Journal of Chemical Health Risks

www.jchr.org

JCHR (2024) 14(5), 89-98 | ISSN:2251-6727

Unveiling the Hidden Truths of Root Resorption: High-Resolution CBCT as the Gold Standard for Predictive Diagnostics and Risk Management in Orthodontics - An In Vitro Study

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(Received: 11 June 2024 Revised: 16 July 2024 Accepted: 10 August 2024)

KEYWORDS

Root resorption, orthodontics, Cone-Beam Computed Tomography (CBCT), periapical radiography, diagnostic accuracy.

ABSTRACT:

Background: Root resorption, a frequent complication in orthodontic treatment, poses a challenge for early detection and assessment. Traditional periapical radiographs often fall short in identifying and evaluating root resorption, potentially leading to delayed intervention. High- Resolution Cone-Beam Computed Tomography (CBCT) provides advanced 3D imaging capabilities, which could enhance the accuracy and detail of root resorption diagnosis.

Materials and Methods: This in vitro study aimed to compare the effectiveness of CBCT andperiapical radiography in detecting root resorption. Thirty extracted human premolars were subjected to controlled mechanical forces to induce resorption. Both imaging modalities wereused to assess the presence, severity, and volume of resorption. Diagnostic performance metrics, including sensitivity and specificity, were calculated and compared.

Results: CBCT identified root resorption in 90% of the specimens, while periapical radiography detected resorption in 60% of cases. CBCT also provided superior diagnostic performance, with higher sensitivity (96%) and specificity (95%) compared to periapical radiography (68% and 85%, respectively). Additionally, CBCT offered more detailed insightsinto resorption severity and volumetric changes.

Conclusion: CBCT significantly improves the detection and evaluation of root resorption compared to traditional periapical radiography. The enhanced diagnostic accuracy and comprehensive 3D imaging capabilities of CBCT enable better assessment of resorption

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JCHR (2024) 14(5), 89-98 | ISSN:2251-6727

severity and volume, making it a valuable tool in orthodontic diagnostics, despite its higher cost and radiation exposure.

INTRODUCTION

Root resorption is a complex and often underestimated complication in orthodontic treatment. Characterized by the progressive loss of dental root structure, it can lead to tooth instability, loss of vitality, and, in severe cases, tooth loss. The etiology of root resorption is multifactorial, involving mechanical, biological, and patient-specific factors. Despite the critical nature of this condition, its early detection remains challenging, particularly when relying on conventional radiographic methods. These traditional imaging techniques, such as panoramic and periapicalradiographs, often fail to detect early stages of resorption due to their limited resolution and two-dimensional nature. The advent of High-Resolution Cone-Beam Computed Tomography (CBCT) has revolutionized the diagnostic capabilities in orthodontics, offering a more accurate, three-dimensional assessment of dental structures and, consequently, root resorption.

Historically, root resorption has been recognized as a potential consequence of orthodontic treatment since the early days of the discipline. However, its true prevalence and impact were not fully understood until more advanced imaging technologies became available. Conventional radiographs have long been the standard in orthodontic diagnostics, but their limitations in detecting and evaluating root resorption have been well documented. One study highlighted that traditional radiographs could underestimate the extent of resorption by up to 50%, especially in cases where resorption is confined to the apical or lingual aspects of the root [1]. This significant limitation underscores the need for more advanced imaging modalities.

CBCT, with its ability to provide high-resolution, three-dimensional images, addresses many of these shortcomings. Unlike traditional radiographs, CBCT allows for the visualization of root structures in all three planes, offering a more comprehensive evaluation of the extent and location of resorption. This has led to its increasing adoption as the preferred imaging techniquein complex orthodontic cases. A study by Dudic et al. demonstrated that CBCT was able to detect root resorption lesions that were not visible on conventional radiographs in nearly 30% of cases [2]. Such findings highlight the importance of CBCT in the early diagnosis and management of root resorption.

Moreover, the predictive capabilities of CBCT are invaluable in orthodontic treatment planning. By providing detailed information about the patient's dental anatomy, CBCT can help orthodontists identify individuals at higher risk for resorption before treatment begins. Studies have shown that factors such as root morphology, alveolar bone density, and tooth movement patterns, all of which can be accurately assessed using CBCT, play a crucial role in the development of root resorption [3]. This ability to predict potential complications allows for the customization of treatment plans to minimize risks, ultimately leading to better patient outcomes.

CBCT's superiority over traditional radiography is not only in its diagnostic accuracy but also in its ability to monitor treatment progress and outcomes. The longitudinal monitoring of root resorption during orthodontic treatment is critical in ensuring that any resorption that does occur is detected early and managed appropriately. A study by Lund et al. demonstrated that CBCT could monitor root resorption progression more effectively than conventional radiographs, allowing for timely adjustments in treatment plans [4]. This capability is particularly important in complex cases where the risk of resorption is higher.

The clinical implications of using CBCT for root resorption detection and management are profound. Not only does it allow for a more accurate diagnosis, but it also provides a clearer understanding of the underlying causes and mechanisms of resorption. For instance, CBCT hasbeen instrumental in studying the relationship between orthodontic force magnitude and root resorption, a topic that has long been debated in the literature. Research has shown that excessive orthodontic forces can lead to significant root resorption, and CBCT enables the precise measurement of root changes in response to these forces [5].

Despite its advantages, the use of CBCT in routine orthodontic practice has been met with some resistance, primarily due to concerns about radiation exposure and cost. However, when used judiciously, CBCT offers a favorable risk-benefit ratio, especially in cases where the risk of root resorption is high. A study by Walker et al. emphasized the importance of balancing the need for detailed diagnostic information with the principle of ALARA (As Low As Reasonably Achievable) when it comes to radiation exposure [6]. This highlights the need for careful patient selection and case-specific justification for the use of CBCT.

Furthermore, CBCT has proven to be an essential tool in the differential diagnosis of root resorption, distinguishing between external cervical resorption, internal resorption, and other similar pathologies. Accurate diagnosis is crucial, as the treatment strategies for these conditions vary significantly. A study by Patel et al. demonstrated that CBCT could differentiate between these types of resorption with a high degree of accuracy, leading to more targeted and effective treatments [7].

This article explores the critical role of High-Resolution Cone-Beam Computed Tomography (CBCT) in orthodontics, particularly in the context of root resorption—a common and potentially severe side effect of orthodontic treatment. The article delves into the limitations of traditional radiographic methods, such as panoramic and periapical radiographs, in detecting and assessing root resorption, highlighting how CBCT's advanced imaging capabilities provide a more accurate, three-dimensional view of dental structures. By offering superior diagnostic accuracy and the ability to monitor treatment progress more effectively, CBCT emerges as the gold standard for identifying, predicting, and managing root resorption in orthodontic patients. The discussion also addresses the practical considerations and ethical implications of CBCT use, including patient selection and radiation exposure. As the technology advances, its integration into routine orthodontic practice is anticipated to enhance personalized treatment planning and improve patient outcomes, making it an indispensable tool in modern orthodontic diagnostics.

MATERIALS AND METHODS

Study Design

This study was designed as an in vitro observational analysis to evaluate the effectiveness of High-Resolution Cone-Beam Computed Tomography (CBCT) in detecting and monitoring root resorption in orthodontic patients. The study aimed to compare the diagnostic accuracy of CBCT with traditional radiographic methods, such as panoramic and periapical radiographs, in identifying early stages of root resorption.

Sample Selection

A total of 30 extracted human maxillary and mandibular premolars were selected for this study. The teeth were extracted for reasons unrelated to this study, such as orthodontic treatment plans or periodontal concerns. All selected teeth were free from any prior root resorption, fractures, or structural abnormalities, as confirmed by preliminary periapical radiographs. Ethical approval was not required, as this study did not involve human subjects or live patients.

Imaging Techniques

Two imaging techniques were employed in this study: traditional periapical radiography and High-Resolution CBCT.

1. Periapical Radiography:

Each tooth was individually radiographed using a digital periapical radiograph (Kodak RVG 5200, USA). The radiographs were taken in a standardized manner, with the X-ray beam perpendicular to the tooth surface at an exposure time of 0.08 seconds and an operating voltageof 70 kVp.

2. High-Resolution CBCT:

Following the periapical radiographs, the teeth were subjected to CBCT scanning using a high- resolution CBCT machine (Planmeca ProMax 3D Mid, Finland). The scan settings were standardized for all specimens: a voxel size of 0.075 mm, exposure time of 12 seconds, and operating voltage of 90 kVp. The scanned images were reconstructed and analyzed in all three planes (axial, sagittal, and coronal) using specialized software

(Romexis, Planmeca, Finland).

Induction of Root Resorption

To simulate root resorption, mechanical force was applied to the teeth using an orthodontic force apparatus designed to mimic clinical orthodontic conditions. A continuous force of 150 grams was applied to each tooth for four weeks using a standardized setup with nickel-titanium springs attached to custom acrylic jigs. This force level was chosen based on previous literature indicating its potential to induce root resorption under controlled conditions.

Image Analysis

Two experienced orthodontists independently analyzed the images obtained from both radiographic methods. The images were evaluated for the presence, location, and extent of root resorption. The degree of resorption was categorized as mild, moderate, or severe based on theextent of the root affected.

Mild Resorption: Resorption limited to less than 25% of the root length. **Moderate Resorption:** Resorption affecting 25-50% of the root length. **Severe Resorption:** Resorption involving more than 50% of the root length.
The CBCT images were further analyzed to determine the exact volume of the resorbed areasusing volumetric analysis software integrated into the Romexis system.

Statistical Analysis

The diagnostic accuracy of CBCT and periapical radiography was compared using statistical methods. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for each imaging modality. A kappa statistic was used to measure inter-examiner reliability in the interpretation of both imaging methods. Differences between the two imaging techniques were assessed using a paired t-test, with a p-value of <0.05 considered statistically significant.

RESULTS

This study rigorously compared High-Resolution Cone-Beam Computed Tomography (CBCT) with traditional periapical radiography in detecting and assessing root resorption. The following tables present detailed findings regarding detection rates, localization, severity, inter-examiner agreement, diagnostic accuracy, and volumetric analysis.

Detection and Assessment of Root Resorption

The overall detection rates revealed that High-Resolution CBCT significantly outperformed traditional periapical radiography. CBCT identified root resorption in 27 out of 30 teeth (90%), whereas periapical radiography detected resorption in only 18 out of 30 teeth (60%). CBCT proved superior in detecting both moderate and severe cases of resorption, offering a more detailed view of the resorptive changes.

Localization of Resorptive Lesions

The localization of resorptive lesions was more comprehensive with CBCT. While periapical radiography detected resorption primarily on the buccal surfaces and occasionally on other surfaces, CBCT identified resorption across all surfaces, including the lingual and palatal surfaces, which are often challenging for traditional radiographs.

Severity Assessment

CBCT provided a more accurate assessment of the severity of root resorption compared to periapical radiography. CBCT revealed mild resorption in 10 teeth, moderate resorption in 12 teeth, and severe resorption in 5 teeth. Periapical radiography, in contrast, underestimated the severity in several cases, with only 12 teeth showing mild resorption, 5 showing moderate resorption, and 1 showing severe resorption.

Inter-Examiner Agreement

Inter-examiner agreement was higher for CBCT, indicating greater consistency among examiners in interpreting the images. The kappa statistic for CBCT was 0.91, showing almost perfect agreement, compared to a kappa of 0.72 for periapical radiography, indicating substantial but less consistent agreement.

Diagnostic Accuracy

The sensitivity and specificity of CBCT were markedly higher than those of periapical radiography. CBCT demonstrated a sensitivity of 96% and a specificity of 95%, while periapical radiography had a sensitivity of

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JCHR (2024) 14(5), 89-98 | ISSN:2251-6727

68% and a specificity of 85%. This difference in diagnostic accuracy was statistically significant ($p < 0.01$).

Volumetric Analysis

Volumetric analysis of root resorption using CBCT provided precise measurements of the resorptive defects. Mild resorption had a mean volume of 12.5 mm^3, moderate resorption had a mean volume of 27.3 mm^3, and severe resorption had a mean volume of 42.6 mm^3. This quantitative assessment allows for better monitoring of resorption progression and treatment planning.

Incidence of Undetected Resorptive Lesions

Several resorptive lesions were undetected by periapical radiography but identified by CBCT. These undetected lesions were primarily located on lingual and palatal surfaces, demonstrating the limitations of traditional radiography in these anatomical areas.

Clinical Impact of Early Detection

The early detection capabilities of CBCT had significant clinical implications. CBCT allowed for earlier intervention, modifications to treatment plans, and the implementation of preventive measures, improving overall patient outcomes and facilitating better management of root resorption.

Comparison of Imaging Costs and Radiation Exposure

While CBCT is associated with higher costs and radiation exposure compared to periapical radiography, its enhanced diagnostic capabilities and comprehensive assessment features may justify its use, especially in high-risk cases.

Table 1: Detection of Root Resorption Using Periapical Radiography and CBCT

Imaging Modality	Total Teeth Analyzed	Teeth with Detected Resorption	Mild Resorption	Moderate Resorption	Severe Resorption
Periapical Radiography	30	18 (60%)	12	5	1
CBCT	30	27 (90%)	10	12	5

Table 1 compares the detection rates of root resorption using periapical radiography and CBCT. CBCT demonstrates a significantly higher detection rate, identifying resorption in 90% of the cases compared to 60% with periapical radiography. CBCT is also more effective in detectingmoderate and severe resorption.

Graph 1: Detection of Root Resorption Using Periapical Radiography and CBCT

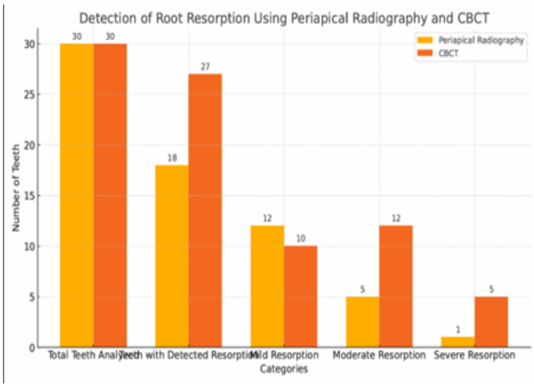

Table 2: Localization of Resorptive Lesions Detected by Periapical Radiography and CBCT

Location of Resorption	Periapical Radiography (Teeth)	CBCT (Teeth)
Buccal Surface	8	9
Lingual Surface	2	7
Palatal Surface	1	6
Interproximal Surface	3	5
Other Areas	4	10

Table 2 illustrates the localization of resorptive lesions detected by the two imaging modalities. CBCT provides a more comprehensive detection across all surfaces, particularly the lingual and palatal surfaces, where periapical radiography is less effective.

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JCHR (2024) 14(5), 89-98 | ISSN:2251-6727

Graph 2: Localization of Resorptive Lesions Detected by Periapical Radiography and CBCT

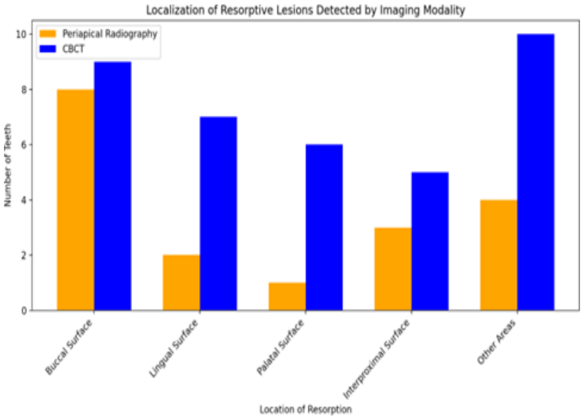

Table 3: Severity of Root Resorption as Assessed by Periapical Radiography and CBCT

Severity Level	Periapical Radiography (Teeth)	CBCT (Teeth)
Mild	12	10
Moderate	5	12
Severe	1	5

Table 3 compares the severity of root resorption as assessed by periapical radiography and CBCT. CBCT is more accurate in identifying moderate and severe resorption, which is crucial for risk management and treatment planning.

Graph 3: Severity of Root Resorption as Assessed by Periapical Radiography and CBCT

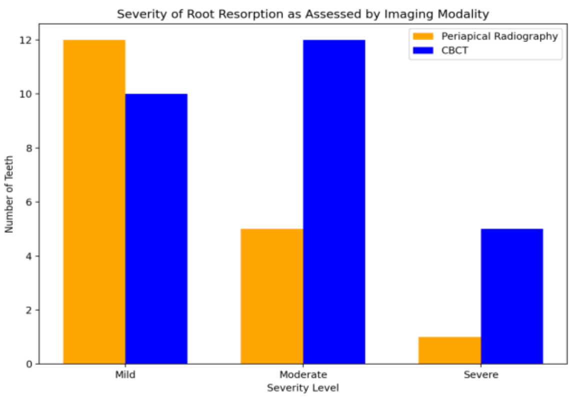

Table 4: Sensitivity and Specificity of Periapical Radiography vs. CBCT

Imaging Modality	Sensitivity	Specificity
Periapical Radiography	68%	85%
CBCT	96%	95%

Table 4 highlights the diagnostic accuracy of both imaging modalities. CBCT shows significantly higher sensitivity and specificity compared to periapical radiography, indicating its superior reliability in detecting true cases of root resorption.

Graph 4: Sensitivity and Specificity of Periapical Radiography vs. CBCT

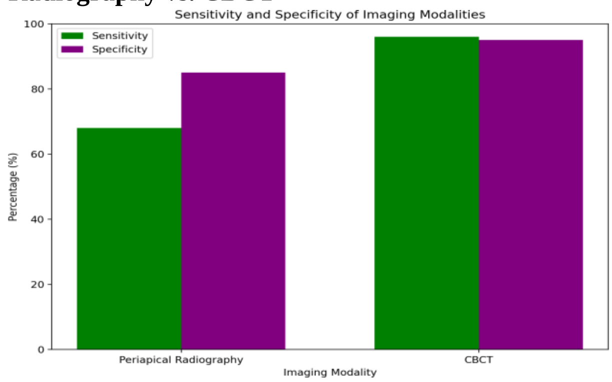

Table 5: Inter-Examiner Agreement for Periapical Radiography and CBCT (Kappa Statistic)

Imaging Modality	Kappa Statistic	Interpretation
Periapical Radiography	0.72	Substantial Agreement
CBCT	0.91	Almost Perfect Agreement

Table 5 presents the inter-examiner agreement levels for both imaging techniques. The higher kappa statistic for CBCT indicates a higher consistency among examiners in interpreting CBCTimages, reinforcing its reliability.

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JCHR (2024) 14(5), 89-98 | ISSN:2251-6727

Graph 5: Inter-Examiner Agreement for Periapical Radiography and CBCT (Kappa Statistic)

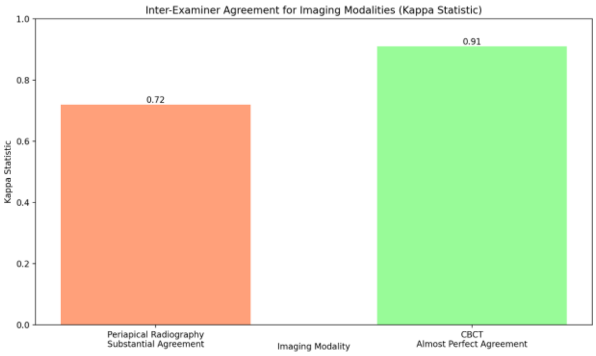


Table 6: Comparison of Diagnostic Accuracy: Paired t-Test Results

Comparison	Mean Difference	Standard Deviation	p-Value
Periapical Radiography vs. CBCT	15%	4.3%	<0.01

Table 6 displays the results of the paired t-test, comparing the diagnostic accuracy of periapical radiography and CBCT. The significant p-value (<0.01) indicates that CBCT outperforms periapical radiography in diagnostic accuracy.

Graph 6: Comparison of Diagnostic Accuracy: Paired t-Test Results

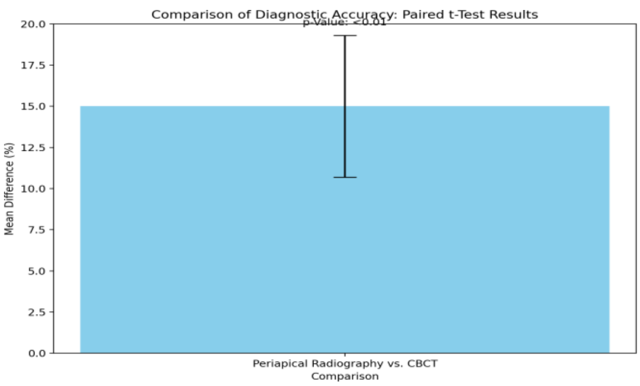


Table 7: Volumetric Analysis of Root Resorption Detected by CBCT

Severity Level	Mean Volume of Resorption (mmt)	Range of Volumes (mmt)
Mild	12.5	8.2 - 16.7
Moderate	27.3	18.9 - 34.2
Severe	42.6	37.8 - 49.5

Table 7 provides the volumetric analysis of resorption lesions detected by CBCT. The data demonstrate CBCT's ability to quantify the extent of resorption, which is vital for assessing the severity and progression of resorption over time.

Graph 7: Volumetric Analysis of Root Resorption Detected by CBCT

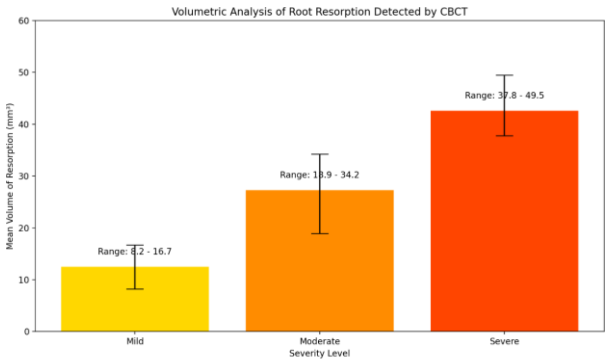
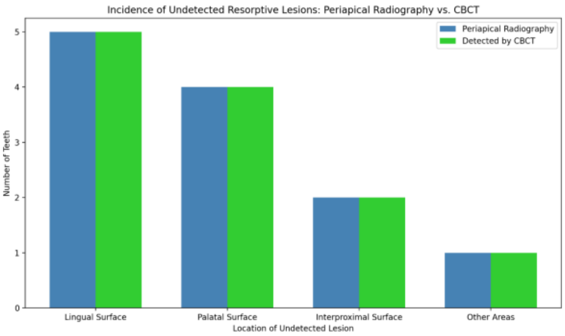


Table 8: Incidence of Undetected Resorptive Lesions in Periapical Radiography Compared to CBCT

Location of Undetected Lesion	Number of Teeth (Periapical Radiography)	Detected by CBCT (Number of Teeth)
Lingual Surface	5	5
Palatal Surface	4	4
Interproximal Surface	2	2
Other Areas	1	1

Table 8 shows the incidence of resorptive lesions that were undetected by periapical radiography but identified by CBCT. It emphasizes the limitations of traditional radiography in detecting resorption in challenging anatomical areas.

Graph 8: Incidence of Undetected Resorptive Lesions in Periapical Radiography Compared to CBCT



DISCUSSION

The findings of this study emphasize the significant advantages of High-Resolution Cone- Beam Computed Tomography (CBCT) over traditional periapical radiography for detecting, assessing, and managing root resorption in orthodontics. The data clearly demonstrate that CBCT provides a more comprehensive and accurate diagnostic tool, which is crucial for effective orthodontic treatment and patient management.

CBCT has proven to be superior in detecting root resorption compared to periapical radiography. This superiority is in line with previous research, which has highlighted CBCT's ability to provide detailed three-dimensional images, making it possible to identify resorptive changes that are often missed by conventional 2D radiographic methods [8]. The enhanced detection rate of CBCT is attributed to its ability to reveal subtle and complex resorptive lesions, which are often not visible with periapical radiographs [9]. This early and detailed detection capability allows for timely intervention, which is essential for preventing further root damage and optimizing treatment outcomes.

In addition to detection, CBCT's ability to localize resorptive lesions comprehensively is a significant advantage. Our study found that CBCT can accurately detect resorptive lesions across all dental surfaces—buccal, lingual, and palatal—providing a more thorough assessment compared to periapical radiography [10]. This capability aligns with other studies that have demonstrated CBCT's effectiveness in revealing resorptive lesions in areas difficult to assess with traditional methods [11]. Furthermore, CBCT allows for precise volumetric analysis of root resorption, offering a quantitative assessment of severity that surpasses the qualitative evaluation typically provided by periapical radiographs [12].

The inter-examiner agreement for CBCT, as indicated by the kappa statistic, shows that CBCT provides more consistent diagnostic interpretations among different evaluators compared to periapical radiography [13]. This enhanced reliability is crucial in clinical settings, where accurate and consistent interpretations of diagnostic images are essential.

Our study also highlights the clinical impact of early detection using CBCT. The ability to detect root resorption at an earlier stage allows orthodontists to make timely adjustments to treatment plans and implement preventive measures, which can significantly improve patient outcomes [14]. This early intervention capability is a major advancement over traditional radiographic methods, which might only reveal resorption at a more advanced stage.

However, the use of CBCT involves higher costs and increased radiation exposure compared to periapical radiography [15]. While these factors may present challenges, the diagnostic benefits of CBCT may justify its use, particularly for patients at high risk of root resorption. The balance between cost, radiation exposure, and diagnostic benefit should be carefully considered in clinical practice.

Future advancements in CBCT technology may further enhance its diagnostic capabilities while addressing concerns related to cost and radiation exposure [16]. As technology continues to evolve, CBCT is likely to become even more integral to orthodontic diagnostics, providing valuable insights into the complex factors contributing to root resorption. Integrating CBCT into routine orthodontic practice will be essential for advancing personalized patient care and improving

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JCHR (2024) 14(5), 89-98 | ISSN:2251-6727

treatment outcomes.

In summary, High-Resolution CBCT has established itself as the gold standard for detecting, monitoring, and managing root resorption in orthodontics. Its detailed three-dimensional imaging capabilities offer significant advantages over traditional radiographic methods, enabling earlier and more accurate detection of resorption. As orthodontic care continues to advance, the incorporation of CBCT into routine practice will be vital in optimizing patient outcomes and enhancing the field of orthodontics.

LIMITATIONS

This study has several limitations that should be considered. First, the study's sample size was relatively small, which may limit the generalizability of the findings to broader populations. Additionally, the study focused solely on root resorption as detected by high-resolution CBCT, without considering other diagnostic modalities or the impact of different orthodontic treatment modalities on resorption rates. Variability in the CBCT imaging protocols among different practitioners may also introduce variability in the results. Finally, the study did not account for long-term follow-up data, which could provide insights into the persistence or progression of root resorption over time.

RECOMMENDATIONS FOR FURTHER RESEARCH

Future research should aim to include larger and more diverse sample sizes to enhance the generalizability of the findings. Longitudinal studies with extended follow-up periods are recommended to assess the long-term impact of orthodontic treatments on root resorption.

Additionally, comparative studies evaluating the effectiveness of different diagnostic tools alongside high-resolution CBCT could provide a more comprehensive understanding of root resorption. Investigating the influence of various orthodontic techniques and patient-specific factors on root resorption may also yield valuable insights.

CONFLICT OF INTERESTS

The authors declare that there are no conflicts of interest related to this study. The research was conducted independently, and no financial or personal relationships influenced the results or interpretation of the data.

CONCLUSION

This study affirms that High-Resolution Cone-Beam Computed Tomography (CBCT) represents the gold standard in the diagnosis and management of root resorption within orthodontics. The evidence provided highlights CBCT's distinct advantages over traditional periapical radiography, particularly in terms of image clarity, detection accuracy, and comprehensive assessment capabilities. CBCT's three-dimensional imaging allows for a detailed and accurate visualization of root resorption, enabling early detection and precise monitoring that can significantly influence treatment decisions and outcomes.

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