Title
Accuracy and reliability of the expected root position setup to evaluate root proximity adjacent to a planned dental implant site

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Accuracy and Reliability of the Expected Root Position Setup to Evaluate Root Proximity Adjacent to a Planned Dental Implant Site

by
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Accuracy and Reliability of the Expected Root Position Setup to Evaluate Root Proximity Adjacent to a Planned Dental Implant Site

Sarah Pi

Abstract

Introduction: It is important to achieve proper root position during orthodontic treatment involving future dental implant placement. However, current methods to evaluate root position are either inaccurate or expose patients to relatively high levels of radiation. A new approach using an expected root position (ERP) setup has previously demonstrated the potential to accurately monitor root position with minimal radiation. The purpose of this study was to evaluate whether the ERP setup is an accurate and reliable method to determine if the roots adjacent to an edentulous site are appropriate for the anticipated dental implant.

Methods: In this retrospective study, the ERP setup was generated for 22 edentulous sites selected from the UCSF Division of Orthodontics patient database. The mesiodistal angulation of all teeth adjacent to the edentulous sites and the mesiodistal space between the teeth were measured in the ERP setup and compared to that of the post-treatment CBCT scan, which served as the control. The intra-operator and inter-operator reliability and agreement between the ERP setup and the post-treatment CBCT scan were assessed using Bland-Altman analysis. The correlation between measurements was further evaluated by the Pearson correlation coefficient.

Results: Both the Bland-Altman plots and the Pearson correlation coefficient displayed strong agreement between the ERP setup and the post-treatment CBCT scan with only 11.4% mesiodistal angulation measurements beyond the clinically acceptable range of ±2.5°. All mesiodistal angulations and distances were strongly correlated with high intra-operator and inter-operator reliabilities.

Conclusion: The method to generate an ERP setup to evaluate the mesiodistal angulation and space of an edentulous site prepared for a future dental implant has been demonstrated to be accurate and reliable.

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INTRODUCTION

Achieving proper root position adjacent to edentulous sites is a major goal of orthodontic treatment for patients who are planned for dental implants.[1–3] Prior to dental implant placement, the root apices of the teeth adjacent to the edentulous site often must be separated with orthodontics to create enough space for the dental implant to be placed between these roots.[1] If insufficient space is created with orthodontic treatment, then the risk of surgical contact and root injury increases during dental implant placement.[4] To ensure proper space has been created, it is often suggested to take a panoramic radiograph or a cone-beam computed tomography (CBCT) scan prior to removal of orthodontic fixed appliances to ensure that proper root position has been attained.[1-2] However, both panoramic radiographs and CBCT scans have their own respective deficiencies that may not make them the ideal radiographic technique to check proper root position adjacent to an edentulous site.

In orthodontic treatment, panoramic radiographs have been traditionally used to evaluate root positions. However, many prior studies have shown that the non-orthogonal x-ray beams directed at the teeth in panoramic radiographs can result in distortions that lead to inaccuracies, making them less ideal for monitoring root position.[5–8] Moreover, previous studies have shown that radiographic techniques should be able to present root angulations with an accuracy of 2.5° in either direction to be considered clinically acceptable, yet panoramic radiographs depict 53-73% of root angulations outside of this clinically acceptable range. [6–9] Consequently, even with a panoramic radiograph, it is still possible that the root positions of teeth adjacent to an edentulous site may not be ideal for implant placement due to these inaccuracies.

The other option to evaluate root positions adjacent to an edentulous site is using a CBCT scan. Unlike panoramic radiographs, CBCT scans accurately depict root position in three dimensions and show dentofacial structures in a 1:1 ratio.[5,10–13] However, older CBCT machines may expose patients to higher levels of radiation compared to panoramic radiographs; therefore, taking multiple CBCT scans to ensure proper root position adjacent to an edentulous site at different time points may not be clinically suggested.[12–14] Even though CBCT technology has advanced towards lower radiation dosages, providers should still follow the ALARA principle and minimize radiation exposure to patients when possible.[15] Accordingly, it would be more desirable to have a technique that can accurately estimate root positions adjacent to an edentulous site in three dimensions while also minimizing radiation exposure to patients.

A new methodology in recent years has demonstrated in multiple studies to have the potential to monitor root position at any stage of orthodontic treatment by generating an expected root position (ERP) setup and needing radiation exposure from only a single pre-treatment CBCT scan.[16–21] Though this new technique has been validated previously, it has not yet been shown to be able to guide the clinician's judgement as to whether there is adequate space between the roots of adjacent teeth, both in terms of mesiodistal angulation and space, for a dental implant to be placed post-treatment. If the root is not positioned ideally, the angulation would need to be corrected by rebracketing the teeth or by placing bends in the archwire.[2] Therefore, the purpose of this study was to evaluate whether the ERP setup is an accurate and reliable way to determine if adjacent root positions are appropriate for the anticipated dental implant without the need to expose the patient to additional CBCT scans prior to debond.

MATERIALS AND METHODS

This retrospective study was approved by the Committee on Human Research at the University of California, San Francisco (UCSF). Records used in this study were obtained from the UCSF Division of Orthodontics patient database. The inclusion criteria for this study were subjects with one or more missing teeth who had completed phase II orthodontic treatment and had pre-treatment and post-treatment digital study models and CBCT scans. Each edentulous site must be for one tooth only and must have both adjacent teeth present. Patients with extensive restorations covering over 2 surfaces of the involved teeth or who had restorations to those teeth completed during orthodontic treatment were excluded from the study. The exclusion criteria also included patients who had poor-resolution CBCT scans and teeth with dilacerated roots. Using the power analysis formula for a one-group descriptive study, $N = 4Z_\alpha^2S^2 \div W^2$, where N = sample size, Z_α is the standard normal deviate for α (1.96 for a 95% confidence interval), S is the standard deviation, and W is the desired total width (set to be 1.00, which is well within the clinically acceptable ±2.5° range), a sample size of 33 teeth with 17 edentulous sites is needed.[22] Fourteen patients who met the criteria were selected based on the available records within the UCSF Division of Orthodontics, yielding a total of 44 teeth with 22 edentulous sites to be measured. Of the 22 sites, there were 14 maxillary regions, consisting of five molars, 2 premolars, four canines, and four lateral incisors; and seven mandibular regions comprised of three molars and four premolars.

All CBCT scans were taken in compliance with the UCSF protocol with a CS9300 Cone Beam 3D Imaging System (Carestream Dental, Atlanta, GA) set at 85 kV(p), 4.0 mA, 6.4-second scan time, 17x11 cm field of view, and voxel size of 0.250 mm. Segmentations of all the teeth from the pre-treatment and post-treatment CBCT scans were created using the CephX modeling service (Orca Dental AI, Herzliya, Israel). All pre-treatment and post-treatment digital scans were either taken directly with an iTero® Element 2 intraoral scanner (Align Technology, Inc., San Jose, CA), or the physical casts were scanned with the iTero® Element 2. The scanned pre-treatment crowns were segmented and individualized using 3-matic software (version 9.0; Materialise, Leuven, Belgium).

Prior to creating an ERP setup, pre-treatment composite teeth were first formed (Fig 1).[16] The pre-treatment CBCT scan from CephX was superimposed as a single part onto the pre-treatment digital model by first approximating with an N-points registration function where three matching points were chosen on the pre-treatment CBCT model and its respective pre-treatment digital model. A global registration function using an iterative closest point algorithm was then applied to complete the superimposition process. The pre-treatment CBCT roots and pre-treatment digital scan crowns adjacent to the edentulous site were then individualized and sutured together creating individual digital composite teeth. To generate the ERP setup, the composite teeth were individually superimposed onto their respective crowns on the post-treatment digital study model using the same N-points superimposition and global superimposition functions (Fig 2). These functions are generally available in several 3D image processing software and are not limited to 3-matic software (Materialise).

The mesiodistal angulation and mesiodistal space were measured for all teeth adjacent to each implant site in both the ERP setup and the post-treatment CBCT scan. To quantify the mesiodistal angulation of the ERP setup, each adjacent tooth was segmented in half using 3-matic. The long axis of each tooth was determined using the root apex and center of the crown.[23,24] If more than one root was present, the distal or distobuccal root adjacent to the edentulous site was used. For the mesiodistal angulation, a point directly to the right of the center of the crown point was chosen (Fig 3). Following the protocol from a previous study, the mesiodistal space was measured three millimeters apical to the cementoenamel junction (CEJ) to best replicate the position of the implant platform, which is suggested to be two to three millimeters apical to the midfacial mucosal position for proper abutment emergence (Fig 4).[25] To account for variability from operator error, all measurements were performed five times, and the resulting mean was later used for further analysis. This same methodology of measuring mesiodistal angulation and mesiodistal space was utilized to measure the teeth for the post-treatment CBCT scan, which served as the control.

Two operators gathered the ERP setup and post-treatment CBCT scan mesiodistal angulation and mesiodistal space for all subjects. Both operators repeated their individual measurements at least one week later, resulting in a total of four sets of measurements for each subject. The operators were trained and calibrated prior to gathering measurements on the 22 edentulous sites and were blinded to which subject they were measuring at all times.

Statistical Analysis

The Bland-Altman method was used to find the agreement between the mesiodistal angulation and the mesiodistal space measurements of the ERP setup and the post-treatment CBCT scan.[26–28] The inter-operator and intra-operator reliabilities were also evaluated using the Bland-Altman method. The number of measurements for all teeth that were beyond the ±2.5° clinically acceptable range, mean difference, and Pearson correlation coefficient (r) were also determined.

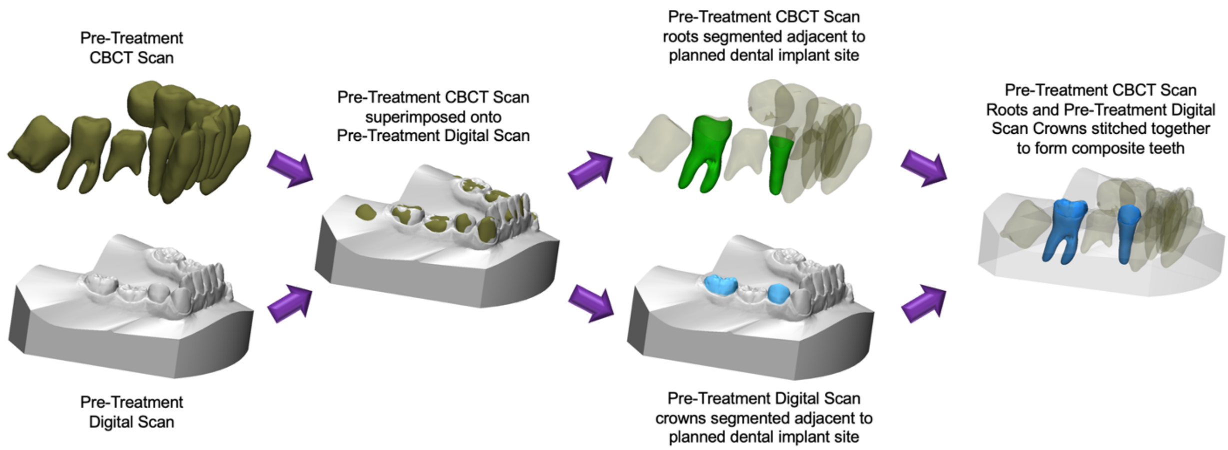

Figure 1. Protocol used to form digital composite teeth. The pre-treatment CBCT scan was superimposed onto the pre-treatment digital scan. Following the superimposition process, the pre-treatment CBCT scan roots and pre-treatment digital scan crowns were segmented on the teeth adjacent to the planned dental implant site and were stitched together to form composite teeth.

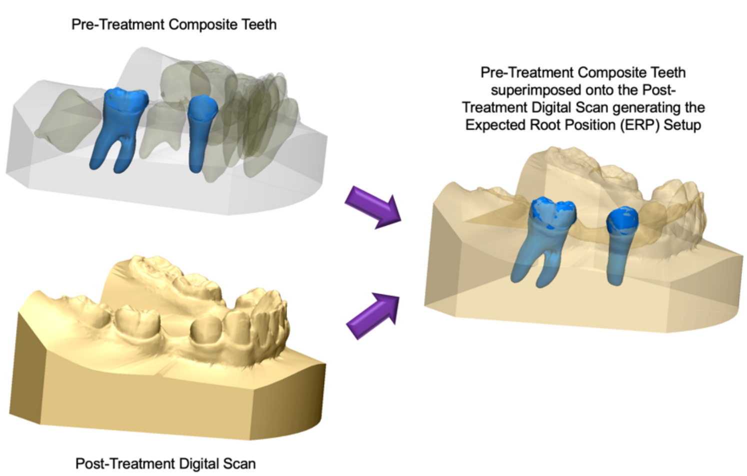

Figure 2. Generation of the ERP setup at post-treatment by superimposing the pre-treatment composite teeth on the post-treatment digital scan.

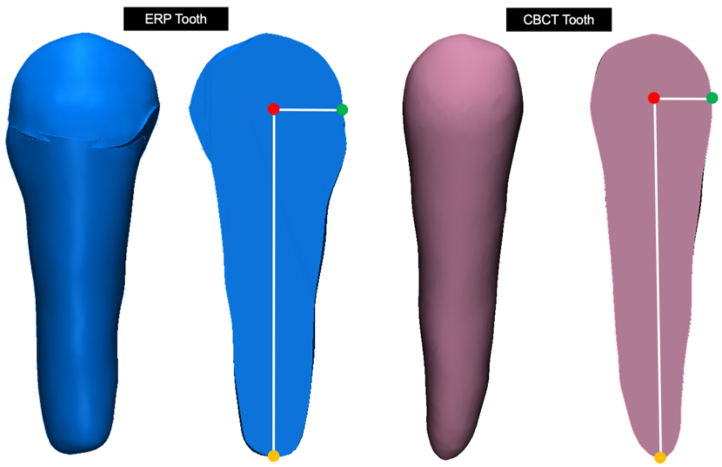

Figure 3. Method used to measure the mesiodistal angulation of a premolar for the ERP setup (blue) and post-treatment CBCT scan (pink). The three points were formed from the center of the root (yellow), center of the crown (red), and a point directly to the right of the crown (green).

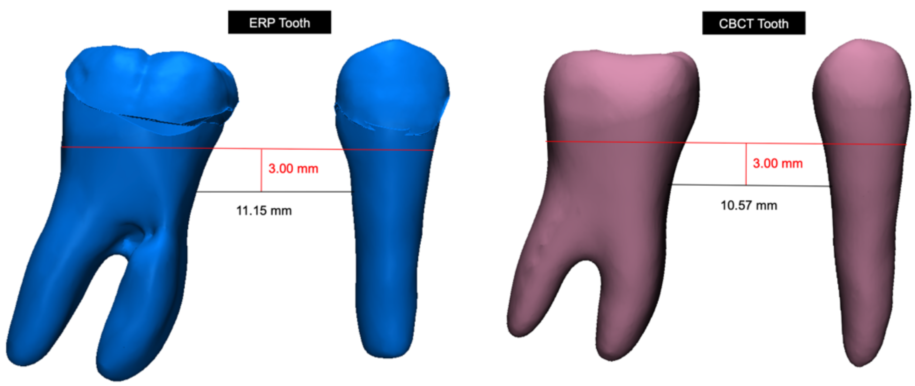

Figure 4. Method used to measure the mesiodistal space of an edentulous site for the ERP setup (blue) and post-treatment CBCT scan (pink). The measurement (black) was made three millimeters apical to the facial cementoenamel junction (red).

RESULTS

The agreement between the ERP setup and the post-treatment CBCT scan was compared to evaluate the accuracy of the ERP setup in assessing root position. Table 1 shows the agreement between the ERP setup and post-treatment CBCT scan measurements for mesiodistal angulation and mesiodistal space. A strong agreement can be seen in the corresponding Bland-Altman plots with the majority of data points within the limits of agreement (Fig 5). Table 2 shows the percentages of teeth that had a measurement difference beyond the ±2.5° clinically acceptable range between the ERP setup and post-treatment CBCT scan for the two operators' four sets of measurements, as well as the mean differences and standard deviations after taking the absolute value of the differences. Twenty of the 176 teeth measurements (11.4%) fell past the clinically acceptable range of ±2.5° for mesiodistal angulation with a total mean difference of 1.15°±0.94°. For the mesiodistal space, the total mean difference came out to be 0.52±0.37mm. The Pearson coefficient in Table 3 also shows strong correlation, with r greater than 0.96 for all four sets of data.

Table 1. Bland-Altman analysis between the ERP setup and post-treatment CBCT scan measurements

	Bias	Lower limit of agreement	Upper limit of agreement	Limit of agreement interval width
Mesiodistal angulation (°)				
Operator 1 Set 1	-0.38	-3.23	2.48	5.71
Operator 1 Set 2	-0.16	-2.96	2.64	5.60
Operator 2 Set 1	-0.27	-3.23	2.68	5.91
Operator 2 Set 2	-0.44	-3.28	2.40	5.68
Mesiodistal space (mm)				
Operator 1 Set 1	0.21	-1.14	1.55	2.69
Operator 1 Set 2	0.20	-0.93	1.32	2.25
Operator 2 Set 1	-0.01	-1.17	1.15	2.32
Operator 2 Set 2	-0.03	-1.32	1.26	2.58

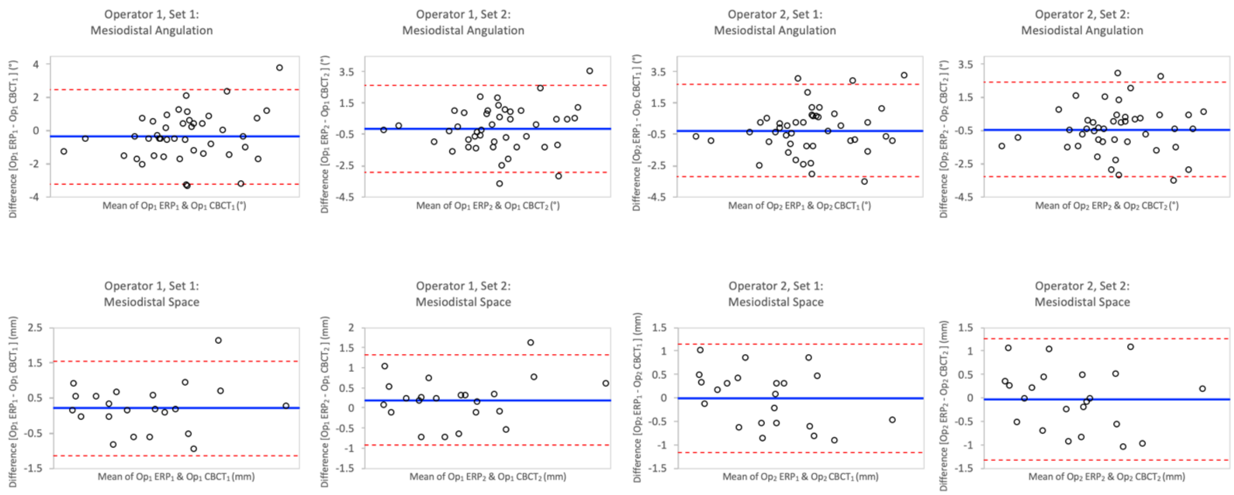

Figure 5. Bland-Altman plots between the two operators' ERP setup and post-treatment CBCT scan measurements for each set of data. For each plot, the x-axis represents the mean of the compared measurements, and the y-axis represents the difference between the compared measurements. The blue line represents the bias, and the red hashed lines represent the upper and lower limits of agreement.

Table 2. Percentages and mean differences

	Operator 1 Set 1	Operator 1 Set 2	Operator 2 Set 1	Operator 2 Set 2	Total
Percentages of mesiodistal angulation measurements outside the clinically acceptable ±2.5° range	4/44 = 9.1%	4/44 = 9.1%	6/44 = 13.6%	6/44 = 13.6%	20/176 = 11.4%
Mean differences of mesiodistal angulation measurements (°)	1.17°±0.92°	1.12°±0.89°	1.16°±0.98°	1.15°±0.97°	1.15°±0.94°
Mean differences of mesiodistal space measurements (mm)	0.54±0.46	0.47±0.38	0.51±0.28	0.54±0.37	0.52±0.37

Table 3. Pearson correlation coefficient (r)

Measurement	Operator 1		Operator 2	
	Set 1	Set 2	Set 1	Set 2
Mesiodistal angulation	0.988	0.988	0.987	0.987
Mesiodistal space	0.969	0.979	0.976	0.967

Regarding the precision of data collection within and between operators, the intra-operator reliability and inter-operator reliability were tested, respectively. The first and second sets of measurements performed by each operator for the ERP setup as well as the post-treatment CBCT scan were compared. Table 4 shows the intra-operator agreement results, and the Bland-Altman plots for both operators display strong agreement for all measurements (Fig 6). Table 5 shows the inter-operator agreement results. The first set of measurements for both the ERP setup and post-treatment CBCT scan were compared between the two operators, as well as the second set of measurements. Again, the Bland-Altman plots between each set of measurements for the two operators demonstrated strong agreement (Fig 7).

Table 4. Bland-Altman analysis for intra-operator reliability

	Bias (°)	Lower limit of agreement (°)	Upper limit of agreement (°)	Limit of agreement interval width (°)
Mesiodistal angulation				
Operator 1 ERP setup	-0.29	-1.70	1.13	2.83
Operator 2 ERP setup	0.10	-1.52	1.72	3.24
Operator 1 post-treatment CBCT	-0.06	-1.36	1.23	2.59
Operator 2 post-treatment CBCT	-0.07	-0.97	0.82	1.79
Mesiodistal space				
Operator 1 ERP setup	0.05	-0.42	0.51	0.93
Operator 2 ERP setup	-0.04	-0.44	0.36	0.80
Operator 1 post-treatment CBCT	0.04	-0.26	0.34	0.60
Operator 2 post-treatment CBCT	-0.06	-0.38	0.27	0.65

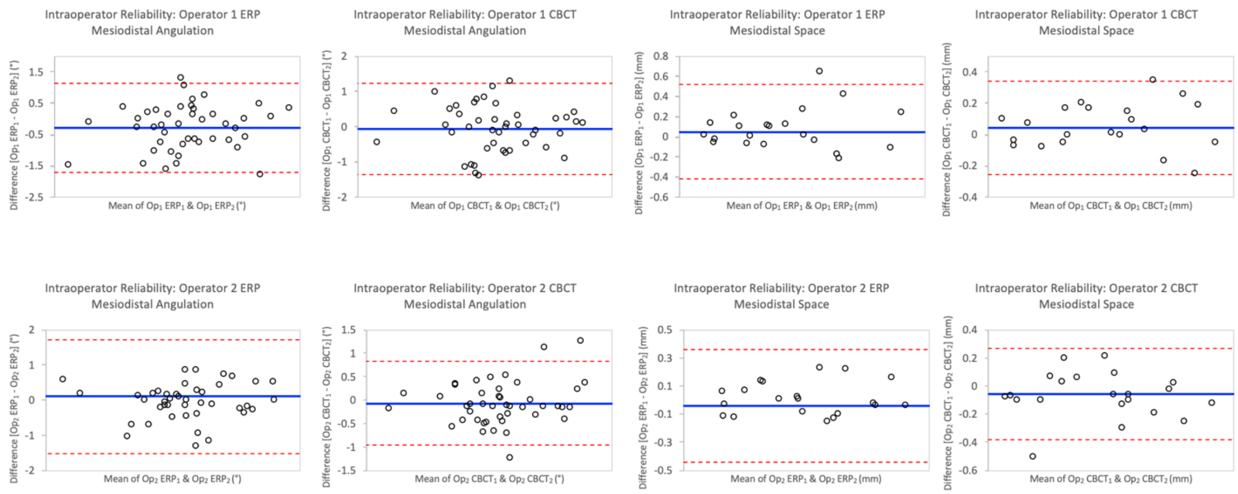

Figure 6. Bland-Altman plots showing intra-operator reliability testing of measurements made in each operator's two sets of ERP setup and post-treatment CBCT measurements. The top row shows the intra-operator reliability of the first operator, while the bottom row shows that of the second operator. For each plot, the x-axis represents the mean of the compared measurements, and the y-axis represents the difference between the compared measurements. The blue line represents the bias, and the red hashed lines represent the upper and lower limits of agreement.

Table 5. Bland-Altman analysis for inter-operator reliability

	Bias (°)	Lower limit of agreement (°)	Upper limit of agreement (°)	Limit of agreement interval width (°)
Mesiodistal angulation				
Set 1 ERP setup	-0.13	-1.52	1.26	2.78
Set 2 ERP setup	0.26	-1.69	2.20	3.89
Set 1 post-treatment CBCT	-0.02	-1.65	1.60	3.25
Set 2 post-treatment CBCT	-0.03	-1.57	1.50	3.07
Mesiodistal space				
Set 1 ERP setup	0.27	-1.24	1.78	3.02
Set 2 ERP setup	0.18	-1.41	1.77	3.18
Set 1 post-treatment CBCT	0.05	-0.87	0.98	1.85
Set 2 post-treatment CBCT	-0.04	-0.97	0.89	1.86

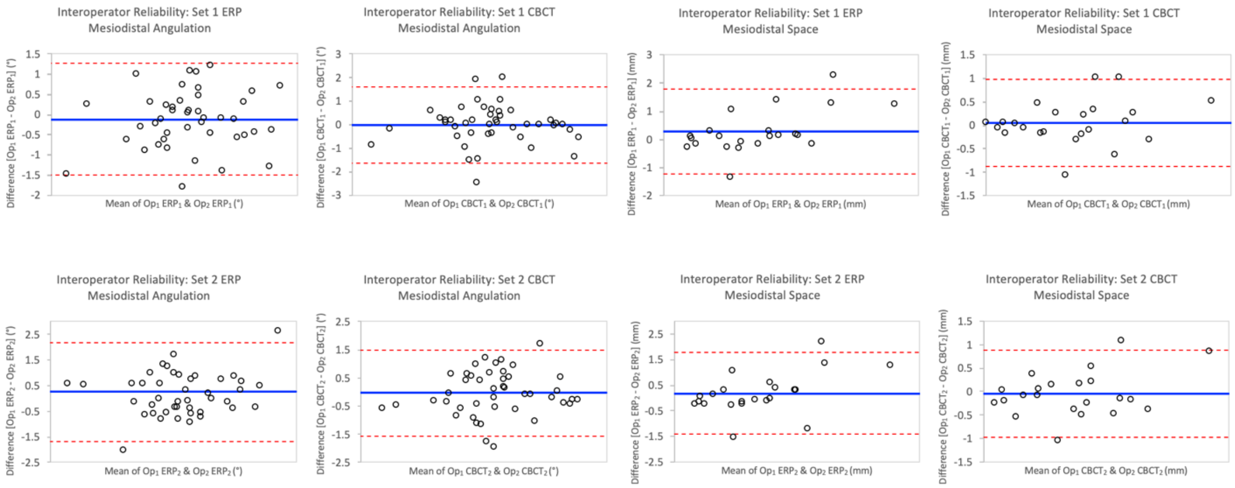

Figure 7. Bland-Altman plots showing inter-operator reliability testing of measurements made between the two operators' ERP setup and post-treatment CBCT measurements. The top row shows the inter-operator reliability for the two operators' first set of measurements, while the bottom row shows the inter-operator reliability for their second set. For each plot, the x-axis represents the mean of the compared measurements, and the y-axis represents the difference between the compared measurements. The blue line represents the bias, and the red hashed lines represent the upper and lower limits of agreement.

DISCUSSION

Successful orthodontic cases treatment planned for future dental implants require proper root positions adjacent to the planned dental implant site.[29,30] Many past studies have looked at how disregard for proper root angulation and distance during implant placement could potentially lead to the necrosis of previously vital adjacent teeth or greater inter-implant crestal bone loss due to violation of the biologic width.[31,32] Thus, it is important for the orthodontist to complete the orthodontic treatment with adequate root positioning; however, post-treatment radiographs are often taken after the patient is debonded. According to the 2020 JCO survey, 78% of providers take post-treatment panoramic radiographs, while only 60% take progress ones.[33] This presents an issue if the clinician finds that there is an error in root proximity or parallelism after the patient has already been debonded where the only way to address this would be for the patient to be bonded again.

An alternative option would be to take both progress and post-treatment radiographs. Because CBCT scans expose patients to higher doses of radiation compared to panoramic radiographs, it may not be clinically suggested to take multiple scans throughout treatment to monitor the roots. As a result, the American Board of Orthodontics recommends the assessment of root angulation using panoramic radiographs despite recognizing that distortions can result in the inaccurate renderings of root angulations.[34] To help with these limitations, a new method was previously developed to evaluate root position with minimal radiation at any point during treatment by generating an ERP setup.[16–21] This study used the mesiodistal angulation and mesiodistal space measurements of edentulous sites to compare the ERP setup and the post-treatment CBCT scan. For this comparison, the differences between the mesiodistal angulation and mesiodistal space in these two imaging techniques are used rather than the true measurements of traditional points. Because the method to measure the mesiodistal angulation and mesiodistal space is consistent across the ERP setup and CBCT scan, the differences will be accurately reflected.[19]

Two operators completed these measurements for all subjects to evaluate the inter-operator reliability. They then repeated the measurements at least one week later to evaluate the intra-operator reliability. Bland-Altman analysis was done to display the inter-operator and intra-operator reliabilities where the ideal bias should be close to zero, and most measurements should be contained within the limits of agreement. This was true for all the Bland-Altman analyses plotted, indicating that the mesiodistal angulation and mesiodistal space measurements performed were reproducible between the two operators as well as within each operator.

In regards to the agreement between the ERP setup and the post-treatment CBCT scan, both the Bland-Altman analysis and Pearson correlation coefficient demonstrated strong agreement and correlation. Again, the Bland-Altman plots for each operator's two sets of data showed biases near zero with few outliers past the limits of agreement, and all Pearson correlation coefficient values were greater than 0.96. The error for the mesiodistal space measurement was generally lower than that of mesiodistal angulation with all mean differences for mesiodistal angulation less than two and all mean differences for mesiodistal space less than one. With only 11.4% of root angulations outside the clinically acceptable ±2.5° range of accuracy, the ERP setup has significantly better accuracy than conventional bidimensional panoramic radiographs which report 53%-73% outside of the clinically acceptable range.[6,7]

Though the ERP setup and post-treatment CBCT scans were strongly correlated, it was worth taking a look at the outliers outside the limits of agreement. When evaluating the entire sample and the outliers, there was no significant difference in accuracy between the ERP setup and post-treatment CBCT scan by dental arch region which was consistent with previous studies.[19,21] Many of these outliers were up to four degrees off possibly from incorrect alignment due to poor segmentation of the tooth from the CBCT scan or discrepancies in the patient models that were extraorally scanned. It is difficult to attain accurate occlusal anatomy with threshold segmentation since the patient is in occlusion; consequently, poor alignment of the crown when superimposing could result in slight discrepancies in root apex alignment (Fig 8). Because the method for the mesiodistal angulation measurement involved a point at the root apex, these inconsistencies in root apices could lead to outlier points even if the body of the roots are in similar positions.

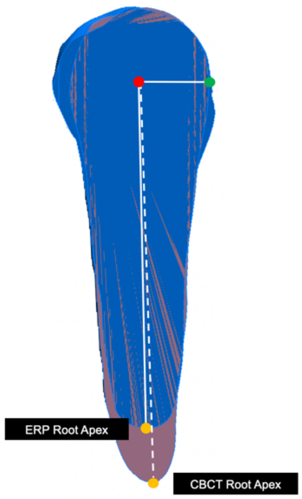

Figure 8. Differences between the composite tooth (blue) and post-treatment CBCT tooth (pink) in mesiodistal angulation resulting from slight discrepancies in root apex alignment.

The subjects of this study were selected based on available records from the Division of Orthodontics at the University of California, San Francisco. Since this study required the ERP setup to be compared to the control CBCT, this would only be possible if both were taken at the same time point, which typically only occurs at post-treatment at UCSF. The authors' previous study on ERP setup at mid-treatment has shown that bands and brackets should not affect the accuracy of the ERP setup. Thus, an ERP setup can ideally be generated using the pre-treatment CBCT scan and any intraoral scan taken in the few appointments prior to debond so that any issues with root proximity and angulation can be addressed while the patient still has brackets on.[21] This would allow providers to generate multiple ERP setups to monitor the roots as they are being corrected without any concerns for additional radiation unlike panoramic radiographs and CBCT scans which expose patients to additional radiation.

Despite all the benefits of this approach to generate an ERP setup, there are limitations to this technique as well. As the authors have previously mentioned, the main limitation currently is that this method is too time consuming to be practical in a clinical setting.[19] Fortunately, new advancements from third-party vendors are emerging, such as from CephX, that can use artificial intelligence to automatically perform threshold segmentation of CBCT scans with sufficient accuracy to generate an ERP setup. With the continued advancement of CBCT technology, intra-oral scanners, image-processing software, and artificial intelligence, this approach to generate an ERP setup should be feasible for clinical use in the near future.

Other limitations include any factors that could decrease the accuracy of crown superimposition of the CBCT tooth onto the digital scan tooth, which is crucial in generating the ERP setup. For example, this would include large existing restorations or any restorations done after the initial CBCT was already taken that would alter the crown anatomy and result in discrepancies in crown superimposition. Because the ERP setup requires a pre-treatment CBCT scan, any patients who did not need an initial CBCT scan would be precluded.

CONCLUSIONS

The ERP setup can accurately and reliably assess the mesiodistal root angulation and space adjacent to an edentulous site planned for a future dental implant.

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