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Validation of novel measurement protocols proposed for the standardized assessment of crestal bone levels: A cone-beam computed tomography study

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ABSTRACT

Purpose: This study was performed to introduce, evaluate, and compare various novel assessment protocols designed for straightforward, reliable, and reproducible measurement of alveolar bone levels. These protocols are intended for standardized periodontal assessment and follow-up, utilizing cone-beam computed tomography (CBCT) images and manipulation of Digital Imaging and Communications in Medicine (DICOM) viewer software.

Materials and Methods: Two experienced oral and maxillofacial radiologists developed 5 distinct radiographic measurement protocols. These techniques were established to assess the alveolar bone level of a periodontally affected upper central incisor using a method that is consistently repeatable across observers. Two additional assessors, blinded to the details of the study, independently applied the protocols to retrieved DICOM files that met the eligibility criteria. A scoring system with 3 subscores was created and used to compare the protocols.

Results: Statistically excellent inter-observer reliability was observed for all protocols, other than protocol 1, which demonstrated moderate reliability. The average discrepancy between measurements taken by the 2 observers was 1.2 mm for protocol 1, 0.81 mm for protocol 2, and less than 0.5 mm for the remaining 3 protocols. All approaches except protocol 4 were straightforward to apply.

Conclusion: This study introduces multiple reliable protocols for the evaluation of periodontal bone levels that ensure consistency across observers. Based on the findings, the double axial lines and incisocrestal distance protocols are recommended. These new assessment approaches, along with any future modifications, may be useful in periodontal assessment, dental implant follow-up, orthodontic evaluation, research, and artificial intelligence model generation. ***(Imaging Sci Dent 20240073)***

KEY WORDS: Alveolar Bone Loss; Periodontitis; Cone-Beam Computed Tomography; Diagnostic Imaging; Dental Implants

Introduction

Radiographic assessment plays a key role not only in the diagnosis and treatment planning of periodontal disease but also in the longitudinal follow-up, as it enables comparison with baseline images.[1,2] The reliability of comparison between radiographs taken at different times depends on the level of standardization achieved.[1,2]

Since its introduction, the use of cone-beam computed tomography (CBCT) for dental diagnostics has become increasingly widespread due to its advantages in accurately evaluating oral and maxillofacial structures.[3,4] CBCT is accepted as a tool for the radiographic assessment of bone in periodontology and orthodontics.[5-7]

However, the reliability of CBCT assessment continues to be investigated due to various factors, including image resolution, manipulation protocol, and bone status.[8-11] The literature varies widely regarding the reliability of CBCT-based bone level measurements, with some research citing an

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acceptable submillimeter margin of error, while another study reported an unacceptable deviation exceeding 2 mm.[9,10]

Although changes in alveolar bone level are key predictive indicators of the prognosis of periodontal status, the literature has primarily focused on CBCT-based single-time measurements for the staging of periodontitis, rather than on the standardized repeatability of measurements during follow-up.[12] In other words, no consensus has been established regarding a CBCT-based follow-up protocol. Furthermore, while many factors that could affect measurement accuracy have been examined,[13,14] to the authors' knowledge, no study has yet explored the various software manipulation-related assessment methodologies.

Thus, the present study was conducted to introduce, evaluate, and compare proposed protocols for obtaining reliable and repeatable measurements of alveolar bone levels on CBCT images.

Materials and Methods

The study protocol received prior approval from the relevant institutional research ethics committee (code: FD-ERU-REC-7). All Digital Imaging and Communications in Medicine (DICOM) files, which were anonymously retrieved, were obtained using a Planmeca Promax 3D machine (Planmeca Oy, Helsinki, Finland) operating at 90 kV and 6 mA, with a voxel size of 0.2 mm. A database search was performed for cases with a field of view that included the upper anterior dental region with a periodontally affected central incisor.

The sample size was determined using version 2 of the spreadsheet sample size calculator, developed by Arifin.[15] The power was set at 90%, with a significance level of 95% and a minimum acceptable reliability of 0.8. Based on a pilot study, the expected reliability was established at 0.96. According to the calculator, the minimum required sample size was 16 cases.

A total of 25 cases were randomly retrieved and subsequently reviewed by 2 experienced oral and maxillofacial radiologists to determine eligibility. To be included, cases had to feature a periodontally affected central incisor without coronal coverage. Images were required to be free of artifacts, such as beam hardening or motion artifacts; any images with such features were excluded. In cases involving 2 periodontally affected central incisors, 1 tooth was chosen at random. Of the 25 initially retrieved DICOM files, 5 were excluded during the secondary review because they did not meet the eligibility criteria.

The assessment protocols were established through a consensus between the 2 oral and maxillofacial radiologists. Each protocol was applied to various cases and subsequently refined. Once a consistent methodology for a protocol was established, it was taught to 2 additional observers—a periodontist and an orthodontist—who independently performed the measurements. The measurement results from these 2 observers were then compared and subjected to statistical analysis. Prior to this, the anonymized DICOM files for the cases had been randomly organized to create 2 distinct datasets containing the same cases, with 1 set allocated to each observer. One radiologist held the key to each

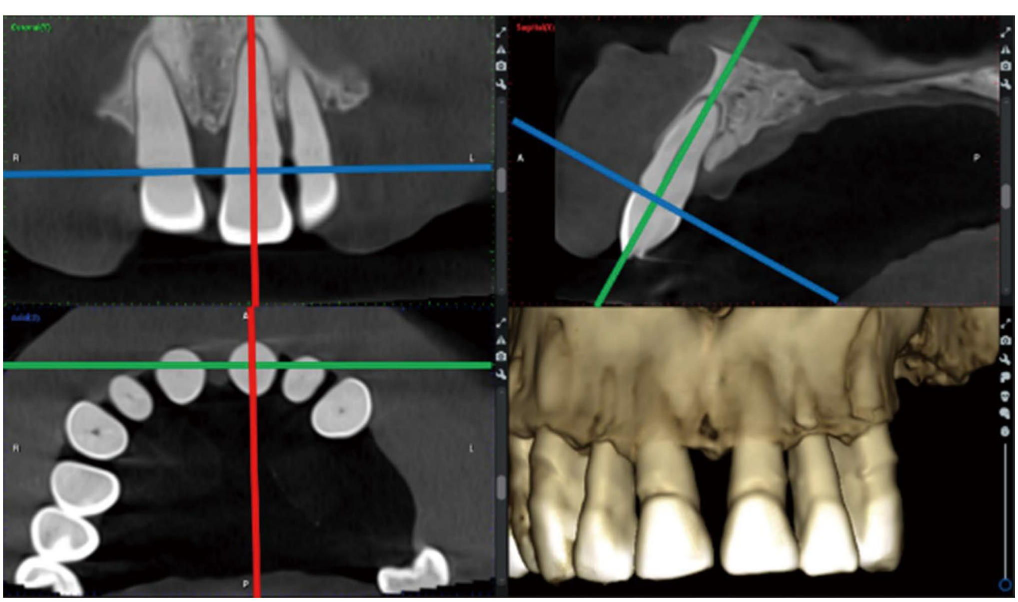

Fig. 1. Multiplanar reformatting module displaying the initial orientation of all reference lines.

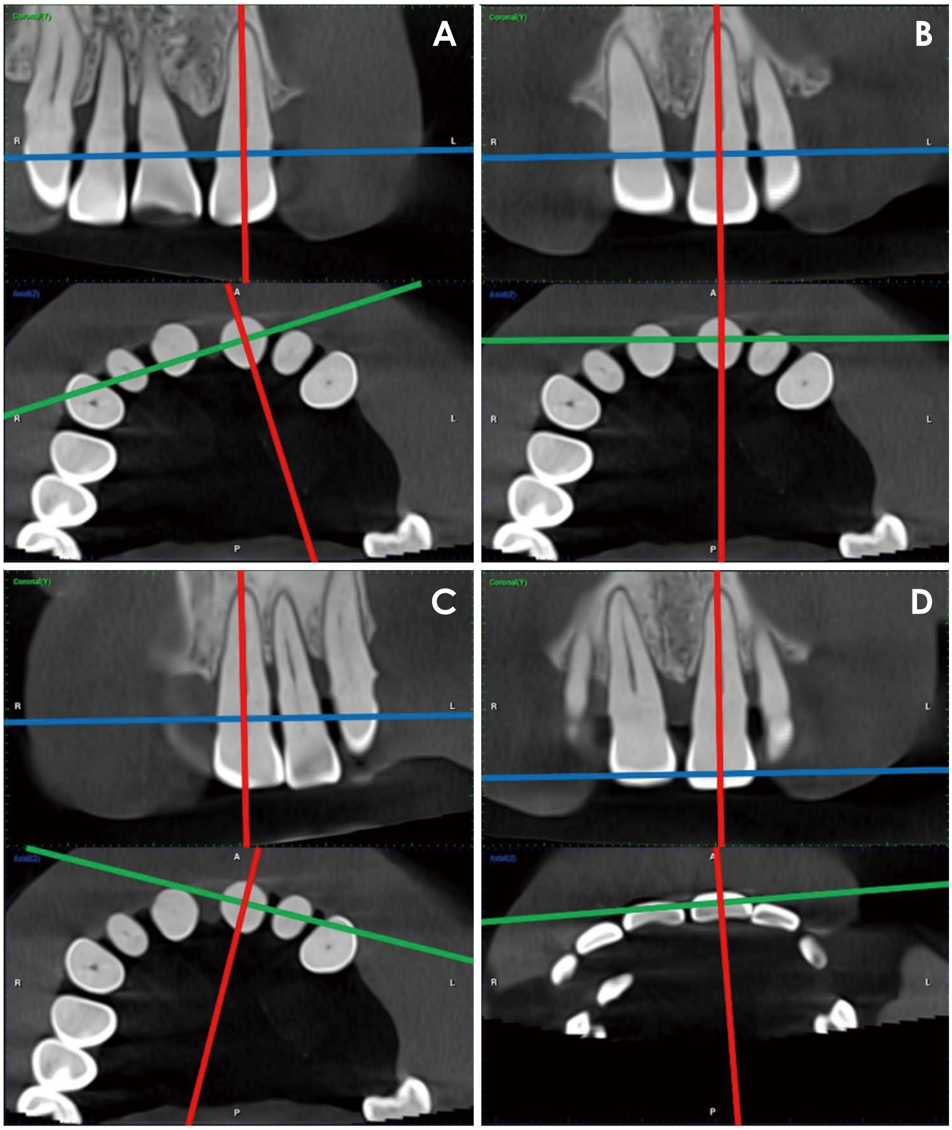

Fig. 2. Corrected axial and coronal slices illustrate the impact of varying reference line orientations in the axial slice (bottom) on bone shape and level (top). A-C. Various orientations are possible at the level of the cementoenamel junction, due to its nearly circular shape. D. Orientation is determined by the incisal edge, presenting only a single possibility and thus offering superior standardization. This latter orientation is employed for protocols 2 to 5.

dataset.

The observers imported the DICOM files into Planmeca Romexis 6.4.2 software (Planmeca Oy) case by case. The multiplanar reformatting module was selected for image manipulation. Before any protocol was applied, the image display parameters were adjusted to achieve a slice thickness of 0.2 mm, a contrast balanced at 0, a density of 2000, and a maximum sharpness of 10. The orientation of the reference lines was initially corrected to align with the tooth's long axis in all views, as depicted in Figure 1. This initial orientation was performed only for protocol 1, while subsequent orientation adjustments were made for the remaining protocols (Fig. 2).

In all protocols, 4 measurement sites were used for each tooth: mid-buccal, mesial, mid-palatal, and distal. The 2 observers performed the measurements blindly, without knowledge of the potential advantages or disadvantages of any protocol. The initial objective was to measure the distance between the cementoenamel junction (CEJ) and the alveolar bone crest using a standardized, repeatable measurement line (or ruler), marked in white in the associated figure images. This measurement line was defined by 2 points: the coronal point, located at the CEJ, and the apical point, found at the level of the alveolar bone crest. In protocols 4 and 5, the coronal reference point was shifted to the incisal edge. Since a sagittal slice was used for this work, 2 reference lines were established: an axial reference line (blue) and a coronal reference line (green). The methodologies for the 5 developed protocols were as follows.

Protocol 1, termed the reference line matching protocol, involved alignment of the axial reference line (blue) with the CEJ, ensuring that its intersection with the coronal

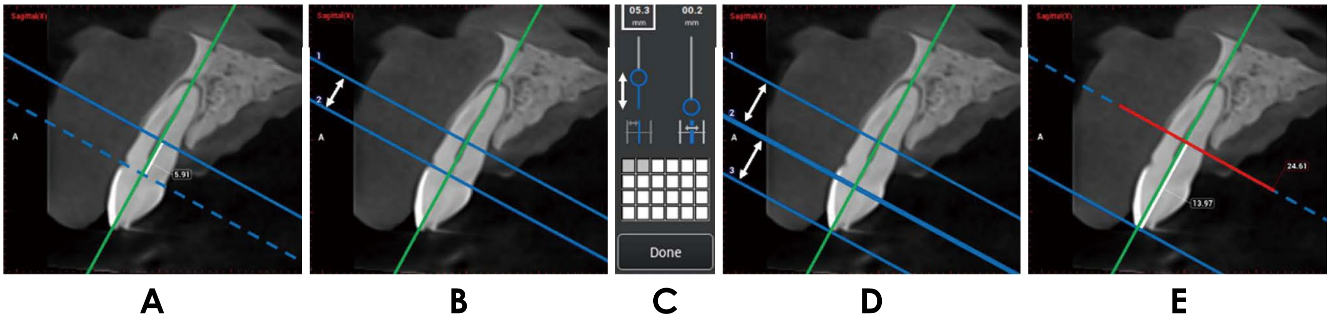

Fig. 3. Various assessment protocols used for labial bone level assessment. A. Protocols 1 and 2. Note the dotted axial line, which represents the previous location of the axial line before being moved apically. Measurement is taken using the ruler (represented by the white line) between the 2 axial levels in tangent with the coronal line (green). B. Protocol 3, which employs 2 axial reference lines. The interslice distance (white arrow) is used as the measurement value, rather than utilizing the ruler as in protocols 1 and 2. C. Further illustration of the measurement method for protocol 3. The interslice distance value of 5.3 mm is used in place of the ruler. D. Protocol 4, which involves 3 axial lines. The coronal reference is shifted to the incisal edge instead of the cementoenamel junction. The central, thicker axial line is positioned midway between the 2 thinner lines, and the interslice distance is adjusted so that 1 of those 2 lines aligns with the incisal edge and the other with the crestal bone level. In this protocol, the measurement value is twice the interslice distance. E. Protocol 5, involving the creation of a red reference line using the ruler. This is done in tangent with the previous position of the axial line apically at the bone level (dotted blue line) before moving the axial line coronally to its final position at the incisal edge. The measurement is taken with the ruler (white line) between the blue axial and the red established reference lines, and in tangent with the coronal reference (green).

reference line (green) marked the initial point of the measurement line (white), or the coronal point. The measurement line was then extended tangentially along the coronal reference line until it reached the apical point, which corresponded to the crestal bone level on the same assigned surface. Finally, the axial reference line was moved apically to the crestal bone level of the same assigned surface for adjustment and accurate repositioning of the apical point, ensuring that the apical point coincided with the intersection of the axial and coronal reference lines (Fig. 3A).

Protocol 2, the incisal edge orientation protocol, applied a modification at the axial view. Here, the coronal reference line (green) was adjusted to align with the incisal edge orientation at the dentinoenamel junction (Fig. 2). Subsequently, the same protocol as previously described was applied (Fig. 3A).

Protocol 3, the double axial lines protocol, was identical to the previous protocol apart from the addition of 2 axial lines (blue lines). The coronal axial line was aligned with the CEJ, while the apical axial line was aligned with the bone crest. The target distance was automatically set to be equal to the interslice distance (the distance between the 2 axial slices), rather than being manually measured with the ruler (white measurement line) as in the previous protocols (Figs. 3B and C).

Protocol 4, the triple axial lines protocol, was identical to the previous protocol, except that the coronal reference point for the measurement line was shifted from the CEJ to the incisal edge, and 3 axial lines were used. The paracentral lines were aligned such that one coincided with the incisal edge and the other with the crestal bone. This alignment was achieved by positioning the central axial line precisely in the middle of the coronal and apical paracentral lines. The required distance measurement was then automatically calculated by doubling the interslice distance (Fig. 3D).

Protocol 5, the incisocrestal distance protocol, first involved alignment of the axial reference line at the crestal bone level. A linear measurement line (shown in red) was drawn tangent to this line. When the axial reference (blue) was shifted coronally, the red measurement line remained as a reference. The axial reference was translated coronally until it reached the incisal edge. The coronal point of the measurement line was manually positioned at the intersection of the axial reference line (blue) and the coronal reference line (green). The apical point was placed at the intersection of the previously established measurement reference line (red) and the coronal reference line (green) (Fig. 3E).

The following triple scoring system was applied to evaluate and compare the protocols:

Score A assessed the statistical inter-observer reliability based on the intraclass correlation coefficient (ICC).[16] A score of 0 was considered to indicate poor reliability (ICC less than 0.5), a score of 1 signified moderate reliability (ICC between 0.5 and 0.75), a score of 2 represented good reliability (ICC between 0.75 and 0.90), and a score of 3 denoted excellent reliability (ICC greater than 0.90).

Score B represented the average difference in measurements, in millimeters (mm), between the 2 observers. A score of 0 indicated an average difference greater than 1 mm, a score of 1 was assigned for an average difference ranging from 0.5 to 1 mm, a score of 2 was given when the average difference was less than 0.5 mm, and a score of 3 denoted that the measurements were identical.

Score C assessed the simplicity of the protocol. A score of 0 was assigned if the protocol necessitated multiple training sessions for the assessors (indicating that it is not simple to teach). A score of 1 was given if only 1 training session was required, a score of 2 was awarded if the protocol required only a demonstration and the observer could perform it correctly on the first attempt, and a score of 3 was given if the protocol could be executed without a demonstration, using only verbal instruction.

Statistical analysis was conducted using SPSS for Windows, version 22 (IBM Corp., Armonk, NY, USA). *P*-values less than 0.05 were considered to indicate statistical significance. Data were presented as ICCs and confidence intervals.

Results

The remaining 20 cases were included to increase the power of the study, as the calculated sample size required was 16 cases. Three cases were excluded due to motion artifacts, 1 due to complete loss of alveolar bone, and 1 because it lacked upper central incisors. In total, 800 measurements were performed, with each observer conducting 400 measurements in total and 80 measurements for each protocol.

The ICC values indicated excellent inter-observer reliability for all protocols, except for protocol 1, which demonstrated moderate reliability (Table 1). The ICC values displayed statistical significance across all protocols. The average measurement discrepancies between the 2 observers were as follows: 1.20 mm for protocol 1, 0.81 mm for protocol 2, 0.47 mm for protocol 3, 0.29 mm for protocol 4, and 0.42 mm for protocol 5. Most protocols required only a single calibration session to train the observers, who subsequently performed correctly. However, protocol 4 necessitated 2 sessions, and protocol 1 was successfully performed after only a demonstration. Table 2 presents the results according to the triple scoring system. Based on these findings, the double axial lines protocol and the incisocrestal distance protocol are recommended.

Table 1. Statistical results for the intraclass correlation coefficient

	Intraclass correlation coefficient	95% confidence interval		*P*-value
		Lower	Upper	
Protocol 1	0.682	0.478	0.803	<0.05
Protocol 2	0.920	0.809	0.959	<0.05
Protocol 3	0.974	0.960	0.984	<0.05
Protocol 4	0.996	0.994	0.998	<0.05
Protocol 5	0.993	0.989	0.995	<0.05

Table 2. Results of the triple scoring system for protocol comparison

Protocol	Score A	Score B	Score C	Sum (maximum total of 9)
Protocol 1	1	0	2	3
Protocol 2	3	1	1	5
Protocol 3	3	2	1	6
Protocol 4	3	2	0	5
Protocol 5	3	2	1	6

Discussion

Although the accuracy of linear measurements using CBCT has been established, standardizing the measurement protocol remains a challenge.[1] Variability in measurements when assessing alveolar bone crest height in baseline or follow-up can lead to misdiagnosis and differing clinical judgments, especially in periodontic and orthodontic cases. Addressing this issue was the objective of the present study.

The multiplanar reformatting module was selected due to its capacity to display the recommended sections for the required quantitative assessment.[17] Only the initial step of maximization was used for a given view, ensuring that other views remained available for associating their display and reference lines with the active view.

A voxel size of 0.2 mm was selected because it is the recommended imaging protocol for precise dental bone level assessment, and using a higher dose with a smaller voxel size has no benefit unless warranted by other indications.[13,18,19] Notably, the use of any radiographic imaging modalities should be justified based on available guidelines,[20,21] and this should only be considered when the benefits outweigh the risks. For instance, CBCT may be appropriate if professional judgment deems it necessary to avoid invasive surgical re-entry, as may be the case in certain regenerative therapies.[22] Conversely, the use of CBCT solely for screening purposes is not warranted due to the associated risk of ionizing radiation. Strict adherence to the principles of ALARA (as low as reasonably achievable) and ALADA (as low as diagnostically acceptable) is essential.[20,21]

Adjusting the image display parameters to achieve maximum sharpness, zero contrast, and balanced density is aimed at ensuring not only the proper visualization of the required anatomy but also the standardization of the display for more reproducible measurements.[23] In this context, DICOM files were exported without the viewer software and subsequently imported by the observers, ensuring that no presets were saved for any case and thereby testing the reproducibility of the methodology.

A phenomenon known as the partial volume effect occurs when a single voxel represents 2 distinct structures, yielding a visual density that represents the average of the 2 structures' densities.[24] This averaging can obscure the precise identification of subtle radio-anatomical landmarks, such as those of the periodontally affected crestal bone and the CEJ. Accurate and universally accepted identification of the alveolar bone crest can be challenging due to variations in its thickness, orientation, and density.[25,26] These factors may lead to an inherent inability to achieve identical assessment results, regardless of the degree of standardization applied.

The partial volume effect necessitated the shift of coronal measurements from the delicate CEJ to the incisal edge. This avoidance of 1 of the 2 delicate anatomical landmarks may have contributed to the superior accuracy observed in protocols 4 and 5. Since the proposed protocols were designed for relative assessment, comparison, and follow-up, altering the coronal reference point from the CEJ to the incisal edge should not impact the measurement of relative changes across images. Additionally, using the incisal edge as a reference point may be advantageous in cases involving cervical caries or full-coverage crowns.

The incisal edge was utilized as the reference line for coronal orientation in the axial view, which was useful for applying the protocol to the upper central incisors (Fig. 2). The upper central incisor was selected for several reasons, including its strategic location and importance, which have made it a focal point for orthodontic and periodontic evaluation during treatment and follow-up.[4,27] Additionally, the literature suggests that measurements in the upper arch and anterior segment are more challenging;[18] if the protocols are successful in these difficult areas, they may be likely to succeed in less challenging sites as well.

To ensure standardization, it was essential that the periodontal measurements did not deviate and that the measurement line was perpendicular to both coronal and apical references, which can sometimes pose difficulties in assessment.[28] In the present study, aligning the measurement line with the vertical coronal reference line was the first step taken to facilitate easy perpendicularity in protocols 1 and 2.

In protocol 3, the use of 2 axial references improved the process by facilitating the parallelism of coronal and apical levels. This approach eliminated the need for manual entry of the 2 measurement points, thereby reducing the potential for placement deviation errors, which could be impactful even when minor. Additionally, it ensured that measurements were exactly perpendicular, with automatic value determination achieved through the calculation of interslice distance. Protocols 4 and 5 introduced a change in the coronal reference line, shifting from the CEJ to the incisal edge, as previously discussed. Furthermore, consistent with methods employed in other studies,[23,28] the specific software's measurement tool was used to draw a simple line that can be used as a reference. This facilitated the creation of a standardized point at the intersection of 2 reference lines and was further applied in protocol 5.

Statistical analysis revealed high interobserver reliability from protocols 2 to 5, with average differences in numerical values of below 1 mm. In the literature, radiographic measurements are considered accurate when they fall within 1 mm of the clinical measurements, aligning with the accepted deviation error for clinical periodontal measurements.[12,29] Generally, measurements should be straightforward and precise, while exhibiting minimal interobserver variability.[12,30] Consequently, a triple scoring system was developed to fully encompass the necessary criteria for reliable measurements.

The categorization of scoring for deviation errors or the numerical differences in observers' readings (mismatches) was based on a 0.5 mm interval. This interval was selected because it has been previously used and recommended as the smallest clinically significant difference in the assessment of periodontal bone levels.[13,18]

A limitation of this study was the absence of a gold standard, which can be attributed to the nature of the study. Additionally, most research involving gold standards comprises *in vitro* studies as opposed to *in vivo* studies, which are lacking in the literature.[12] Further research should aim to address the study limitations and refine the methodology, with the goal of establishing a widely accepted guideline for researchers and clinicians. Moreover, software development companies should avoid restricting the axial interslice distance to 12 mm, as this constraint posed complications for protocol 4 in this study.

In conclusion, this study successfully established multiple reliable protocols for the linear assessment of periodontal bone levels that ensure consistent measurements across observers. Based on the findings, the double axial lines protocol and the incisocrestal distance protocol are recommended. These protocols, along with any future modifications to them, are suggested for use in periodontal assessment, dental implant monitoring, orthodontic evaluation, research, and the development of artificial intelligence models.

Conflicts of Interest: None

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