Original Article

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Dentistry Section

Evaluation of Electromagnetic Interference from Smartphones on Working Length Determination using an Electronic Apex Locator: An In-vitro Study

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ABSTRACT

Introduction: With advancements in technology, in endodontics, the adoption of Electronic Apex Locators (EALs) has risen as they provide greater accuracy while lowering radiation exposure. Many devices, including smartphones, emit Radiofrequency (RF) waves through fixed antennas, creating Electromagnetic Fields (EMF) that may cause Electromagnetic Interference (EMI). Such interference has the potential to affect circuits within EALs, possibly impacting their accuracy during Working Length (WL) determination. Evaluating this interference in an in-vitro model helps determine whether routine smartphone use can affect WL determination and potentially influence endodontic treatment outcomes.

Aim: To assess the effect of smartphones on performance of EALs in determining WL.

Materials and Methods: The present in-vitro study was carried out in the Department of Conservative Dentistry and Endodontics in the Bharati Vidyapeeth Dental College, Pune, Maharashtra, India, through the span of three months from July to September 2024. Extracted intact single canal single rooted mandibular premolars with mature apex were primarily included. A total of 180 teeth were decoronated to standardise a length of 14 mm and provide a stable reference point. Actual Working Length (AWL) was established with a K-file of size 10 into each canal. Each tooth was mounted in a plastic bottle filled with normal saline to simulate periodontium-like conductivity, and to complete the circuit EAL's lip clip was inserted into the bottle as well. Samples were partitioned into five groups: Group 1: Control (no smartphone present), Group 2: Smartphone in close proximity, no mode activated, Group 3: Smartphone at 35 cm, no mode activated, Group 4: Smartphone in close proximity with bluetooth, mobile data, Wi-Fi, and calling modes activated, Group 5: Smartphone at 35 cm with all modes activated. Data normality was confirmed using the Shapiro-Wilk test ($p>0.05$). For intergroup comparisons, One-way Analysis of Variance (ANOVA) was utilised. Results with p-values below 0.05 were deemed statistically significant.

Results: Descriptive analysis of WL measured using a fifth-generation EAL revealed the lowest mean values in Group 3 (12.98 ± 0.60), followed by Group 4 (13.05 ± 0.58) and Group 5 (13.06 ± 0.58), while the highest mean WL was observed in Group 1 (13.26 ± 0.49) and Group 2 (13.18 ± 0.49). Intergroup comparison using one-way ANOVA showed no statistically significant differences in WL among the five groups ($p>0.05$). Tukey's post-hoc analysis further confirmed the absence of significant pairwise differences between groups.

Conclusion: The results of the present in-vitro study suggests that smartphones, whether active or inactive and regardless of distance, do not interfere with EAL performance. Thus, smartphones may be safely used in dental operatories without concern for EMI affecting WL accuracy.

Keywords: Electromagnetic fields, Mobile phone, Root canal treatment

INTRODUCTION

Precise WL measurement is a basic necessity for successful endodontic root canal treatment and directly affects endodontic outcome [1]. The determination of accurate WL limits all biomechanical and obturation procedures to the root canal system and ideally to the apical constriction, denoted as the optimal biological end-point [1,2]. Working short of this area could provide inadequate debridement and microbial contamination, while overextension could cause damage to apical tissues and involve extrusion of debris and irrigation fluids and could cause postoperative pain and delays in periapical healing [3,4]. The measurement of accurate WL is a sine qua non for effective canal disinfection and three-dimensional obturation and aids maximum canal preparation and enhanced apical third irrigation and apical seal and thus directly requires preventing endodontic failures and events such as periapical disease [5].

For their high degree of accuracy, EALs are in wide usage in contemporary endodontic practice, hence reducing reliance on radiographic methods. Basically, these devices calculate the electrical impedance within the root canal system in order to locate the apical constriction [6,7]. With the increased presence of smartphones within dental operatories, the potential for EMI has been raised. Smartphones generate RF waves with their use of calling, mobile data transmission, Wi-Fi, and bluetooth, which affect sensitive electronic devices through perturbation of its circuitry [8]. EMI effects of mobile phones on medical devices such as pacemakers, electrocardiographs, and infusion pumps have been reported [9]. However, evidence regarding their influence on the accuracy of EALs remains limited and inconclusive.

The aim of this study was to evaluate the potential EMI caused by smartphones on the accuracy of WL determination using an EAL under in-vitro conditions.

The objectives of the present study were to evaluate the effect of smartphones in active and inactive modes on the accuracy of WL determination using an EAL, to assess the influence of varying distances between the smartphone and the EAL on measurement accuracy, to compare WL values obtained with and without smartphone exposure, and to determine whether smartphone use in the dental operatory environment affects endodontic precision.

Null hypothesis (H_0) was presence, operational mode, and distance of a smartphone do not cause any significant difference in WL determination using an EAL.

Alternate (research) hypothesis (H_1) was the presence, operational mode, and/or distance of a smartphone cause a significant difference in WL determination using an EAL due to EMI.

MATERIALS AND METHODS

The present in-vitro study was carried out in the Bharati Vidyapeeth Dental College (Department of Conservative Dentistry and Endodontics)., Pune, Maharashtra India, through the span of three months from July to September 2024. The institutional ethics committee (EC/NEW/INST/2021/MH/0029) approved the research protocol. The sample size was statistically calculated and estimated using data obtained from a previous study [10].

Convenience sampling was employed in this in-vitro study. All extracted teeth that fulfilled the inclusion criteria and were available during the study period were included. Although convenience sampling was used due to the in-vitro nature of the study, the sample size was not time-bound. Since the present study employed a convenience sampling technique and did not involve any follow-up period, attrition of samples was not anticipated. All selected samples were readily available and evaluated within the defined study duration. Therefore, an attrition rate was not incorporated into the sample size calculation, as complete data acquisition was ensured for all included samples.

Sample size calculation: The sample size (n) is derived by using the comparing two means formula:

$n = (\sigma_1^2 + \sigma_2^2/\kappa)\ (Z_1\text{-}\alpha/_2+Z_1\text{-}\beta)^2$

Δ^2

Where, σ_1 = standard deviation of Group 1,

σ_2 = standard deviation of Group 2

Δ = difference in group means [10]

The mean value for Group 1 was 21.4, compared to 20.2 for Group 2, resulting in a difference of 1.2 between the groups. The standard deviation was 1.67 for Group 1 and 1.97 for Group 2. The variance was calculated as 2.7889 for Group 1 and 3.8809 for Group 2.

κ = ratio = n2/n1 = 1

Z1-α/2 = two-sided Z value (e.g., Z=1.96 for 95% Confidence Interval).

Z1-β = power of the study (80% power, critical value of 0.84)

Substituting the values in the above formula,

n= 36 samples per group

A total sample size of 180 samples is derived (considering 5 groups; 36 samples per group).

Total sample size = 180 samples

A total of 180 non carious premolars, extracted for orthodontic and periodontal conditions, were utilised. All tooth samples were sterilised by immersion in a 10% formalin solution and stored in distilled water until use.

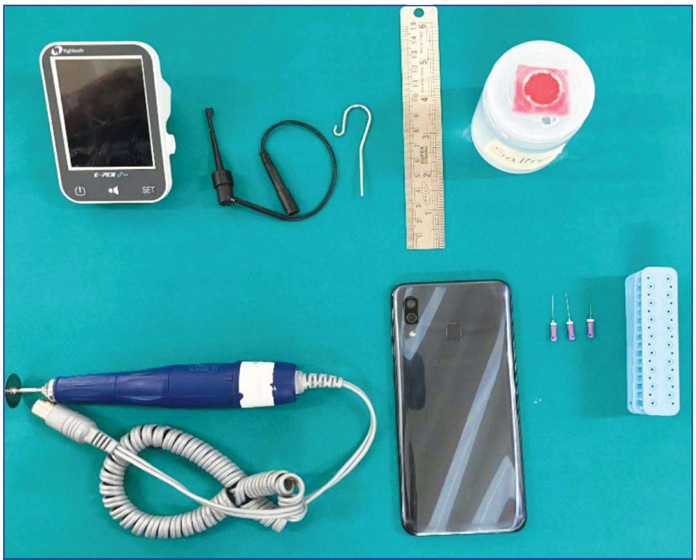
Inclusion criteria: Extracted intact single canal single rooted mandibular premolars with mature apex.

Exclusion criteria: Teeth with root caries, restoration, severely angulated roots, calcified root canals, cracked tooth, shape or size anomalies, internal or external resorption of root, primary teeth and teeth that are previously treated with root canal treatment will be excluded.

Strict anonymisation was maintained while the samples were collected.

Study Procedure

Sample preparation: Armamentarium used in the present in-vitro study is showed in [Table/Fig-1]. A total of 180 extracted teeth were decoronated at the Cemento-Enamel Junction (CEJ) to obtain a root of standardised length of 14 mm, thereby ensuring uniform access preparation and a consistent coronal reference point for determining the WL [Table/Fig-2].



[Table/Fig-1]: Armamentarium.

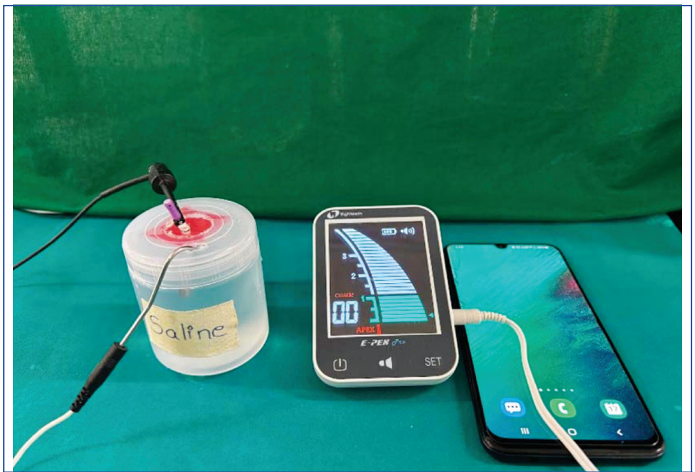
[Table/Fig-2]: Decoronation done for standardisation.

The AWL of each specimen was identified carefully by using a K file of size 10, the canal was explored till the tip of K-file could be visualised at the foramen of root apex. At this stage, the rubber stopper was rectified and aligned with the predetermined reference point. Subsequently, each tooth was stabilised within an individual plastic container, and the lip clip of the apex locator was also secured inside the container to complete the electrical circuit [11]. Normal saline was used within the container to serve as the conducting medium. Eighteeth Medical E-Pex Apex Locator (product of Changzhou Sifary Medical Technology Co. Ltd., China) was used for determination of WL throughout the current study. Then all 180 samples were subjected to a total of five groups of experiments in a series for further investigations [Table/Fig-3].

Group 1 served as the control group, in which no smartphone was present in the experimental room, thereby eliminating any potential EMI. In Group 2, a smartphone was placed in close proximity to the EAL with all communication modes switched off, to assess the effect of mere physical presence of the device without active signal transmission [Table/Fig-4]. Group 3 involved placement of the smartphone at a standardised distance of 35 cm from the EAL with all modes deactivated, allowing evaluation of the influence of distance alone in the absence of signal emission [12]. Group 4, the

Groups (N=36)	Intervention
Group 1	Control group (No smartphones in room).
Group 2	Smartphone in close proximity to Electronic Apex Locator (EAL) without any mode activation.
Group 3	Smartphone kept at 35 cm from EAL without any mode activation.
Group 4	Smartphone in close proximity to EAL with bluetooth, mobile data, Wi-Fi and calling modes activation.
Group 5	Smartphone kept at 35 cm from an EAL with bluetooth, mobile data, Wi-Fi and calling modes activation.

[Table/Fig-3]: Experimental groups.



[Table/Fig-4]: Smartphone in close proximity to Electronic Apex Locator (EAL) without any mode activation (Group 2).

smartphone was kept in close proximity to the EAL with bluetooth, mobile data, Wi-Fi, and calling modes activated simultaneously, to simulate maximum electromagnetic exposure. Group 5 assessed the combined effect of distance and active signal transmission, with the smartphone positioned at 35 cm from the EAL while all communication modes were activated.

In this study, all WL measurements were performed by a single adequately trained MDS postgraduate student to ensure procedural uniformity; however, examiner calibration and inter-/intraexaminer reliability assessment were not performed.

STATISTICAL ANALYSIS

For statistical evaluation, software edition 26.0 of Statistical Package for Social Sciences (SPSS) (IBM Corporation, Armonk, New York, USA) was employed. The descriptive and inferential statistics were applied to evaluate the different parameters examined in this study. For intergroup comparisons of continuous variables, One-way ANOVA was utilised, and Tukey's post-hoc procedure was utilised for intergroup comparisons. All the analyses were executed with a 95% confidence interval, and results with p-values below 0.05 were deemed statistically significant.

RESULTS

In this study, descriptive statistics of WL using 5th generation EAL amongst different groups were performed. It was noted that the mean value of Group 3 (12.98±0.60) was lowest followed by Group 4 (13.05±0.58) and Group 5 (13.06±0.58); whereas the highest mean value of WL was noted for Group 1 (13.26±0.49) and then Group 2 (13.18±0.49). Thus, it can be interpreted that Group 3 showed lesser WL whereas Group 1 showed higher WL [Table/Fig-5].

In this study, intergroup comparison of WL with the help of an EAL between different groups was performed using one-way ANOVA. This comparison did not show any statistically significant (p-value >0.05) differences within the five groups regarding WL [Table/Fig-6].

[Table/Fig-6] Intergroup comparison of Working Length (WL) using EAL between different groups was performed using One-way

Groups	N	Minimum	Maximum	Mean	Std. deviation
Group 1	36	12.50	14.50	13.26	0.49
Group 2	36	12.00	14.00	13.18	0.49
Group 3	36	12.00	13.50	12.98	0.60
Group 4	36	12.00	14.00	13.05	0.58
Group 5	36	11.50	14.00	13.06	0.58

[Table/Fig-5]: Descriptive analysis of working length (mm) measured with an electronic apex locator across different groups.

Comparative groups	Sum of squares	df	Mean square	F	p-value
Group 1 to Group 5	1.750	4	0.438	1.417	0.230

[Table/Fig-6]: Intergroup comparison of Working Length (WL) using Electronic Apex Locator (EAL).
Test applied – ANOVA *p-value <0.05 statistically significant
df : Degrees of freedom; F: Fisher's variance ratio

ANOVA. This comparison did not show any statistically significant (p-value >0.05) differences between the five groups for WL.

In this study, pairwise intergroup comparisons of WL evaluated with an endodontic apex locator were implemented with Tukey's post-hoc procedure. The analysis showed no statistically significant differences (p>0.05) in WL among the five groups [Table/Fig-7].

Groups	Groups	Mean difference	p-value
Group 1	Group 2	0.08333	0.969
	Group 3	0.27778	0.216
	Group 4	0.20833	0.505
	Group 5	0.19444	0.574
Group 2	Group 1	-0.08333	0.969
	Group 3	0.19444	0.574
	Group 4	0.12500	0.875
	Group 5	0.11111	0.915
Group 3	Group 1	-0.27778	0.216
	Group 2	-0.19444	0.574
	Group 4	-0.06944	0.984
	Group 5	-0.08333	0.969
Group 4	Group 1	-0.20833	0.505
	Group 2	-0.12500	0.875
	Group 3	0.06944	0.984
	Group 5	-0.01389	1.000
Group 5	Group 1	-0.19444	0.574
	Group 2	-0.11111	0.915
	Group 3	0.08333	0.969
	Group 4	0.01389	1.000

[Table/Fig-7]: Pairwise multiple Intergroup comparison of Working Length (WL) using Electronic Apex Locator (EAL) between different groups.
Tukey's post-hoc test, *p-value <0.05 statistically significant

Clinically, these findings indicate that fifth-generation EALs demonstrate resistance to EMI from smartphones and, as such, can be considered reliable in routine dental practice. A trend toward reduced WL values was observed when the smartphones were in close proximity, though this effect failed to achieve statistical significance. However, practical recommendations include adherence to manufacturer guidelines regarding the use of devices and minimising unnecessary electronic interference, especially under different clinical or in-vivo conditions.

DISCUSSION

An EAL is now contemplated as an essential instrument in endodontics for precise determination of WL [13,14]. These devices function by assessing the electrical resistance or impedance within the root canal, allowing accurate identification of the apical constriction [6,13]. Given their electronic nature, there has been ongoing concern about the possible interference of Electromagnetic Fields (EMFs) from common devices such as smartphones, particularly in clinical settings where such devices are frequently used [15].

In this in-vitro study, the WL measurements recorded by the EAL showed no statistically significant differences, regardless of whether a smartphone was placed in direct proximity or at a distance of 35 cm, and irrespective of whether mobile functions such as Wi-Fi, bluetooth, mobile data, or calling were activated. These findings indicate that EMI from smartphones does not significantly affect the performance of EALs under the tested conditions.

This result corroborates findings from Raje M et al., who concluded that the proximity of mobile phones did not influence the accuracy of WL determination using EALs, Hurstel J et al., and Sidhu P et al., using different models of EALs and mobile devices, also reported similar results, emphasising that modern EALs are well-shielded against ambient electromagnetic radiation, including that from smartphones [16-18]. Previous studies by Jain D et al., and Nogueira Leal Silva EJ et al. have also confirmed that EALs maintain precision even in the presence of EMFs under controlled conditions [12,19].

The mechanism behind potential interference lies in the emission of EMFs from smartphones, which may disrupt the low-frequency electrical signals used by EALs to measure impedance [20]. However, as previous studies have indicated, such interference is typically minimal and clinically insignificant unless the device is in extremely close proximity and poorly shielded [17,18].

Moreover, the current study utilised saline as the embedding medium for the teeth, which is known to provide electrical conductivity characteristics similar to those of the periodontium [21]. According to Kaufman AY et al., and saline and alginate are both reliable mediums for in-vitro EAL testing [21], as they mimic the in-vivo environment to a reasonable extent, thereby enhancing the validity of the findings [22,23].

Some earlier research had suggested that EMFs from various electronic devices could interfere with medical instruments. For instance, Altamura G et al., reported EMI-related malfunctions in cardiac pacemakers due to mobile phones and other devices [24]. However, it is important to distinguish between the sensitivity of life-sustaining implantable devices and EALs, which are specifically designed to function in environments containing common electronic interference [25].

It is also important to note that the design and shielding of both smartphones and dental devices have significantly improved over the years [17,18]. Modern smartphones are designed with electromagnetic shielding that reduces stray emissions, and similarly, newer EALs are constructed with improved circuit stability and resistance to EMI [14,17]. This technological advancement may explain the lack of significant interference observed in this and other contemporary studies [12,16].

Despite the increasing integration of wireless technologies in dental clinics, this study reinforces the evidence that EAL accuracy is not compromised by the presence or operation of mobile phones nearby [16,17]. This is of clinical relevance, as many dentists now use smartphones and tablets for accessing patient records, taking intraoral photos, and using digital reference tools during procedures [26].

However, caution is advised in extrapolating these in-vitro results directly to clinical situations. In-vivo, factors such as patient movement, saliva, blood, and other anatomical variations may influence EAL readings [27,28]. Furthermore, while no interference was observed in this controlled setup, the cumulative effect of multiple EMF-emitting devices in a real-world dental operatory has not yet been thoroughly studied [29].

The current research work was carried out under the null hypothesis that the availability, functioning state, and distance of a smartphone would have no effect on the accuracy of WL measurement with an EAL. The alternative hypothesis stated that EMI produced by smartphones would be a significant contributing factor affecting the accuracy of EALs' measurement of WL. The results of this study showed that mean WL values among all study groups were equal without statistical significance ($p>0.05$). As intergroup comparison showed no significant difference in WL, the null hypothesis stating no difference between groups was accepted. Hence, this study proved that electromagnetic wave interference produced by a smartphone does not interfere with electronic circuits of currently available EALs systems. Silva EJ et al., and Mohan N et al., reached similar conclusions with similar research showing that using a mobile phone has no significant effect on the accuracy of measurement of newer-generation EALs systems with respect to measurement accuracy [19,30]. The resistance to EMI of contemporary apex locators has been ascribed to technological advances such as multifrequency impedance analysis and improved signal filtering [14]. In this regard, the findings of the current study support the use of contemporary EALs in dental offices, where the use of smartphones is unavoidable.

Future research should aim to further improve the accuracy and reliability of EALs under diverse clinical conditions, particularly in teeth with complex apical anatomy and periapical pathology. Standardised in-vitro and in-vivo study designs are needed to better compare device performance and define optimal clinical protocols. As exposure to EMFs continues to increase, the influence of emerging wireless technologies on apex locator accuracy warrants further investigation. The development of devices with enhanced signal processing and electromagnetic shielding may reduce susceptibility to external interference.

Advances in digital technology, including artificial intelligence and multimodal imaging integration, may enable next-generation apex locators to provide more precise and adaptive WL determination. Finally, long-term clinical outcome studies are necessary to clarify whether improvements in electronic measurements result in higher endodontic treatment success rates and enhanced patient safety.

Limitation(s)

This was an in-vitro study under controlled conditions, which may in itself fail to completely mimic the real situation of the clinical setting in terms of differences in tissue conductivity or other patient-related factors. Only one particular model of EAL was used in this study for testing, which is incapable of drawing general inferences about all other locators of similar functionality. Furthermore, other common EMI sources in dental practices were also untested in this study. Its inability to test other common electromagnetic wave-emitting devices in dental practices such as intraoral cameras, curing lights, or laptops. Its usage of saline solution as the conduction medium of choice in this task, which is quite all right but whose actual conductivity properties are likely to be quite different from those of actual tissue in the human body. In the current in-vitro study, confounding factors, which might have affected WL measurements, were closely controlled. The confounding factors include tooth type, canal morphology, apical maturity, canal patency, size of the file, irrigant conductivity, and human variability. In this study, it was made certain that all specimens were single-rooted premolars, taken from the lower jaw, having intact apices and single canal morphology, which helped reduce variability. Moreover, measurements were taken using a common file size (ISO #10), common embedding media (normal saline), and common apex locator. As all confounding factors were controlled, there was no need for statistical adjustment. However, calibration of the examiners and reliability assessment were not conducted, which may introduce a possible source of measurement variability.

CONCLUSION(S)

The result of this investigation suggests that the use of the smartphone, in its fully functional capacity, does not generate potentially harmful electromagnetic interference towards the operation of electronic apex locators in an in-vitro environment. It is therefore safe to conclude that the use of the smartphone in the dental operatory has no bearing on the accuracy of the determination of the working length during use of the electronic apex locator. Future advances in the ability of the devices to resist electromagnetic interference could make them even safer for use in the dental environment.

REFERENCES

[1] Ingle JI, Bakland LK, Baumgartner JC. Ingle's Endodontics. 6th ed. Hamilton: BC Decker; 2008. p. 233-245.
[2] Kuttler Y. Microscopic investigation of root apexes. J Am Dent Assoc. 1955;50(5):544-52.
[3] Sjögren U, Figdor D, Persson S, Sundqvist G. Influence of infection at the time of root filling on the outcome of endodontic treatment of teeth with apical periodontitis. Int Endod J. 1997;30(5):297-306.
[4] Ng YL, Mann V, Gulabivala K. Outcome of secondary root canal treatment: A systematic review of the literature. Int Endod J. 2008;41(12):1026-46.
[5] Schilder H. Cleaning and shaping the root canal. Dent Clin North Am. 1974;18(2):269-96.
[6] Kaufman AY, Keila S, Yoshpe M. Accuracy of a new apex locator: An in-vitro study. Int Endod J. 2002;35(2):186-92.
[7] Barakat RM, Almohareb RA, Alharbi AO, Alhazmi A, Alomar R. Comparative accuracy and reliability of three electronic apex locators in determining the apical constriction of molar canals: A micro-CT evaluation. J Clin Med. 2024;13(17):5199. Doi: 10.3390/jcm13175199.
[8] van Lieshout EJ, van der Velde ET, Meijer R, Korevaar JC, Vroom MB, Schultz MJ. Interference by new-generation mobile phones on critical care medical equipment. Crit Care. 2007;11(5):R98.
[9] Calcagnini G, Bartolini P, Floris M, Triventi M, Cianfanelli P, Scavino G, et al. Electromagnetic interference to infusion pumps from GSM mobile phones. Conf Proc IEEE Eng Med Biol Soc. 2004;2004:3515-18. Doi: 10.1109/IEMBS.2004.1403988. PMID: 17271047.
[10] Mann NS, Kaur S, Gupta D, Sapra S. Does mobile data and wifi interfere with electronic apex locator? Eur Chem Bull. 2023;12(issue 8):6141-51.
[11] Hussein HM. The effect of Wi-Fi signals on the measurement accuracy of electronic apex locator during root canal therapy. Mustansiria Dental Journal. 2018;14(1):8-15.
[12] Jain AS, Asrani H, Singhal AC, Asrani A, Deshmukh P, Jain D. Do mobile phones cause interference on electronic apex locators? An in-vitro study; Endodontology. 2017;29(2):142-45. | Doi: 10.4103/endo.endo_5_17.
[13] Gordon MPJ, Chandler NP. Electronic apex locators. Int Endod J. 2004;37(7):425-37.
[14] Ricucci D, Langeland K. Apical limit of root canal instrumentation and obturation, part 2: A histological study. Int Endod J. 1998;31(6):394-409.
[15] Lawrentschuk N, Bolton DM. Mobile phone interference with medical equipment and its clinical relevance: A systematic review. Med J Aust. 2004;181(3):145-49.
[16] Raje M, Shetty P, Kambli V, Keswani K, Padwal S, Lokhande V. Effect of electromagnetic radiation from cell phone on working length determination by electronic apex locator: An in vivo study. Saudi Endodontic Journal. 2024;14(3):356-60.
[17] Hurstel J, Guivarc'h M, Pommel L, Camps J, Tassery H, Cohen S, et al. Do cell phones affect establishing electronic working length? J Endod. 2015;41(6):943-46. Doi: 10.1016/j.joen.2015.02.007. Epub 2015 Mar 19. PMID: 25799536.
[18] Sidhu P, Shankargouda S, Dicksit DD, Mahdey HM, Muzaffar D, Arora S. Evaluation of interference of cellular phones on electronic apex locators: An in-vitro study. J Endod. 2016;42(4):622-25. Doi: 10.1016/j.joen.2015.12.027. Epub 2016 Feb 3. PMID: 26850688.
[19] Nogueira Leal Silva EJ, Muniz BL, Carvalho NK, Sassone LM, de Almeida Neves A. Electromagnetic interference of smartphones on apex locators: An in vivo study. Endodontic Practice. 2016;10(3):161-65.
[20] De Sarkar M, Kundabala M, Shetty N. Effect of cell phone radiation on electronic apex locator. Int J Dev Res. 2018;8(2):12170.
[21] Kaufman AY, Fuss Z, Keila S. Reliability of different embedding media for in-vitro evaluation of electronic apex locators. Int Endod J. 1997;30(4):272-76.
[22] Venturi M, Breschi L. A comparison between two electronic apex locators: An ex vivo investigation. Int Endod J. 2007;40(5):362-73.
[23] Siddiqui AY. Influence of embedding medium on ipex electronic apex locator accuracy: An ex vivo comparative study using Alginate, Saline, and Gelatin Models. J Contemp Dent Pract. 2023;24(10):733-38. Doi: 10.5005/jp-journals-10024-3583. PMID: 38152904.
[24] Altamura G, Toscano S, Gentilucci G, Ammirati F, Castro A, Pandozi C, et al. Influence of digital cellular phones on cardiac pacemakers: In-vitro and in vivo evaluation. Pacing Clin Electrophysiol. 1997;20(8):1996-2002.
[25] Wisaratapong T, Pechaksorn N, Liabsuetrakul T, Lohawijarn W. The effect of electromagnetic interference produced by smartphones using 5G network on patients with permanent pacemakers (EMS5G-PPM study). J Interv Cardiol. 2024;2024:3550004.
[26] Alrehaili RS, Almuzaini S, Alrajhi J, Dashti A, Alsuroor O, Alzahrani F, et al. Teledentistry in the era of digital dentistry: Clinical applications, patient experience, and equity-oriented policy implications. Cureus. 2025;17(12):e100137. Doi: 10.7759/cureus.100137.
[27] Hu H, Liu M, Yang J, Zhu L, Min Y, Yang Q. Electronic apex locator 'apical constriction' reading versus micro-computed tomography landmarks in molars: An in-vitro study. BMC Oral Health. 2026;26(1):318. Doi: 10.1186/s12903-026-07714-y. PMID: 41555346; PMCID: PMC12905839.
[28] Koç S, Harorlı H, Kuştarcı A. In-vitro evaluation of the accuracy of electronic apex locators and cone-beam CT in the detection of oblique root fractures. Dentomaxillofac Radiol. 2024;53(7):509-14.
[29] Bohay RN, Bencak J, Kavaliers M, Maclean D. A survey of magnetic fields in the dental operatory. J Can Dent Assoc. 1994;60(9):835-40. PMID: 7922804.
[30] Mohan N. Smartphone use may not interfere with working of Electronic Apex Locator: Study. Medical Dialogues. Jan 18, 2021.

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