001			
Lower limit and 95% CI	0.3745		0.3233 to 0.4258	
Upper limit and 95% CI	0.9365		0.8852 to 0.9877	
Regression Equation	y = -1.326 + 0.116x			
	SE	t	P	95% CI
Intercept	0.530	-2.502	0.018	-2.411 to -0.240
Slope	0.031	3.742	0.001	0.052 to 0.179

Fig. 6. Bland—Altman plots showing the differences between RWL and AL file tip positions for Tri Auto ZX2® and VDW.GOLD® RECIPROC® at the 1.0 (A, B) and 0.5 (C, D) marks.

Discussion

This study used an ex vivo model with extracted teeth embedded in alginate-filled acrylic blocks to evaluate the accuracy of EAL-integrated endodontic motors (22–24). Alginate was chosen for its favorable electrical conductivity, providing higher accuracy than other embedding materials and closely simulating clinical conditions (24–27).

Root lengths were measured using ImageJ software, which allows high-resolution, reproducible measurements with minimal operator bias. Unlike conventional rulers limited by scale resolution and visual alignment, ImageJ enables precise measurement of instrument tips and reference points, even when stoppers are covered by flowable composite. This aligns with ElAyouti and Löst (28), who reported improved accuracy using a mounting model attached to a micrometer compared with conventional visual methods prone to stopper misalignment, reading errors, and operator bias. Previous studies also confirmed that digital measurement methods yield accuracy comparable to manual measurements without significant differences (29, 30).

For gutta-percha removal, Mtwo retreatment files (25/.05) were selected due to their apically active cutting design and smaller taper, which facilitate efficient removal of filling material while minimizing canal wall damage (31, 32). Their use also allows working length measurement in the presence of residual material, thereby better reflecting clinical conditions. Compared with ProTaper Next X2 (25/.06), the smaller taper helps preserve the original apical diameter while enabling precise length determination. Residual filling material may influence canal impedance and affect EAL performance, highlighting the relevance of this approach for evaluating electronic working length measurements in retreatment scenarios.

The results of this study demonstrated that measurements obtained at the 1.0 mark setting were predominantly within the acceptable range relative to the AL and remained within the root canal, whereas the 0.5 mark setting resulted in a substantially higher proportion of measurements extending beyond the apical limit. The median difference at the 0.5 mark was 0.59 mm, indicating that more than 50% of samples exceeded 0.5 mm beyond the AL, reflecting frequent overextension. Tufenkci and Kalayci (11) reported an overextension rate of 10–16% at the 0.5 mark during retreatment, while Uzun et al. (13) observed rates of up to 60%; in contrast, the present study demonstrated a higher incidence of approximately 80%. These discrepancies may be attributed to differences in experimental design, types of EAL devices, retreatment procedures (including gutta-percha removal techniques), and the timing of working length determination.

These findings were supported by ICC analysis, which demonstrated higher agreement at the 1.0 mark (0.876–0.897) than at the 0.5 mark (0.670–0.692). Bland–Altman analysis further confirmed this, showing narrow limits of agreement and minimal bias at both marks; however, greater dispersion was observed at the 0.5 mark, with more values falling outside the limits of agreement, indicating lower reliability. In contrast, measurements at the 1.0 mark were more consistently distributed within the limits of agreement, reflecting improved precision and reliability. Clinically, the use of the 1.0 mark during gutta-percha removal may reduce the risk of overextension beyond the apex, thereby minimizing apical overinstrumentation during retreatment.

Regarding the devices evaluated in this study, both systems demonstrated comparable accuracy at both marks, indicating that Tri Auto ZX2® and VDW.GOLD® RECIPROC® can be effectively used in root canal retreatment with similar performance. This may be attributed to the accuracy of their integrated EALs—Root ZX in the Tri Auto ZX2® and Raypex 5 in the VDW. GOLD® RECIPROC®—both of which determine working length based on impedance measurements at two frequencies. These findings are consistent with Wrbas et al. (33), who reported no statistically significant difference in working length accuracy between Raypex 5 and Root ZX. However, the slight variations in measured lengths observed in this study may be attributed to differences in device kinematics and EAL technology, and may largely result from variations in root length among samples.

Root canal conditions critically influence EAL accuracy. In this study, canal conditions were standardized, but root length variations were retained to better reflect clinical scenarios. Although previous studies have examined the presence and type of gutta-percha during retreatment, the direct effect of residual gutta-percha length on EAL accuracy remains unclear. Residual gutta-percha has been reported to interfere with impedance-based measurements of EALs (12, 13) and may lead to overestimation of EAL readings (11, 34), whereas different types of root canal filling materials do not significantly affect measurement accuracy. EAL performance may also vary across retreatment stages; Cardoso et al. (14) demonstrated that EALs were generally accurate throughout most stages, except after apical patency for endodontic retreatment had been achieved. These findings suggest that residual debris and gutta-percha alter electrical conductivity within the canal, indirectly affecting EAL reading. Therefore, in shorter canals with less residual gutta-percha, files traverse a smaller volume of material, facilitating removal and faster circuit completion, which may reduce the risk of working length overestimation beyond the apex.

Future studies should standardize root length to ensure consistent residual gutta-percha, allowing more accurate assessment of EAL measurement reliability. This study used maxillary premolars with straight roots, while clinical retreatments often involve complex anatomies, such as curved or calcified canals, which may challenge EAL performance and require further investigation.

Conclusion

Under the conditions designed in this ex vivo study, both endodontic motors incorporated with EAL, Tri Auto ZX2® and VDW.GOLD® RECIPROC®, can be used for working length measurement during root canal filling retrieval. Working length reading at 1.0 mark should be more preferable than reading at 0.5 mark from both devices.

Conflicts of Interest

The authors have no conflict of interest relevant to this article.

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