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CASE SERIES

Tactile Method for Orthograde Exploration of the Apical Foramen in Non-vital Permanent Teeth with Open Apices: Case Series

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ABSTRACT

This research assessed the interobserver agreement and precision of the tactile method (TM) during orthograde exploration of the apical terminal portion of permanent teeth with necrotic pulps and open apices. Nine non-vital teeth with incomplete root development from nine patients were included. Two observers analyzed preoperative cone beam computed tomography (CBCT) images to determine the distance between the incisal reference point and the apical terminal portion at four apical measurement points: buccal, lingual, distal, and mesial. The shortest of these points was considered the tomographic working length (TWL) and was used as control group. Subsequently, endodontic access and light chemo-mechanical brushing of the main canals were performed, followed by radiographic working length (RWL) establishment. Two different operators applied the TM using a #25 manual K-file (Dentsply Maillefer, Ballaigues, Switzerland) pre-curved in the tip at a 90° angle. The same four apical measurement points were explored, and the tactile method working length (TMWL) was determined. Interobserver agreement was assessed using Bland-Altman method. Wilcoxon signed-rank test and Student's t-test were used to analyze the correlation between methods ($p \leq 0.05$). The measurements conducted for TM and TWL showed a high level of agreement (0.486 and -0.144 mm, respectively). Compared with the control group (TWL) and TMWL, the RWL showed no significant correlation (<0.001 and 0.0068, respectively). TM demonstrated a reliable level of inter-observer agreement and could prove valuable when treating permanent teeth exhibiting non-vital pulps and open apices, especially in cases with radiographic evidence of external inflammatory apical resorption.

Keywords: Interobserver agreement, open apices, reliability, tactile method, working length determination

HIGHLIGHTS

- This study represents the first human investigation into the interobserver agreement and accuracy of tactile method readings during orthograde exploration of the apical portion in permanent teeth with non-vital pulp and open apices.
- The tactile method demonstrated a reliable level of interobserver agreement.
- The tactile method could serve as a valuable adjunctive tool in cases of immature apical anatomy, endodontic infection, and radiographic evidence of external inflammatory root resorption.
- The tactile method is not suggested for use in all cases of teeth with open apices and non-vital pulp, and its application should be viewed as supplementary by the clinician.

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INTRODUCTION

The absence of a well-established apical constriction, divergent apical anatomy, and the presence of an irregular terminal portion resulting from defects caused by external inflammatory root resorption are characteristics that make teeth with open apices and non-vital pulps some of the most complex endodontic challenges for clini-

cians, including experienced specialists (1, 2). One of the main challenges in these scenarios is to avoid intraoperative accidents caused by the unintentional introduction of foreign bodies into periapical tissues or adjacent anatomical areas (3). To prevent this, it is crucial to precisely determine the working length.

The Tactile Method (TM), as proposed by ElAyouti et al. (4), is a technique intended as a supplementary measure during the working length determination phase for teeth with open apices and non-vital pulps. This involves the use of a 25 manual K-file with its tip bent at a 90° angle, and the rubber stop's black line aligned with the direction of the bend to perform circumferential orthograde exploration of the apical terminal portion of these teeth. However, this method was proposed on findings from an *in vitro* study, and no clinical studies have analyzed its performance in patients.

According to guidelines from evidence-based medicine and dentistry, before conducting a clinical trial focused on a procedure that lacks substantial scientific evidence in humans and is not a fundamental component of the standard treatment protocol, such as the TM, it is advisable to perform a clinical observational study (5). This approach helps generate preliminary results regarding the procedure's safety for patients, as well as its impact on decision-making in clinical practice (6). Therefore, the aim of this study was to analyze the inter-observer agreement and the accuracy of the TM during orthograde exploration of the apical terminal portions of permanent teeth with non-vital pulp and open apices *in vivo*.

MATERIALS AND METHODS

Case Selection

This case series study was approved by the Institutional Ethics Committee of University Center of Health Sciences (CUCS) (registration number: C.I./21/2019), and the STROBE guidelines were followed. The subjects were treated in full compliance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for procedures involving humans. Criteria for inclusion in the study consisted of

- Patients with a permanent straight single-rooted tooth with Vertucci type I configuration, open apex, and endodontic infection.
- Patients exhibiting no acute symptoms during their first appointment.
- Teeth requiring any endodontic procedure for a non-vital pulp and an open apex.
- Presence of a stable occlusal or incisal reference point.
- Requirement for a preoperative cone beam computed tomography (CBCT) according to Patel et al. (7) criteria.
- Informed consent was obtained from the participating patients or their guardians.

Subjects meeting any of the following criteria were excluded from the study.

- Roots exhibiting curvatures or a "C" shape.
- Apical foramen sizes ISO 80 or smaller, as determined intraoperatively.
- Pulp diagnosis of previous endodontic treatment and incomplete removal of filling material from the root's apical region.
- Root canals were too narrow, preventing the file used for TM measurements from reaching the terminal portion of the root.
- In cases in which the incisal/occlusal reference point was altered intraoperatively.
- Roots in which any TM measurement zone did not yield a reliable reading by the operators.

A total of nine teeth with open apices and apical periodontitis from nine patients were included (Table 1) (8). Their respective medical and dental histories were documented, followed by an analysis of relevant extra- and intraoral findings. Cold and electrical sensitivity tests were applied to the involved tooth and adjacent teeth, after which probing depth and mobility were assessed. During radiographic analysis, the presence of teeth with open apices was confirmed using the criteria suggested by Plascencia et al. (9): Absence of a well-established apical constriction, incomplete root length, and visual estimation of the thickness of the apical foramen with a diameter ISO ≥90.

Establishment of Tomographic Working Length (TWL)

After confirming that cases required CBCT according to the criteria established by Patel et al. (7), they were referred to the Ra-

TABLE 1. Demographic parameters of the nine cases are included in this study

Case	Age (y)	Sex	Tooth*	Stage of root development**	Pulpal diagnosis	Periapical diagnosis
1	14	Female	35	III	Pulp necrosis	Asymptomatic apical periodontitis
2	15	Male	22	III	Pulp necrosis	Asymptomatic apical periodontitis
3	18	Male	35	III	Pulp necrosis	Chronic apical abscess
4	16	Male	11	III	Pulp necrosis	Asymptomatic apical periodontitis
5	9	Female	32	II	Pulp necrosis	Normal periapical tissues
6	25	Female	35	III	Previously initiated therapy	Asymptomatic apical periodontitis
7	10	Male	11	III	Pulp necrosis	Chronic apical abscess
8	13	Female	12	II	Pulp necrosis	Asymptomatic apical periodontitis
9	13	Female	21	II	Pulp necrosis	Asymptomatic apical periodontitis

*: FDI nomenclature, **: Cvek's classification (8). I: < 1/2 root length, II: 1/2 root length, III: 2/3 root length, IV: Wide open apical foramen and nearly completed root length, V: Closed apical foramen and completed root development. Cvek stages I, II, and III show wide and divergent apical openings. FDI: World Dental Federation

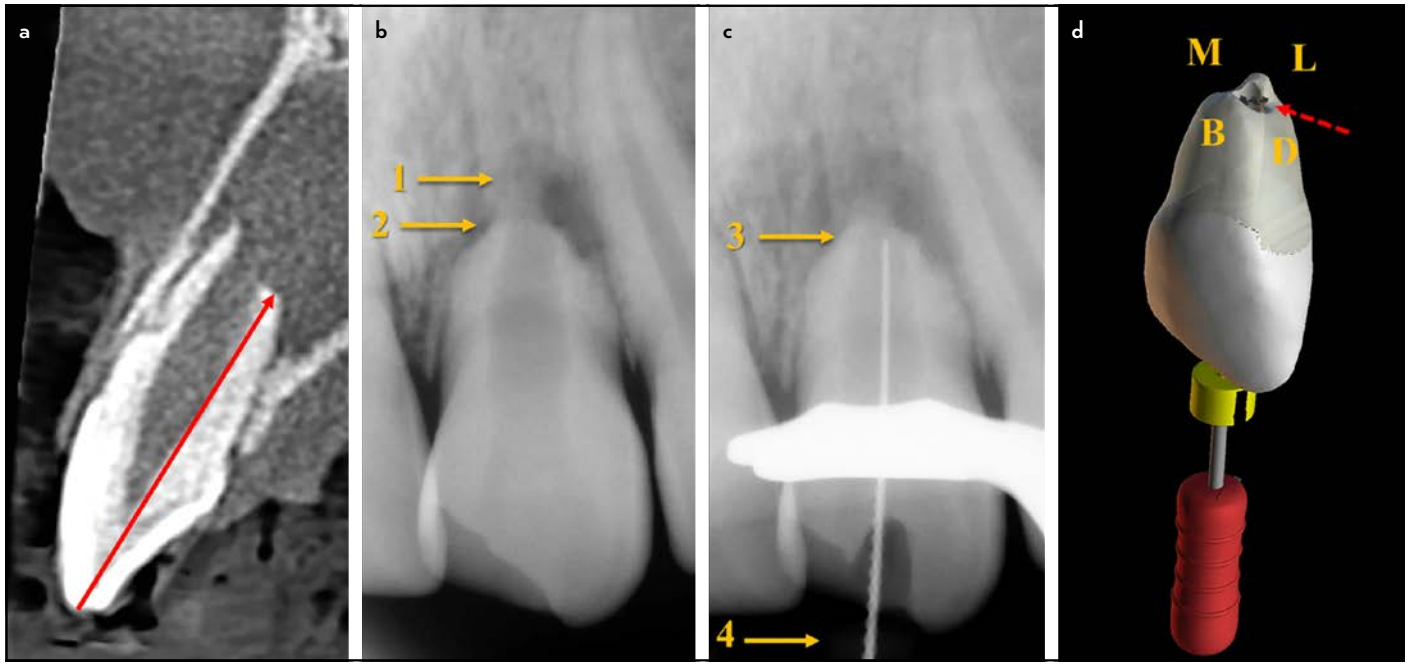

Figure 1. Representative images of the different measurements performed in this study. (a) Tomographic Working Length (TWL) (control group) with the measuring point in the lingual direction (red arrow) in case #8. Radiographic Working Length (RWL) determination according to Gutmann & Leonard's criteria (10) in case #9: (b) steps 1 and 2, (c) steps 3 and 4. (d) The shortest of the apical measurement points (red dotted arrow) was considered as Tactile Method Working Length (TMWL), as shown in a three-dimensional reconstruction of case #9

B: Buccal, L: Lingual, D: Distal, M: Mesial

diology Department. A Carestream CS 9500 scanner (Carestream Health, Inc., NY, USA) was utilized, set to high resolution with a voxel size of 76 µm ×76 µm ×76 µm, a field of view of 5 cm ×5 cm, a tube voltage of 70 kVp, and a current of 8 mA, for an exposure time of 10.8 seconds (resulting in 466 exposures per acquisition).

Following an appropriate calibration process consisting of a detailed visual and practical demonstration of the measurement protocol using the software (CS 3D Imaging, Carestream Dental LLC, Atlanta, USA), two observers analyzed the nine CBCT scans independently (M.D. and A.O.). The "measure" function of the software was used to draw a straight line through the longitudinal axis of the root in both the coronal and sagittal planes for each tooth to measure the distance (in millimeters) from the incisal reference point to the apical terminal portion at four distinct apical measurement points: buccal (B), lingual (L), distal (D), and mesial (M) (Fig. 1a). The average of the measurements from both observers for each measurement zone was calculated. The area with the shortest distance was then identified and recorded as the TWL, which was used as the control group.

Clinical Procedure

Based on the collected clinical and imaging findings, respective pulpal and periapical diagnoses were established, followed by a treatment plan encompassing either apexification or revascularization techniques. Subsequently, after confirming that the cases met the inclusion criteria, the patient, parent, or guardian was invited to participate in this research. All patients followed the same treatment protocol at the initial appointment. After obtaining informed consent, local anesthesia was administered, and a dental dam was placed. Once asepsis of the operative field was accomplished using 5.25% NaOCl, the pulp chamber was accessed, and the teeth's non-vital pulp nature was confirmed. All clinical procedures were performed using magnified vision (OPMI PICO Microscope, Oberkochen, Germany). To prevent excessive weakening, cervical pre-flaring of the root was avoided. Then, irrigation with 5 mL of 2.5% NaOCl and the location canal were initially negotiated using a size #25 manual K-file.

Following the steps proposed by Gutmann and Leonard (10), which are used for cases with open apices, apical periodontitis, and external inflammatory root resorption, the radiographic working length (RWL) was determined (Fig. 1b, c):

- **Step 1:** In the preoperative radiograph, a new radiographic apex was established.
- **Step 2:** The terminal point of the root wall located most coronally or incisally and exhibiting normal radiodensity was visually identified. This point corresponds to the terminal point of the root canal, which is surrounded by apical dentine, in 360° of its circumference.
- **Step 3:** The manual file was inserted until its tip reached the terminal portion of the root, which showed normal radiodensity.
- **Step 4:** A stable and reproducible coronal or incisal reference point was selected, documented in the patient's record, and photographed for future reference.

If the first manual file fitting into the apical portion was of an ISO size less than #80, the case was excluded. Subsequently,

chemo-mechanical cleaning of the middle and apical thirds was performed by lightly brushing the internal walls of the root canal with a #40 manual K-file. For irrigation, 10 mL of 2.5% NaOCl was applied using a hypodermic syringe, a 30G gauge and side-vented needle. The needle tip was consistently positioned 2 mm short of the RWL. After drying the root canal with sterile paper points, calcium hydroxide paste (Sultan Calcium Hydroxide USP; Sultan Healthcare, York, PA, USA) was applied as intra-canal dressing. The access cavity was sealed with temporary cement (Cavit G; 3M ESPE, St Paul, MN, USA), and post-operative and post-operative care instructions were issued.

After 10 days, patients were assessed to ensure that they were free of signs and symptoms. Local anesthesia was administered, and a dental dam was placed, replicating the aseptic conditions as described for the first session. The coronal sealing material was removed, and the intracanal dressing was removed by irrigation with 10 mL of 1% NaOCl and mechanical lightly cleaning with a #40 manual K-file.

Tactile Method Measurement Protocol

This process was executed by two different operators who utilized new and previously sterilized #25 size, 25mm K-files (Dentsply-Maillefer, Ballaigues, Switzerland). In total, eighteen files were required for the nine cases because each file was used exclusively for one reading before being discarded. The readings were conducted by two endodontists from the Department of Endodontics, each one with at least 10 years of clinical experience and certification by the Mexican Board of Endodontics (H.P. & M.U.), and both underwent the same calibration process before applying the TM. To achieve this, the operators attended a detailed oral and visual presentation in which the study objectives were explained. This was followed by a comprehensive visual and practical demonstration of the TM measurement protocol. Specific instructions regarding procedural steps, instruments, and techniques to follow were provided. Subsequently, the participants performed the TM procedure on three extracted permanent teeth with artificially created open apices.

It is noteworthy that the application of the TM did not alter the prognosis of any established treatment plans, nor did it compromise patient comfort; it merely added approximately

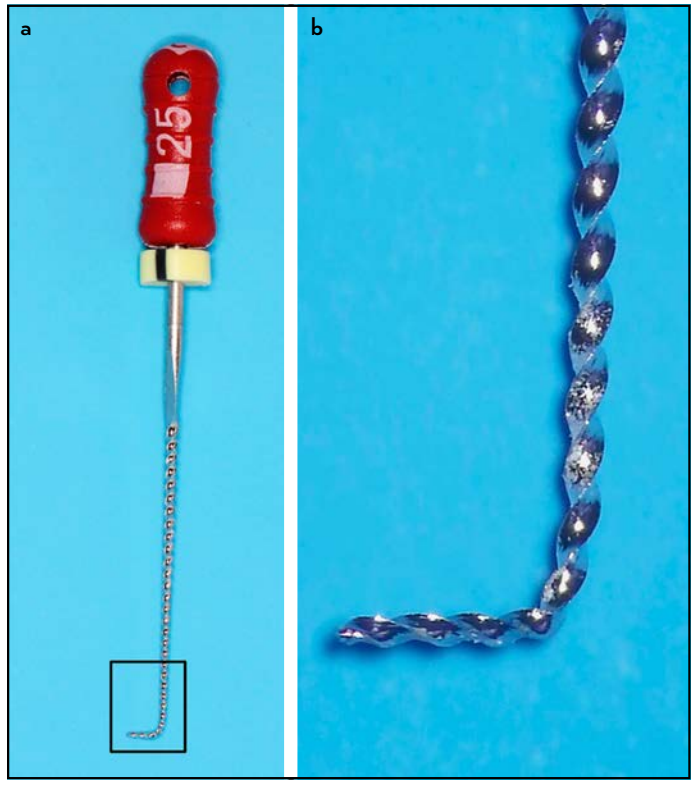

Figure 2. (a) New K-file #25 with a bent tip. (b) The tip was bent from 0.5 mm to 1 mm at a 90° angle and used to perform the Tactile Method measurement protocol

10 minutes to the duration of each case. Initially, a resident (M.A-T.) provided Operator #1 with a new and sterilized #25 size K-file, who then bent its tip from 0.5mm to 1mm at a 90° angle using stainless steel dressing pliers with a serrated tip for a positive grip (DP18L Hufriedy, Chicago, USA) (Fig. 2). The angle of the newly bent tip was confirmed to be perpendicular through both visual and magnified verification (OPMI PICO Microscope, Oberkochen, Germany). The resident also informed the operator of the coronal reference point and the RWL established at the first appointment. Special attention was ensured so that the black line on the rubber stop aligned with the direction of the bent tip. The file was then gently curved along its remaining length to facilitate its engagement with the root's terminal portion.

TABLE 2. Results obtained (in millimeters) during the determination of RWL, TWL, and TMWL

Case	RWL	TWL				TMWL			
		Buccal	Lingual	Mesial	Distal	Buccal	Lingual	Mesial	Distal
1	18	16.7	16.7	16.95	16.85	17.5	17	16.5	17.5
2	20	20	19.35	12.7	12.95	20	19	19.5	19.25
3	21	20	19.65	20.2	20.15	20.25	20.5	20.5	20.25
4	18.5	18.8	19.8	16.25	16.9	18.75	18.5	18.5	19.5
5	15	12.4	11.1	8.45	7.7	14.5	15	14.75	14.5
6	17.5	17.15	18	17.35	16.95	17	17	17	16
7	25	23.85	23.85	23.6	23.05	25	25.25	25	25
8	16	16.65	15.3	16.35	16.15	16	16	17.25	16
9	14	14.3	13.25	15.35	13.95	14.5	13.75	13.75	14

RWL: Radiographic working length, TWL: Tomographic working length, TMWL: Tactile method working length

Next, the file was inserted into the root canal with the bent tip directed toward the internal dentine wall and was moved apically until it engaged firmly at a point within the measurement zones or until resistance was encountered upon attempting to remove it from the root canal. Care was taken to maintain the file position, and the rubber stop was adjusted using a dressing plier to align with the preestablished coronal reference point. The file was then cautiously rotated to disengage and remove it from the root canal. Using X16 magnification (OPMI PICO Microscope, Oberkochen, Germany), the working length was determined using an endodontic millimeter ruler. For reproducibility, this process was performed twice in each measurement zone. If any measurement point failed to provide reliable reading, the case was excluded.

From the four readings obtained using the TM (B, L, D and M), the measurement point providing the shortest length was selected as the working length, termed the Tactile Method Working Length (TMWL) (Fig. 1d). Once Operator #1 completed their readings, Operator #2 proceeded with their respective measurements following the previously described process. To maintain blinding between the two operators, each operator performed the measurements independently. After all TM measurements were recorded by both operators, the case was concluded according to the initially established treatment plan. Patients were advised to take 250 mg of paracetamol every 8 hours should they experience any discomfort and were scheduled for postendodontic restoration.

Statistical Analysis

All measurements were recorded in an Excel spreadsheet and were transferred and analyzed using SPSS 20.0 (IBM, Chicago USA) software for Windows. The significance level was set at $p \leq 0.05$.

First, descriptive statistics were used to analyze general patient parameters, and the average of each pair of readings were calculated. Subsequently, the Bland-Altman method was employed to establish the level of interobserver agreement for the measurements performed during TWL and TMWL determination. The student's t-test was applied to determine if the average significantly deviated from 0, and linear regression was used to assess whether the observed differences between the pairs of measurements were evenly distributed along the magnitude of the traces. Finally, the initial pairs of measurement averages were analyzed using the Bland-Altman method and Wilcoxon signed-rank tests to estimate the magnitude of the differences between TWL, RWL, and TMWL.

RESULTS

This study included nine cases, corresponding to nine patients, with an average age of 14.77 years. The anterior incisors were the most frequently treated teeth (n=6, 66.66%), followed by the mandibular premolars (n=3, 33.33%). Table 2 presents the results obtained during the determination of the RWL and presents the average of the pairs of readings performed at each apical measurement point for the TWL

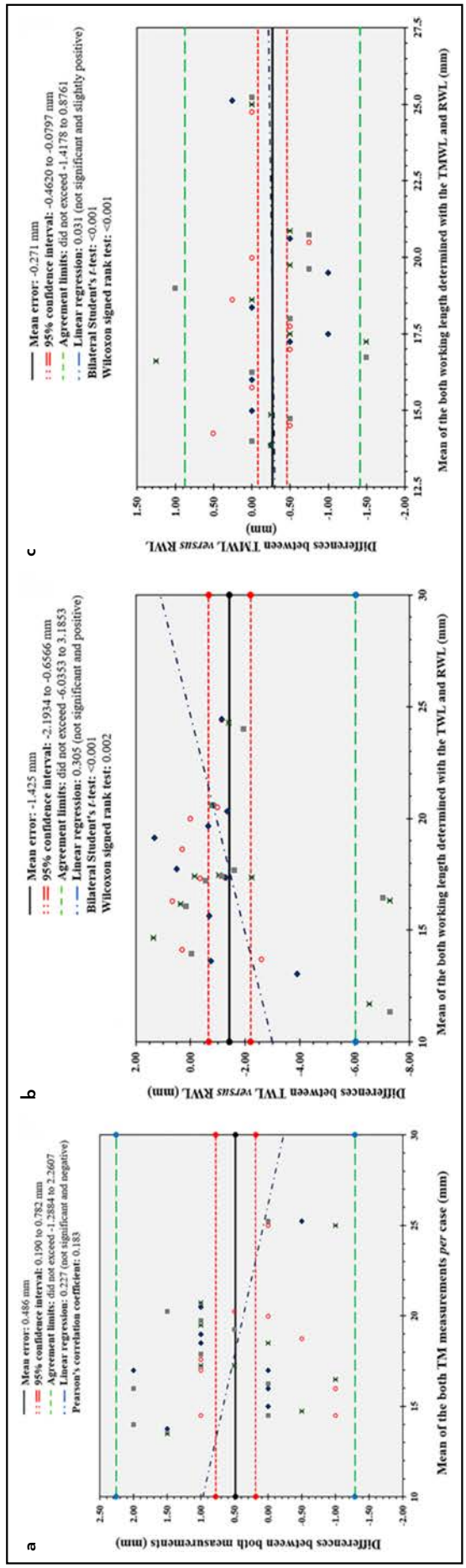

Figure 3. (a) Scatterplots showing the distribution among pairs of readings obtained with the Tactile Method (TM) in the nine cases, along with the magnitude of the measurements. (b) Bland-Altman plot comparing the Tomographic Working Length (TWL) versus Radiographic Working Length (RWL). (c) Bland-Altman plot comparing TWL versus Tactile Method Working Length (TMWL)

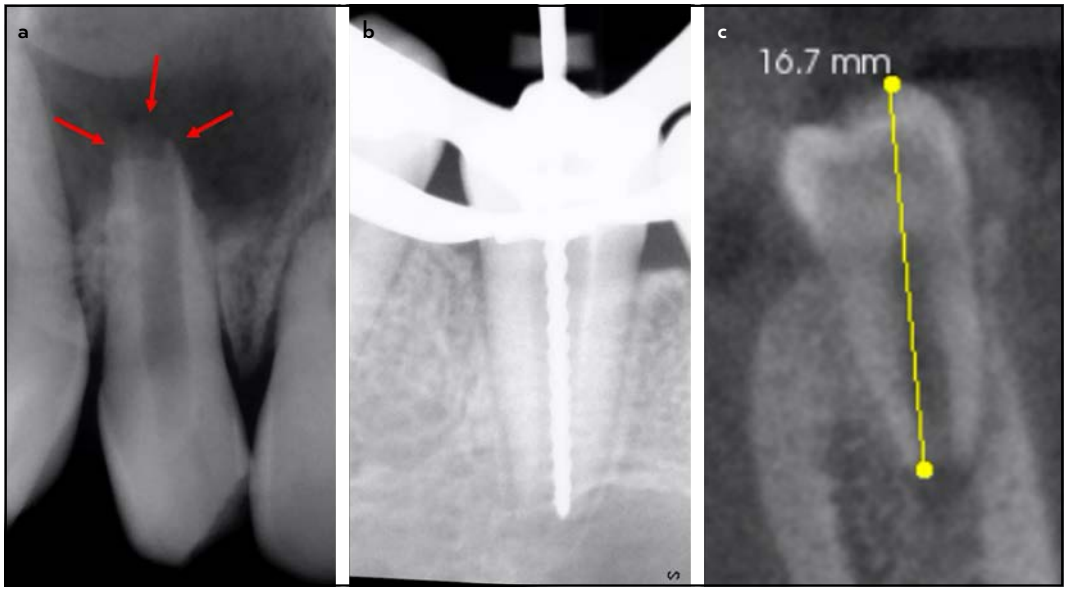

Figure 4. (a) Preoperative radiograph of case #8 showing necrotic pulp, open apex, and several external inflammatory root resorption defects in the apical terminal portion (red arrows), which were identified for both operators during orthograde exploration with the Tactile Method (TM). (b) Radiographic Working Length (RWL) determination according to Gutmann & Leonard's criteria (10) in case #1, where there was a lack of correlation with the control group. (c) While the RWL was 18 mm, the Tomographic Working Length (TWL) in the lingual apical zona was 16.790 mm

and TMWL. No harmful events were reported in this study, including file fractures, flare-ups, or other adverse incidents.

Interobserver Agreement

The Bland-Altman method revealed that the tracings duplicated by the academics during the establishment of the TWL (or control group) exhibited a high level of inter-observer agreement (magnitude of error: -0.144 mm).

In addition, the same Bland-Altman analysis demonstrated that the pairs of readings conducted by the two operators during the TM measurement protocol showed a minimal magnitude of error of 0.486 mm, where the slope of the linear regression was negative (0.227), evenly distributed, and not statistically significant according to the Pearson Correlation Coefficient (0.183) (Fig. 3a). The results support that the TM readings were reliable and unbiased. Included cases presented irregular apical anatomy by external inflammatory root resorption (Fig. 4a).

Correlation between Methods TWL, TMWL and RWL

The Bland-Altman method and the Wilcoxon signed-rank test demonstrated statistically significant differences when comparing the control group (TWL) with RWL (-1.425 mm and p=0.002, respectively) (Fig. 3b), as well as in the correlation between TMWL and RWL (-0.271 mm and p<0.001, respectively) (Fig. 3c). This indicates that establishing working length through the traditional visual analysis of radiographs is unreliable in teeth with open apices and apical periodontitis. Figure 4b illustrates the relevance of these findings, showing a mandibular second premolar with an RWL of 18 mm. However, both the control group (TWL) and the TM concurred that the lingual apical zone was shorter than initially estimated.

DISCUSSION

Given the morphological and microbiological challenges presented by teeth with open apices and non-vital pulp, precisely determining the working length is critical to ensuring successful endodontic outcomes and preventing intraoperative accidents. For teeth with mature roots, electronic apex locators can be used to establish the root apex end point (11). However, it has been shown that their readings for immature roots (with an apical diameter greater than 60 endodontic file) are unreliable (12). Consequently, operators require alternative methods to circumvent these limitations.

The TM was proposed to examine the immature apical portion through the root canal by using a #25 K-file with its tip bent at a 90° angle (4). Despite a review of the literature, no scientific evidence was found regarding the efficacy of this technique in clinical settings. Thus, this study represents the first human investigation into the inter-observer agreement and accuracy of TM readings during orthograde exploration of the apical portion in permanent teeth with non-vital pulp and open apices.

The sample size and the stringent selection criteria adhering to the Patel et al. (7) guidelines for the use of CBCT constitute a significant weakness of this study and compromise the universality of the results. Future studies should conduct controlled clinical trials to more thoroughly explore the clinical efficacy of this method. Despite these limitations, methodological strengths enhance the study's validity. The case series design of this study increases the real-world applicability of the findings, offering a stark contrast to previous TM study limited to *in vitro* environment (13). Moreover, although the observers were experienced endodontists, they underwent rigorous calibration to ensure consistency

in their assessments. Additionally, blinding was rigorously maintained during patient treatment to ensure independent and unbiased readings by each professor.

The results of this study support that TM provides clinically safe and reproducible measurements, thereby suggesting its potential utility in managing permanent teeth with non-vital pulp and open apices. Conversely, a substantial discrepancy was noted between the parameters obtained for RWL and TWL. This inconsistency suggests that the conventional method for determining the working length of teeth with these anatomies is unreliable. That is, it is accurate but not precise. Additionally, the detection of external inflammatory root resorption in some cases reinforces the limitations of periapical radiography, particularly for defects located on the buccal or lingual sides of affected roots (14). TM demonstrated capacity to identify such external inflammatory root resorption irregularities, as depicted in Figure 4a. When considering the advantages identified in this study, alongside the absence of harmful events reported by patients, and compared with the approximately 10 additional minutes added to the duration of each case when applying the technique, TM offers greater benefits than risks.

Consequently, these findings support the proposition that TM could serve as a valuable adjunctive tool in cases of permanent, straight, single-rooted teeth with a Vertucci type I configuration, a stable occlusal or incisal reference point, immature apical anatomy, an apical foramen size of ISO ≥90, endodontic infection, and radiographic evidence ofexternal inflammatory root resorption , particularly when CBCT scanning is unavailable or deemed unsuitable due to the patient's age. However, the inherent limitations of this study, as previously described, must be considered, particularly those related to the sample size. Therefore, the results presented should be interpreted with caution and further clinical studies are necessary to confirm these findings (15).

The statistically significant differences observed between RWL, TWL, and TMWL emphasize the importance of carefully selecting methods for determining working length in teeth with open apices. While RWL measurements are widely used, their lack of precision in such cases may result in suboptimal cleaning and shaping, potentially compromising treatment success. TWL measurements, although highly accurate, are not always feasible due to cost, equipment availability, or patient-related considerations. The introduction of TMWL offers a practical and reliable alternative in cases where CBCT is unavailable and provides measurements comparable to those of TWL. Furthermore, the ability of TM to detect external inflammatory root resorption enhances its value in treatment planning because accurate diagnosis and localization of resorptive defects are critical for achieving successful outcomes in endodontic therapy.

It is crucial to note that TM is not suggested for use in all cases of teeth with open apices and non-vital pulp. Instead, its application should be viewed as supplementary by the clinician and not as a replacement for radiographic determination of working length. This technique could be among the range of procedures that a clinician should know and apply to very specific cases. Additionally, based on the current scientific evidence available for the TM, we do not recommend that general dentists or less experienced clinicians implement it until more robust evidence supports its use. Furthermore, operators should follow the prescribed clinical protocol for TM meticulously to prevent procedural accidents.

CONCLUSION

The TM has shown a reliable level of inter-observer agreement and could show a potential utility during managing permanent teeth with non-vital pulp and open apices, particularly in instances showing radiographic signs of external inflammatory root resorption.

Disclosures

Informed consent: Written informed consent was obtained from the patient for the publication of the case report and the accompanying images.

Authorship Contributions: Concept – M.A.T., H.P., G.G.; Design – M.A.T., M.D., A.O.B.; Supervision – M.D.; Data collection and/or processing – M.A.T., M.U., R.S.; Data analysis and/or interpretation – H.P., G.G.; Literature search – A.O.B., M.U., R.S.; Writing – M.A.T., H.P., A.O.B., M.U.; Critical review – G.G.

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