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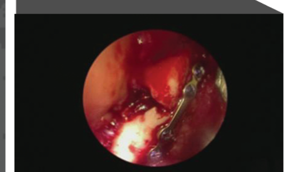

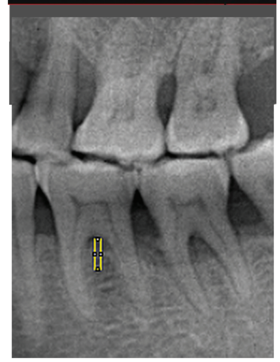

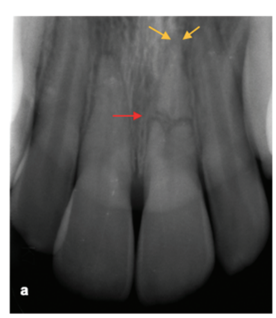

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CLINICAL DENTISTRY AND RESEARCH 2025; 49(1): 2-10 Original Research Article

ASSESSMENT OF TRABECULAR CHANGES IN FURCATION INVOLVEMENT USING FRACTAL ANALYSIS

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ABSTRACT

Background and Aim: To evaluate the potential impact of the presence and extent of furcation involvement (FI) on trabecular bone changes, both on digital orthopantomography (OPG) and cone-beam computed tomography (CBCT) images, using fractal analysis.

Materials and Methods: In the present study, a total of 51 mandibular molars, of which 28 were determined as degree I FI (FI-I), and 23 were determined as degree II FI (FI-II) were included, while 43 mandibular molars without any evidence of FI (non-FI) served as the control group. Fractal dimensions (FD) were calculated using digital panoramic and CBCT images with Image J software. Receiver operating characteristic (ROC) analysis was used to compare the FD-FI diagnostic capacity of OPG and CBCT images.

Results: The FD values of digital panoramic and CBCT images were significantly higher in the control group than in the FI-I and FI-II groups ($p<0.05$). Also, the FD calculated on digital panoramic radiographs was markedly higher than the FDs of CBCT in all groups ($p<0.05$). The area under ROC curves for differentiating FI-I from the non-FI group were 0.752 and 0.828, and to diagnose FI-II were 0.877 and 0.902 for OPG_FD and CBCT_FD, respectively.

Conclusion: As fractal analysis has the potential to determine the presence, extent, and severity of FI in both panoramic and CBCT images, it can serve as a measure for a thorough analysis of cases with FI. When FI is considered a vital complexity factor in periodontal diseases/conditions, the benefit of reliable measures for early and accurate diagnosis of FI becomes more crucial.

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INTRODUCTION

Complexity is one of the major highlights of the recent classification entitled the Classification of Periodontal and Peri-Implant Diseases and Conditions, which is associated with the extent and severity of periodontal destruction, the treatment planning, prognosis, and long-term outcomes of periodontal treatment.[1]Complexity is such crucial that it has the potential to change the stage of periodontitis and the mode of treatment such as complex periodontal treatments and/or multidisciplinary treatment approaches.[1,2] Among the well-defined complexity factors, probing depths, pattern of bone loss, tooth mobility, missing teeth, bite collapse, and residual ridge defect size are listed, and furcation involvement (FI) is one of the crucial complexity factors.[2] The complexity is a new context that the Classification of Periodontal and Peri-Implant Diseases and Conditions brings to daily dental practice. Complexity is important because it is related to treatment, prognosis, long-term results, stage levels, and treatment options. As complexity increases, treatments become more multidisciplinary and complex, and since FI is an important complexity factor, early and accurate diagnosis of FI is crucial. [2,3]

Furcation involvement occurs when periodontal disease causes bone resorption in the bi- or trifurcation area of a multi-rooted tooth,[4] as alveolar bone destruction leads to bone defects around the teeth and in the inter-radicular region.[5] The anatomy of the furcation is known to facilitate the retention of bacterial deposits and complicate oral hygiene procedures and periodontal debridement.[6] Therefore, the successful treatment of FI is still challenging. Accurate diagnosis of FI plays a key role in selecting a specific treatment option among various proposed treatment models and approaches (e.g., conservative, resective, or regenerative therapy).[7] The clinical diagnosis, treatment decisions, and classification systems currently used for FI may be affected by an array of factors, including root morphology, the configuration of the residual inter- and peri-radicular bone, the length of the root trunk, and the degree of root separation.[8] It is crucial to detect FI early, as advanced stages of FI may make treatment difficult and negatively impact treatment success.[3] A meticulous radiographic examination often provides evidence in the early stages of furcation involvement and clinical diagnosis.[7]

Radiographic examination allows the assessment of anatomical features of tooth root, surrounding alveolar bone, and alveolar defects relating to the pattern and extent of bone resorption.[5] However, 2-dimensional imaging techniques routinely used to evaluate periodontal structures have inherent disadvantages, such as superimposition and blurring of anatomical structures that prevent precisely detecting intraosseous defects and furcation involvement.[9] On the other hand, these limitations can be overcome by three-dimensional (3D) imaging using cone-beam computed tomography (CBCT), which provides precise images with the potential to display small structures such as periodontal defects.[9] Although the benefits of various imaging modalities in periodontal evaluation are very evident, generally, the amount of bone destruction is underestimated on radiographs, mainly since bone changes can be seen on radiographs after 30% to 50% of the bone mineral structure is resorbed.[10–12] Therefore, advanced analysis of radiographic images is suggested to potentially increase the diagnostic capacity of radiographic examination in cases such as the early stages of periodontitis.[11,12]

Fractal analysis (FA) is a mathematical method to assess complex structures. It is defined quantitatively as the fractal dimension (FD), which represents the degree of complexity of a geometric structure.[13,14] Fractal analysis is primarily used in medicine and dentistry to determine the severity and progression of existing disease or to diagnose a potential disease. It is stated that FD detected on radiographs reflects the changes in trabecular bone density and mineral loss in the bone.[15–17] A higher degree of FD indicates that the bone architecture is more complex and the spaces within the bone are less, while a small FD suggests that the bone has a more porous structure.[15,18]

Radiological imaging techniques can detect alveolar bone level, pattern, and size of bone defects. The value of radiographs for diagnosing periodontal disease is based on their potential to predict disease severity and progression and evaluate treatment outcomes.[5] Trabecular changes caused by periodontitis and the severity of the disease can be determined quantitatively with fractal analysis.[19] Studies on the quantitative comparison of panoramic radiography and CBCT imaging methods in evaluating furcation involvement are limited in the literature. Therefore, the present study aimed to evaluate the trabecular changes caused by FI on panoramic radiographs and CBCT images with fractal analysis.

MATERIALS AND METHODS

Sample Selection

The study was approved by the Institutional Ethics Committee (GO 22/899) and conducted following the Helsinki Declaration of 1975, as revised in 2013. This study was performed on patients with both CBCT scans, including the mandible and digital panoramic images obtained for dental reasons. Written and verbal informed consents were obtained before radiologic imaging. All radiographic images were retrieved from the archive of the Dentomaxillofacial Radiology Department between August and December 2022. The inclusion criteria for all groups were those over 18 years of age and those with mandibular first or second molars. Exclusion criteria comprised poor diagnostic quality images (i.e., positioning, motion, or metal artifacts), large intraosseous lesions, mandibular fractures involving the region of interest, and periapical lesions extending towards the furcation area of mandibular molars. The relevant teeth with horizontal through-and-through furcation defects were also excluded. Degree I and II FI groups comprised 28 mandibular molars from 23 patients and 23 mandibular molars from 22 patients, respectively. Degree 0 FI consisting of 43 mandibular molars from 31 individuals were included in the study as a control group.

Image Acquisition

Digital panoramic images were obtained with a panoramic X-ray device (Morita Veraview IC5, J. Morita MFG Corp., Kyoto, Japan). The exposure parameters were 1-7.5 mA, 60-70 kVp, and 5.5-10 s. CBCT scans were performed by an i-Cat Next Generation device (Imaging Sciences International, Hatfield, PA, USA) with the parameters as follows: 3–8 mA, 120 kVp, 0.20 mm voxel, 16 × 6-13 cm field-of-view and 26 s scan time. All images were evaluated on a 24-inch LCD monitor with 1920 × 1080 resolution (Dell, Round Rock, TX, USA).

Radiographic Examination

Assessment of Furcation Involvement (FI)

The level of horizontal alveolar bone loss on the mandibular molars' furcation area was assessed by an experienced periodontist (BA) on CBCT images, with a slice thickness of 0.2 mm, by using i-CAT Vision software (Imaging Sciences International, Hatfield, PA, USA). The degree of FI was determined according to the section with the highest bone loss in the axial view. A line tangent to the adjacent roots was drawn on this section. The distance between this line and the deepest point of the bone defect was used to classify FI according to the Hamp et al.[20] classification system. Intra-class correlation coefficient (ICC) was used for calculating inter-rater agreement for the depth of furcation involvements, and accordingly, the repeatability of the measurements was found to be consistent (ICC: 0.97; 95% CI 0.91-0.99). Mandibular first and second molars with Degree I FI (FI-I) and Degree II FI (FI -II) were selected and included in the case group in the study, whereas the control group consisted of molar teeth with no evidence of FI (non-FI).

FD Analysis

All radiographic images were examined using Image J (Image J software, version 1.53, National Institutes of Health), a Java-based 64-bit software for Windows, available free of charge from https://imagej.nih.gov/ij/download.html. The rectangle tool of software was used to select region of interest (ROI). The ROI size was chosen carefully in the furcation region to consist of the maximum available field near the furcation entrance, excluding the surrounding structures such as the root lamina dura or periodontal ligament. Based on the prior training with the molar teeth with a narrow distance between roots, the largest possible rectangular ROI size for both imaging modalities was 4 x 20 pixels, avoiding anatomical structures such as dental root, lamina dura, or periodontal ligament space. It was standardized for each tooth (Figure 1). ROI was assessed on CBCT images in the sagittal section, which showed the most significant bone loss. Measurements were carried out by an experienced dentomaxillofacial radiologist (NK). All radiographic images were stored in a TIF (Tagged Image File) file format. Fractal analysis was performed according to the box-counting algorithm described in White and Rudolph's method.[17] Initially, the determined ROI was duplicated and blurred using a Gaussian blur filter (sigma=35 pixels). Following the subtraction of ROI from the main image, a grey value of 128 was added to each pixel location. After this step, the image was binarized with the software's threshold tool with a brightness value 128. Thereafter, the process was continued with this sequence of events: erosion, dilatation, inversion, and skeletonization of the image (Figure 2). Then, the fractal box count tool calculated the FD value of the skeletonized image.

Statistical Analysis

A statistical power analysis was conducted using G*Power 3.1, employing t-tests based on previous research data.[21] With an alpha of 0.05, 80% power, and a 0.60 effect size, a sample size of 36 was estimated for both case and control groups. Considering the possibility of missing data, 10% more than the estimated number of samples were included in the study. Descriptive statistics included count for data with categorical variables mean values ± standard deviations or median (IQR) for data with continuous variables. Data normality was assessed with the Kolmogorov–Smirnov test. The difference in measurements between the groups (non-FI and FI-I - FI-II) was determined with a chi-square test for sex, a one-way ANOVA test for age, and independent-samples Kruskal-Wallis test for OPG-FD and CBCT-FD. The significance values were adjusted using the Bonferroni correction to account for multiple tests. Related-samples Wilcoxon signed-rank test was performed to compare OPG-FD and CBCT-FD within the groups. Spearman's and Pearson's correlation coefficients were performed according to the normal distribution to assess the correlation between OPG-FD, CBCT-FD, and furcation depth measurements. Analysis of covariance (ANCOVA) test was performed to compare fractal dimensions between the groups, eliminating the effect of age as the covariate. Receiver operating characteristic (ROC) analysis was used to compare the FI diagnostic capacity of OPG and CBCT images, and ROC curves were used to find the optimal cut-off values. Optimal sensitivity and specificity thresholds for FI diagnosis were established using the Youden method. OPG_FD and CBCT_FD ROC curves of FI-I and FI-II were compared with ROC curves of the control group for pairwise comparisons of ROC curves. All statistical tests were carried out with SPSS (v.26, IBM Corp, NY, USA), and two-tailed $p<0.05$ was accepted as a significant difference.

RESULTS

In this study, 51 mandibular FI (FI degree I= (FI-I) F/M:14/14, mean age: 51.9±11.9. FI degree II (FI-II) F/M:11/12, mean age 49.9±12.2) and 43 mandibular molars without FI were included (F/M:22/21, mean age 41.3±13.4). Although it was comparable between the groups in terms of sex ($p>0.05$), the mean age of the control group was markedly lower than the case groups ($p<0.05$). The median values of fractal dimensions measured from both OPG and CBCT images were significantly higher in the control group than in the FI groups (FI-I and FI-II) ($p<0.05$). (Table 1). Furthermore, it was observed that fractal dimensions in CBCT and OPG were significantly associated with FI even when the impact of age was removed with ANCOVA analysis ($p<0.001$).

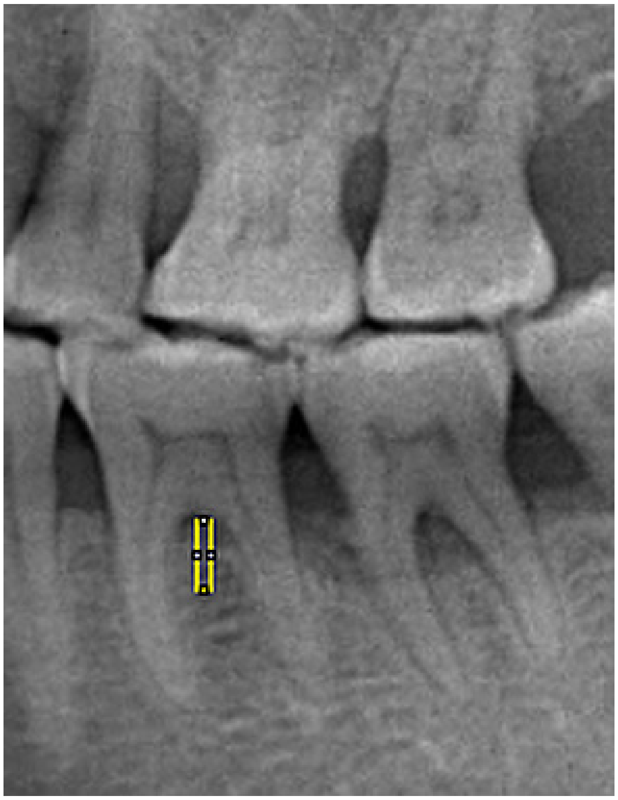

Figure 1. Cropped panoramic image showing the selection of ROI (4 x 20 pixels) in the left mandibular first molar with FI-I.

Table 2 displays the FD values of the different degrees of FI in OPG and CBCT images. OPG-FD values were higher than CBCT-FD values in all groups ($p<0.05$). The area under ROC curve (AUC) for the diagnosis of FI-I using OPG-FD measurement was 0.752 ($P<0.001$; 95% CI, 0.63-0.87) with optimal sensitivity and specificity of 54% and 91% at a cut-off value lower than 0.55 (Figure 3A). The ROC AUC for the diagnosis of FI-I using CBCT_FD values was 0.828 ($p<0.001$; 95%CI, 0.73-0.92) with optimal sensitivity and specificity of 82% and 77% at a cut-off value lower than 0.50 (Figure 3B). This indicated that CBCT-FD had a superior ability to diagnose FI-I defects than OPG-FD.

The AUC of OPG_FD and CBCT_FD between no FI and FI-II were 0.877 ($p<0.001$; 95%CI, 0.79-0.96) and 0.902 ($p<0.001$; 95%CI, 0.83-0.97), respectively. In distinguishing FI-II from no FI, the sensitivity and specificity for OPG_FD were 65% and 95%, respectively; for CBCT_FD, were 100% and 77%, respectively. For detecting FI-II, the cut-off values of OPG_FD and CBCT_FD were set at 0.54 and 0.51,

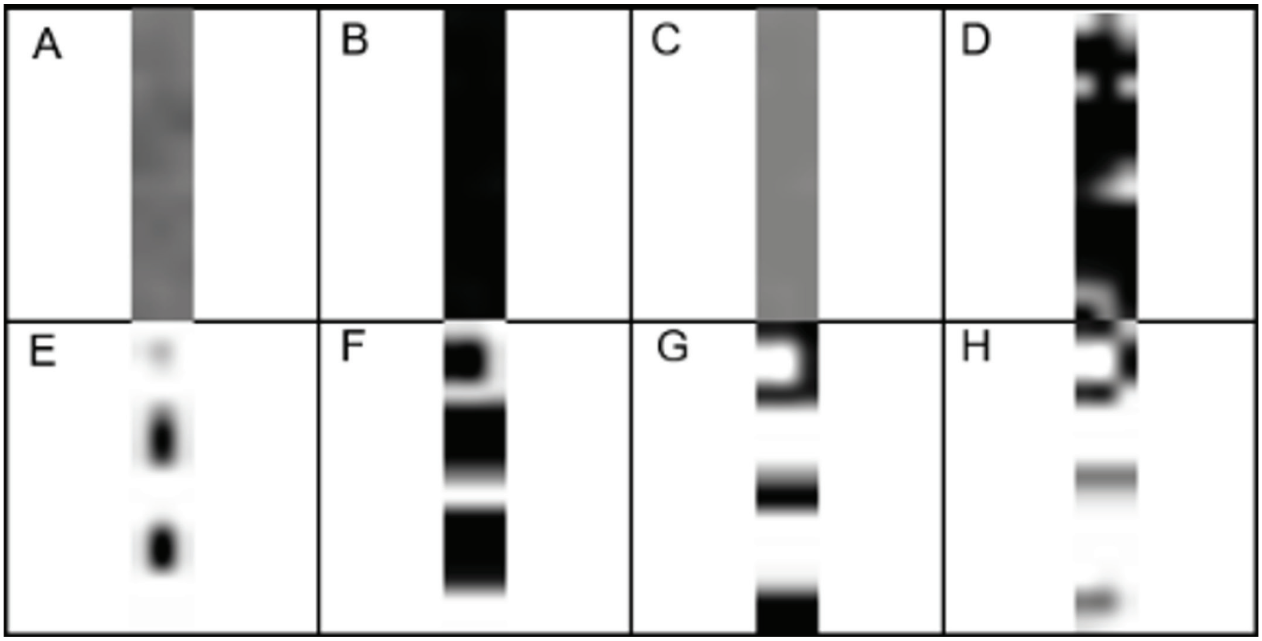

Figure 2. Steps of fractal dimension analysis. (A) Cropped and duplicated ROI. (B) The blurred image was then subtracted from the original image. (C) Addition of a gray value of 128 to each pixel location. (D) Application of 128 threshold value (E) Erosion. (F) Dilatation. (G) Inversion. (H) Skeletonization

Table 1. Comparison of the groups in terms of age, gender and fractal dimension measurements.

	Furcation Involvement (FI)			
	Degree 0 (N=43)	Degree I (N=28)	Degree II (N=23)	p*
Sex (F/M)	22/21	14/14	11/12	0.967
Age	41.3 ± 13.4	51.9 ± 11.9	49.9±12.2	0.002[1,2]
OPG_FD	0.66 (0.07)	0.55 (0.17)	0.46 (0.25)	<0.001[1,2]
CBCT_FD	0.57 (0.15)	0.41 (0.18)	0.34 (0.22)	<0.001[1,2]

OPG: orthopantomography, CBCT: Cone-beam computed tomography. FD: fractal dimension
* Significance between FI degree 0, 1 and 2 groups. Chi-square test for sex. One-way ANOVA test for age. Independent-Samples Kruskal-Wallis test for OPG-FD and CBCT-FD. Significance values have been adjusted by the Bonferroni correction for multiple tests.
1 Significance between FI degree 0 and degree 1 (p=0.003 for age; p=0.001 for OPG-FD; p<0.001 for CBCT-FD)
2 Significance between FI degree 0 and degree 2 (p=0.032 for age; p<0.001 for OPG-FD; p<0.001 for CBCT-FD)

Table 2. Differences between OPG_FD and CBCT_FD according to the groups.

Groups	OPG-FD	CBCT-FD	p*
Degree 0	0.66 (0.07)	0.57 (0.15)	<0.001
Degree I	0.54±0.14	0.39±0.12	<0.001
Degree II	0.48±0.13	0.33±0.12	<0.001

* Significance between OPG-FD and CBCT-FD within the groups. Related-samples Wilcoxon signed rank test for FI degree 0 group. Paired Samples T-Test for FI degree 1 and degree 2 groups.

respectively (Figure 3C-D). The AUC values in both imaging techniques were relatively high. By applying fractal analysis, FI-II could be distinguished from healthy alveolar bone with high success in both CBCT and OPG images. Comparing fractal dimension measurements for the capability to detect both FI-I and FI-II, no statistically significant difference

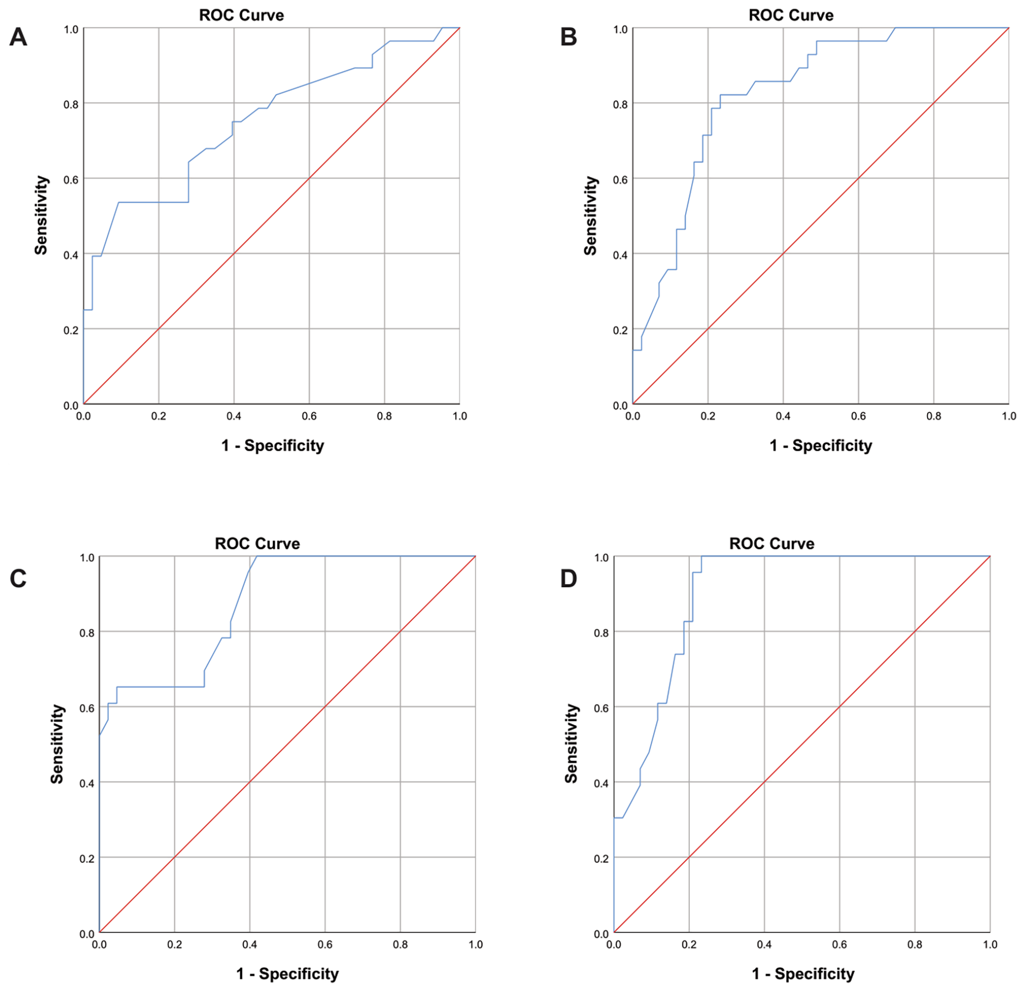

Figure 3. Graphs illustrating the ROC results for detection of FI-I using OPG_FD (A) and CBCT_FD (B) values; and FI-II using OPG_FD (C) and CBCT_FD (D) values.

was observed between the ROC curves of CBCT_FD and OPG_FD (p=0.222 for FI-I, p=0.639 for FI-II). No significant correlation was found between OPG-FD, CBCT-FD, and depth of the furcation measurements in the control and FI-I groups (p>0.05). Nevertheless, the FI-II group had a significant positive correlation between FD values of OPG and CBCT images and a significant negative correlation between fractal dimensions of CBCT images and furcation depth measurements (p<0.05).

DISCUSSION

The present study evaluated the efficiency of the fractal analysis method in detecting FI in mandibular molars. Although there are studies examining bone changes in periodontitis with fractal analysis, to our knowledge, this is the first study to evaluate FI with fractal analysis method on panoramic and CBCT images. According to the Classification of Periodontal and Peri-Implant Diseases and Conditions, periodontitis is defined based on the stage and grade levels of the disease. The stage of periodontitis is determined by disease severity, complexity, extent, and distribution.[1] Moreover, complexity factors such as FI may cause the stage of periodontitis to be elevated to a higher level.[1] FI also increases the complexity of periodontitis treatment, and an accurate evaluation of these defects is needed in treatment planning for optimal treatment outcomes.[2] However, the complex root morphology of molars and the anatomical and topographic relationship between the roots may make identifying the furcation defects on 2-D radiographic images difficult.[7] CBCT imaging allows detailed examination of furcation involvement and improves diagnosis and treatment decisions.[22,23] Fractal analysis is a valuable alternative to quantitatively evaluate trabecular changes in alveolar bone defects, including furcation involvement.[12,21]

In the literature, studies show the alveolar bone changes in periodontitis with FD analysis. Aktuna-Belgin et al.[12] demonstrated that the mean FD values of the mandibular first molar in patients with periodontitis were significantly lower than those of periodontally healthy individuals.[12] In a previous study evaluating the furcation region of mandibular molars on periapical radiographs, it was observed that the FD value of the control group was significantly higher than that of the periodontitis group.[21] In another study with digital periapical radiographs, it was stated that FD values of healthy periodontal bone differed significantly from moderate and severe periodontitis. However, there was no statistically significant difference between FD values of periodontally healthy bone and mild periodontitis.[11] Also, Updike et al.[19] reported substantial differences in FD between the healthy controls and moderate periodontitis groups and between control and severe periodontitis groups. At the same time, there was no significant difference in FD between moderate and severe periodontitis groups.[19] A previous study evaluating healthy gingiva and moderate periodontitis with fractal analysis on digital images to determine the initial trabecular bone changes in periodontitis established that the detection of bone changes in the interdental trabecular pattern of early stages of periodontal destruction may be able to make with the fractal analysis.[24] In line with previous results, the present study displayed that FD values of degree I and II furcation involvements in both CBCT and OPG images were significantly lower than those of periodontally healthy molars, even though the difference of FD values between degree I and II FI was not statistically significant. Consequently, fractal analysis can effectively distinguish changes in trabecular bone structures among periodontal health, furcation involvement, and interdental bone defects, as shown in previous studies.

In the present study, the mean age of the control group was significantly lower than the FI group. The prevalence of periodontitis increases from 15-19 years to 50-54 years of age.[25] The significant age difference between the control group and the periodontitis groups with furcation defect can be attributed to the fact that most of the individuals in this study were in the age range where the severity of periodontitis increases with age. However, the significant relationship between fractal dimension and furcation involvement did not change when the impact of age was eliminated. Hereby, fractal dimension measurement on digital OPG and CBCT images has been shown to have diagnostic capacity for detecting furcation defects regardless of age. The present study's comparison of ROC curves indicated no significant difference between CBCT and OPG images in detecting furcation involvements by the fractal analysis method. Although CBCT showed a superior ability to diagnose FI-I than OPG in this study, it can be assumed that performing fractal analysis on OPGs obtained to detect periodontal bone loss can provide accurate detection of FI.

The complex anatomical structure of the furcation region of molars is a limiting factor for fractal dimension measurement. While determining the ROI region, attention was paid to including the same structures, and the ROI area was limited due to the furcation anatomy. Moreover, fractal analysis was performed on each molar's OPG and CBCT images. Another limitation of this study is that the measurement of FD in CBCT imaging was limited to the sagittal sections. Due to the superimposition of the molar roots on the furcation region, fractal analysis could not be performed on cross-sectional CBCT images. Finally, further studies that exclude other factors that may impact bone metabolism and periodontal health, as well as clinical measurements of furcation involvement, are needed to reveal more clearly the relationship between FI and fractal dimension.

The current study emphasizes the crucial importance of early and accurate diagnosis of the presence and extent of FI as a complicating factor. This can significantly influence the decision-making process, treatment outcomes, and the long-term success of periodontal treatment. Furthermore, it underscores the need for a comprehensive evaluation of dental images to better support clinical examinations.

CONCLUSION

As fractal analysis has the potential to determine the presence and the severity of FI in both panoramic and CBCT images, it can serve as a measure for a thorough analysis of cases with FI. Additionally, fractal analysis's quantitative and non-invasive features suggest its use in evaluating FI.

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AUTHORSHIP CONTRIBUTIONS

Design of the work: NT, BA and NK, the acquisition and interpretation of the data: BA and NK, drafting the manuscript: BA, revising critically and final approval of the version: NT, BA, and NK.

DATA AVAILABILITY STATEMENT

The data supporting this study's findings are available from the corresponding author upon reasonable request. The data are not publicly available because of privacy or ethical restrictions.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS STATEMENT

The present study was approved by the Institutional Ethics Committee (GO 22/899).

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COMPARISON OF INTERNAL FIXATION METHODS AND MINIMAL INVASIVE SURGICAL APPROACHES IN THE TREATMENT OF MANDIBULAR FRACTURES

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ABSTRACT

Background and Aim: Mandibular fractures are one of the most common fracture types in the maxillofacial region, with condylar and angular fractures being particularly prevalent. In recent years, endoscopic approaches, have become increasingly widespread as alternatives to traditional internal fixation methods, in the treatment of maxillofacial traumas. The endoscopic treatment of mandibular fractures is a minimally invasive technique. The aim of this study is to evaluate and compare the clinical and radiological outcomes of endoscopy-assisted open reduction and internal fixation (EAORIF) and conventional open reduction and internal fixation (ORIF) in the treatment of mandibular fractures.

Materials and Methods: In this study, 18 patients diagnosed with mandibular fractures were randomly divided into two groups. Nine patients underwent EAORIF, while the remaining patients underwent ORIF under general anesthesia. Postoperative evaluations were conducted clinically and radiologically to assess the advantages and disadvantages of both techniques.

Results: No significant difference was found in both methods in terms of age, time between trauma and operation, and hospital stay ($p>0.05$). However, the surgical duration was longer in the EAORIF group ($p<0.05$). No significant differences were observed between the two groups in terms of occlusion stability and fracture healing ($p>0.05$).

Conclusion: These findings suggest that EAORIF is an effective minimally invasive alternative to conventional ORIF, offering improved postoperative recovery despite its technical complexity.

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INTRODUCTION

Open Reduction and Internal Fixation (ORIF) is a traditional method that has been widely used for fracture treatment. This technique involves large surgical incisions to gain direct access to the fracture site, allowing for precise anatomical reduction and stabilization with plates and screws. However, ORIF has certain disadvantages. The large incisions can cause damage to surrounding tissues, which prolongs the recovery period and increases the risk of infections.[1]

Endoscope-Assisted Open Reduction and Internal Fixation (EAORIF) is a more minimally invasive approach that uses smaller incisions, reducing the risk of tissue damage. This accelerates recovery and reduces complications, particularly infections. Additionally, it may offer aesthetic advantages by leaving smaller scars.[2] However, EAORIF also has limitations. It requires endoscopic visualization, which demands the surgeon's expertise and specialized equipment, increasing costs and making it unsuitable for some complex fractures.

Endoscopy is defined as the process of inserting an illuminated and steerable device into the body through a natural opening or through a surgical incision, used to visualize internal structures.[3,4] With the use of endoscopy in diagnosis and treatment planning, treatment methods in the oral and maxillofacial region have also changed.[5,6] The complex and delicate anatomical structures of this region and the limited access area have led to the necessity of enlarging and illuminating the relevant area in intraoral procedures.[7] In line with these goals, endoscopy has become a promising tool. Endoscopic surgery or minimally invasive surgery has become accepted and standard in many surgical specialties.[8]

Endoscopy has various application areas in the maxillofacial region. Although the indications for open and closed reduction in treatments are controversial, ORIF is definitely necessary in some cases where conservative treatments are not sufficient.[9] Open reduction can be performed with internal fixation, intraoral or extraoral approach. The extraoral approach is the frequently preferred treatment approach as it increases the visibility and accessibility of the surgical area. In literature, extraoral treatment approaches such as preauricular, postauricular, retromolar and submandibular are mentioned, and the success of these treatments is confirmed by previous studies.[10,11] Although the extraoral approach to fractures provides comfort in terms of reduction and fixation, there is a risk of nerve damage.

In particular, ORIF of mandibular condyle fractures is limited by the potential risk of facial nerve damage as well as the risk of arterial bleeding, scarring in the incision area, and a narrow surgical field.[12,13] These limitations lead surgeons to choose nonsurgical methods such as intermaxillary fixation. Nowadays, with the widespread use of minimally invasive surgery, it is seen that maximum beneficial results are achieved even in complex surgeries. Endoscopy-assisted open treatment methods offer a minimally invasive approach to mandibular condyle fractures, shortening the healing period and reducing complications. Both intraoral and extraoral approaches provide lower infection rates and better aesthetic results compared to traditional surgical methods. In long-term follow-up, it has been observed that these techniques allow successful results, especially in complex cases, and provide rapid healing.[14,15] This study aims to compare the clinical and radiological outcomes of EAORIF and ORIF in mandibular fracture treatment in terms of postoperative recovery, complication rates, and functional outcomes.

MATERIALS AND METHODS

This clinical research was supported by Dicle University Scientific Research Projects Coordination Office with project number DİŞ.20.022. Ethics committee approval was received from Dicle University Faculty of Dentistry Local Ethics Committee, dated 24.06.2020 and with protocol number 2020-26. 18 adult patients diagnosed with mandibular fractures at Dicle University Faculty of Dentistry, Department of Oral and Maxillofacial Surgery were included in the study. These patients were treated between March 2023-March 2024.

Patients were randomly divided into 2 groups based on their order of admission and different surgical treatment methods (ORIF and EAORIF) were applied to compare the outcomes (n=9). Fracture type, location, and degree of displacement of the fragments were evaluated with panoramic radiographs and computed tomography. After routine examination procedures, the patients were operated under general anesthesia. The fracture site was fully exposed, and the fracture fragments were manually reduced. Following proper alignment of the fracture, stabilization was achieved by directly placing plates and screws. During ORIF, titanium alloy plates and screws were used. The shape and size of the plates were planned according to the characteristics of the fracture. While placing the fixation materials, care was taken to protect the soft tissues and neural structures. Once stabilization of the fracture site was ensured, the surgical field was irrigated, and the incision was closed in layers.

The EAORIF surgical procedures were completed with a 4 mm diameter rigid 30 degree viewing angle endoscope system (Karl-Storz® Tuttlingen, Germany). First, a small incision was made to gain access to the fracture site. The endoscope was guided through this incision to the fracture site and provide extensive visualization of the surgical field. The manipulation of the fracture segments was performed using small surgical instruments. After achieving anatomical reduction, titanium plates and screws were placed for internal fixation. The size and shape of the plates were selected based on the type and location of the fracture. Under endoscopic visualization, the position of the plates and screws was confirmed. The surgical field was cleaned with minimal bleeding, and the incision was closed. During the surgeries, extraoral or intraoral approaches were determined based on each patient's clinical condition and the characteristics of the fracture. The extraoral and intraoral approaches were applied according to indications. Some of the surgical procedures were recorded as digital videos and photographs (Figure 1). The patients' hospital stay and surgical operation times were recorded. Then, the patients were followed up at 1 month and 3 months. In this process, patients' occlusion evaluation was done using cephalometric and panoramic radiographs. Angle classification was taken as reference in the evaluation. Angle class 1 cases were accepted as normal occlusion, and occlusion types occurring in other cases were described as malocclusion (Table 1).

Statistical Analysis

Statistical Package for the Social Sciences for Windows (version 21.0, IBM Corp., Armonk, NY, US) was used in the statistical evaluation of the research data. Quantitative variables were presented as mean±standard deviation (SD), and categorical variables were presented as number and percentage (%). Whether the data conformed to a normal distribution was checked with Shapiro Wilk's normality test. Independent t test was used for the age variable while Mann Whitney U test was used for the variables of time between trauma and operation, surgical procedure duration in minutes, and hospital stay duration in days. Chi-square ($\chi 2$) analysis (Continuity Correction test and Fisher's Exact test) was used in the analysis of categorical variables. Spearman correlation analysis was performed for the relationship between variables. Hypotheses were taken two-sided and $p \leq 0.05$ was considered a statistically significant result.

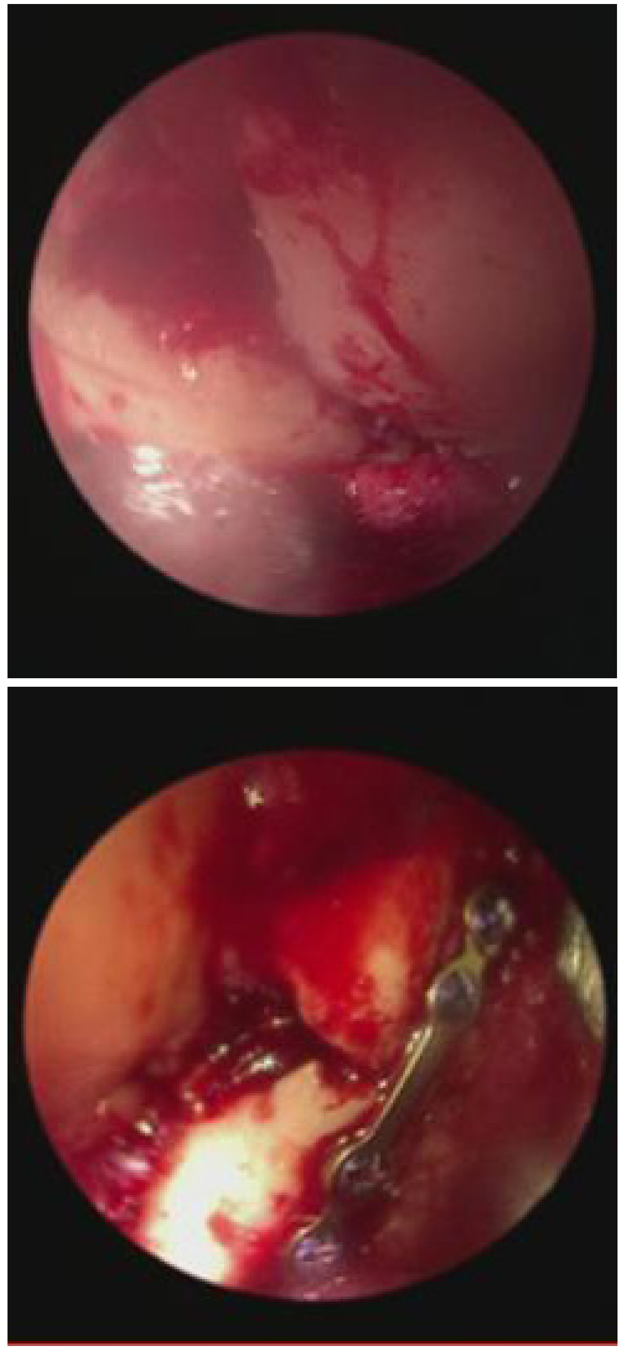

Figure 1. Image of the mandibular fracture line (top) and treatment of fractured segments after mini plate screw fixation with EAORIF method (bottom).

RESULTS

The average age range was between 23-72. Two of the 18 patients were female. While the time between trauma and surgical operation varied between 7 and 12 days in 16 patients, 2 patients could be operated after intensive care (1 was after 1.5 months, and 1 was after 2 months). In the EAORIF group, 2 patients had a right parasymphyseal left condyle fracture, 3 patients had an angulus fracture, 1 patient had a bilateral angulus fracture, and 3 patients had parasymphyseal fractures. In the ORIF group, 2 patients had condyle fractures, 4 patients had angulus fractures, and 3 patients had parasymphyseal fractures. The mean surgical time was approximately 90 ± 15 minutes for patients undergoing ORIF and 150 ± 25 minutes for those undergoing EAORIF. It was observed that these times varied depending on the number of fractures and the location of the fracture.

The trauma etiologies of the patients varied due to assault, falling from height, traffic accident and pathological formation. Patients underwent intermaxillary fixation (IMF) for 2 to 6 weeks after surgery. In patients with mandible fracture accompanied by condyle fracture, IMF was applied for 15 days due to the risk of ankylosis. No major complications were encountered during the intraoperative period. No permanent facial nerve injury was observed in either group.

Extraoral swelling occurred for 2 weeks in one patient who underwent EAORIF via the transparotidal approach. Complete recovery was observed after 2 weeks.

In the evaluation of occlusion in patients treated with ORIF, as a result of the 1st and 3rd month post-operative controls, normoocclusion was observed in all cases, while normoocclusion was observed in 6 of the patients treated with the EAORIF method and malocclusion was observed in 3 patients.

No statistically significant difference was found in both methods in terms of age, time between trauma and operation, and hospital stay ($p>0.05$). It was observed that the surgical procedure time in patients who underwent EAORIF method increased to a statistically significant extent ($p<0.001$) (Table 2).

There was no statistically significant difference between the two groups in terms of gender, etiology, fracture localization, post-operative fixation time and post-operative occlusion ($p>0.05$) (Table 3).

DISCUSSION

The management and treatment of facial fractures have evolved significantly over the past century. In particular, over the last 10 years, surgeons have increasingly used endoscopic techniques to achieve accurate fracture repairs while minimizing the morbidity associated with the surgical approach in the management of facial fractures.[16,17] Traditionally, most condylar fractures have been managed with closed techniques, typically involving intermaxillary fixation and elastics. Open approaches were avoided to minimize treatment morbidity, the risk of facial nerve damage and the presence of a visible facial scars.[18] The main point in the widespread use and development of endoscopic methods are the search for less invasive methods.[19] The use of endoscopic-assisted surgery has become preferred due to visualization through a small incision, good visualization of the area in hard-to-access area surgeries, absence of visible scars, reduced risk of surgical trauma and bleeding, and lower risk of nerve damage.[20] The goal of endoscopically assisted or minimally invasive surgery is to preserve health, reduce surgical trauma, increase flap/wound stability, allow stable primary wound closure, reduce surgical time, and minimize patient discomfort and side effects. Additionally, this technique requires a core team of endoscopic and specially trained surgeons.[21] Considering the advantages and disadvantages of both methods, the most appropriate treatment option should be determined depending on the patient's condition and the surgeon's experience.

The study reported by Lee et al.[22] is the first large clinical series in which subcondylar fractures were treated with endoscopically assisted open reduction. It was observed that 22 subcondylar fractures treated with the intraoral approach yielded successful functional results.[22] In a later study, Lee et al.[23] treated 40 patients with subcondylar fractures with an endoscope-assisted approach and observed a temporary facial nerve injury along with 3 plate fractures. Lee et al.[23] showed that EAORIF did not avoid facial nerve damage and did not increase the risk of reoperation compared to ORIF.

According to the findings of Lee et al.[22] and Cavalcanti et al.[24], the EAORIF method increases operation time. They concluded that this difference is related to factors inherent to the method, such as equipment usage and surgical precision. This aligns with the results of our study. Cavalcanti et al.[24] show that EAORIF does not prevent facial nerve lesion. On the other hand, EAORIF has shown that it does not increase the need for reoperation compared to ORIF for the treatment of mandibular condyle fractures.

Although no cases of facial nerve injury were observed in our study, the potential risk associated with surgical

Table 1. Distribution of demographic and operative data of operated patients. ORIF: Open Reduction and Internal Fixation, EAORIF: Endoscope Assisted Open Reduction and Internal Fixation, M/F: Male/Female Min: Minutes

Patient	Age	Gender	Etiology	Time Between Trauma and Operation	Fracture Localization	Surgical Approach	Surgical Procedure Duration	Duration of Hospitalization	Post-op intermaxillary fixation time	Post-op occlusion
PATIENT 1	25	M	ASSAULT	7 DAYS	CONDYLAR FRACTURE	(ORIF) PREAURICULAR INCISION	80 MIN	2 DAYS	1-2 WEEKS	NORMOOCCLUSION
PATIENT 2	45	M	ASSAULT	8 DAYS	CONDYLAR FRACTURE	(ORIF) PREAURICULAR INCISION	75 MIN	2 DAYS	1-2 WEEKS	NORMOCCLUSION
PATIENT 3	50	M	ASSAULT	10 DAYS	ANGULUS FRACTURE	(ORIF) SUBMANDIBULAR INCISION (RISDON)	100 MIN	2 DAYS	4 WEEKS	NORMOCCLUSION
PATIENT 4	28	M	TRAFFIC ACCIDENT	8 DAYS	PARASYMPHYSEAL FRACTURE	(ORIF) INTRAORAL INCISION	80 MIN	1 DAY	4 WEEKS	NORMOCCLUSION
PATIENT 5	36	F	PATHOLOGICAL FORMATION	7 DAYS	PARASYMPHYSEAL FRACTURE	(ORIF) INTRAORAL INCISION	75 MIN	1 DAY	4 WEEKS	NORMOCCLUSION
PATIENT 6	42	M	ASSAULT	12 DAYS	PARASYMPHYSEAL FRACTURE	(ORIF) SUBMANDIBULAR INCISION (RISDON)	80 MIN	2 DAYS	4 WEEKS	NORMOCCLUSION
PATIENT 7	38	M	ASSAULT	12 DAYS	ANGULUS FRACTURE	(ORIF) SUBMANDIBULAR INCISION + INTRAORAL INCISION	80 MIN	2 DAYS	4 WEEKS	NORMOCCLUSION
PATIENT 8	26	M	TRAFFIC ACCIDENT	10 DAYS	PARASYMPHYSEAL FRACTURE	(ORIF) INTRAORAL INCISION	85 MIN	1 DAY	4 WEEKS	NORMOCCLUSION
PATIENT 9	47	M	TRAFFIC ACCIDENT	7 DAYS	ANGULUS FRACTURE	(ORIF) SUBMANDIBULAR INCISION	95 MIN	2 DAYS	4 WEEKS	NORMOCCLUSION
PATIENT 10	52	F	FALLING FROM HEIGHT	8 DAYS	PARASYMPHYSEAL FRACTURE	(EAORIF) INTRAORAL INCISION	135 MIN	1 DAY	4 WEEKS	NORMOCCLUSION
PATIENT 11	29	M	FALLING FROM HEIGHT	10 DAYS	PARASYMPHYSEAL FRACTURE	(EAORIF) INTRAORAL INCISION	140 MIN	1 DAY	4 WEEKS	NORMOCCLUSION
PATIENT 12	44	M	ASSAULT	75 DAYS	RIGHT PARASYMPHYSEAL LEFT CONDYLAR FRACTURE	(EAORIF) TRANSPAROTIDAL APPROACH SUBMANDIBULAR INCISION	170 MIN	3 DAYS	1-2 WEEKS	MALOCCLUSION
PATIENT 13	60	M	ASSAULT	45 DAYS	RIGHT PARASYMPHYSEAL LEFT CONDYLAR FRACTURE	(EAORIF) INTRAORAL INCISION	165 MIN	2 DAYS	1-2 WEEKS	MALOCCLUSION
PATIENT 14	34	M	ASSAULT	10 DAYS	BILATERAL ANGULUS FRACTURE	(EAORIF) INTRAORAL APPROACH, ADDITIONAL TRANSBUCCAL INCISION FOR SCREW PLACEMENT	175 MIN	3 DAYS	4 WEEKS	MALOCCLUSION
PATIENT 15	54	M	ASSAULT	8 DAYS	ANGULUS FRACTURE	(EAORIF) INTRAORAL APPROACH, ADDITIONAL TRANSBUCCAL INCISION	150 MIN	2 DAYS	4 WEEKS	NORMOCCLUSION
PATIENT 16	33	M	TRAFFIC ACCIDENT	10 DAYS	ANGULUS FRACTURE	(EAORIF) SUBMANDIBULAR INCISION	140 MIN	2 DAYS	4 WEEKS	NORMOCCLUSION
PATIENT 17	28	M	TRAFFIC ACCIDENT	8 DAYS	ANGULUS FRACTURE	(EAORIF) SUBMANDIBULAR INCISION	145 MIN	2 DAYS	4 WEEKS	NORMOCCLUSION
PATIENT 18	41	M	TRAFFIC ACCIDENT	8 DAYS	PARASYMPHYSEAL FRACTURE	(EAORIF) INTRAORAL INCISION	140 MIN	1 DAY	4 WEEKS	NORMOCCLUSION

Table 2. Mann whitney U test and Independent T-test analysis results

	ORIF		EORIF		
	mean±SS	Median(Min-Max)	mean±SS	Median(Min-Max)	P
Age	37.44 ±9.38	38.00 (25-50)	41.67 ±11.63	41.0 (28-60)	0.409*
Time Between Trauma and Operation	83.33 ±8.66	80.00 (75-100)	151.11 ±14.95	145.00 (135-175)	0.294
Surgical Procedure Duration	9.00 ±2.062	8.00 (7-12)	20.22 ±23.78	10.00 (8-75)	0.000
Hospital Stay Duration (Day)	1.67 ±0.50	2.00 (1-2)	1.89 ±0.78	2.00 (1-3)	0.552

* Independent T-test was used in age analysis.
Mann Whitney u test was used in the analysis of other variables.

Table 3. Analysis of categorical variables using Chi-square ($\chi 2$) test (Continuity Correction test and Fisher's Exact Test)

		ORIF NUMBER n(%)	EAORIF NUMBER n(%)	P
GENDER	F	1(50%)	1(50%)	1.000[a]
	M	8(50%)	8(50%)	
ETIOLOGY	Assault	5(55.6%)	4(44.4%)	0.375[c]
	Traffic accident	3(50%)	3(50%)	
	Pathological Fracture	1(100%)	0(0%)	
	Falling From Height	0(0%)	2(100%)	
	Condyle	2(100%)	0(0%)	
	Angulus	4(57.1%)	3(42.9%)	
FRACTURE LOCALIZATION	Parasymphysis	3(50%)	3(50%)	0.273[c]
	Right Parasymphysis. Left Condyle	0(0%)	2(100%)	
	Bilateral Angulus	0(0%)	1(100%)	
POST-OP IMF DURATION	1-2 Weeks	2(50%)	2(50%)	1.000[a]
	4 Weeks	7(50%)	7(50%)	
POST-OP OCCLUSION	Normoocclusion	9(60%)	6(40%)	0.206[b]
	Malocclusion	0(0%)	3(100%)	

a. Continuity Correction test
b. Fisher's Exact Test
c. Chi-square tes

approaches, particularly extraoral techniques, remains a significant concern. This emphasizes the importance of meticulous dissection and anatomical precision to minimize complications and is consistent with the existing literature.

Sanati-Mehrizy et al.[25] in their analysis, representing the largest patient cohort undergoing endoscopic mandibular fracture fixation, including 509 patients, found an acceptably low rate of postoperative complications, including permanent nerve damage, complications, and fixation failure. In the present study, no significant difference was found between the two groups. It was concluded that the treatment duration of patients who received only EAORIF was longer than that patients who received ORIF, due to the need for technical knowledge and skills, as well as sensitivity required in the use of equipment. Additionally, it was observed that the scar appearance was significantly more satisfactory in patients who underwent EAORIF.

Similar to the present study, Haug et al.[26] stated that the endoscope-assisted approach took longer than the traditional approach and longer operation time and investment costs for equipment cause the endoscopic approach to be more expensive than the traditional method. Ellis et al.[27] evaluated post-operative occlusion photographically in 142 trauma patients. While malocclusion was detected in 22% of patients treated with the closed reduction method, all cases were reported as normoocclusion in patients treated with the open reduction method.[28] In our study, cephalometric and panoramic radiographs were used when evaluating the post-operative occlusion of the patients. Based on our findings, malocclusion was not observed in patients treated with the ORIF method, while malocclusion was detected in 33% of the patients treated with the EAORIF method.

The limitation of the present study is the small sample size, which is due to the rarity of patients with mandible fractures. Future studies with a larger sample size will provide more satisfactory and generalizable results. The treatment methods demonstrated a satisfactory level of effectiveness and patient safety. Additionally, the low complication rates observed following the application of the treatment methods, along with high patient satisfaction, serve as further indicators of the clinical success of our findings.

CONCLUSION

Based on the present study, both surgical approaches are suitable for treating mandible fractures, as both treatment methods gave similar and good results in clinical and functional parameters. In terms of operation time, it was observed that the procedure time increased significantly in patients treated with the EAORIF method.

The impact of fracture localization and number on operation time was limited, with a similar distribution observed between the groups. This supports the conclusion that the time difference is method-related. Apart from this, no distinguishing differences or complications were found. However, as the number of patients increases, complications and facial nerve injuries may occur, especially in condyle fractures, and it is inevitable that the risk of complications increases with the increase in surgical operation time. Therefore, further studies with larger sample sizes should be conducted to reach consensus on this controversial issue.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS STATEMENT

Ethics committee approval was received from Dicle University Faculty of Dentistry Local Ethics Committee, dated 24.06.2020 and with protocol number 2020-26.

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COMPARISON OF MARGINAL BONE LOSS IN CONICAL, CYLINDRICAL, AND PASSIVELY INSERTED PRESS-FIT DENTAL IMPLANTS DURING THE FIRST 3 MONTHS OF OSSEOINTEGRATION

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ABSTRACT

Background and Aim: This study investigated the effects of implant macrodesign on early marginal bone loss (MBL), a key predictor of implant longevity.

Materials and Methods: The MBL values of Bego Semandos® (Group I: conical), Straumann BL® – SLA modified surface (Group II: cylindrical), and I-System (Group III: press-fit) implants were measured on postoperative 3 months cone beam computed tomographic images at 6 points of each implant. The "total MBL" for each implant was calculated by averaging MBL at 6 points. The buccal and lingual MBL values were determined by averaging the measurements at 3 points on each side.

Results: A total of 57 implants were analyzed. No significant differences were observed in the average total MBL values between groups ($p>0.05$). The cylindrical implants showed significantly higher buccal MBL (0.30 ± 0.22 mm) than lingual MBL (0.17 ± 0.37 mm) ($p=0.048$). The conical and cylindrical implants exhibited insignificantly higher total MBL in the maxilla and mandible, respectively ($p>0.05$). Conical implants had an insignificantly higher total MBL in the anterior region than that in the posterior region ($p>0.05$).

Conclusions: Cylindrical implants may be avoided in alveolar crests with higher buccal resorption, to prevent early buccal MBL. Cylindrical and conical implant placements should be preferred in the maxilla and mandible, respectively, with proper countersinking. Cylindrical implants may minimize the early MBL in the anterior region. Although implant macrodesigns do not significantly differ in average total MBL levels, passive press-fit implants may ensure more homogeneous early MBL across both jaws and regions.

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INTRODUCTION

Dental implants are the most common tools used to replace missed teeth in contemporary dentistry. Long–term success of implants depends on oral hygiene status, smoking status, immunocompromised status, surgical technique, biocompatibility of the material, surface characteristics, macrodesign, and bone and gingiva quality and quantity. Furthermore, excellent osseointegration is the initial step in achieving long–term uneventful function.[1]

Excessive marginal bone loss (MBL) within the first 3 months indicates suboptimal osseointegration. An MBL of 0.45–0.86 millimeters is estimated during the first 3 months of osseointegration.[2,3] An initial MBL higher than the normal range ensures progressive peri–implantitis, resulting in early implant failure.[4] The existence of diabetes, an insertion torque of more than 40 Newton or less than 20 Newton, and early reopening of the implant for healing cap installation were risk factors for MBL.[2] Share stress is commonly responsible for the excessive peri–implant bone loss.[5] However, the macrodesign that lessens the share stress and alleviates MBL in the first 3 months of osseointegration has not been broadly revealed.

The present study was designed to determine whether the macrodesign of dental implants affects early MBL. For this purpose, the MBL amounts of conical, cylindrical, and passive press-fit implants were compared for the first 3 months of the osseointegration period. The null hypothesis posited the absence of any statistically significant difference among the average MBL values of the different implant macrodesigns.

MATERIALS AND METHODS

The present retrospective study was conducted in accordance with the STROBE guidelines with the approval of the Non-Interventional Clinical Research Ethics Committee of Hacettepe University (approval no: 2024/14–28), following the Declaration of Helsinki on Medical Research on Human Subjects.

The primary outcome is the average MBL values of the implants. The sample size was determined using G*Power version 3.1.9.7 software (Heinrich Heine University, Düsseldorf, Germany) at a significance level of 0.05 and an effect size of 0.71, with a statistical power of 95%. The effect size was established based on a previous study.[6]

The research was conducted on 3 months postoperative Cone Beam Computed Tomography (CBCT) images of patients who underwent dental implant surgery using Bego Semandos® (BEGO GmbH & Co. KG, Bremen, Germany) (Group I: conical macrodesign), Straumann BL® – SLA modified surface (Institut Straumann AG, Basel, Switzerland) (Group II: cylindrical macrodesign), and I-System (Novodent SA, Yverdon Les Bains, Switzerland) (Group III: press-fit macrodesign) implants at Hacettepe University, Faculty of Dentistry, Department of Oral and Maxillofacial Surgery between 01/01/2018 and 01/08/2024. Patients with high-risk cardiovascular and pulmonary diseases, smoking habit, an immunocompromised status such as a history of organ transplantation, malignancy, chemotherapy, radiotherapy, corticosteroid usage, antimetabolite agent intake, uncontrolled diabetes, pregnancy, lactation, oral contraceptive intake, and bone augmentation at the implant site were excluded from the study. Groups I and II had dental implants that required some degree of primary stabilization force during insertion (active implants), while group III did not (passive implant).

All dental implants were placed following the proper drilling procedure, in accordance with each firm's placement protocol. The coronal margin of each implant was placed at the same level as that of the alveolar crest. All implants were inserted by the 2-stage and delayed placement protocols following tooth extraction, and the soft tissues were primarily closed using 3.0 silk material (Doğsan Medical Materials Co., Trabzon, Turkey) after the placement of cover screws. All patients received 500 mg amoxicillin tablets (Largopen®, Bilim İlaç San. Tic. Aş., İstanbul, Turkey) 3 times daily, 550 mg naproxen sodium tablets (Apranax Fort®, Abdi İbrahim İlaç San. Tic. Aş., İstanbul, Turkey) twice daily, and 0.12% chlorhexidine mouthwash (Andorex®, Humanis Sağlık Aş., İstanbul, Turkey) 3 times daily for 7 days postoperatively. Patients allergic to penicillin were administered 150 mg clindamycin tablets twice daily. Following a 3 months healing period, the osseointegration status of the implants was examined using CBCT image acquisition before prosthetic loading.

All CBCT images were acquired using the i-CAT Next Generation system (Imaging Sciences International, Hatfield, PA, USA). To ensure uniformity, a laser beam was used to standardize the head positions of all patients. The CBCT device had the following technical specifications: tube voltage of 120 kVp, tube current of 5 mA, pulsed radiation exposure time of 7 seconds, voxel sizes of 0.125 mm (for 8x8 cm and 16x4 cm), and Field of Views of 0.20 mm and 0.25 mm.

All measurements were performed by the same practitioner on the 3 months postoperative CBCT images using the CS 3D Imaging (version 3.8.6) software (Carestream Dental LLC, Atlanta, USA). To calculate the MBL values, 3 cross-sections passing through the midline; 1.2 mm distal and mesial of the midline were used for each implant. For each section, a line that passed from the midpoint of the apex to the midpoint of the coronal margin of the implant was determined as the mid-axis of each implant. A line perpendicular to the mid–axis was drawn on the coronal margin of the implants and was described as an implant coronal marginal line. The perpendicular distances of the adjacent marginal bone to the coronal marginal line on the buccal and lingual aspects of the implants were measured on the aforementioned 3 CBCT image sections for each implant (Figure 1). The average MBL at the six points was determined as the total MBL value of each implant. For each implant, buccal and lingual MBL values were calculated by determining the mean MBL measurements at 3 points on the buccal and lingual sides, respectively. Total MBL values were compared between the groups. Buccal and lingual MBL values were statistically compared within groups to reveal the marginal bone loss pattern of each macrodesign. The total MBL values of the implants inserted in the maxilla and mandible were compared within groups to reveal the osseointegration performance of each macrodesign in the different jaws. The total MBL values of the implants inserted in the anterior (teeth 1, 2, and 3) and posterior (teeth 4, 5, 6, and 7) regions were statistically compared within groups to reveal the osseointegration performance of each macrodesign in different locations.

To evaluate intra–examiner reliability, a one–way interclass correlation coefficient (ICC) model was used in a confidence interval of 95%. The same examiner performed measurements on 15 randomly selected implants twice, with a 3-week interval between measurements. The correlation coefficients for both assessments ranged from 0.942 to 0.981. The interclass correlation coefficient (ICC) exhibited excellent reliability (ICC = 0.962 ± 0.012; 95% confidence interval, CI).

Non-parametric tests were applied because of the non–normally distributed data according to the Shapiro–Wilk test. Descriptive statistics are reported in terms of median and interquartile range (iqr). The variables within groups were statistically compared using the Wilcoxon signed-rank test. The variables among the groups were statistically compared using the Kruskal Wallis test and the Dunn's post hoc test. In all assessments, statistical significance was determined at $p<0.05$. Analyses were performed using the SPSS version 21 software (IBM Co., Armonk, NY, USA).

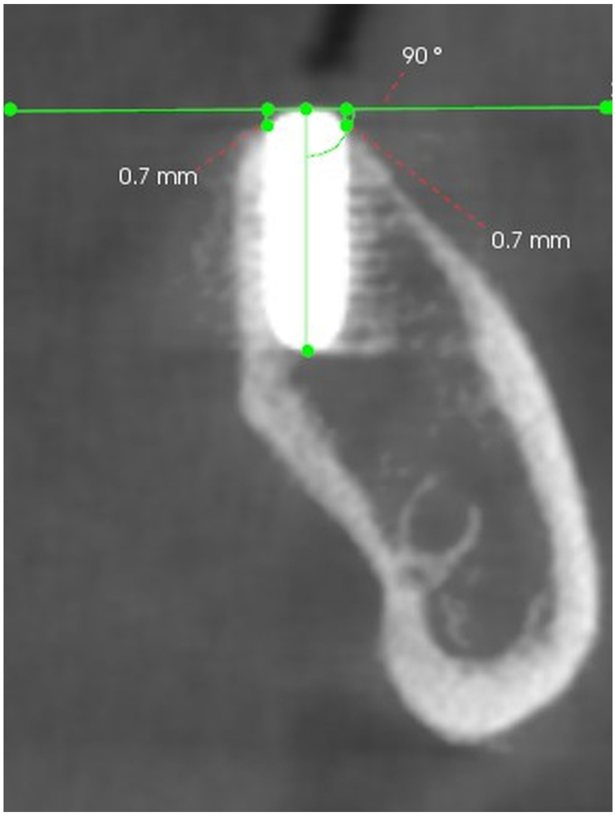

Figure 1. Assessment of buccal and lingual marginal bone loss using the CBCT cross-section intersecting the implant's midline in group II.

RESULTS

Three implants in 3 patients were excluded from groups I (1 implant in 1 patient because of failure), II (1 implant in 1 patient because of subcrestal placement), and III (1 implant in 1 patient because of subcrestal placement). A total of 57 dental implants were included in the study, which were inserted in 14 patients (4 males, 10 females; median age: 54.50; iqr of age: 24.25; age-range: 32 – 73 years). Groups I, II, and III each had 19 implants. The median of the diameter and length of the implants in groups I, II, and III were 4.10 – 10.00, 4.10 – 10.00, and 4.00 – 8.00 mm, respectively. No significant differences were observed in the diameter and length values of the groups.

The median and iqr total MBL value for all implants was 0.21 and 0.40 mm. The median total marginal bone loss values of groups I, II, and III are shown in Table 1. No significant difference was observed among the total marginal bone loss values of groups I, II, and III.

The median buccal and lingual MBL values of groups I, II, and III are shown in Table 2. In group II, buccal MBL values were significantly higher than the lingual MBL values (P = 0.048). The median total MBL values of the implants inserted in the mandible and maxilla in groups I, II, and III are shown in Table 3. No significant difference was found between the total MBL values of the implants inserted in the mandible and maxilla in groups I, II, and III.

The mean total MBL values of the implants inserted at the anterior and posterior locations are shown in Table 4. No significant difference was found between the total MBL values of the implants inserted in the anterior and posterior locations in groups I, II, and III.

DISCUSSION

MBL occurs between 1.06 and 1.22 mm in the first 12 months of osseointegration of the dental implants.[7,8] In the following years, the amount of bone resorption stabilizes to an average of 0.1 mm per year. More than 50% of the MBL during the first 12 months of osseointegration occurs in the first 3 months of healing.[9] This outcome makes the first 3 months of implant osseointegration vital for long–term success. To achieve ideal healing with minimal bone resorption, the osseointegration performance of different implant macrodesigns should be investigated in detail. The present study revealed that conical, cylindrical, and passive press–fit implant designs did not have significantly different total MBL values during the first 3 months of osseointegration. The results are coherent to the outcomes of Su YH et al.[10] that reveals conical and cylindrical implants do not have significantly different MBL in the first 3 months of healing. However, a comparison of the MBL of press–fit passive implants with active conical or cylindrical implants is lacking in the literature. The present study proves that the press–fit implant design does not significantly reduce MBL values in the first 3 months of osseointegration compared to active conical or cylindrical implants.

When MBL patterns of different implant macrodesigns were compared, only cylindrical implants had significantly higher resorption values on the buccal side in the present study. In the literature, when a cylindrical implant was immediately inserted to the socket following tooth extraction, MBL was observed significantly higher in the buccal side coherent to the present study.[11] Implants are placed in a more palatal location and have a larger gap on the buccal side between the bone and implant in the immediate insertion protocol. This may have caused higher buccal bone resorption during the immediate insertion of cylindrical implants. The present study proves that early resorption of the buccal alveolar bone occurs significantly higher than that of the lingual bone, even though the implants are inserted into the alveolar crest in a more central position for the delayed placement protocol. A thick cortical bone provides higher resistance to resorption in peri–implant area.[12,13] It has been shown that cortical bone thickness is higher on the lingual side of the mandible and maxilla.[14] Hence, this could be the reason for the significantly higher resistance to resorption in the lingual bone during the osseointegration period of the cylindrical implants in the present study.

Even though existence of proportionally higher cortical bone provides lesser dental implant failure rates in long term,[15] it causes more MBL than bone tissues with a higher spongiosa component.[16,17] Higher cortical bone existence generates higher insertion torque values.[18] A higher insertion torque was responsible for the increased early MBL.[19,20] In the present study, conical and cylindrical implants generated higher MBL in the maxilla and mandible, respectively, although the differences between the jaws were insignificant in each macrodesign. For conical implants, the surgical site preparation process for all mandibular implants was finalized with marginal cortical bone preparation using proper countersink drills in accordance with the instructions provided by the manufacturer. However, this procedure was not performed for cylindrical implants inserted in the mandible and maxilla if the insertion torque did not exceed 40 N. Countersinking may provide placement of conical implants with ideal insertion torque values, which could be the reason for the insignificantly lower MBL values of the conical implants inserted in the mandible. Higher cortical bone existence without a countersinking procedure could be the reason for the insignificantly higher MBL value for cylindrical implants inserted in the mandible.

While several studies have revealed that dental implants inserted in the posterior region have significantly higher early MBL levels than those in the anterior region,[21] others have shown that there is no significant difference between the early MBL levels of implants inserted in the posterior and anterior regions.[22] The present study revealed that conical implants have insignificantly more MBL in the anterior region than in the posterior region. Maxillary and mandibular anterior regions have thinner cortical and cancellous bone than the posterior regions of the jaws.[23,24] Furthermore, anterior regions of the jaw have more cortical components,

Table 1. Median total marginal bone loss values of the groups

	Group I	Group II	Group III	Comparison of all Groups (Kruskal Wallis with Dunn's post hoc test) P Value
Median TMBL	0.23 (0.68)	0.20 (0.18)	0.21 (0.41)	0.654

TMBL: Total Marginal Bone Loss, the values were given as median (interquartile range)

Table 2. Median buccal and lingual marginal bone loss values of the groups

	Group I		Comparison Within Group I (Wilcoxon) *P* Value	Group II		Comparison Within Group II (Wilcoxon) *P* Value	Group III		Comparison Within Group III (Wilcoxon) *P* Value
	Buccal	Lingual		Buccal	Lingual		Buccal	Lingual	
Median MBL	0.00 (0.34)	0.20 (1.02)	0.600	0.27 (0.35)	0.00 (0.24)	0.048*	0.13 (0.62)	0.00 (0.41)	0.087

* $P < 0.05$, MBL: Marginal Bone Loss, the values were given as median (interquartile range)

Table 3. Median marginal bone loss values of the groups for mandible and maxilla

	Group I		Comparison Within Group I (Wilcoxon) *P* Value	Group II		Comparison Within Group II (Wilcoxon) *P* Value	Group III		Comparison Within Group III (Wilcoxon) *P* Value
	Mandible	Maxilla		Mandible	Maxilla		Mandible	Maxilla	
Median TMBL	0.17 (0.20)	0.35 (0.71)	0.109	0.29 (0.17)	0.16 (0.13)	0.104	0.39 (0.58)	0.20 (0.34)	0.715

TMBL: Total Marginal Bone Loss, the values were given as median (interquartile range)

Table 4. Median marginal bone loss values of the groups for posterior and anterior regions

	Group I		Comparison Within Group I (Wilcoxon) *P* Value	Group II		Comparison Within Group II (Wilcoxon) *P* Value	Group III		Comparison Within Group III (Wilcoxon) *P* Value
	Posterior	Anterior		Posterior	Anterior		Posterior	Anterior	
Median TMBL	0.17 (0.64)	0.44 (1.12)	0.225	0.21 (0.14)	0.18 (0.18)	0.484	0.18 (0.41)	0.25 (0.00)	0.655

TMBL: Total Marginal Bone Loss, the values were given as median (interquartile range)

particularly in the mandible.[25] A thin bone with a higher cortical component is a risk factor for early MBL.[26] In light of the present study, a conical implant design may increase the risk of early MBL in anterior regions with narrow alveolar bones and should be avoided in the anterior regions.

In the literature, significantly higher insertion torque and primary stabilization values can be achieved in conical implants than in cylindrical implants.[27] However, higher insertion torque values resulted in significantly higher bone resorption values during osseointegration. Hence, providing optimum osteointegration is a very thin line, and macrodesign of the implants affects osseointegration parameters such as insertion torque and implant stability quotient.[19,20] The present study provides valuable outcomes for choosing different macrodesigns in different jaw locations to achieve ideal osseointegration and reveals that the passive press-fit implant design provides a more homogenous MBL pattern in different jaws, locations, and aspects of the adjacent alveolar bone.

Several studies have revealed that subcrestal placement increases the success of passive implants.[28-30] Subcrestal placement can provide protection from undesired force exposure during osseointegration and can minimize the risk of micromovement that can cause failures. However, crestal

placement of passive implants did not significantly increase the failure rate compared with active implants in the present study. The present study did not include any patients who had one– or double–jaw total implant restorations in the passive implant group. Therefore, all patients have an existent occlusion, which could protect the passive implants from destructive forces during the first 3 months of osseointegration. Further studies should be performed to reveal the potential effects of total or partial edentulism on the osseointegration success of passive implants placed at the marginal crest level.
The initial cortical and spongiosa bone thicknesses and the adjacent soft tissue status of the recipient sites were not evaluated prior to implant insertion in the present study. The relationship between implant diameter and MBL was not investigated. Furthermore, the MBL values were not calculated according to the thread design and microsurface characteristics of the implants. A longer observation period could reveal the potential effects of various abutment and prosthesis designs on the MBL and implant longevity. More comprehensive outcomes can be obtained with a larger sample size. Further studies should be performed on the MBL of various implants inserted in regions that have previously undergone bone or soft tissue augmentation using different techniques.

CONCLUSION

Within the limitations of the present study, the use of cylindrical implants can be avoided in alveolar crests with higher existent resorption at the buccal side to prevent progressive MBL in the same aspect. If cylindrical implants are used in the mandible, the minimum adjacent buccal marginal bone thickness may be increased to 2 mm because of the increased risk of buccal bone resorption. Conical and cylindrical implants can be chosen for the mandible and maxilla, respectively, and a countersinking procedure should not be skipped when cylindrical implants are inserted in the mandible to minimize MBL. Cylindrical implants may be administered in the anterior region to minimize early MBL. Passive press-fit implants are not superior to active cylindrical or conical implants in reducing MBL during the osseointegration period.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS STATEMENT

The present study was approved by the Non-Interventional Clinical Research Ethics Committee of Hacettepe University (approval no: 2024/14–28).

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CLINICAL DENTISTRY AND RESEARCH 2025; 49(1): 26-33 Original Research Article

RESTORATION REMOVAL USING HIGH-SPEED HANDPIECES WITH OR WITHOUT THE FIBER-OPTIC LIGHT

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ABSTRACT

Background and Aim: The aim of this study was to evaluate the differences in cavity dimension changes associated with the removal of tooth-colored restorations using high-speed handpieces with or without fiber-optic light.

Materials and Methods: Five recently graduated dentists (6 months-1 year of professional experience) were assigned to remove 40 Class I composite restorations. Half of the restorations were removed using a high-speed handpiece with fiber-optic light, and the other half with a handpiece without light. Cavity dimensions changes were measured using a periodontal probe and a digital micrometer at nine defined regions of the tooth preparation. Measurements were recorded at two stages: before restoration removal and after removal (with/without fiber-optic light). Analyses were conducted to assess changes in cavity dimensions and the unnecessary removal of sound tissue. Statistical analysis was performed using the Mann-Whitney U test to compare non-normally distributed data between the two groups, with a significance level set at $p < 0.05$.

Results: Restorations removed with high-speed handpieces with fiber-optic light resulted in significantly less unnecessary cavity dimension changes compared to those removed without light ($p<0.05$). The use of high-speed handpiece with fiber-optic light demonstrated a statistically significant advantage in preserving the cavity integrity ($p<0.05$).

Conclusion: The use of high-speed handpieces with fiber-optic light significantly reduced unnecessary cavity dimension changes compared to those without light, demonstrating their potential to enhance precision and support minimally invasive dentistry.

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INTRODUCTION

Modern dentistry increasingly favors tooth-colored restorative materials due to their aesthetic advantages and the ability to perform more conservative cavity preparations. However, during the replacement of restorations, distinguishing between composite resin remnants and natural tooth structure becomes nearly impossible, especially when using water-cooled rotary instruments. Compared to amalgam restorations, the removal of tooth-colored restorations is associated with higher risks, including over-preparation, excessive removal of tooth structure, unnecessary weakening of structural integrity, and prolonged treatment durations.[1-5] Moreover, the difficulty in differentiating tooth-colored materials from natural tooth tissue may cause challenges such as reduced adhesive bond strength and/or marginal seal of the new restorations due to remnants of the old restoration.[6]

As the conventional removal procedures for tooth-colored materials become more complex, time-consuming, and less predictable, the need for innovative diagnostic approaches arises. Attempts to enhance visibility, such as the use of photochromic cavity liners[5] or selecting materials with significantly different shades,[7] have shown limited success. The intrinsic fluorescence of resin-based composites under UV light was first highlighted by forensic experts for its diagnostic potential, long before its use in dental applications.[8,9] Early studies suggested the use of UV light for examining cavities after restoration removal,[10] with subsequent research showing that most resin composite brands exhibit fluorescence levels higher than those of natural tooth tissues.[11,12] Techniques leveraging this property have been developed to improve the identification and removal of tooth-colored restorations, demonstrating increased accuracy and efficiency.[13]

However, while such advancements have shown potential, their integration into conventional dental practices is often limited by cost and accessibility challenges, particularly in regions with lower socioeconomic resources. Furthermore, their incorporation into preclinical student education poses additional challenges due to the complexity and cost of these technologies. Integrating fiber-optic light features into traditional dental handpieces enables clinicians to illuminate darker areas of the oral cavity, enhancing visibility during procedures. However, it remains uncertain whether these devices provide significant advantages in preserving healthy tooth structure and supporting minimally invasive dentistry, or if they merely function as an accessory with limited practical value.

Thus, the aim of this *in vitro* study is to evaluate the differences in cavity dimension changes associated with the removal of tooth-colored restorations using high-speed handpieces, with or without fiber-optic light. The null hypothesis of this study states that there is no statistically significant difference in cavity dimension changes between high-speed handpieces with and without fiber-optic light during the removal of tooth-colored restorations.

MATERIALS AND METHODS

Sample Size Calculation

A power analysis was conducted using G*Power software (version 3.1) to determine the required sample size. With an alpha error probability of 0.05, a statistical power of 80% ($1-\beta = 0.80$), and an effect size of 0.8, the analysis indicated that a minimum of 36 specimens (18 per group) was required. Thus, a total of 40 specimens (20 per group) was included, slightly exceeding the minimum required sample size.

Cavity Preparation and Measurements

The preparation of 40 occlusal Class I cavities was performed on mandibular first molar plastic teeth (Frasaco APT, Tettnang, Germany) mounted in phantom head dental chair simulators. The procedures were carried out by five recently graduated dentists with 6 months to 1 year of professional experience with normal vision who underwent a standardized training program and calibration prior to the study. They were instructed to completely remove the restorations while avoiding unnecessary extension of the cavities. To minimize bias, all samples were randomly assigned to the dentists, and the procedures were conducted under identical conditions, including operatory dental chair light illumination in the same laboratory environment. The consistency of cavity preparations was verified independently to ensure standardization and accuracy. The flow chart of the study is presented in Figure 1.

The procedures were performed following routine standardized protocols under continuous water cooling, using a high-speed traditional handpiece (Alegra TE–95, W&H, Bürmoos, Austria). The occlusion preparations were performed using round and cylinder diamond burs (#G801-314-018-F, #G835R-314-010-4-F Diatech; Coltène/Whaledent, Altstätten, Switzerland). The cavities were standardized with an occluso-gingival depth of 2 mm and

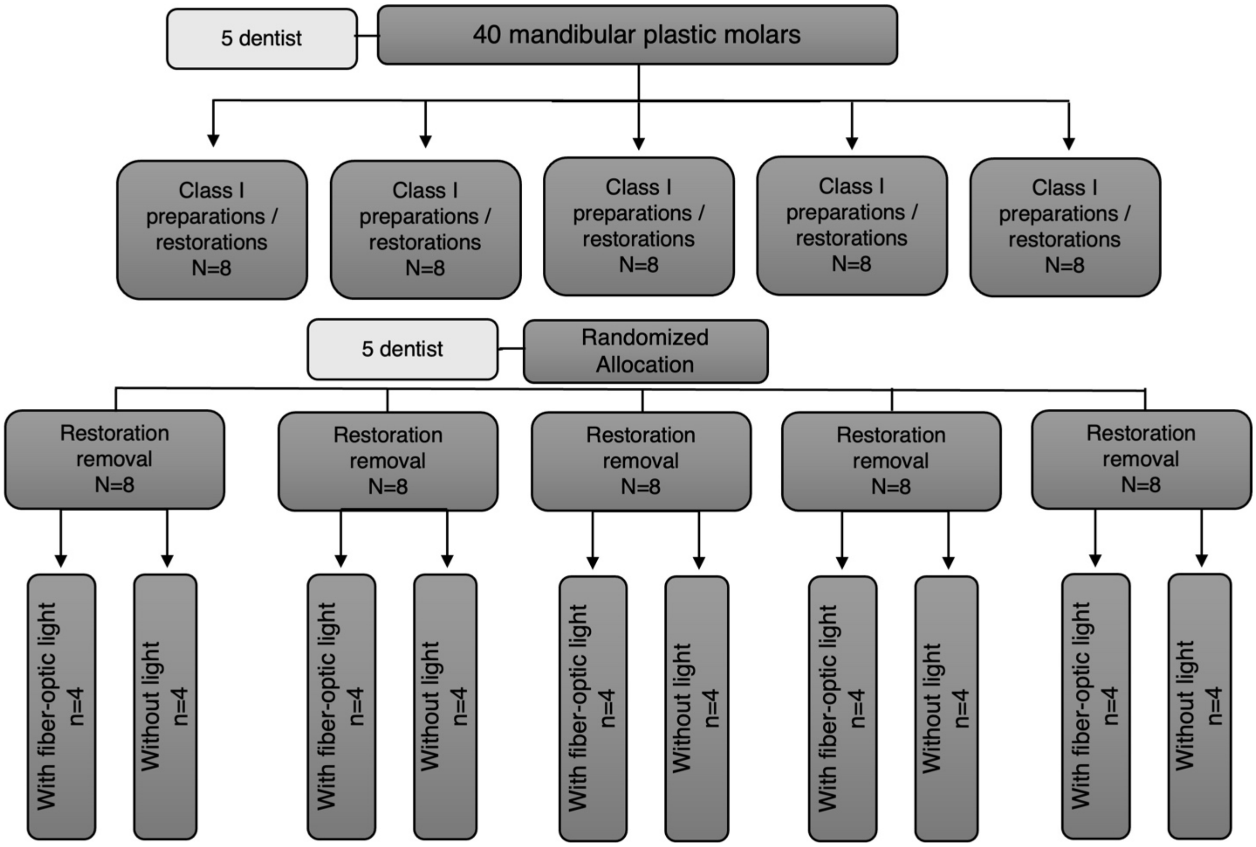

Figure 1. Flowchart of the study

a box-shaped configuration, with no beveling applied to the margins. All preparations were independently inspected by two experts to ensure consistency and adherence to the standardized dimensions.

Measurements of all prepared cavities were conducted using a periodontal probe (Hu-Friedy, Chicago, IL, USA), followed by validation with a digital micrometer (Digital micrometer, IP65, Mitutoyo MC, Tokyo, Japan) with a precision of ±0.01 mm, based on standardized testing principles for dental materials analysis.

Measurements were recorded at six occluso-pulpal regions: disto-buccal (DB), disto-lingual (DL), central fossa buccal (CB), central fossa lingual (CL), mesio-buccal (MB), and mesio-lingual (ML) edges, and three bucco-lingual regions: between the distal cusps (D), at the center of the central fossa (C), and between the mesial cusps (M). The cavity preparation procedures adhered to internal protocols to ensure consistency in occluso-gingival depth (2 mm) and box-shaped configuration. The initial measurements (M0) of cavity dimensions were then obtained.

Restoration Procedure

Following cavity preparation and measurements, the samples were rinsed with an air-water spray and dried using compressed air at a pressure of 2.5 kgf/cm² from a distance of 5 cm. Subsequently, the universal adhesive (Prime&Bond, Dentsply Sirona, Charlotte, NC, USA) was applied in self-etch mode for 20 s, in accordance with the manufacturer's instructions. The surfaces were then air-dried for 5 s using an air-water spray to ensure solvent evaporation and polymerized for 20 s using an LED curing light (Cromalux 1200, Mega-Physik, Rastatt, Germany) at a distance of 1 mm. The cavities were then restored with nanohybrid resin composite (Ceram-X Duo, Dentsply DeTrey, Konstanz, Germany) in increments no thicker than 2 mm using a hand instrument to ensure a gap-free application, with each layer light-cured for 20 s at a 1 mm distance.

The restorations were finished using bud-shaped fine-grit diamond bur (G368-314-016-3.5-F, Diatech; Coltène/Whaledent, Altstätten, Switzerland) under constant water cooling with a high-speed handpiece. The restoration surfaces were polished using silicon polishing system (KerrHawe HiLuster Plus; Kerr, CA, USA) with a low-speed handpiece-micromotor system (WE 56 Alegra Contra Angle Handpiece, AM 25 BC Micromotor, W&H, Bürmoos, Austria). Occlusal adjustments were performed by fine-grit diamond burs and verified with articulating paper.

Restoration Removal Procedure

The restored samples were randomly assigned to same five recently graduated dentists, with each dentist allocated eight samples. Care was taken to ensure that none of the dentists worked on restorations they had initially performed. Each student removed 4 restorations using a high-speed handpiece with fiber-optic light (Alegra TE-95 LQ, W&H, Bürmoos, Austria) and the other 4 restorations using a conventional high-speed handpiece without light (Alegra TE–95, W&H, Bürmoos, Austria). Prior to the procedures, all dentists completed a standardized training program and performed two trial preparations to ensure consistency. These trial preparations were independently evaluated by two experts. This experimental design simulated a clinical scenario where restorations are removed by a different clinician.

Subsequent to the restoration removal, the samples were examined by two independent experts to ensure consistency. Measurements were conducted using the same procedure applied in the initial measurements, with all measurements performed by a blinded researcher to avoid bias. The measurements were categorized into M1 (with fiber-optic light handpiece) and M2 (without light handpiece) values.

To determine dimensional changes and evaluate the preservation of tooth structure, the final measurements were subtracted from the baseline cavity dimensions (M0). The analysis focused on occluso-pulpal and bucco-lingual measurements to assess the effects of the two handpiece types.

To further minimize bias, the five dentists performing the removal procedures and the researcher conducting the measurements were blinded to group assignments. All measurements were conducted by a single researcher and reviewed by two independent experts to ensure consistency and accuracy.

Statistical analysis involved calculating the differences between the baseline measurements (M0) and the post-removal measurements using a high-speed handpiece with fiber-optic light (M1-M0) and without light (M2-M0) for each specimen. Δ represents the dimensional change calculated as the difference between baseline (M0) and post-removal measurements (M1 or M2), (Dimensional change at the disto-buccal region [ΔDB], dimensional change at the disto-lingual region [ΔDL], dimensional change at the central fossa buccal region [ΔCB], dimensional change at the central fossa lingual region [ΔCL], dimensional change at the mesio-buccal region [ΔMB], dimensional change at the mesio-lingual region [ΔML], dimensional change between the distal cusps [ΔD], dimensional change at the center of the central fossa [ΔC], dimensional change between the mesial cusps [ΔM]).

Statistical Analysis

The normality of the data distribution was assessed using the Shapiro-Wilk and Kolmogorov-Smirnov tests. Since the data did not follow a normal distribution, the Mann-Whitney U test was applied to compare differences between the two groups (with fiber-optic light and without light). Measures of central tendency were evaluated using median values. All statistical analyses were performed using SPSS software version 20.0 (IBM Corp., Armonk, NY, USA), and a p-value of <0.05 was considered statistically significant.

RESULTS

The influence of high-speed handpieces with and without fiber-optic light on the preservation of healthy tooth structure was analyzed through dimensional changes (Δ) at specific regions.

Table 1 presents the mean±SD, median, minimum, and maximum values of cavity dimension changes following the removal procedures with and without fiber-optic light. Statistical significance was set at $p<0.05$.

Occluso-pulpal Measurements

Significant differences were observed in ΔDB, ΔCB, ΔCL, and ΔMB ($p<0.05$), where the handpiece with fiber-optic light demonstrated superior preservation of healthy tooth structure. The largest reduction in dimensional change was noted at ΔMB. No statistically significant differences were observed in ΔDL and ΔML ($p>0.05$).

Bucco-lingual Measurements

For the bucco-lingual regions, a significant difference was observed in ΔM ($p<0.05$), indicating better preservation of tooth structure achieved by the fiber-optic light handpiece. However, no significant differences were detected in ΔD and ΔC ($p>0.05$).

Table 1. Mean±SD, median, minimum, and maximum values of cavity dimensions changes following removal procedures with and without fiber-optic light.

Removal		Δ DB	Δ DL	Δ CB	Δ CL	Δ MB	Δ ML	Δ D	Δ C	Δ M
With Fiber-optic Light (M1-M0)	Mean± SD	0.16±0.21	0.18±0.1	0.15±0.09	0.1±0.64	0.07±0.06	0.18±0.23	0.16±0.08	0.12±0.1	0.11±0.09
	Median	0.1*	0.2	0.1*	0.1*	0.1*	0.15	0.15	0.1	0.1*
	Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Max	1.0	0.4	0.4	0.2	0.2	0.8	0.3	0.4	0.3
Without Light (M2-M0)	Mean ±SD	0.28±0.17	0.25±0.15	0.23±0.13	0.19±0.13	0.19±0.11	0.19±0.1	0.21±0.12	0.18±0.14	0.23±0.15
	Median	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Max	0.7	0.5	0.5	0.4	0.3	0.4	0.4	0.4	0.5

*Indicates a statistically significant difference ($p < 0.05$)
Δ represents the dimensional change between baseline (M0) and post-removal measurements (M1 or M2). Occluso-pulpal regions (ΔDB: Dimensional change at the disto-buccal region, ΔDL: Disto-lingual, ΔCB: Central fossa buccal, ΔCL: Central fossa lingual, ΔMB: Mesio-buccal, ΔML: Mesio-lingual) and bucco-lingual regions (ΔD: Dimensional change at the distal region, ΔC: Central fossa, ΔM: Mesial) measurements are expressed as the difference between the baseline cavity dimensions (M0) and post-removal values (M1: with fiber-optic light, M2: without light).

DISCUSSION

Despite advancements in preventive measures and oral health education, managing dental caries through restorations remains a core aspect of dental practice. Over time, all restorations inevitably undergo degradation, requiring periodic intervention and management. Factors contributing to this include marginal defects, secondary caries, fractures of the restoration or adjacent tooth structure, and aesthetic concerns. Ultimately, it is clear that restorations are not permanent solutions and will require further intervention as they deteriorate.[14] The decision to intervene in an existing restoration often relies on the operator's subjective judgment, influenced by factors like the patient's age, the restoration's size and location, and particularly a change in dentist. When a new dentist takes over a case, they may apply different criteria or approaches, potentially leading to unnecessary interventions.[15]

Restoration removal often leads to excessive cavity enlargement or unnecessary removal of hard tissue. Repeated treatments on the same tooth progressively result in irreversible and unnecessary loss of tooth structure.[3] In modern dental practice, the increased use of tooth-colored restorations has contributed to over-prepared cavities during retreatments, largely due to the lack of integration of advanced technologies into clinical practice.[14] Compared to amalgam, the removal of resin-based restorations can result in up to twice the amount of structural tooth loss.[16]

This study evaluated the impact of high-speed handpieces with and without fiber-optic light on changes in tooth preparation dimensions during the removal of tooth-colored restorations. The results revealed that handpieces with fiber-optic light significantly preserved initial preparation dimensions, supporting minimally invasive dentistry principles. Consequently, the null hypothesis was rejected due to the observed differences between the two handpiece types.

Krejci et al.[17] evaluated volumetric cavity dimensions following the removal of different restorative materials and proposed the development of color indicators to enhance the visualization of the tooth-restoration interface. In line with this, a study comparing cavity dimensions during the removal of restorations made with different restorative materials, the use of a photochromic cavity liner was reported to create no significant difference.[5] On the other hand, a recent *in vitro* study, evaluated a white-opaque flowable composite as a depth marker and optical aid during restoration removal, assessing tooth structure loss in terms of weight and volume. The findings suggested that using a white-opaque flowable liner as a depth marker could provide practitioners with a visual aid during composite restoration replacement, effectively minimizing tooth structure loss.[18] However, the use of an additional material during restoration placement may not always be practical, feasible, or aesthetically acceptable. Thus, an aid that can be integrated during the removal process appears to be a more suitable option.

In a study comparing the fluorescence-aided identification of restorations (FAIR) method with fiber-optic illuminated handpieces for the selective removal of tooth-colored resin-based composite restorations, the FAIR method demonstrated superior outcomes, including more precise removal and preservation of sound tooth structure.[2] These findings align with our results, which also emphasized the advantages of fiber-optic light in minimizing cavity dimension changes. Moreover, composite resin and amalgam restorations were removed from occlusal cavities of primary molars using conventional high-speed burs and ultrasonic diamond tips, with findings indicating a comparable amount of tooth structure loss across both methods.[19] The use of the fiber-optic light in the handpieces for fluorescence excitation has been demonstrated to be an effective approach for implementing the fluorescence-aided identification technique (FIT), significantly enhancing the removal of tooth-colored restorations.[20] Similarly, Dettwiler et al.[21] compared the conventional composite removal technique with the FIT in terms of completeness, selectivity, and duration in an in vitro study using direct restored permanent posterior teeth. Their findings indicated that FIT facilitates the selective and efficient removal of tooth-colored composites. Additionally, Leontiev et al.[22] evaluated the accuracy of the conventional illumination method and the FIT in differentiating composite restorations from intact teeth. Their findings indicated that FIT is significantly more reliable than the conventional illumination method for detecting composite restorations. Despite the success of these advanced techniques, their high cost, relative time demands, and difficulty in clinical integration remain significant barriers. However, the present findings demonstrated that solely the inclusion of fiber-optic light in high-speed handpieces significantly reduced cavity dimension changes during restoration removal, thus supporting minimally invasive approaches. This underscores the importance of further research and highlights that even a simple modification, such as integrating light into conventional dental handpieces, can yield clinically meaningful improvements.

High-speed dental handpieces with fiber-optic light were introduced in the late 1980s and early 1990s.[23] This innovation provided direct illumination of the working area through integrated fiber-optic light sources in the handpiece head, enhancing visibility and precision for dental procedures. Given their ability to improve visibility, these handpieces can be considered a standard tool for both preclinical student training and routine clinical practice, ensuring consistency in dental education and patient care.

Restoration replacement has previously been evaluated using weight measurements, which assess the amount of material removed during the procedure by calculating the difference in weight before and after restoration removal.[16,17] Some studies have used superimposed photographs to investigate differences in the surfaces and contours of restorations and cavities.[1,7,9,24]

Other researchers have utilized intraoral scanners to collect three-dimensional data sets,[2,5] while Klein et al.[20] further employed these devices for comparative analyses. In the current study, a periodontal probe and a digital micrometer were used to analyze cavity preparations, as commonly utilized in preclinical student training and only linear dimensions were analyzed. Although more advanced techniques have been introduced, the use of a readily accessible periodontal probe by clinicians has also revealed statistically significant differences in the results. Further studies employing advanced measurement tools could potentially yield more precise or striking results, providing deeper insights into the cavity preparation outcomes.

Within the limitations of this study, several factors should be considered when interpreting the results. Firstly, this was an *in vitro* study, which may not fully replicate the complex clinical conditions encountered *in vivo,* such as the presence of saliva, blood, and patient movement. Secondly, the use of plastic teeth, rather than natural teeth, may have influenced the accuracy of the cavity preparation and material removal outcomes, particularly in mimicking the hardness and structural variability of dentin and enamel.[3] Additionally, only linear and surface dimensions were evaluated, as three-dimensional analysis tools were not utilized in this study. This could limit the comprehensive assessment of volume changes and microstructural alterations in the cavities. Lastly, the findings are based on a specific set of materials, handpieces, and operator experience, which may not be universally applicable. Future studies incorporating clinical conditions, natural teeth, and advanced three-dimensional measurement tools are recommended to validate and expand upon these findings, while also considering the broader implications of integrating fiber-optic technology into routine dental practice.

CONCLUSION

This *in vitro* study highlights the significant advantages of using high-speed handpieces with fiber-optic light for the removal of tooth-colored restorations. The findings demonstrate that fiber-optic light enhances precision during the restoration removal process, leading to significantly less unnecessary cavity dimension changes compared to handpieces without light. These results support the potential of fiber-optic light technology to improve restorative dentistry outcomes by preserving cavity integrity and promoting minimally invasive principles.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS STATEMENT

Ethical approval was not required, as the research did not involve clinical studies or patient data.

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TOP 100 PUBLICATIONS IN ORTHODONTICS AND ORTHOGNATHIC SURGERY: RANKED BY ANNUAL CITATION RATES

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ABSTRACT

Background and Aim: The aim of this study is to identify the 100 articles in orthodontics and orthognathic surgery based on the annual citation rate, to reveal the scientific impact of these articles, and to identify the key research areas and trends shaping the literature.

Materials and Methods: Articles and reviews were searched in the Scopus database using the keywords "orthodon*" and "orthognat*," resulting in 217,121 publications. The publications were ranked based on their annual citation rates, identifying the top 100 most influential articles. Data visualization was conducted using VOSviewer and the Bibliometrix Biblioshiny R-package, while Microsoft Excel was utilized for data tabulation.

Results: The articles with the highest annual citation rate span the period from 1982 to 2024. The highest annual citation rate is 45.33, with a total citation count of 272. The journals that have published the most articles are the American Journal of Orthodontics and Dentofacial Orthopedics and The Angle Orthodontist. The United States of America (USA) is the most contributing country, while Saveetha University is the most contributing institution. The most contributing author was Franchi L. Thematic areas prominently featured clear aligners, artificial intelligence, and digital dentistry.

Conclusions: The annual citation rate offers a contemporary perspective on the scientific impact of articles, indicating that modern treatment approaches and digital technologies are emerging trends in the literature. The findings indicate that an approach based on the annual citation rate provides a more balanced and up-to-date evaluation of scientific impact.

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INTRODUCTION

Over the past two decades, substantial advancements have been achieved in orthodontics, particularly through integrating digital dentistry and artificial intelligence technologies.[1] Among these developments, noteworthy are the rapid rise in popularity of orthodontic treatments using clear aligners,[2] the implementation of digital scanning and three-dimensional modeling systems enabling more precise and personalized treatment planning,[3,4] and the effective management of the treatment process through artificial intelligence, allowing for more reliable predictions of potential treatment outcomes. Digital dentistry, particularly in aligner treatments, has facilitated a more comfortable, aesthetic, and accelerated treatment process for patients by enabling the production of patient-specific aligners using 3D printing technology.[5] Additionally, AI-supported software enables more precise planning of tooth movements, resulting in more predictable treatment outcomes.[6-8] Keeping up with current developments in orthodontics is crucial for enhancing the quality of clinical practice and meeting patients' increasing expectations by effectively adapting to rapidly advancing technologies. However, the ever-increasing number of published articles presents a significant challenge for both researchers and clinicians in identifying studies of the highest quality and greatest clinical effectiveness.[9] Therefore, systematically evaluating the existing literature and providing comprehensive insights to readers through bibliometric analyses are becoming increasingly important.[10-12] Bibliometric analyses assess the citation performance, impact, and contributions of scientific publications within a specific field, facilitating the identification of exemplary studies and thematic trends. Analyzing high-impact publications is particularly crucial for understanding advancements in orthodontics and orthognathic surgery, as well as for identifying studies that significantly influence the direction of future research.[13]

A common approach in existing literature is to evaluate the 100 most impactful articles in orthodontics based on their total citation counts.[14-16] Nevertheless, it is expected that older publications will accumulate a higher number of citations. To address this issue, creating a top 100 list based on the annual citation rate offers a more reliable and balanced analysis.

This study represents the first investigation to identify the most significant articles in the fields of orthodontics and orthognathic surgery based on annual citation rates, aiming to address a notable gap in knowledge within these areas. Previous bibliometric studies in orthodontics have typically employed ranking systems based solely on the total number of citations each article has received.[9,15,16,17] Evaluating an article's impact based solely on total citation count can be misleading. High-quality and original articles published more recently may be overlooked with this approach,[18] as studies generally accumulate more citations the longer they remain in the literature.[19] Research indicates that articles often achieve their highest scientific impact between 10 and 20 years after publication.[15,20] Therefore, the future impact of recently published articles is frequently underestimated. The average annual citation rate is a valuable metric that more accurately reflects the scientific potential of newer articles, which have not yet accumulated a high total citation count.[20,21]

This study aims to evaluate the most impactful publications in the fields of orthodontics and orthognathic surgery literature, ranked according to annual citation rate, by employing bibliometric analysis. The data obtained will provide insights into how research in orthodontics and orthognathic surgery has evolved and identify which topics have attracted greater attention within the scientific community.

MATERIALS AND METHODS

On August 30, 2024, a search was conducted in the Scopus database using the query: (ALL ("orthodon*") OR ALL ("orthognat*")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (EXCLUDE (PUBYEAR, 2025)), which included articles and reviews, while excluding publications from the year 2025. The search encompassed all fields, resulting in a total of 217,121 exported publications. Subsequently, an Excel formula was developed to calculate the annual citation rate [Total number of citations of the article / (2024 – publication year of the article +1)]. Publications were then ranked based on this calculated annual citation rate.

To identify relevant articles, two researchers independently reviewed the publications ranked according to their annual citation rates. Initially, articles were evaluated based on their titles and abstracts. In cases of uncertainty, the full texts were examined to determine relevance to the study topic. The lists compiled by both researchers were subsequently compared by a third researcher. Any discrepancies were discussed and resolved through an online meeting involving all three researchers, resulting in the final selection of the top 100 articles. Following this selection, the two researchers conducted an additional online meeting to classify the articles according to topic areas and study types.

For the bibliometric analysis and visualization of data obtained in this study, VOSviewer (Center for Science and Technology Studies, Leiden University) and the Bibliometrix Biblioshiny R-package software programs were utilized. These software packages offer advanced visualization tools, enabling detailed examination and interpretation of bibliometric maps.[22]

VOSviewer version 1.6.20 was downloaded from the official VOSviewer website. To prevent incorrect processing of the exported .csv dataset by the software, the data were initially opened and edited in Microsoft Excel (Microsoft, Inc., Redmond, Washington). These edits involved correcting various inaccuracies, including author names, journal titles, and country names.

The Biblioshiny R-package is a unique open-source tool designed for conducting comprehensive science mapping analyses. It supports a recommended workflow for performing bibliometric analyses and is programmed in the R language, making it flexible, easily upgradable, and compatible with other statistical R packages.[23] These features make it particularly valuable in a continuously evolving field such as bibliometrics. For analysis with Biblioshiny, data were exported in ".bib" format, processed within the software, and subsequently visualized. Microsoft Excel was used for data tabulation. Ethical approval was not required, as the research did not involve clinical studies or patient data.

RESULTS

A comprehensive search of the Scopus database, using keywords related to orthodontics and orthognathic surgery, yielded a total of 217,121 articles. These articles were ranked according to their annual citation rates, and the top 100 most-cited articles were selected (Table 1). The selected articles span the period from 1982 to 2024. The article with the highest annual citation rate received 45.33 citations per year, accumulating a total of 272 citations.

Among the countries contributing most significantly, the USA ranked first with 32 articles and 10,726 citations, followed by Italy with 14 articles and 3,674 citations, and India with 12 articles and 2,352 citations (Table 2). Saveetha University was the leading contributing institution with 7 articles and 1,419 citations, followed by the University of Michigan with 6 articles and 2,118 citations, and the University of Florence with 4 articles and 1,732 citations (Table 3).

The most productive author was Franchi L. with 4 articles and 1,732 citations, followed by McNamara Jr. J. A. with 3 articles and 1,573 citations (Table 4). Figure 1 illustrates the distribution of the top 100 articles, ranked by annual citation rate, across the studied period.

The analysis of authors' keywords revealed that the most frequently occurring terms were orthodontics, systematic review, artificial intelligence, deep learning, clear aligners, machine learning, orthognathic surgery, periodontal ligament, cervical vertebrae, and bone remodeling. The results of the frequency analysis of authors' keywords are presented in Figure 2. Figure 3 illustrates the distribution of trending authors' keywords over the years, while Figure 4 depicts the network structure of these keywords. Additionally, Figure 5 demonstrates the geographical distribution of contributing countries.

The most common thematic areas were aligners (19 articles), artificial intelligence (11 articles), and digital dentistry (9 articles) (Table 5). The most frequently encountered study types included systematic reviews (23 articles), narrative literature reviews (18 articles), and prospective studies (14 articles) (Table 6). The journals publishing the highest number of articles were the American Journal of Orthodontics and Dentofacial Orthopedics and the Angle Orthodontist (Table 7).

DISCUSSION

The average annual citation rate is an essential metric, accurately reflecting the scientific potential of newer articles that have not yet accumulated high total citation counts.[20,21] This study addresses a notable gap in the field by presenting a ranking based on annual citation rates, providing an objective assessment of how effectively studies maintain or increase their scientific influence over time.

Three major databases—Google Scholar, Scopus, and Web of Science (WoS)—are commonly utilized for bibliometric analyses. Among these, Scopus is the most widely employed database due to its reliable information collection and advanced analytical tools.[24] The utilization of the Scopus database in our study ensured reliable data collection and provided a robust foundation for the analysis. Its extensive journal coverage and detailed bibliometric analysis capabilities enabled accurate identification of the

Tablo 1. Top 100 most cited articles ranked by annual citation rate

No	Title	Authors	Year of Publications	Total Citations	Citations Per Year	Thematic Field	Type of Study	Source Title	Correspond Author's Country
1	Evaluation of Three-Dimensional Changes in Pharyngeal Airway Following Isolated Lefort One Osteotomy for the Correction of Vertical Maxillary Excess: A Prospective Study	Vijayakumar Jain S.; Muthusekhar M.R.; Baig M.F.; Senthilnathan P.; Loganathan S.; Abdul Wahab P.U.; Madhulakshmi M.; Vohra Y.	2019	272	45.33	Airway space	Prospective study	Journal of Maxillofacial and Oral Surgery	India
2	Efficacy of clear aligners in controlling orthodontic tooth movement: A systematic review	Rossini G.; Parrini S.; Castroflorio T.; Deregibus A.; Debernardi C.L.	2015	443	44.3	Aligners	Systematic review	Angle Orthodontist	Italy
3	How sample size influences research outcomes	Faber J.; Fonseca L.M.	2014	476	43.27	Importance of sample size	Narrative literature review	Dental Press Journal of Orthodontics	Brazil
4	Development and validation of a formula for objective assessment of cervical vertebral bone age	Chandrasekar R.; Chandrasekhar S.; Sundari K.K.S.; Ravi P.	2020	213	42.6	Cervical vertebral maturation	Methodological study	Progress in Orthodontics	India
5	The Cervical Vertebral Maturation (CVM) method for the assessment of optimal treatment timing in dentofacial orthopedics	Baccetti T.; Franchi L.; McNamara Jr. J.A.	2005	813	40.65	Cervical vertebral maturation	Methodological study	Seminars in Orthodontics	Italy
6	Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: A systematic review of the literature	De Vos W.; Casselman J.; Swennen G.R.J.	2009	616	38.5	Cone-beam computed tomography	Systematic review	International Journal of Oral and Maxillofacial Surgery	Belgium
7	Has Invisalign improved? A prospective follow-up study on the efficacy of tooth movement with Invisalign	Haouili N.; Kravitz N.D.; Vaid N.R.; Ferguson D.J.; Makki L.	2020	191	38.2	Aligners	Prospective study	American Journal of Orthodontics and Dentofacial Orthopedics	USA
8	Advances in orthodontic clear aligner materials	Bichu Y.M.; Alwafi A.; Liu X.; Andrews J.; Ludwig B.; Bichu A.Y.; Zou B.	2023	74	37	Aligners	Narrative literature review	Bioactive Materials	Canada

9	Orthodontic tooth movement: The biology and clinical implications	Li Y.; Jacox L.A.; Little S.H.; Ko C.-C.	2018	238	34	Tooth movement	Narrative literature review	Kaohsiung Journal of Medical Sciences	USA
10	A 2003 update of bone physiology and Wolff s law for clinicians	Frost H.M.	2004	709	33.76	Alveolar bone	Narrative literature review	Angle Orthodontist	USA
11	Effectiveness of clear aligner therapy for orthodontic treatment: A systematic review	Robertson L.; Kaur H.; Fagundes N.C.F.; Romanyk D.; Major P.; Flores-Mir C.	2020	157	31.4	Aligners	Systematic review	Orthodontics and Craniofacial Research	Canada
12	Factors associated with the stability of titanium screws placed in the posterior region for orthodontic anchorage	Miyawaki S.; Koyama I.; Inoue M.; Mishima K.; Sugahara T.; Takano-Yamamoto T.	2003	666	30.27	Anchorage	Retrospective study	American Journal of Orthodontics and Dentofacial Orthopedics	Japan
13	The analysis of errors in orthodontic measurements	Houston W.J.B.	1983	1269	30.21	Error in cephalometric measurement	Narrative literature review	American Journal of Orthodontics and Dentofacial Orthopedics	United Kingdom
14	Precision and trueness of dental models manufactured with different 3-dimensional printing techniques	Kim S.Y.; Shin Y.S.; Jung H.D.; Hwang C.J.; Baik H.S.; Cha J.Y.	2018	211	30.14	Digital dentistry	Experimental study	American Journal of Orthodontics and Dentofacial Orthopedics	South Korea
15	Global distribution of malocclusion traits: A systematic review	Alhammadi M.S.; Halboub E.; Fayed M.S.; Labib A.; El-Saaidi C.	2018	208	29,71	Prevalence of malocclusion	Systematic review	Dental Press Journal of Orthodontics	Saudi Arabia
16	Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner	Flügge T.V.; Schlager S.; Nelson K.; Nahles S.; Metzger M.C.	2013	347	28.92	Digital models	Prospective study	American Journal of Orthodontics and Dentofacial Orthopedics	Germany
17	Root resorption associated with orthodontic tooth movement: A systematic review	Weltman B.; Vig K.W.L.; Fields H.W.; Shanker S.; Kaizar E.E.	2010	432	28.8	Root resorption	Systematic review	American Journal of Orthodontics and Dentofacial Orthopedics	USA
18	Worldwide prevalence of malocclusion in the different stages of dentition: A systematic review and meta-analysis	Lombardo G.; Vena F.; Negri P.; Pagano S.; Barilotti C.; Paglia L.; Colombo S.; Orso M.; Cianetti S.	2020	142	28.4	Prevalence of malocclusion	Systematic review	European Journal of Paediatric Dentistry	Italy

19	Artificial intelligence in orthodontics: Evaluation of a fully automated cephalometric analysis using a customized convolutional neural network	Kunz F.; Stellzig-Eisenhauer A.; Zeman F.; Boldt J.	2020	137	27.4	Artificial intelligence	Prospective study	Journal of Orofacial Orthopedics	Germany
20	Biomechanical and biological responses of periodontium in orthodontic tooth movement: up-date in a new decade	Li Y.; Zhan Q.; Bao M.; Yi J.; Li Y.	2021	109	27.25	Tooth movement	Narrative literature review	International Journal of Oral Science	China
21	Accuracy of a computer-aided surgical simulation protocol for orthognathic surgery: A prospective multicenter study	Hsu S.S.P.; Gateno J.; Bell R.B.; Hirsch D.L.; Markiewicz M.R.; Teichgraeber J.F.; Zhou X.; Xia J.J.	2013	317	26.42	Digital dentistry	Prospective study	Journal of Oral and Maxillofacial Surgery	USA
22	Automated identification of cephalometric landmarks: Part 2-Might it be better than human?	Hwang H.W.; Park J.H.; Moon J.H.; Yu Y.; Kim H.; Her S.B.; Srinivasan G.; Aljanabi M.N.A.; Donatelli R.E.; Lee S.-J.	2020	132	26.4	Artificial intelligence	Methodological study	Angle Orthodontist	South Korea
23	Influence of the three-dimensional printing technique and printing layer thickness on model accuracy	Zhang Z.C.; Li P.L.; Chu F.T.; Shen G.	2019	157	26.17	Digital dentistry	Experimental study	Journal of Orofacial Orthopedics	China
24	Clear aligners in orthodontic treatment	Weir T.	2017	209	26.13	Aligners	Narrative literature review	Australian Dental Journal	Australia
25	Cellular, molecular, and tissue-level reactions to orthodontic force.	Krishnan V.; Davidovitch Z.	2006	495	26,05	Tooth movement	Narrative literature review	American Journal of Orthodontics and Dentofacial Orthopedics	India
26	Can ChatGPT be used in oral and maxillofacial surgery?	Balel Y.	2023	52	26	Artificial intelligence	Prospective study	Journal of Stomatology, Oral and Maxillofacial Surgery	Türkiye
27	Clinical effectiveness of Invisalign® orthodontic treatment: a systematic review	Papadimitriou A.; Mousoulea S.; Gkantidis N.; Kloukos D.	2018	181	25.86	Aligners	Systematic review	Progress in Orthodontics	Switzerland
28	Direct 3D printing of clear orthodontic aligners: Current state and future possibilities	Tartaglia G.M.; Mapelli A.; Maspero C.; Santaniello T.; Serafin M.; Farronato M.; Caprioglio A.	2021	102	25.5	Aligners	Narrative literature review	Materials	Italy

29	Mechanisms of tooth eruption and orthodontic tooth movement	Wise G.E.; King G.J.	2008	428	25.18	Tooth movement	Narrative literature review	Journal of Dental Research	USA
30	CBCT in orthodontics: Assessment of treatment outcomes and indications for its use	Kapila S.D.; Nervina J.M.	2015	248	24,8	Cone-beam computed tomography	Narrative literature review	Dentomaxillofacial Radiology	USA
31	How well does Invisalign work? A prospective clinical study evaluating the efficacy of tooth movement with Invisalign	Kravitz N.D.; Kusnoto B.; BeGole E.; Obrez A.; Agran B.	2009	396	24.75	Aligners	Prospective study	American Journal of Orthodontics and Dentofacial Orthopedics	USA
32	Orthodontic management of a dilacerated central incisor and partially impacted canine with unilateral extraction – A case report	Felicita A.S.	2017	193	24.13	Impacted tooth	Case report	Saudi Dental Journal	India
33	Comparison of pterygomaxillary dysjunction with tuberosity separation in isolated Le Fort I osteotomies: a prospective, multi-centre, triple-blind, randomized controlled trial	Christabel A.; Anantanarayanan P.; Subash P.; Soh C.L.; Ramanathan M.; Muthusekhar M.R.; Narayanan V.	2016	216	24	Surgical technique	Clinical trial	International Journal of Oral and Maxillofacial Surgery	India
34	Factors affecting the clinical success of screw implants used as orthodontic anchorage	Park H.-S.; Jeong S.-H.; Kwon O.-W.	2006	450	23.68	Anchorage	Longitudinal study	American Journal of Orthodontics and Dentofacial Orthopedics	South Korea
35	Mini-implant for orthodontic anchorage.	Kanomi R.	1997	661	23,61	Anchorage	Case report	Journal of Clinical Orthodontics : JCO	Japan
36	A comparison of treatment effectiveness between clear aligner and fixed appliance therapies	Ke Y.; Zhu Y.; Zhu M.	2019	141	23.5	Aligners	Systematic review	BMC Oral Health	China
37	Automated identification of cephalometric landmarks: Part 1—Comparisons between the latest deep-learning methods YOLOV3 and SSD	Park J.H.; Hwang H.W.; Moon J.H.; Yu Y.; Kim H.; Her S.-B.; Srinivasan G.; Aljanabi M.N.A.; Donatelli R.E.; Lee S.J.	2019	139	23.17	Artificial intelligence	Prospective study	Angle Orthodontist	South Korea

38	The impact of malocclusion on the quality of life among children and adolescents: A systematic review of quantitative studies	Dimberg L.; Arnrup K.; Bondemark L.	2015	230	23	Prevalence of malocclusion	Systematic review	European Journal of Orthodontics	Sweden
39	Automated Skeletal Classification with Lateral Cephalometry Based on Artificial Intelligence	Yu H.J.; Cho S.R.; Kim M.J.; Kim W.H.; Kim J.W.; Choi J.	2020	115	23	Artificial intelligence	Prospective study	Journal of Dental Research	South Korea
40	Obstructive sleep apnea and orthodontics: An American Association of Orthodontists White Paper	Behrents R.G.; Shelgikar A.V.; Conley R.S.; Flores-Mir C.; Hans M.; Levine M.; McNamara J.A.; Palomo J.M.; Pliska B.; Stockstill J.W.; Wise J.; Murphy S.; Nagel N.J.; Hittner J.	2019	137	22.83	Obstructive sleep apnea	Expert consensus document	American Journal of Orthodontics and Dentofacial Orthopedics	USA
41	An Improved Version of the Cervical Vertebral Maturation (CVM) Method for the Assessment of Mandibular Growth	Baccetti T.; Franchi L.; McNamara Jr. J.A.	2002	523	22,74	Cervical vertebral maturation	Longitudinal study	Angle Orthodontist	Italy
42	Treatment outcome and efficacy of an aligner technique - regarding incisor torque, premolar derotation and molar distalization	Simon M.; Keilig L.; Schwarze J.; Jung B.A.; Bourauel C.	2014	250	22.73	Aligners	Prospective study	BMC Oral Health	Germany
43	The cervical vertebral maturation method: A user's guide	McNamara J.A.; Franchi L.	2018	158	22.57	Cervical vertebral maturation	Narrative literature review	Angle Orthodontist	USA
44	Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment	Årtun J.; Bergland S.	1984	925	22,56	Enamel conditioning	Experimental study	American Journal of Orthodontics and Dentofacial Orthopedics	Norway
45	Accuracy of 3-dimensionally printed full-arch dental models: A systematic review	Etemad-Shahidi Y.; Qallandar O.B.; Evenden J.; Alifui-Segbaya F.; Ahmed K.E.	2020	112	22.4	Digital dentistry	Systematic review	Journal of Clinical Medicine	Australia
46	Wolff's Law and bone's structural adaptations to mechanical usage: an overview for clinicians.	Frost H.M.	1994	694	22.39	Alveolar bone	Longitudinal study	Angle Orthodontist	USA

47	Accuracy and reproducibility of dental replica models reconstructed by different rapid prototyping techniques	Hazeveld A.; Huddleston Slater J.J.R.; Ren Y.	2014	245	22.27	Digital dentistry	Comparative study	American Journal of Orthodontics and Dentofacial Orthopedics	Netherlands
48	The development of an index of orthodontic treatment priority	Brook P.H.; Shaw W.C.	1989	798	22.17	Orthodontic treatment priority	Methodological study	European Journal of Orthodontics	United Kingdom
49	Orthodontic extrusion of Ellis Class VIII fracture of maxillary lateral incisor – The sling shot method	Felicita A.S.	2018	155	22.14	Orthodontic treatment duration	Case report	Saudi Dental Journal	India
50	Scope and performance of artificial intelligence technology in orthodontic diagnosis, treatment planning, and clinical decision-making - A systematic review	Khanagar S.B.; Al-Ehaideb A.; Vishwanathaiah S.; Maganur P.C.; Patil S.; Naik S.; Baeshen H.A.; Sarode S.S.	2021	87	21.75	Artificial intelligence	Systematic review	Journal of Dental Sciences	Saudi Arabia
51	Biomechanics of clear aligners: hidden truths & first principles	Upadhyay M.; Arqub S.A.	2022	65	21,67	Aligners	Narrative literature review	Journal of the World Federation of Orthodontists	USA
52	Prevalence of white spot lesions during orthodontic treatment with fixed appliances	Tufekci E.; Dixon J.S.; Gunsolley J.C.; Lindauer S.J.	2011	300	21,43	White spot lesions	Prospective study	Angle Orthodontist	USA
53	Role of osteopontin in bone remodeling and orthodontic tooth movement: a review	Singh A.; Gill G.; Kaur H.; Amhmed M.; Jakhu H.	2018	150	21.43	Tooth movement	Narrative literature review	Progress in Orthodontics	Canada
54	The tissue, cellular, and molecular regulation of orthodontic tooth movement: 100 Years after Carl Sandstedt	Meikle M.C.	2006	397	20.89	Tooth movement	Narrative literature review	European Journal of Orthodontics	New Zealand
55	Clinical recommendations regarding use of cone beam computed tomography in orthodontic treatment. Position statement by the American Academy of Oral and Maxillofacial Radiology	Scarfe W.C.	2013	249	20.75	Cone-beam computed tomography	Retrospective study	Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology	USA
56	Efficiency, effectiveness and treatment stability of clear aligners: A systematic review and meta-analysis	Zheng M.; Liu R.; Ni Z.; Yu Z.	2017	165	20.63	Aligners	Expert consensus document	Orthodontics and Craniofacial Research	China

57	The efficacy of mesenchymal stem cells to regenerate and repair dental structures	Shi S.; Miura M.; Seo B.M.; Robey P.G.; Bartold P.M.; Gronthos S.	2005	412	20.6	Periodontal ligament	Experimental study	Orthodontics and Craniofacial Research	Australia
58	Prevalence of malocclusion and orthodontic treatment need in the United States: estimates from the NHANES III survey.	Proffit W.R.; Fields Jr. H.W.; Moray L.J.	1998	555	20,56	Prevalence of malocclusion	Cross-sectional study	The International Journal of Adult Orthodontics and Orthognathic Surgery	USA
59	Clinical effectiveness of clear aligner treatment compared to fixed appliance treatment: an overview of systematic reviews	Yassir Y.A.; Nabbat S.A.; McIntyre G.T.; Bearn D.R.	2022	61	20.33	Aligners	Systematic review	Clinical Oral Investigations	Iraq
60	Angular photogrammetric analysis of the soft-tissue facial profile of Indian adults	Pandian K.; Krishnan S.; Kumar S.	2018	141	20,14	Craniofacial morphology	Cross-sectional study	Indian Journal of Dental Research	India
61	Effect of micro-osteoperforations on the rate of tooth movement	Alikhani M.; Raptis M.; Zoldan B.; Sangsuwon C.; Lee Y.B.; Alyami B.; Corpodian C.; Barrera L.M.; Alansari S.; Khoo E.; Teixeira C.	2013	241	20,08	Tooth movement	Case series	American Journal of Orthodontics and Dentofacial Orthopedics	USA
62	A Prospective Study of the Risk Factors Associated with Failure of Mini-implants Used for Orthodontic Anchorage	Cheng S.J.; Tseng I.Y.; Lee J.J.; Kok S.-H.	2004	421	20,05	Anchorage	Prospective study	International Journal of Oral and Maxillofacial Implants	Taiwan
63	Mechanical and geometric properties of thermoformed and 3D printed clear dental aligners	Jindal P.; Juneja M.; Siena F.L.; Bajaj D.; Breedon P.	2019	120	20	Aligners	Experimental study	American Journal of Orthodontics and Dentofacial Orthopedics	United Kingdom
64	Three-Dimensional Treatment Planning of Orthognathic Surgery in the Era of Virtual Imaging	Swennen G.R.J.; Mollemans W.; Schutyser F.	2009	318	19,88	Digital dentistry	Methodological study	Journal of Oral and Maxillofacial Surgery	Belgium
65	Treatment outcome with orthodontic aligners and fixed appliances: A systematic review with meta-analyses	Papageorgiou S.N.; Koletsi D.; Iliadi A.; Peltomaki T.; Eliades T.	2020	99	19,8	Aligners	Systematic review	European Journal of Orthodontics	Switzerland
66	Deep learning for cephalometric landmark detection: systematic review and meta-analysis	Schwendicke F.; Chaurasia A.; Arsiwala L.; Lee J.H.; Elhennawy K.; Jost-Brinkmann P.G.; Demarco F.; Krois J.	2021	79	19,75	Artificial intelligence	Systematic review	Clinical Oral Investigations	Germany

67	Accuracy of clear aligners: A retrospective study of patients who needed refinement	Charalampakis O.; Iliadi A.; Ueno H.; Oliver D.R.; Kim K.B.	2018	135	19,29	Aligners	Retrospective study	American Journal of Orthodontics and Dentofacial Orthopedics	USA
68	Accuracy of virtual planning in orthognathic surgery: a systematic review	Alkhayer A.; Piffkó J.; Lippold C.; Segatto E.	2020	96	19,2	Digital dentistry	Systematic review	Head and Face Medicine	Germany
69	A systematic review of the accuracy and efficiency of dental movements with invisalign®	Galan-Lopez L.; Barcia-Gonzalez J.; Plasencia E.	2019	115	19,17	Aligners	Systematic review	Korean Journal of Orthodontics	Spain
70	"Safe zones": A guide for miniscrew positioning in the maxillary and mandibular arch	Poggio P.M.; Incorvati C.; Velo S.; Carano A.	2006	363	19,11	Anchorage	Retrospective study	Angle Orthodontist	Italy
71	Isolation and characterization of multipotent human periodontal ligament stem cells	Gay I.C.; Chen S.; MacDougall M.	2007	343	19,06	Periodontal ligament	Methodological study	Orthodontics and Craniofacial Research	USA
72	Midpalatal suture maturation: Classification method for individual assessment before rapid maxillary expansion	Angelieri F.; Cevidanes L.H.S.; Franchi L.; Gonçalves J.R.; Benavides E.; McNamara Jr. J.A.	2013	228	19	Rapid maxillary expansion	Retrospective study	American Journal of Orthodontics and Dentofacial Orthopedics	Brazil
73	Quality of life assessment in patients with dentofacial deformity undergoing orthognathic surgery - A systematic review	Soh C.L.; Narayanan V.	2013	228	19	Orthognathic surgery	Systematic review	International Journal of Oral and Maxillofacial Surgery	India
74	3D printing in orthognathic surgery – A literature review	Lin H.H.; Lonic D.; Lo L.J.	2018	133	19	Digital dentistry	Literature review	Journal of the Formosan Medical Association	Germany
75	Applications of artificial intelligence and machine learning in orthodontics: a scoping review	Bichu Y.M.; Hansa I.; Bichu A.Y.; Premjani P.; Flores-Mir C.; Vaid N.R.	2021	76	19	Artificial intelligence	Scoping review	Progress in Orthodontics	South Africa
76	Is inflammation a friend or foe for orthodontic treatment?: Inflammation in orthodontically induced inflammatory root resorption and accelerating tooth movement	Yamaguchi M.; Fukasawa S.	2021	76	19	Root resorption	Narrative literature review	International Journal of Molecular Sciences	Japan

77	Impacted Central Incisors in the Upper Jaw in an Adolescent Patient: Orthodontic-Surgical Treatment—A Case Report	Malcangi G.; Inchingolo A.D.; Patano A.; Coloccia G.; Ceci S.; Garibaldi M.; Inchingolo A.M.; Piras F.; Cardarelli F.; Settanni V.; Rapone B.; Corriero A.; Mancini A.; Corsalini M.; Nucci L.; Bordea I.R.; Lorusso F.; Scarano A.; Giovanniello D.; Dipalma G.; Posa V.M.; Di Venere D.; Inchingolo F.	2022	57	19	Impacted tooth	Case report	Applied Sciences (Switzerland)	Italy
78	Study on the role of nano antibacterial materials in orthodontics (a review)	Budi H.S.; Jameel M.F.; Widjaja G.; Alasady M.S.; Mahmudiono T.; Mustafa Y.F.; Fardeeva I.; Kuznetsova M.	2024	19	19	Antibacterial materials in orthodontics	Systematic literature review	Brazilian Journal of Biology	Iraq
79	Orthodontic measurements on digital study models compared with plaster models: A systematic review	Fleming P.S.; Marinho V.; Johal A.	2011	265	18,93	Digital models	Systematic review	Orthodontics and Craniofacial Research	United Kingdom
80	Clinical use of miniscrew implants as orthodontic anchorage: Success rates and postoperative discomfort	Kuroda S.; Sugawara Y.; Deguchi T.; Kyung H.M.; Takano-Yamamoto T.	2007	339	18,83	Anchorage	Retrospective study	American Journal of Orthodontics and Dentofacial Orthopedics	Japan
81	Association of orthodontic force system and root resorption: A systematic review	Roscoe M.G.; Meira J.B.C.; Cattaneo P.M.	2015	187	18,7	Root resorption	Systematic review	American Journal of Orthodontics and Dentofacial Orthopedics	Denmark
82	Tooth-borne vs bone-borne rapid maxillary expanders in late adolescence	Lin L.; Ahn H.W.; Kim S.J.; Moon S.C.; Kim S.H.; Nelson G.	2015	187	18,7	Rapid maxillary expansion	Clinical trial	Angle Orthodontist	South Korea
83	3D planning in orthognathic surgery: CAD/CAM surgical splints and prediction of the soft and hard tissues results - Our experience in 16 cases	Aboul-Hosn Centenero S.; Hernández-Alfaro F.	2012	243	18,7	Digital dentistry	Clinical trial	Journal of Cranio-Maxillofacial Surgery	Spain
84	Elastodontic Therapy of Hyperdivergent Class II Patients Using AMCOP® Devices: A Retrospective Study	Inchingolo A.D.; Ceci S.; Patano A.; Inchingolo A.M.; Montenegro V.; Di Pede C.; Malcangi G.; Marinelli G.; Coloccia G.; Garibaldi M.; Kruti Z.; Palmieri G.; De Leonardis N.; Rapone B.; Mancini A.; Semjonova A.; Nucci L.; Bordea I.R.; Scarano A.; Lorusso F.; Ferrara E.; Farronato M.; Tartaglia G.M.; Di Venere D.; Cardarelli F.; Inchingolo F.; Dipalma G.	2022	56	18,67	Class II malocclusion	Retrospective study	Applied Sciences (Switzerland)	Romania

85	Rapid orthodontics with alveolar reshaping: Two case reports of decrowding	Wilcko W.M.	2001	444	18,5	Alveolar bone	Case series	International Journal of Periodontics and Restorative Dentistry	USA
86	Rapid maxillary expansion for pediatric obstructive sleep apnea: A systematic review and meta-analysis	Camacho M.; Chang E.T.; Song S.A.; Abdullatif J.; Zaghi S.; Pirelli P.; Certal V.; Guilleminault C.	2017	148	18,5	Rapid maxillary expansion	Systematic review	Laryngoscope	USA
87	Incidence of white spot formation after bonding and banding	Gorelick L.; Geiger A.M.; Gwinnett A.J.	1982	795	18,49	White spot lesions	Retrospective study	American Journal of Orthodontics and Dentofacial Orthopedics	USA
88	Retention procedures for stabilising tooth position after treatment with orthodontic braces	Littlewood S.J.; Millett D.T.; Doubleday B.; Bearn D.R.; Worthington H.V.	2016	166	18,44	Orthodontic bonding techniques	Systematic review	Cochrane Database of Systematic Reviews	United Kingdom
89	Failure rates and associated risk factors of orthodontic miniscrew implants: A meta-analysis	Papageorgiou S.N.; Zogakis I.P.; Papadopoulos M.A.	2012	239	18,39	Anchorage	Systematic review	American Journal of Orthodontics and Dentofacial Orthopedics	Greece
90	Miniscrews as orthodontic anchorage: a preliminary report.	Costa A.; Raffainl M.; Melsen B.	1998	495	18,33	Anchorage	Narrative literature review	The International Journal of Adult Orthodontics and Orthognathic Surgery	Italy
91	Multiclass CBCT Image Segmentation for Orthodontics with Deep Learning	Wang H.; Minnema J.; Batenburg K.J.; Forouzanfar T.; Hu F.J.; Wu G.	2021	73	18,25	Artificial intelligence	Prospective study	Journal of Dental Research	Netherlands
92	Comparison of pain perception, anxiety, and impacts on oral health-related quality of life between patients receiving clear aligners and fixed appliances during the initial stage of orthodontic treatment	Gao M.; Yan X.; Zhao R.; Shan Y.; Chen Y.; Jian F.; Long H.; Lai W.	2021	73	18,25	Aligners	Prospective study	European Journal of Orthodontics	China
93	Biomimetic Effect of Nano-Hydroxyapatite in Demineralized Enamel before Orthodontic Bonding of Brackets and Attachments: Visual, Adhesion Strength, and Hardness in in Vitro Tests	Scribante A.; Dermenaki Farahani M.R.; Marino G.; Matera C.; Rodriguez Y Baena R.; Lanteri V.; Butera A.	2020	91	18,2	Orthodontic bonding techniques	Laboratory study	BioMed Research International	Italy

94	Automatic classification and segmentation of teeth on 3D dental model using hierarchical deep learning networks	Tian S.; Dai N.; Zhang B.; Yuan F.; Yu Q.; Cheng X.	2019	109	18,17	Artificial intelligence	Cross-sectional study	IEEE Access	China
95	Prevalence of white spot lesion formation during orthodontic treatment	Julien K.C.; Buschang P.H.; Campbell P.M.	2013	217	18,08	White spot lesions	Retrospective study	Angle Orthodontist	USA
96	Predictability of orthodontic tooth movement with aligners: effect of treatment design	Castroflorio T.; Sedran A.; Parrini S.; Garino F.; Reverdito M.; Capuozzo R.; Mutinelli S.; Grybauskas S.; Vaitiekūnas M.; Deregibus A.	2023	36	18	Aligners	Longitudinal study	Progress in Orthodontics	Italy
97	Perceptions of dental professionals and laypersons to altered dental esthetics: Asymmetric and symmetric situations	Kokich V.O.; Kokich V.G.; Kiyak H.A.	2006	341	17,95	Aesthetic	Cross-sectional study	American Journal of Orthodontics and Dentofacial Orthopedics	USA
98	Microimplant-assisted rapid palatal expansion appliance to orthopedically correct transverse maxillary deficiency in an adult	Carlson C.; Sung J.; McComb R.W.; MacHado A.W.; Moon W.	2016	158	17,56	Rapid maxillary expansion	Case report	American Journal of Orthodontics and Dentofacial Orthopedics	USA
99	Web-based fully automated cephalometric analysis by deep learning	Kim H.; Shim E.; Park J.; Kim Y.J.; Lee U.; Kim Y.	2020	87	17,4	Artificial intelligence	Methodological study	Computer Methods and Programs in Biomedicine	South Korea
100	The hierarchy of stability and predictability in orthognathic surgery with rigid fixation: An update and extension	Proffit W.R.; Turvey T.A.; Phillips C.	2007	312	17,33	Orthognathic surgery	Retrospective study	Head and Face Medicine	USA

Table 2. The most contributing countries with more than two publications

Country or Region	Number of Articles	Number of Citations
USA	32	10726
Italy	14	3674
India	12	2352
South Korea	9	1746
Germany	8	1366
China	8	908
United Kingdom	6	2687
Japan	5	1951
Brazil	5	1138
Canada	5	597
Saudi Arabia	5	645
Canada	5	597
Australia	4	809
Greece	4	657
Belgium	3	1120
Taiwan	3	871
United Arab Emirates	3	345

Table 3. Institutions contributing the most with more than two publications

Source title	Number of Articles	Number of Citations
Saveetha University	7	1419
University of Michigan	6	2118
University of Florence	4	1732
Seoul National University	4	550
University of North Carolina	3	1111
Yonsei University	3	415
University of Alberta	3	372

Table 4. Authors contributing the most with more than two publications

Authors	Number of Articles	Number of Citations
Franchi L.	4	1732
McNamara Jr. J.A.	3	1573
Flores-Mir C.	3	372
Kim H.	3	362

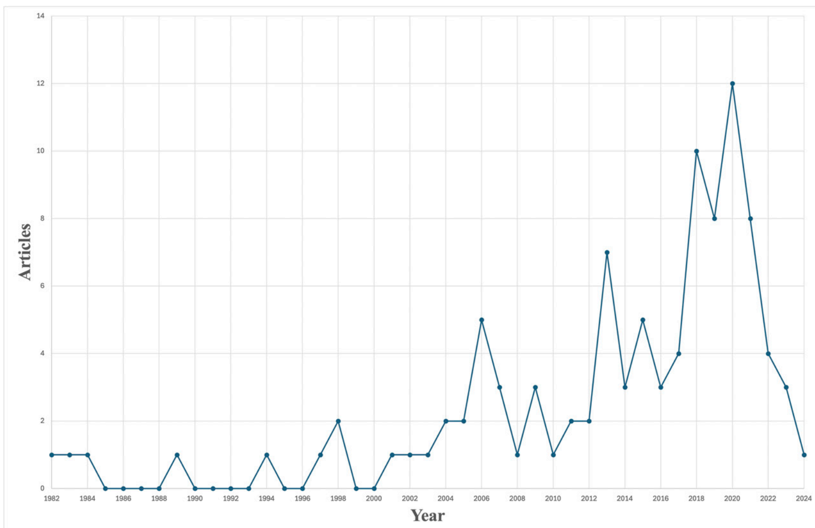

Figure 1. Distribution of the top 100 articles ranked by annual citation rate by year

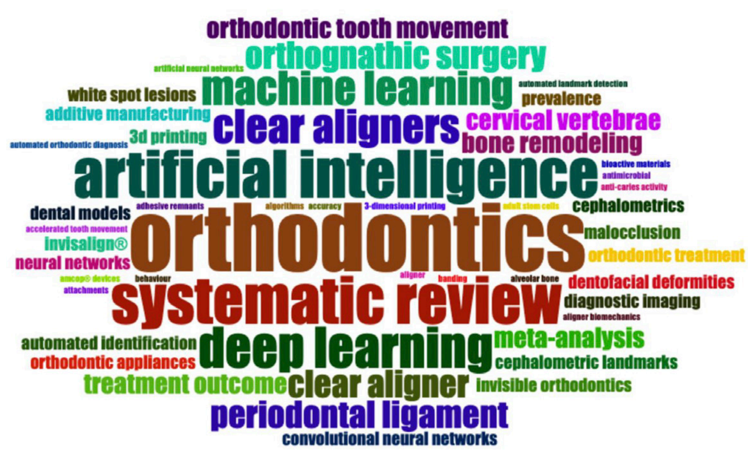

Figure 2. Frequency analysis of author's keywords

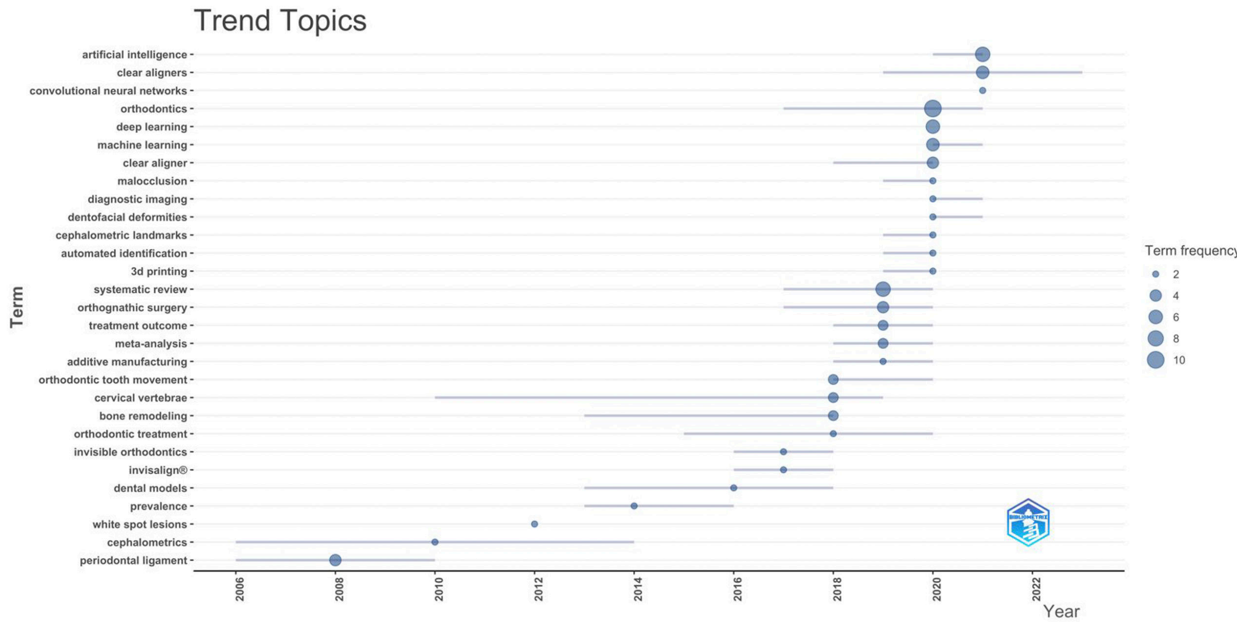

Figure 3. Annual distribution of trending authors' keywords

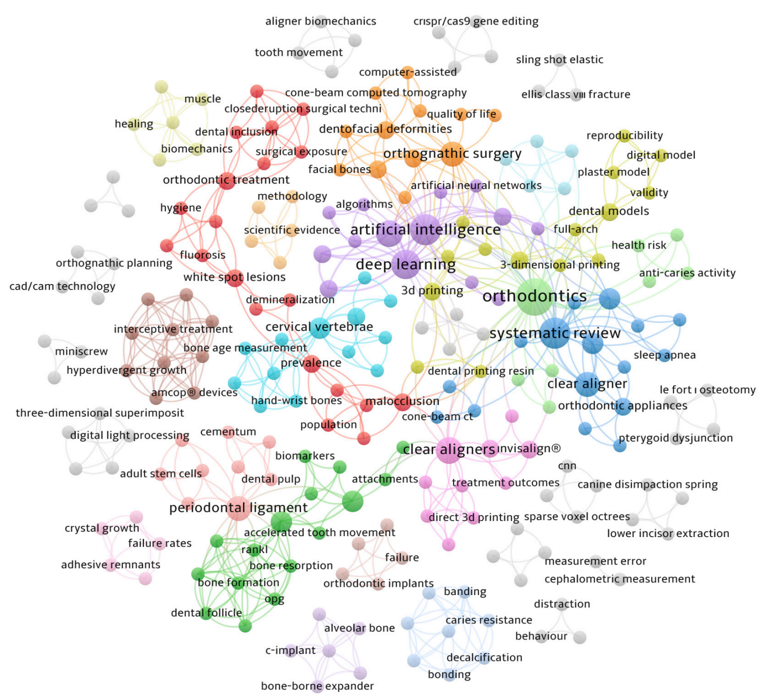

Figure 4. Network structure of author's keywords

most influential articles in orthodontics and orthognathic surgery based on their annual citation rates.

Web of Science and Scopus have traditionally been the two most commonly used databases for bibliometric analyses.[25] These databases have been extensively compared through direct coverage comparisons[26,27] as well as citation-based comparative studies.[28] Numerous comparative analyses have demonstrated that while Scopus offers broader journal coverage, Web of Science is more selective regarding the journals' indexes. Specifically, approximately 99.11%

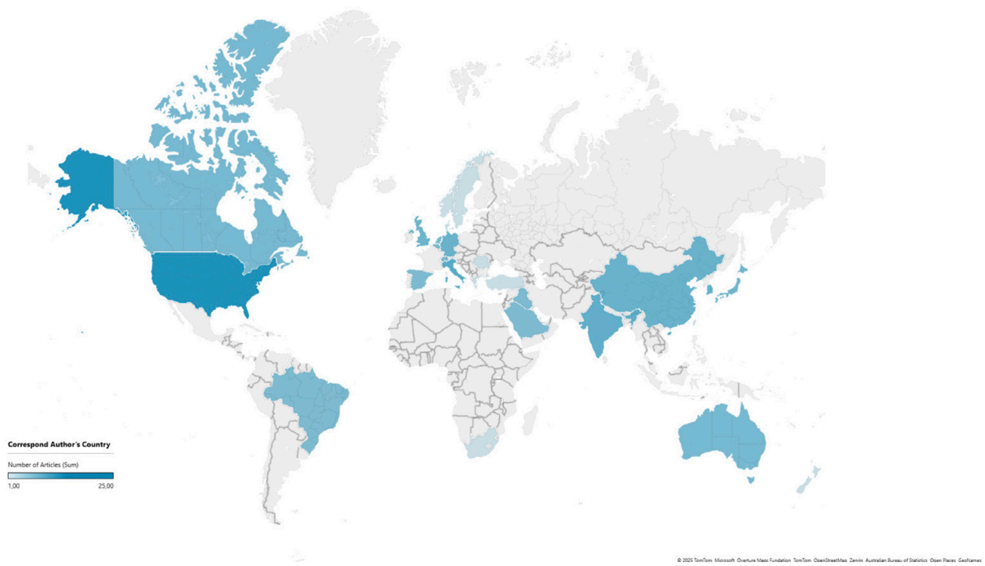

Figure 5. Geographical distribution of contributing countries.

of journals indexed in Web of Science are also included in Scopus, whereas only 33.93% of Scopus-indexed journals appear in Web of Science.[25] Given that our study focuses specifically on identifying the top 100 influential publications, the Scopus database was preferred due to its broader coverage.

Upon examination of the articles ranked by annual citation rate, it was determined that the selected articles were published between 1982 and 2024, with the highest density of publications observed in 2020 (12 articles). The article with the highest annual citation rate (45.33 citations per year) was published in 2019.[29] The majority of the top 100 articles appeared in recent years, notably in 2018 (10 articles), 2019 (8 articles), 2020 (12 articles), and 2021 (8 articles). While bibliometric studies utilizing total citation counts typically concentrate article distributions between 2000 and 2010,[16,30] our study highlights newer and more contemporary research by employing the average annual citation rate as the ranking criterion.

The publication with the highest total citation count and the publication with the highest annual citation rate[29] were found to be different. The article with the highest total citation count was older, whereas the highest annual citation rate belonged to a more recent publication from 2019. From another perspective, although the publication with the highest annual citation rate[29] accumulated a total of 272 citations, the publication with the lowest annual citation rate[31] within the top 100 had a higher total citation count (312 citations). This finding highlights that relying solely on total citation counts can be misleading, underscoring the significance of annual citation rate as an essential metric. Therefore, evaluating studies based on the annual citation rate provides a valuable complementary approach, allowing recent but impactful publications to achieve appropriate recognition.

The American Journal of Orthodontics and Dentofacial Orthopedics (AJODO) and The Angle Orthodontist are the two journals that have contributed most significantly to this study, establishing themselves as leaders in orthodontic scientific research. The rigorous research published in these journals has consistently positioned them at the forefront of the field, with their articles frequently cited, thereby reinforcing their impact within the scientific community. Our analysis further supports previous bibliometric studies indicating that high-impact publications tend to be concentrated in a limited number of journals.[16,32] In addition, the AJODO and The Angle Orthodontist particularly stand out as prominent platforms for influential research. This evaluation, based on annual citation rates, further emphasizes the central role these journals play in shaping research trends and scholarly discourse (Table 7).

The United States ranks first among contributing countries, with 32 articles accumulating a total of 10,726 citations. The leading role of the United States in orthodontics and orthognathic surgery literature is evident both in terms of the number of publications and citations received,

Table 5. Thematic fields of the top 100 most cited articles ranked by annual citation rate

Thematic Field	Number of Articles
Aligners	19
Artificial intelligence	11
Digital dentistry	9
Anchorage	8
Tooth movement	7
Cervical vertebral maturation	4
Prevalence of malocclusion	4
Rapid maxillary expansion	4
Cone-beam computed tomography	3
Alveolar bone	3
Root resorption	3
White spot lesions	3
Digital models	2
Impacted tooth	2
Periodontal ligament	2
Orthognathic surgery	2
Orthodontic bonding techniques	2
Airway space	1
Importance of sample size	1
Error in cephalometric measurement	1
Class II malocclusion	1
Surgical technique	1
Obstructive sleep apnea	1
Enamel conditioning	1
Orthodontic treatment priority	1
Orthodontic treatment duration	1
Craniofacial morphology	1
Antibacterial materials in orthodontics	1
Aesthetic	1

Table 6. Study types of the top 100 most cited articles ranked by annual citation rate

Type of Study	Number of Articles
Systematic review	23
Narrative literature review	18
Prospective study	14
Retrospective study	10
Methodological study	7
Experimental study	5
Case report	5
Longitudinal study	4
Cross-sectional study	4
Clinical trial	3
Case series	2
Expert consensus document	2
Scoping review	1
Laboratory study	1
Comparative study	1

aligning closely with findings from previous bibliometric studies.[15,32,33] The dominance of the U.S. in orthodontics and orthognathic surgery is consistent with earlier research in this field. Additionally, the analysis based on annual citation rates has shown that the United States has conducted the highest number of studies focusing on aligners, whereas South Korea has emerged as a leader in research related to artificial intelligence.

Among the contributing institutions, Saveetha University emerges prominently as the leading institution, contributing 7 articles that have collectively received 1,419 citations. The notable contribution of Saveetha University underscores its significant role in orthodontic and orthognathic surgery research.[34] The recent prominence of institutions like Saveetha University highlights changing global academic dynamics and increasing regional diversity within the orthodontic and orthognathic surgery literature. The contributing institutions identified in this study span Europe, Asia, and North America, underscoring the importance of global academic collaboration and the growing influence of research centers across different geographical regions.

Among authors, Franchi L. stands out as the top contributor, with 4 articles and 1,732 citations, making him the most impactful author. Previous research has identified Franchi L. as one of the most prolific and frequently cited authors, particularly in the fields of rapid maxillary expansion (RME) and maxillary protraction.[35,36] The known effectiveness of maxillary protraction and RME in individuals with higher growth potential, coupled with the direct influence of treatment timing on outcomes,[37] may explain the high citation rate of Franchi's studies observed in our analysis. Furthermore, among the contributing authors, McNamara Jr.J.A. was notable for achieving a high citation count (1,573 citations) despite publishing fewer articles, reinforcing that scientific impact depends not only on publication quantity but also on the quality and originality of the research. The identified contributing authors thus include both established and highly influential researchers whose work

Table 7. The most contributing journals with more than two publications

Source	Documents	Citations	Total Link Strength
American Journal of Orthodontics and Dentofacial Orthopedics	22	8569	43
Angle Orthodontist	11	3879	27
European Journal of Orthodontics	5	1606	12
Orthodontics and Craniofacial Research	5	1346	18
Progress in Orthodontics	5	658	15
International Journal of Oral and Maxillofacial Surgery	3	1063	4
Journal of Dental Research	3	617	3
Applied Sciences (Switzerland)	2	116	0
BMC Oral Health	2	394	14
Clinical Oral Investigations	2	142	12
Dental Press Journal of Orthodontics	2	689	2
Head and Face Medicine	2	417	4
Journal of Oral and Maxillofacial Surgery	2	637	3
Journal of Orofacial Orthopedics	2	297	5
Saudi Dental Journal	2	348	0
The International Journal of Adult Orthodontics	2	1052	4

significantly shapes the orthodontic literature.

In our study, articles were ranked based on their annual citation rates, highlighting prominent thematic areas such as clear aligners, artificial intelligence, and digital dentistry. These results underscore the rapidly growing importance of digital technologies in orthodontic and orthognathic surgery literature, as well as their increasingly widespread adoption in clinical practice in recent years.[38-40] Aligners emerged as the most studied topic, represented by 19 articles, followed by artificial intelligence with 11 articles, and digital dentistry with 9 articles.

In recent years, there has been a notable increase in research activity related to clear aligner treatments, corresponding with a growing volume of publications on this topic.[39] In previous bibliometric studies evaluating the top 100 articles based on total citation count, only one publication on clear aligners and two publications on digital dentistry were included.[16] This discrepancy occurs because older studies typically accumulate more citations over time, overshadowing more recent and influential research. In contrast, our analysis based on annual citation rates placed aligners and digital dentistry prominently among the top positions, thereby highlighting contemporary and emerging topics that might otherwise be overlooked.

The most frequently encountered study types were systematic reviews (23 articles) and narrative literature reviews (18 articles), indicating that comprehensive reviews and studies systematically summarizing existing literature attract significant attention within the orthodontic and orthognathic surgery literature.

When examining studies based on total citation counts,[16] differences in thematic areas were observed. One notable distinction is that rankings based on total citation counts often highlight more established orthodontic topics, such as anchorage and root resorption, because these subjects have been studied extensively over longer periods and thus accumulate more citations. In contrast, rankings based on annual citation rates place greater emphasis on innovative and technological areas, such as aligners, artificial intelligence, and digital dentistry. This suggests that these contemporary topics have rapidly attracted attention and achieved high citation rates within shorter periods. While evaluations based on total citation counts generally highlight classical, well-established areas, our study, utilizing annual citation rates, better reflects current trends in orthodontics literature and emphasizes the increasing importance of innovative treatment methods. Although a large number of articles were considered using the Scopus database, one of the potential limitations of our study is the possibility of omitting certain relevant publications indexed in other databases, such as Web of Science (WoS), Dimensions, PubMed, Google Scholar, and the Cochrane Library.

CONCLUSIONS

This study represents the first bibliometric analysis to identify the most influential articles in orthodontics and orthognathic surgery based on annual citation rates. Unlike traditional approaches that rely solely on total citation counts, utilizing the annual citation rate provides a more dynamic and contemporary assessment of an article's scientific impact over time. The findings reveal that modern treatment methodologies, digital technologies, artificial intelligence, and clear aligners are rapidly emerging trends in the current literature. Additionally, the prominent roles played by American journals and institutions underscore the geographic concentration of scientific contributions, particularly from the USA. These results offer valuable insights into the growing significance of innovative approaches in orthodontics and orthognathic surgery literature, highlighting potential directions for future research. By employing the annual citation rate, our study provides a more balanced and timely evaluation compared to traditional methods, allowing recent, influential studies to receive appropriate recognition and visibility in the field.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS STATEMENT

Ethical approval was not required, as the research did not involve clinical studies or patient data.

FINANCIAL SUPPORT

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CLINICAL DENTISTRY AND RESEARCH 2025; 49(1): 57-63 Case Report

MANAGEMENT OF A HORIZONTAL ROOT FRACTURE IN AN IMMATURE MAXILLARY CENTRAL INCISOR: A CASE REPORT

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ABSTRACT

Root fractures constitute 0.5-7% of all dental traumas. It is important to understand the etiology, diagnosis, management and prognosis of root fractures. There are different treatment options ranging from conservative treatment methods involving observation and follow-ups to complex surgical procedures. It is possible to preserve tooth structure and have a long-term good prognosis for root fractures with immediate, appropriate treatment and follow-up procedures. In this case report, the management and favourable healing of a horizontal root fracture located in the middle third of an immature permanent maxillary central incisor is presented. Throughout the 36-month follow-up period, the tooth was successfully preserved both aesthetically and functionally.

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INTRODUCTION

Root fractures involve the pulp, dentin, cementum and comprise 0.5-7% of all dental traumas.[1] This type of injury most commonly occurs during the permanent dentition between the ages of 11 and 20, and maxillary anterior teeth are the most affected teeth due to a frontal impact.[2,3,4] Root fractures may occur in any direction as vertical fractures, horizontal fractures (transverse) or oblique fractures (as apical toward the palatal surface or apical toward the labial surface). The shearing stress zones resulting from a frontal impact on the tooth usually determine the fracture line.[5] Horizontal root fractures are classified according to the location of the root fracture, the fracture may be located in the cervical, middle or apical third of the root.[6] The patient's age, level of root development, pulpal status, localization and direction of the fracture line, the degree of the mobility, displacement of the coronal fragment and timely intervention are factors affecting the prognosis.[4,6,7]According to the current guidelines of the International Association of Dental Traumatology (IADT), emergency management of horizontal root fractures depends on repositioning (if the coronal fragment is displaced) and stabilization of the mobile coronal segment with a passive and flexible splint for 4 weeks. If the fracture line is in the cervical third of the root, splinting may be necessary for up to 4 months. Regular clinical and radiological follow-ups are recommended for at least 5 years. When there are clinical and radiographical symptoms of pulp infection or necrosis, endodontic treatment of only the coronal fragment may be required, as in most cases the apical fragment maintains its vitality.[8] Root fractures with appropriate diagnosis and treatment protocols in the literature have been reported to have a success rate of up to 80% in children.[9]

In this case report, the management and 36-month follow-up period of an immature maxillary left central incisor with a horizontal fracture in the middle third of the root is presented.

CASE REPORT

A healthy, 8-year-old girl was referred to our Pediatric Dentistry Clinic with the complaint of her traumatized maxillary anterior teeth due to a traffic accident a week ago. No signs of injury were observed in the perioral tissues of the patient. The clinical examination revealed subluxation injury on the immature maxillary right central incisor and the maxillary left central incisor showed Grade 2 mobility without a displacement. The radiographic examination revealed a horizontal fracture in the middle third of the root in maxillary left central incisor (Figure 1). The treatment plan and possible outcomes were explained to the patient and her family, treatment was initiated after written informed consent was given by the patient's parents. The treatment chosen was in accordance with the current recommendations of the IADT guidelines.[8] The teeth were stabilized with a bonded passive and flexible splint (Figure 2), the traumatic anterior deep-bite was slightly eliminated by placing compomer restorative material on the mandibular primary molars, oral hygiene instructions were given, soft diet was recommended and the patient was scheduled for follow-up visits.

After 4 weeks, the splint was removed, since the maxillary left central incisor still had Grade 1 mobility, compomers placed to eliminate traumatic anterior deep-bite on the mandibular primary molars were not removed and it was decided to monitor the mobility. Fracture line, pulpal status, and root development were followed up with regular clinical and radiographic controls (Figure 3). At the 8th month follow-up, tooth 21 had only physiological mobility, so the compomers were removed. At 36 months, maxillary central incisors were asymptomatic. In the maxillary left central incisor, radiographically there were no pathological changes, thickening of the dentinal walls of the root, completed root development and a slight root canal obliteration were observed (Figure 4). The patient and the parents continue controls without any aesthetic and functional complaints. Figure 5 demonstrates the intraoral view of the central incisors at 36-months follow-up.

DISCUSSION

This report is based on three years of clinical and radiographic review with spontaneous healing of a traumatized permanent incisor tooth with horizontal root fracture. Appropriate treatment procedures applied at the right time can help to preserve the tooth structure, leading to the long-term survival of the tooth. At the 36-month follow-up, the tooth was clinically healthy, and radiographic examination showed a successful outcome.

In young permanent teeth having incomplete root development, root fractures are less common compared to luxation injuries due to the flexibility of the alveolar socket. However, a careful, comprehensive clinical and radiographic examination is crucial for determining the presence of root

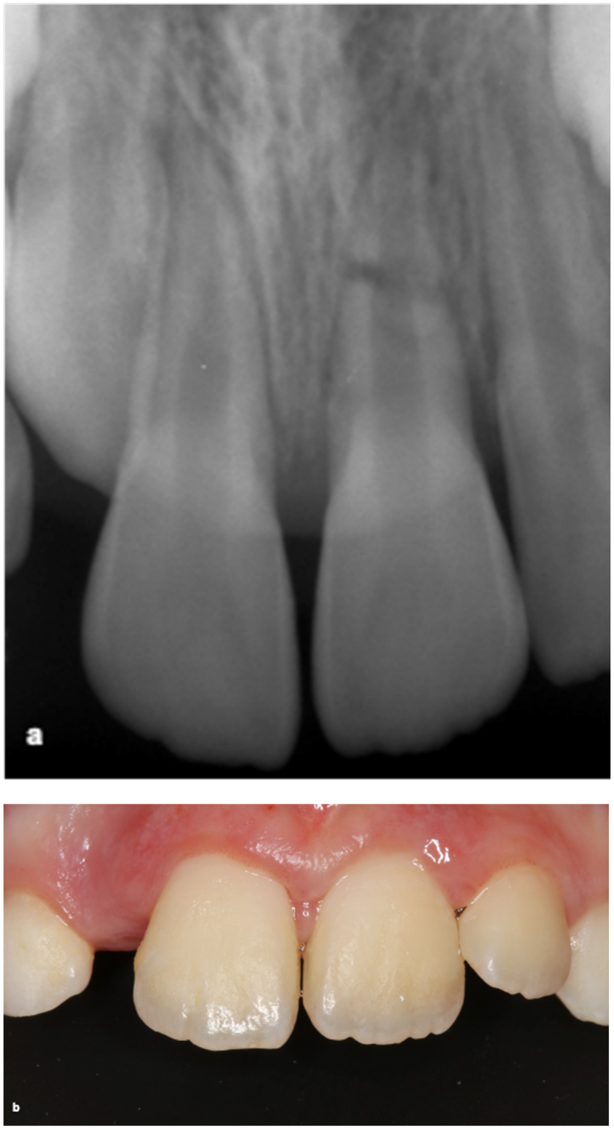

Figure 1. a) Initial intraoral periapical radiograph b) Initial intraoral view

Figure 2. Intraoral view after splint placement

fractures.[5] If there is no displacement or mobility of the coronal fragment, the root fracture cannot be detected without a proper radiographic imaging.[10] Radiographs taken from different angles are important for diagnosing root fractures.[10] IADT guidelines recommend to take a parallel periapical radiograph, two additional periapical radiographs taken from different angles, and an occlusal radiograph to detect root fractures.[11] The use of Cone Beam Computed Tomography (CBCT) is recommended when radiographs do not provide sufficient information for treatment planning.[8] Though, some root fractures may occur without any signs or symptoms during the initial clinical and radiographic examinations and may become evident at subsequent follow-up period due to the inflammatory response that will be in the fracture line, so it is important to follow-up dental traumas with regular adequate radiographic examinations specially in the early post-trauma period.

Root fractures involve different tissues of teeth and supporting tissues including the pulp, dentin, cementum and periodontal ligament. Thus, in root fractures there are complex healing patterns of these different tissues. Healing of a root fracture depends on pulp vitality and the health of the periodontium.[11] The displacement of the coronal root fragment may lead to pulp necrosis of the coronal root fragment with the reduced or severed blood supply. As all the forces during trauma have been absorbed by the fracture site, the apical root fragment is commonly not affected by the injury and the pulp in apical part of the root remains healthy and have the best prognosis.[5,12] The healing potential of fractures that occur in the apical third of the root is higher. Cvek et al.[9] reported an 80% survival rate for 534 teeth with root fractures over a period of up to 10 years. When excluding cervical fractures with a poorer long-term prognosis, this rate increased to 88%.[9] Root fractures may be accompanied by other types of injuries such as subluxation, concussion, lateral luxation, extrusion or avulsion of the coronal fragment and crown fractures. When there is a root fracture, the periodontal ligament at the fracture line and surrounding the coronal fragment is damaged. But when there is a concurrent injury, the damage of the periodontal ligament is greater. Therefore, such concurrent injuries can significantly impact the treatment management and prognosis negatively.[10,13] In this case, the absence of displacement of the coronal root fragment and the absence of any other injuries accompanying the root fracture are considered to have a positive effect on the prognosis of the root fractured tooth.

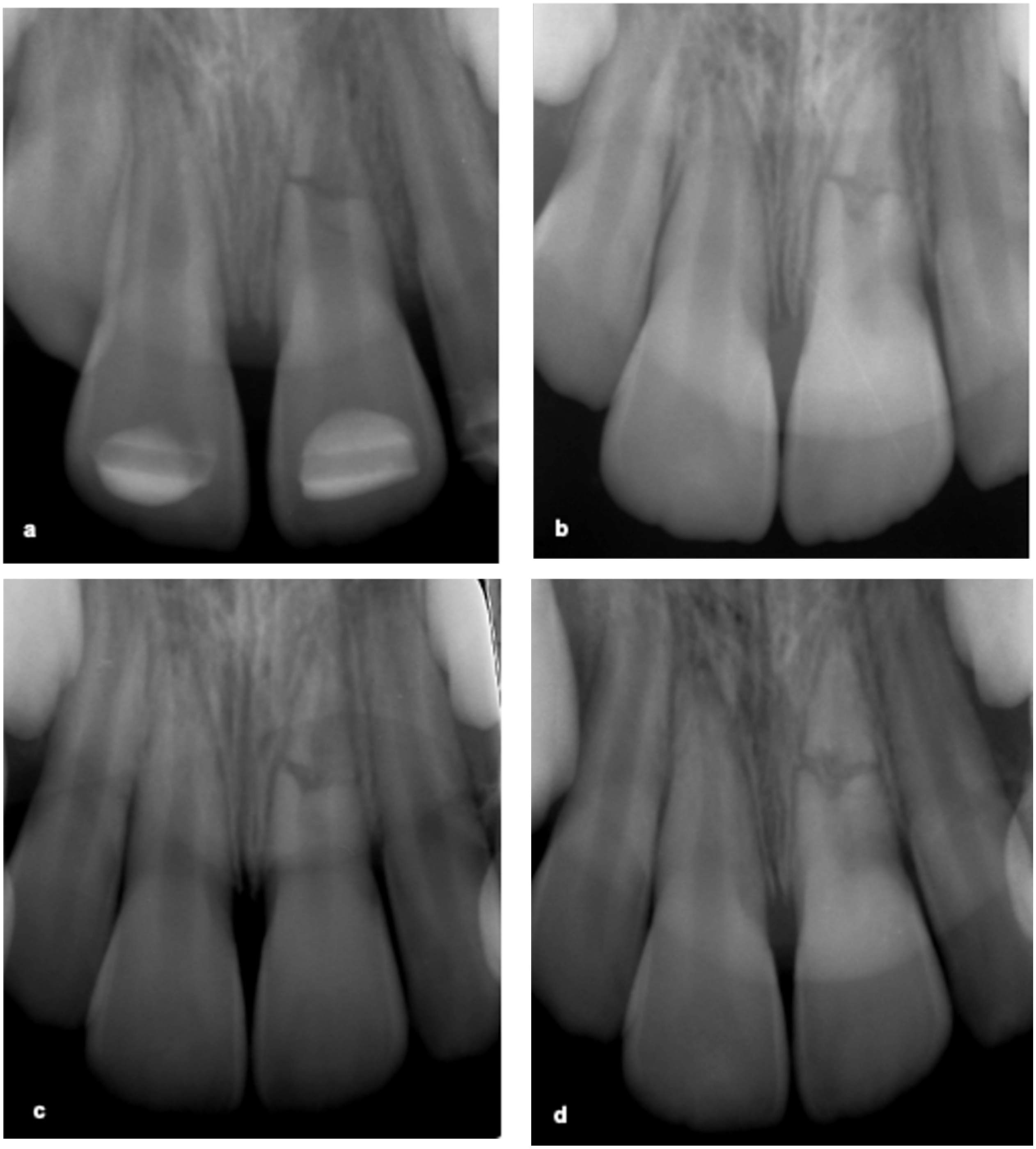

Figure 3. Radiographic follow-up at **a)** 4 weeks **b)** 3 months **c)** 6 months and **d)** 1 year

After traumatic injuries, regular follow-ups including detailed clinical and radiographic assessments as well as pulp sensitivity tests are recommended. However, the pulp's response to these tests is not reliable immediately after trauma. Deciding to start root canal treatment based only on a negative response to pulp tests after traumatic injury is not a proper approach.[8,14] Root canal treatment is indicated when there are objective signs of pulp necrosis and infection, such as pain, swelling, apical periodontitis, root resorption or periapical radiolucency on

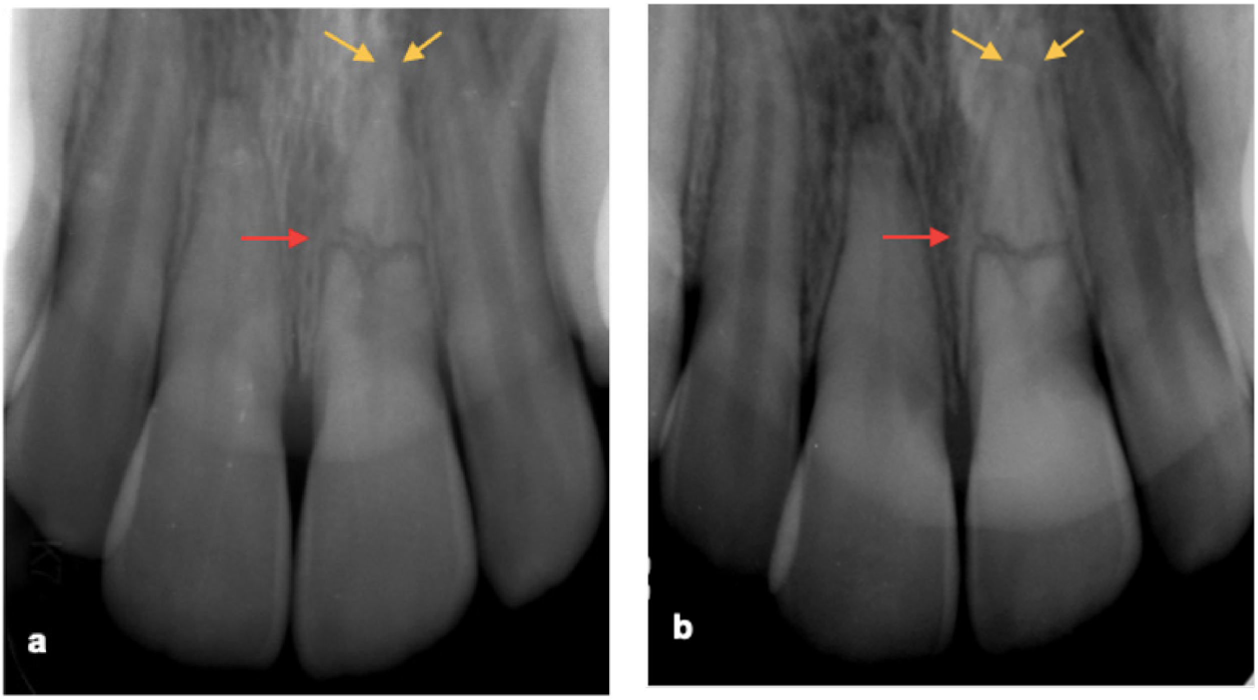

Figure 4. Radiographic follow-up at a) 2 years and b) 3 years (Yellow arrows indicate the apex closure and red arrows indicate the healing of the fracture line with calcified tissue and connective tissue.)

Figure 5. Intraoral view at 3-year follow-up

radiographs.[8,15,16] The infection of the pulp in the coronal fragment is typically caused by bacterial contamination at the time of the injury or immediately afterward and when the fracture line is supra-crestal located, dental plaque in the gingival sulcus may be the source of bacteria.[10] In most cases, only root canal treatment of the coronal fragment is sufficient because the pulp of the apical fragment is usually healthy. However, if pulpal pathologies develop in the apical fragment, root canal treatment of both the coronal and apical fragments up to the root apex or root canal treatment of the coronal part followed by apicectomy of the apical fragment is required. A 10-year survival rate of root fractures has been reported to be 87% with an appropriate treatment approach.[10] Andreasen et al[5] listed 15 studies which had a combined total of 1017 teeth, with only 274 (26.9%) teeth developing pulp necrosis.

Mobility, if present in the coronal fragment, needs to be evaluated. However, the presence of mobility in the coronal fragment alone does not indicate the presence of pulp pathology. The present case was treated in accordance with current IADT guidelines, with a flexible splint for 4 weeks. Continued mobility of the coronal fragment after splint removal is a potential situation and there is no additional recommendation other than follow-up for clinically and radiographically asymptomatic teeth with continued mobility in the guidelines.[8,9] In this case report, slight mobility persisted after the splint was removed. Considering that traumatic occlusion may adversely affect the healing process during the period of continued mobility, it was aimed to maintain stabilization by preventing traumatic occlusion during this period. The mobility of the fractured root tooth decreased over the time and the compomers placed on the deciduous molars was removed at the 8th month when physiological mobility was observed. Since no clinical or radiographic pathologic findings were observed during the 8-month period of continued mobility, the presence of pulp pathology was not considered. Additionally, both teeth responded positively to an electric pulp test and a cold test. Different healing patterns have been described for root fractures and these responses, ranging from hard tissue healing to healing with granulation tissue, have been reported in many studies.[17,18,19] Andreasen et al.[12] reported that 30% of 400 teeth with root fractures healed with hard tissue interposition, 43% with connective tissue interposition, 5% with both hard tissue and connective tissue interposition, and 22% did not heal due to pulp necrosis and infection.The type of response will depend on several factors. Healing is dependent on the response of the pulp and the periodontal ligament, which compete to repair the injury. In this case, the fracture line healing with calcified and connective tissue interposition in the immature maxillary incisor was observed. This type of healing can be observed before the growth of the alveolar bone is completed in young patients, similar to the 8-year-old young girl in this case. In this type of healing, the coronal fragment erupts normally within the alveolar downgrowth process, but the apical fragment remains in the position as at the time of the injury.

Partial or complete pulp obliteration, coronal discoloration, and root resorption may develop after root fractures.[5,20] In this horizontal root fracture, a slight root canal obliteration was observed. Pulp canal calcification observed after root fractures ranges from 69% to 73%.[21,22,23] The presence of this calcification should not be considered as a poor prognosis because the pulp can produce dentin when only it is viable, healthy. So pulp canal calcification should be considered as a normal physiological response.

The time elapsed after trauma, the status of root development, mobility and displacement of the coronal fragment, the diastasis between fragments, location of the fracture are important factors affecting the healing and prognosis of root fractures.[4,9,12] In young permanent teeth, the potential regenerative properties of the pulp positively affect the healing of root fractures.[11,12,24] Providing the best conditions for healing, repositioning and stabilization of the fractured fragment is very important. In this case, with a non-invasive conservative approach that included splinting, prevention of traumatic occlusion during the early healing period and post-traumatic care with regular follow-ups, the immature tooth with a horizontal root fracture successfully maintained both aesthetically and functionally in the mouth.

CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

ETHICS STATEMENT

Written informed consent was obtained from the parents.

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