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Original Article

Evaluation of the Effect of Calcium Hydroxide Residues Including Different Vehicles on the Accuracy of Electronic Apex Locators

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Simay Koç[1], Damla Erkal[1], Dide Tekinarslan[1] and Kürşat Er[1]

Abstract

Aim: This study aimed to evaluate the effect of the residues of the calcium hydroxide (CH) dressings with different vehicles on the accuracy of two different electronic apex locators (EALs).

Materials and Methods: Endodontic access cavities were prepared at 120 single-rooted maxillary premolars. The actual length (AL) was determined under a stereomicroscope at ×15 magnification. After the preparation of the canals, electronic length (EL1) was measured using Propex Pixi and EndoRadar Pro. Samples were divided into one control (without CH) and five experimental groups according to the different CH vehicles (saline, mono propylene glycol, methylcellulose, silicone oil, and chlorhexidine), and calcium CH dressing was placed. After the removal of CH using 4 mL of 17% EDTA irrigation with EDDY, EL was measured again and recorded as EL2. The difference was calculated by subtracting AL from EL1 and EL2. The amount of CH residues was assessed using software.

Results: There was no significant difference among the groups after removal of the CH dressing for both EALs ($p > .05$). The type of vehicle did not affect the residual amount of CH. Due to the residual CH, the accuracy of both EALs was compromised. However, the success rate of Propex Pixi was significantly reduced in the presence of CH remnants.

Conclusion: Propex Pixi and EndoRadar were more accurate in the measurements before the application of CH dressing than after. There was no discernible impact of vehicle type on the residual amount of CH. This study emphasizes the necessity of completely removing CH dressings prior to the use of EAL to enhance the accuracy of the working length determination in endodontic practice.

Keywords

Calcium hydroxide, Residual material, Electronic apex locator, Root canal therapy

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Introduction

Properly defining the working length (WL) and the point of treatment completion, referred to as apical constriction, are essential in endodontic treatment to ensure a positive prognosis for the treated tooth.[1] Radiographic and electronic techniques are presently employed for ascertaining the accurate length of root canals. However, due to the constraints associated with radiography, there has been a growing reliance on electronic devices in recent times. Electronic apex locators (EALs) have proven to be efficient and consistent in identifying the apical foramen.[2]

The presence of microorganisms within the root canal system plays a crucial role in the development of endodontic pathologies.[3,4] Despite significant advancements in root canal instrumentation procedures, none of the existing techniques can completely eradicate microorganisms from the root canals.[5] Consequently, alongside instrumentation, the use of intracanal medication has been recommended to disinfect the root canal system and enhance the success of root canal treatment (RCT), particularly in cases requiring multiple visits.[6] Calcium hydroxide (CH), when combined with a suitable vehicle, has emerged as the most commonly employed intracanal medicament in endodontics due to its favorable antimicrobial properties against a wide range of

[1]Department of Endodontics, Faculty of Dentistry, Akdeniz University, Antalya, Turkiye

Corresponding author:
Kürşat Er, Department of Endodontics, Faculty of Dentistry, Akdeniz University, Antalya 07058, Turkiye.
E-mail: mkursater@gmail.com

microorganisms relevant to endodontic infections, as well as its biocompatibility.[7,8]

Various substances and vehicles have been combined with CH to facilitate its insertion into root canals or enhance its biological, chemical, physical, or microbiological properties. These include chlorhexidine (CHX), ciprofloxacin, metronidazole, iodine-potassium iodide, iodoform, silicone oil, anesthetic solution, glycerin, polyethylene glycol, and propylene glycol.[9–14] The choice of the vehicle significantly influences the rate at which CH dissociates into hydroxyl and calcium ions, thereby impacting its physical and chemical characteristics.[15] However, before the filling, CH needs to be removed as its presence on the root canal walls hampers the penetration of sealers into dentinal tubules.[16] Consequently, several techniques and irrigants have been introduced for CH removal.[17]

Studies[18,19] have demonstrated that despite instrumentation and irrigation, the root canal walls cannot be completely cleaned, resulting in the presence of CH residues, especially in the apical portion of the canal. Uzunoglu et al.[19] conducted an in vitro study that revealed these CH residues had a negative impact on the accuracy of Root ZX. However, information on the influence of CH residues on newer EALs, specifically EndoRadar Pro (Woodpecker, Guilin, China) and Propex Pixi (Dentsply Maillefer, Ballaigues, Switzerland), is lacking. Additionally, there is limited evidence on how different CH vehicles (e.g., saline, mono propylene glycol [MPG], methylcellulose, silicone oil, and CHX) impact CH residue retention and EAL accuracy, underscoring a significant knowledge gap in endodontic practice.

This study aimed to evaluate and compare the effect of CH residues prepared with different vehicles (saline, MPG, methylcellulose, silicone oil, and CHX) on the accuracy of two different EALs (EndoRadar Pro and Propex Pixi). The null hypothesis stated that the accuracy of EALs used in this study was not affected by the residual CH associated with different vehicles.

Materials and Method

The sample size was decided after the pilot study, which included five samples for each group. G*Power 3.1.9.7 program was used to calculate the sample size, and for each group, the sample size should be a minimum of 18 (power = 0.95, effect size = 0.5, significance level of $a = 0.05$). Finally, 20 teeth in each group were selected. The Clinical Research Ethics Committee of Akdeniz University, Antalya, Türkiye reviewed and approved the study construction with decision number KAEK-399.

The inclusion criteria were as follows: permanent, single-rooted maxillary premolars with one root canal. After inspecting the teeth under a stereomicroscope (Zeiss Stemi, Carl Zeiss/GmbH, Germany), teeth with previous RCT or cracks and fracture lines were excluded from the study. Any remaining hard and soft tissue remnants on the teeth were removed using a scaler. The presence of a single, oval-shaped canal was confirmed, and periapical radiographs were taken from both mesiodistal and buccolingual angles. To prevent the teeth from drying, they were stored in saline until the experiment.

Determination of Actual Length

The incisal edges or cusps of the included teeth were flattened to create a stable and reliable coronal reference point after preparing the endodontic access cavities in all teeth. Under a stereomicroscope (Zeiss Stemi) at ×15 magnification, a #10 K-type file was advanced until it was visible apically where the resorption area begins. The rubber stopper was attached to the incisal edge at the first time when the file was seen, and then the length between the tip of the file and the rubber stopper was calculated with a digital caliper and noted as the AL. To minimize operator errors, this process was repeated three times for each tooth.

Determination of Electronic Length (EL1)

Teeth were prepared using ProTaper Next (Dentsply Maillefer, Ballaigues, Switzerland) files X1, X2, X3, and X4 in sequential order. After each file, irrigation was performed using 2.5 mL of 2.5% sodium hypochlorite (NaOCl). Prior to the measurement, the teeth were rinsed with 5 mL of saline. Subsequently, all teeth were embedded in an alginate model to measure the electronic length (EL1) using two different EALs: Propex Pixi (Dentsply Maillefer) and EndoRadar (Woodpecker, Guilin, China).

Use of CH as an Intracanal Medication

After the teeth were numbered, a random number generator application was employed to generate the arbitrary numbers. The teeth were randomly separated into groups according to type of vehicle. The teeth were divided into one control group (without CH) and five experimental groups based on the different vehicles used with CH (saline, MPG, methylcellulose, silicone oil, and CHX. In all groups, a CH dressing (Kalsin, Izmir, Türkiye) was placed 2 mm short of

the WL in each root canal using a lentulo file (size #30, Jensen JP-1, USA).

Group 1 (No CH dressing, control) (*n* = 20): After drying the root canals with paper points, the electronic length (EL2) was determined using the Propex Pixi and EndoRadar EALs. No CH dressing was placed in the teeth of this group.

Group 2 (Saline) (*n* = 20): A freshly prepared CH dressing with 0.9% saline (OSEL, Istanbul, Türkiye) in a 1:1 ratio was placed using a lentulo.

Group 3 (MPG) (*n* = 20): CH dressing was prepared freshly by mixing CH powder and MPG (Gemici Tic., İstanbul, Türkiye) in a 1:1 ratio, then it was placed using a lentulo.

Group 4 (Silicone Oil) (*n* = 20): CH dressing was prepared freshly by mixing CH powder and silicon oil (Cadenca, İzmir, Türkiye) in a 1:1 ratio, then it was placed using a lentulo.

Group 5 (Methyl Cellulose) (*n* = 20): CH dressing was prepared freshly by mixing CH powder and methyl cellulose (Rokim, Yenilab Lab., Kocaeli, Türkiye) in a 1:1 ratio, then it was placed using a lentulo.

Group 6 (CHX) (*n* = 20): CH dressing was prepared freshly by mixing CH powder and CHX (Microvem, Altun Medikal, Sakarya, Türkiye) in a 1:1 ratio, then it was placed using a lentulo.

After the presence of CH in the root canal was verified with periapical radiographs, all the teeth were stored at 37˚C and 100% relative humidity for 7 days to simulate the intraoral conditions.

Removal of CH

To remove the CH dressing from all teeth, a combination of saline and 17% ethylenediaminetetraacetic acid (EDTA) irrigation was used. First, 5 mL of saline was used to rinse the root canals, followed by the application of 2 mL of 17% EDTA. The EDTA irrigation was activated using an EDDY sonic activation device (VDW, Munich, Germany) for 20 s, and this process was repeated three times. For all six groups, a total of 6 mL of EDTA was used, with 60 s of activation. These procedures were performed by a single operator and repeated consistently across all groups.

Determination of Electronic Length (EL2)

After the removal of the CH dressing, a #40 K-file was used to navigate through the entire canal until the signals "0.0" were displayed on the screen of the Propex Pixi and EndoRadar Pro devices. Once these signals remained consistently displayed for 5 s, a rubber stopper was attached, and the length between the file tip and the rubber stopper was measured using a digital caliper. This process was repeated three times for each tooth, and the mean value of the three measurements was recorded as EL2.

These procedures were repeated by a single operator for all six groups, with each group being tested on different days to ensure consistency and accuracy. The measurements exhibited a high level of dependability within the same operator, as evidenced by a Pearson correlation coefficient of more than 0.99. A single operator conducted the EWL measurements, which were subsequently read and recorded by another operator. To find the discrepancy, the AL was subtracted from the EL. Positive values indicate measurements beyond the WL; negative values are short of the WL.

Analyzing the Residues of CH

Following the electronic measurement, the roots were split into two halves to assess the presence of residual CH dressing. In order to prevent intracanal contact, the access cavity was sealed with a temporary filling material, while the teeth were divided into two halves. By dividing the buccolingual grooves in a manner that prevented access to the root canal system, the process was executed using a chisel and hammer. Images of the root canal space were captured using a stereomicroscope (Stemi DV4; Carl Zeiss, Gottingen, Germany) at a magnification of ×6. The captured images were then transferred to image analyzing software (ImageJ v1.53e; National Institutes of Health, Maryland, USA) to quantify the amount of residual CH in the root canal space, measured in mm^2 (Figure 1). The percentage of CH residues in the entire root canal and only in the apical third were calculated separately.

Statistical Analysis

The Shapiro–Wilk test revealed that there was no normal distribution for WL measurements. The Wilcoxon signed-rank test and Kruskal–Wallis test were used to analyze the data obtained from WL measurements and the one-way ANOVA test was used to evaluate the amount of residual

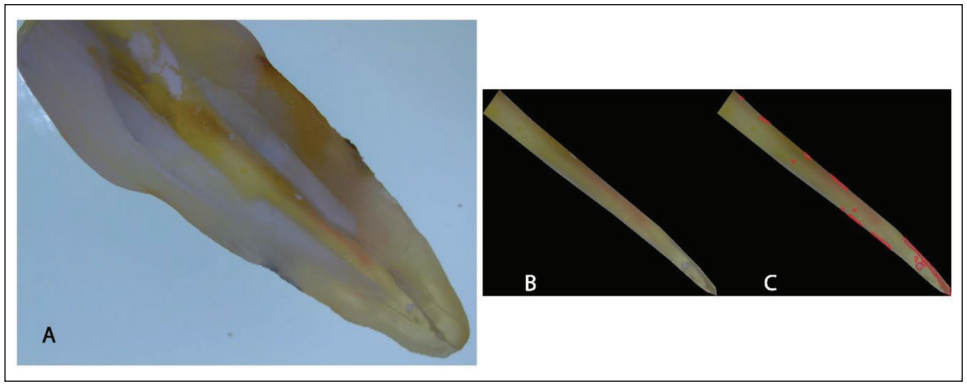

Figure 1. (A) A Representative Image of CH Residues on the Entire Root Canal Wall; (B) The Root Canal Space Has Been Defined as Specified in the Software; (C) Residual CH on Root Canal Space Was Indicated with Red Patch in the Software.

CH (SPSS 20.0, Chicago, IL, USA). The significance level was accepted as $p = .05$.

Results

In this study, the impact of CH dressing residues associated with different vehicles on the accuracy of two different EALs, and the residual amount of CH for each group were presented in Table 1. After the removal of the CH dressing, there was no significant difference in the accuracy of both EALs at ±0.5 mm tolerance among the groups. The percentage of the total and apical portion of the residual CH is shown in Table 2 in detail. CH residues were detected in the root canal space of all specimens. The choice of CH vehicle did not affect the removal of CH, and no statistical differences were observed among the five experimental groups. The accuracy of Propex Pixi and EndoRadar Pro, with a ±0.5 mm tolerance range before the application of CH and after the removal of CH, is presented in Table 3. It was found that Propex Pixi provided more accurate results before the application of CH compared to after ($p = .011$).

Discussion

In this study, a total of 120 fully developed human maxillary premolars with a single root were utilized. The effect of different vehicles on the amount of residual CH and the effect of residual CH on the accuracy of different EALs were evaluated. There was no significant difference among the groups after removal of the CH dressing for both EALs. The residual amount of CH was not influenced by the kind of vehicle. The residual CH negatively impacted the accuracy of both EALs. Nevertheless, the efficacy of Propex Pixi was notably diminished when CH residues were present.

Table 1. The Accuracy of EALs for Each Group at ±0.5 mm Tolerance Range.

EL2-AL	Propex Pixi *n* (%)	*p* Value	EndoRadar Pro *n* (%)	*p* Value
Group 1	18 (90)	.403	19 (95)	.155
Group 2	14 (70)		15 (75)	
Group 3	14 (70)		18 (85)	
Group 4	15 (75)		17 (90)	
Group 5	18 (90)		13 (65)	
Group 6	16 (80)		15 (75)	

Table 2. The Percentage of the Total and Apical Portion of the Residual CH.

Groups	Total Residual CH (%)	*p* Value	Apical Residual CH (%)	*p* Value
Group 2	7.08 ± 1.39	.399	13.59 ± 2.88	.063
Group 3	6.70 ± 1.73		14.48 ± 4.20	
Group 4	6.62 ± 1.26		12.05 ± 2.72	
Group 5	7.63 ± 2.06		13.96 ± 2.93	
Group 6	7.19 ± 2.36		12.25 ± 2.70	

Table 3. The Accuracy of Propex Pixi and EndoRadar Pro at ±0.5 mm Tolerance Range Before the Application of CH and After the Removal of CH was Shown.

EAL	EL1-AL *n* (%)	EL2-AL *n* (%)	*p* Value
Propex Pixi	112[a] (93.3)	95[b] (79.2)	.011
EndoRadar Pro	102[a, b] (85.0)	97[b] (80.8)	

Note: Values shown in lower case letters indicate the difference between pairwise comparisons of measurements.

Redetermination of WL may also be required at each appointment and root canal preparation. Therefore, the combination of both using electronic and radiographic methods has been declared to increase the accuracy of determined WL.[20] However, when radio-opaque CH dressing is used as an intracanal medicament between visits, visualizing the file tip becomes challenging on

conventional radiographs. Additionally, achieving complete cleaning of CH dressing from root canals can be difficult even with the utilization of various irrigation activation techniques.[21,22] Hence, in such cases, the use of EAL alone may be sufficient for accurate WL determination.[23]

To the best of our knowledge, there is currently no irrigation protocol that has been able to completely remove CH from the root canal walls as described in the literature. Previous studies[21,22,24,25] have also reported difficulties in achieving complete removal of CH using various tested protocols. In existing literature, passive ultrasonic activation (PUA) is widely acknowledged as the optimal method for activating irrigants.[26] Donnermeyer et al.[27] concluded that both EDDY and PUA were significantly more effective than other activation systems in removing CH. They attributed this superiority to the anticipated enhancement in fluid flow resulting from the higher frequency of EDDY in comparison to other sonic irrigation devices, coupled with the greater amplitude of the polymer rod tip in EDDY relative to PUA. In this study, a 17% EDTA activated with EDDY was employed to remove as much CH dressing as possible, based on the findings of previous studies.[19,22] According to the present study results, the choice of CH vehicle did not affect the residual amount of CH dressing in five experimental groups, and no statistical differences were observed among these groups. In addition, while the accuracy of EndoRadar Pro was not affected by the presence of CH residues, the accuracy of Propex Pixi was significantly affected. Therefore, the null hypothesis was rejected.

The use of CH, which has been the most used intracanal medicament, is also a valuable weapon for the elimination of bacterial biofilm on the infected root canal walls.[28] The antimicrobial action of CH is attributed to its ability to increase the pH within the root canal space and surrounding tissues by releasing hydroxyl ions.[29] Various vehicles can be used to prepare CH dressing, each with different water-solubility properties. In this study, the preferred vehicles of CH, including saline, MPG, methylcellulose, silicone oil, and CHX, were utilized. The amount of residual CH did not differ significantly among the five experimental groups, which is consistent with the findings of most previous studies.[30–32] However, some previous studies[17,33] reported that the removal of CH associated with methyl cellulose and silicone oil was more difficult from the root canal system. This inconsistency can be attributed to variations in the irrigation protocols employed during the cleaning procedure of CH.

In a study conducted by Ali et al.[34] the residual volume of CH associated with different solutions was evaluated. The study found that the *N*-methyl-2-pyrrolidone (NMP)-based group had a lower residual volume compared to the group prepared with distilled water. However, there was no significant difference in residual volume between the methylcellulose, glycerin, and lidocaine-based groups compared to the distilled water group. Another previous study[32] investigated the removal of CH associated with silicone oil, 2% CHX gluconate, and propylene glycol. It concluded that the type of CH vehicle did not play a significant role in the persistence of CH residues on the root canal walls. The results of the present study were consistent with previous studies, demonstrating no significant difference among the groups associated with saline, MPG, methylcellulose, silicone oil, and CHX in terms of the percentage of residual CH dressing.

Several studies[19,23,35] have investigated the impact of CH residues on the accuracy of EALs. Uzunoglu et al.[19] found that CH remnants in the root canal space had a negative effect on the accuracy of Root ZX. Ustun et al.[23] examined the accuracy of Mini Root ZX at a ±0.5 mm tolerance level and demonstrated that an increase in the amount of residual CH dressing proportionally affected the accuracy of the EAL. Shojae et al.[35] reported no difference in accuracy between Raypex 6 and Root ZX after the removal of CH dressing. In the current study, the accuracy of Propex Pixi and EndoRadar Pro was evaluated before the application of CH and after its removal. The results showed that while the accuracy of EndoRadar Pro was not affected by the presence of CH residues, the accuracy of Propex Pixi was significantly affected. This can be explained by the distinct operational mechanisms of the devices for which manufacturers do not supply comprehensive explanations. Furthermore, the use of different CH vehicles in the study did not impact the accuracy of either EAL. The findings of the study highlight important therapeutic implications for the use of EALs in the presence of residual CH. The accuracy of Propex Pixi was significantly undermined by CH residues, perhaps resulting in incorrect estimations of the canal's WL. This mistake may elevate the risk of over-instrumentation or under-instrumentation, potentially resulting in issues such as inadequate cleansing of the canal area or insufficient filling of the canal during obturation.

In addition, a study by Xu et al.[36] revealed that none of the agitated irrigation techniques could remove CH from root canals completely. In the present study, the residual percentage of CH in the apical third was greater than the total percentage of CH in the root canal. The reason for the larger part of CH paste residues in the apical third may be the low effectiveness of irrigation solutions due to the

irregular dentin tubules in this region and the small diameter of the canal.

Xu et al.[36] assessed the efficacy of different irrigation methods—conventional needle irrigation, passive ultrasonic irrigation, sonic irrigation, and the XP-endo finisher—in eliminating Vitapex paste from the canal system. The results demonstrated that passive ultrasonic irrigation was significantly more successful in removing residues than conventional approaches, highlighting the necessity for new strategies to tackle complex canal anatomies. Denna et al.[37] assessed the efficacy of the rotary instrument XP-endo Finisher for the removal of CH, utilizing various irrigation protocols, and demonstrated that the extraction of CH from the coronal and middle thirds was more effective than from the apical third across double-rooted upper premolars. This case demonstrates that in several clinical scenarios, the apical third of the root was the most challenging region for the removal of intracanal medicament. In addition, CH residues may negatively impact the intratubular penetration of the sealer and the adhesive interface with radicular dentin, as well as the physical properties of the epoxy resin-based endodontic sealer, hence diminishing the efficacy of endodontic therapy.[38]

A prior study[39] demonstrated that the WL undergoes changes at various stages of RCT and retreatment. Hence, it is imperative to carefully observe this parameter, particularly following the process of flaring and preparation in RCT. The authors proposed that this surveillance is essential in order to avoid excessive use of instruments and excessive filling of the root canals.[39] From a clinical standpoint, it is recommended to verify the complete clearance of the root canals prior to utilizing the EALs in order to guarantee enhanced accuracy of the devices. When intracanal medication is used, residual material could stay in the canal similar to retreatment cases, and it has been demonstrated that this affects the accuracy of the EALs. Therefore, to enhance the prognosis of the cases, it is recommended to integrate the utilization of the EAL with other WL assessment approaches.

In this study, an alginate model was utilized for electronic measurements, and the teeth were split to measure the surface area of the root canal space. The *in vitro* setup of the study offers several advantages, including the ability to conduct repeatable evaluations, directly compare different applications, and avoid the complexities associated with natural tooth morphology. However, it is important to acknowledge that this *in vitro* setup does have limitations. It cannot fully replicate the *in vivo* conditions encountered within the oral cavity. Factors such as the presence of surrounding tissues, blood flow, and natural tooth dynamics are absent in this experimental setup. Therefore, caution should be exercised when extrapolating the findings of this study to clinical practice. Further research involving *in vivo* studies is warranted to validate the results and assess the clinical relevance of the findings. The effects of new irrigation activation methods, such as novel laser activation and the GentleWave system, on CH removal should be evaluated, as well as their impact on the accuracy of EALs. Furthermore, in this study, it was stated that although most of the paste was eliminated from the root canals, there was still residue present in the canal system. This residue proved challenging to remove using only one removal approach. In order to enhance the effectiveness of CH removal, it is possible to employ a combination of two or more removal approaches and extend the duration of the procedure.

The removal of CH is difficult, particularly in irregular root canals.[40] The predominant irrigation solutions for the elimination of CH are chelation agents, including EDTA, citric acid (CA), phosphoric acid, and maleic acid, which dissolve the intracanal paste by chelating calcium ions. However, recent studies have highlighted the erosive impact of these chelators on dentin, potentially increasing the fracture susceptibility of roots.[40] Keskin et al.[41] showed that a 10% glycolic acid concentration effectively eliminated substantially more CH paste from resorption cavities compared to EDTA when utilized with passive ultrasonic irrigation.

Valuable insights into the challenges of CH residue removal in more complex canal anatomies, where effective cleansing is more demanding, would be gained by extending research to multi-rooted teeth. The accuracy of EALs across a wide range of endodontic cases could be enhanced by optimizing vehicle selection and treatment protocols for a broader range of clinical scenarios.

Conclusion

Within the limitations of the present study, it was found that the type of CH vehicle used did not have a significant impact on the residual amount of CH. It was observed that the accuracy of both EALs used in this study was affected by the residual CH. Nevertheless, the accuracy of Propex Pixi was considerably diminished when CH remnants were present. These findings suggest that the choice of EAL may have implications for accuracy in cases where CH has been used as an intracanal medicament. For optimal accuracy of EALs, clinical protocols should include comprehensive removal of CH dressing. This should involve evaluation to assess and confirm the complete removal of CH, and potentially incorporate novel technologies or techniques to improve cleaning efficiency. The findings should help

clinicians choose CH vehicles that minimize residue retention or establish EAL-specific irrigation regimens with additional confirmation. Modifying the protocol could enhance measurement accuracy, leading to more predictable and successful endodontic outcomes. Residual CH has a detrimental impact on the accuracy of EALs, and it is important to consider these results cautiously, considering the specific limitations of the study, and further research is needed to validate these findings in a clinical setting.

Authors' Contributions

SK and KE participated in designing the study. SK, DT, and DE participated in generating the data for the study. SK and KE participated in gathering the data for the study. SK participated in the analysis of the data. SK and KE have had access to all the raw data of the study. SK and KE have reviewed the pertinent raw data on which the results and conclusions of this study are based. SK and KE have approved the final version of this article. SK and KE guarantee that all individuals who meet the journal's authorship criteria are included as authors of this article.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethics Approval

Clinical Research Ethics Committee of Akdeniz University, Türkiye reviewed and approved the study construction with decision number KAEK-399.

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Informed Consent

Not applicable

ORCID iD

Kürşat Er https://orcid.org/0000-0002-0667-4909

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