Accuracy and reliability of the expected root position setup on clinical decision making of root position at midtreatment

Robert J. Lee,[a] Jaemin Ko,[a] Justyn Park,[b] Sarah Pi,[b] Denise Devgon,[c] Gerald Nelson,[a] David Hatcher,[d] and Snehlata Oberoi[d]
San Francisco, Calif

Introduction: Accurate root position is imperative for successful orthodontic treatment that is stable and functional. Current methods to monitor root position are either inaccurate or use relatively high levels of radiation. A method to generate an expected root position (ERP) setup has been reported to have the potential to accurately evaluate root position with minimal radiation. The purpose of this study was to determine the accuracy and reliability of the clinical decisions made on root position using the ERP setup. **Methods:** This retrospective study included 10 subjects who had pretreatment and midtreatment cone-beam computed tomography (CBCT) scans and study models. An ERP setup was generated for all patients at midtreatment. Four examiners assessed both the CBCT scan and ERP setup and made clinical decisions regarding the root position with each method. Cohen's kappa was determined to assess intraoperator and intermethod reliability. Sensitivity, specificity, positive predictive value, and negative predictive value were calculated to determine the accuracy of the ERP setup. **Results:** The kappa values for intraoperator reliability for both the CBCT scan and ERP setup fell within the 0.61-0.80 range. The kappa values for intermethod reliability between the CBCT scan and ERP setup fell within the 0.61-0.80 range for all tooth groups. The sensitivity of the ERP setup ranged from 0.72 to 0.90, specificity ranged from 0.89 to 0.97, positive predictive value ranged from 0.57 to 0.85, and negative predictive value ranged from 0.93 to 0.99. **Conclusions:** This study demonstrated that the ERP setup, when compared with the gold standard CBCT scan, was accurate and reliable in making clinical decisions regarding root position at midtreatment. (Am J Orthod Dentofacial Orthop 2019;156:566-73)

One of the goals of orthodontic treatment is to maneuver the crown and root of all teeth into an esthetic, stable, and functional occlusion. The principles that orthodontists generally adhere to for achieving this ideal occlusion are Andrews' 6 keys to normal occlusion, which are based on crown information from study models.[1] However, 2 of these keys, mesiodistal angulation and buccolingual inclination, were later found to also depend on root position because of variations in crown morphologies, inconsistencies in crown-root angulations, and short crown length relative to root length.[2-7]

Proper root position and parallelism are imperative for adequate occlusal function, periodontal health, and restorative treatment. Previous studies have reported that satisfactory root position and parallelism are important to distribute occlusal forces evenly and yield proper occlusal and incisal function.[2,8] Other studies have demonstrated that periodontal or restorative treatment may be compromised if adjacent roots are too close to one another.[9,10] Root proximity is also a potential cause for a poorly shaped gingival embrasure.[11] Furthermore, root proximity of 1.0 mm or less has been reported to lead to more rapid periodontal breakdown, jeopardized health of the interproximal space, and horizontal bone loss.[12-16]

Ideal bracket placement will result in an optimal occlusion with minimal amounts of wire bending.[17] However, perfect bracket placement at the initial bonding is uncommon and difficult to accomplish. To correct an improperly placed crown or root resulting from a bracket positioning error, a practitioner may either make an

[a]Division of Orthodontics, University of California, San Francisco, San Francisco, Calif.
[b]School of Dentistry, University of California, San Francisco, San Francisco, Calif.
[c]Department of Preventive & Restorative Dentistry, University of California, San Francisco, San Francisco, Calif.
[d]Department of Orofacial Sciences, University of California, San Francisco, San Francisco, Calif.
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Address correspondence to: Robert J. Lee, 707 Parnassus Ave, Ste D3000, San Francisco, CA 94143; e-mail, Robert.Lee3@ucsf.edu.
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adjustment to the archwire or reposition the bracket. Carlson and Johnson[18] reported a treatment protocol that many practitioners follow, in which there is a "reset" appointment at midtreatment to reposition any bracket positioning errors after the initial leveling and aligning of the dentition. At this midtreatment reset appointment, clinical and radiographic assessments are performed to evaluate crown and root position. A common reason to reposition a bracket would be to address a root parallelism problem found on radiographic assessment. However, an accurate radiographic technique is required to properly gauge root positions.

Panoramic radiographs have traditionally been used to assess root positions in orthodontic treatment. In a *Journal of Clinical Orthodontics* survey of American orthodontists, in 2014, 68% of respondents reported that they took progress panoramic radiographs, and 76% of respondents reported that they took posttreatment panoramic radiographs to evaluate root position.[19] However, previous reports have found that panoramic radiographs are inaccurate in gauging root position because of distortions that occur as a result of the nonorthogonal x-ray beams directed at the teeth.[20-23] The American Board of Orthodontics also acknowledges that panoramic radiographs are not ideal for the assessment of root position and does not score the roots adjacent to canines.[24]

Cone-beam computed tomography (CBCT) is another common radiographic technique used in orthodontics. In contrast with panoramic radiographs, CBCT scans accurately portray root position in 3 dimensions and show dentofacial structures in a 1:1 ratio.[20,25-28] However, older CBCT machines may expose patients to higher levels of radiation than panoramic radiographs, so using multiple CBCT scans to continually evaluate root position may expose patients to more risks than benefits, especially in children.[27-29] Although advances in CBCT technology have led to lower radiation dosages, practitioners should follow the "as low as reasonably achievable principle" and, when possible, refrain from exposing patients to radiation.[30] Thus, a technique that can accurately assess root position and minimize radiation exposure to patients is preferable to CBCT scans.

In recent years, a new technique that generates an expected root position (ERP) setup has been reported to have the potential to evaluate root position at any stage of orthodontic treatment, with radiation exposure from only a single pretreatment CBCT scan.[31-35] The proof of concept of this technique was demonstrated to be feasible in an ex-vivo typodont model, and clinically in 1 patient at posttreatment and another patient at a midtreatment resets appointment.[31-33] In addition, the mesiodistal angulation and buccolingual inclination of the ERP setup was quantified to be as accurate and reliable as its corresponding CBCT scan within a $\pm$ 2.5° range of clinical acceptability.[34,35] However, the ERP setup approach has not yet been demonstrated to have the capability to guide the clinician in executing bracket repositioning as an alternative to CBCT scans at midtreatment. The purpose of this study was to determine the diagnostic reliability of the clinical decisions made on root position using the ERP setup at midtreatment.

MATERIAL AND METHODS

This retrospective study was granted ethical approval (approval no. 10-00564) by the Committee on Human Research at the University of California, San Francisco (UCSF). Patient records for this study were obtained from the patient database at the UCSF Division of Orthodontics. The inclusion criteria for this study were that subjects had to have undergone phase II orthodontic treatment and had study models and CBCT scans taken at both a pretreatment and midtreatment appointments. Subjects who had restorations performed between the pretreatment and midtreatment appointments, or who had extensive restorations covering greater than 2 surfaces, were excluded. In addition, the exclusion criteria also included teeth with dilacerated roots and subjects who had poor-resolution CBCT scans. A sample size of 10 subjects who met the criteria based on convenience sampling was used based on the available records found at the UCSF Division of Orthodontics. A power analysis determined that a sample size of 10 subjects, which included 270 teeth, would allow this study to estimate sensitivity of 90%, with a 95% confidence of width of 0.08, which is sufficient power for this study.

To generate the ERP setup at midtreatment, a pretreatment CBCT scan and midtreatment digital model are required. The Anatomodel 3D modeling service (Anatomage, San Jose, Calif) was used for the individual tooth segmentations for all teeth from the pretreatment CBCT scans used in this study. All CBCT scans were taken with a CS9300 Cone Beam 3D Imaging System (Carestream Dental, Atlanta, Ga). The CBCT scan protocol at the UCSF Division of Orthodontics was to take a pretreatment CBCT scan set at 17 $\times$ 11 cm field of view; 85 kVP, 4.0 mA; 0.250-mm voxel size; scan time, 6.40 seconds, and a midtreatment CBCT scan set at 10 $\times$ 10 cm field of view; 85 kVP, 4.0 mA; 0.180-mm voxel size; scan time, 8.00 seconds. Digital models of the midtreatment study models were constructed using Ortho Insight software (MotionView Software, Hixson, Tenn) extraoral laser scanner. Ortho Insight software

was used to segment all digital crowns of the midtreatment study models which were exported as PLY files. The segmented pretreatment CBCT teeth obtained from the Anatomodel 3D modeling service (Anatomage) and the midtreatment digital crowns obtained from Ortho Insight (MotionView Software) were both imported into 3-matic software (version 9.0; Materialise, Leuven, Belgium). In 3-matic (Materialise), the ERP setup was generated through a superimposition process of the pretreatment CBCT teeth onto their corresponding midtreatment digital crown (Fig 1). The first step in this superimposition process is to use the "N points registration" function to grossly select 3 corresponding points on both the crown of the pretreatment CBCT tooth and its respective midtreatment digital crown. Next, any obvious error in crown and root mesiodistal angulation and buccolingual inclination of the CBCT teeth were repositioned using the translation and rotation functions. During this CBCT tooth realignment process, operators estimate and match the alignment of the long axes of the pretreatment CBCT teeth and midtreatment digital crowns to their best judgment. The final part of this superimposition process used the "global registration" function in 3-matic (Materialise), which uses an iterative closest point algorithm. These functions are not limited to 3-matic software (Materialise) and are commonly available in many 3D image processing software.

To determine whether the ERP setup would allow a practitioner to make an accurate and reliable diagnosis of root position during orthodontic treatment, 4 examiners evaluated both the root position of the ERP setup and its corresponding midtreatment CBCT scan (Fig 2). These examiners were instructed, based on their clinical experience and treatment philosophy, to select teeth for which they would reposition a bracket because of root position and to also specify whether the root required mesial or distal root tip. The examiners were also instructed to base their selections from solely the ERP setup or CBCT scan, and to not consider the occlusion or marginal ridges in their decision making. Two of the examiners were third-year UCSF orthodontic residents, and the other 2 examiners were full-time UCSF faculty, both with over 15 years of clinical experience. All examiners were experienced with using Dolphin Imaging (version 11.9, Dolphin Imaging & Management Solutions, Chatsworth, Calif), which was used to view the CBCT scans, and were also shown how to view, rotate, translate, and zoom in and zoom out the ERP setups in 3-matic (Materialise).

The presentation orders for each set of midtreatment ERP setups and CBCT scans evaluated by the examiners were randomly created using a random number generator. To assess intraoperator reliability, the examiners evaluated all ERP setups and CBCT scans twice for 4 sets of assessments. The examiners alternated between assessing CBCT scan or ERP setup each week for 4 weeks. One week was given between each assessment to mitigate bias that may occur from remembering a past assessment. The first set of CBCT/ERP assessments was labeled "Set 1" and the second set of CBCT/ERP assessments was labeled "Set 2." The examiners were blinded on the subjects they were evaluating at all times.

Statistical analysis

All statistical analysis was performed using SPSS software (version 25.0; SPSS, Chicago, Ill). Intraoperator and intermethod reliability were assessed with Cohen's kappa. For the intermethod reliability, the analysis was stratified by tooth group. The teeth grouped together included the following: contralateral teeth, first and second molars, first and second premolars, and central and lateral incisors. Kappa values were considered almost perfect between 0.81 and 1.00, substantial between 0.61 and 0.80, moderate between 0.41 and 0.60, fair between 0.21 and 0.40, slight between 0.20 and 0.00, and poor below 0.00 based on the guidelines suggested by Landis and Koch.[36]

Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for both Set 1 and Set 2 using the following formulas: sensitivity (Se = TP/[TP + FN]), specificity (Sp = TN/[TN + FP]), PPV (PPV = TP/[TP + FP]), and NPV (NPV = TN/[TN + FP]), where TP is true positive, FP is false positive, FN is false negative, and TN is true negative. For the diagnosis of root position, a TP meant that the recommended root movement assessed in the CBCT scan was accurately diagnosed in the ERP setup in the correct direction. An FP meant that the ERP setup recommended a change in root position when the CBCT scan recommended no movement. An FP meant that the CBCT scan recommended a change in root position, whereas the ERP setup either recommended no movement or a change in root position in the wrong direction. A TN meant that both the CBCT scan and ERP setup recommended no root movement.

RESULTS

A total of 270 teeth in 10 patients were evaluated by 4 examiners comparing the midtreatment CBCT scan and ERP setup. Intraoperator reliability was tested to determine the precision of clinical decisions made by examiners for both the midtreatment CBCT scan and ERP setup. Table I shows the kappa values for intraoperator

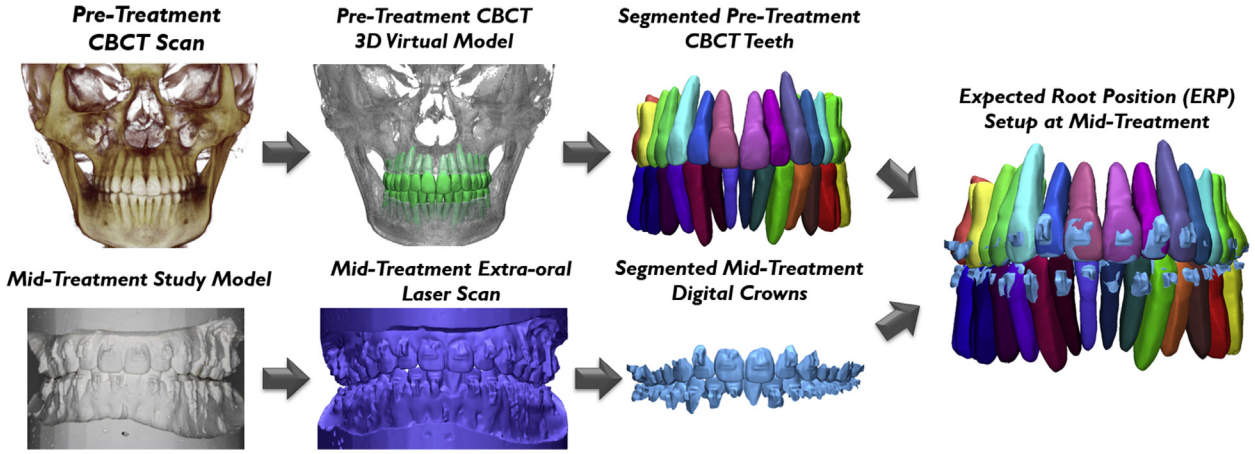

Fig 1. Protocol to generate an ERP setup at midtreatment. The teeth from the pretreatment CBCT scan are segmented. A study model at the orthodontic stage of interest, in this case at midtreatment, is scanned with an extraoral laser scanner, and the digital crowns are segmented. The individualized pretreatment CBCT teeth are superimposed onto the midtreatment digital crowns yielding the ERP setup.

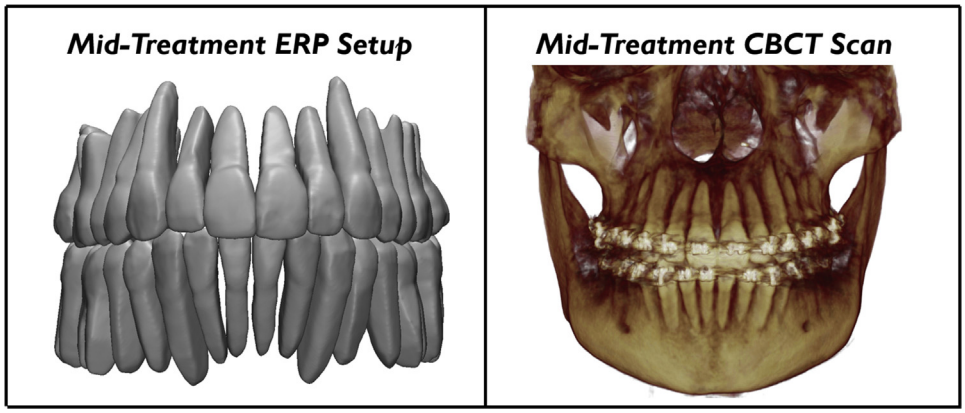

Fig 2. Examiners evaluated the root position for both the ERP setup (*left*) and its corresponding midtreatment CBCT scan (*right*).

reliability of the CBCT scan and ERP setup, respectively; these values fell within the 0.61-0.80 range, showing substantial agreement for all examiners with both methods.

To assess the agreement between the clinical decisions on root position determined by the midtreatment CBCT scan and ERP setup, intermethod reliability was tested. Table II shows the kappa values for intermethod reliability between the midtreatment CBCT scan and ERP setups stratified by tooth groups. The kappa values for intermethod reliability between the CBCT scan and ERP setup in both Set 1 and Set 2 fell within the 0.61-0.80 range for all tooth groups, indicating substantial agreement in the clinical decisions made on root position between the 2 methods. Table II also shows the kappa values between the CBCT scans of Set 1 and Set 2 in which most tooth groups had substantial agreement and fell within the 0.61-0.80 range. Only the kappa values of the maxillary canine and mandibular incisor groups had better agreement, which fell within the 0.81-1.00 range, while the mandibular canine group had worse agreement, which fell within the 0.41-0.60 range.

To assess the diagnostic reliability of the ERP setup in making clinical decisions on root position, the sensitivity, specificity, PPVs, and NPVs between the midtreatment CBCT scans and ERP setups were calculated for each tooth group in both Set 1 and Set 2 (Table III). In Set 1 and Set 2, sensitivity ranged from 0.72 to 0.90, specificity ranged from 0.89 to 0.97, PPV ranged from

Table I. Intraoperator reliability for CBCT scan and ERP setup

Examiner	*Method*	*Kappa (95% CI)*
1	CBCT	0.79 (0.70-0.88)
1	ERP	0.75 (0.65-0.85)
2	CBCT	0.75 (0.64-0.86)
2	ERP	0.67 (0.54-0.79)
3	CBCT	0.73 (0.63-0.83)
3	ERP	0.69 (0.59-0.78)
4	CBCT	0.78 (0.68-0.88)
4	ERP	0.64 (0.53-0.75)

0.57 to 0.85, and NPV ranged from 0.93 to 0.99. Table III also shows the diagnostic reliability between the CBCT scans of Set 1 and Set 2, in which sensitivity ranged from 0.79 to 0.94, specificity ranged from 0.87 to 0.98, PPV ranged from 0.62 to 0.92, and NPV ranged from 0.95 to 0.99.

DISCUSSION

The objective of this study was to determine whether the ERP setup could accurately and reliably be used to make clinical recommendations for bracket repositioning based on root position at a midtreatment appointment. Because CBCT scans have been found to accurately depict root position, the midtreatment CBCT scan was used as the gold standard imaging technique that the ERP setup was compared against.[20,25-28] Occlusion and marginal ridges were not considered in this study when evaluating root position to minimize the variables in this study. Four examiners with varying levels of clinical experience were chosen to assess whether clinical experience and treatment philosophy played a role in the diagnostic reliability of the ERP setup. To test the reproducibility of the clinical decisions made, the midtreatment CBCT scan and ERP setups were both evaluated twice for a total of 4 completed assessments for each examiner. One week was given between each assessment to reduce the bias in the results that may occur from remembering a past assessment.

The intraoperator reliability for the clinical decisions made by both the CBCT scans and ERP setups was found to have substantial agreement based on Cohen's kappa for all 4 examiners. This finding suggested that a difference in clinical experience and treatment philosophy did not affect the reproducibility of the clinical decisions made using either method. Interoperator reliability was not tested in this study because this study was designed to determine whether clinical experience and treatment philosophy affected the reproducibility of the clinical decisions on root position made by the ERP setup. Interoperator reliability would be necessary if the examiners were calibrated to an exact degree of root angulation that necessitated a bracket reposition. However, calibrating the examiners in this fashion would prevent the examiners from making true clinical decisions based on their treatment philosophies, which was the focus of this study.

After validating the reproducibility of the clinical decisions made within operators, the reliability between the 2 methods, CBCT scan and ERP setup, was tested. The intermethod reliability testing between the CBCT scan and ERP setup found substantial agreement between the CBCT scan and ERP setup, which indicates that the ERP setup had reliability similar to the CBCT scan in making clinical decisions on root position. Kappa values between the CBCT scans of Set 1 and Set 2 were also determined for each tooth group to serve as a benchmark for comparison. Because the kappa values between the CBCT scans of Set 1 and Set 2 were found to be similar to the kappa values found between CBCT scan and ERP setup, this further supported the reliability of the ERP setup in making clinical decisions on root position.

The diagnostic reliability of the ERP setup was also determined using sensitivity, specificity, PPV, and NPV calculations. Similar to the intermethod reliability testing, the diagnostic reliability between the CBCT scans of Set 1 and Set 2 was calculated to serve as a benchmark for comparison. The ranges for diagnostic reliability calculated between the CBCT scans of Set 1 and Set 2 were all similar to the ranges calculated between the CBCT scan and ERP setup of Set 1 and Set 2, which indicated satisfactory diagnostic reliability for the ERP setup in clinical decision making regarding root position. In addition, on closer examination of the clinical decisions made by the 4 examiners, it was often observed that, when adjacent teeth needed subtle adjustment in the root position, an examiner would switch between which adjacent tooth to move between assessments using either method. For example, to correct a minor discrepancy in root position between premolars, an examiner would often switch between distal root tip on a first premolar and mesial root tip on a second premolar between assessments. These minor changes in clinical decision making were the main reason that the ERP setup was not more accurate in the calculations of sensitivity, specificity, PPV, and NPV. However, this observation suggests that the ERP setup may be more accurate than the calculations indicate.

Although this study has demonstrated that the ERP setup may be diagnostically reliable to make clinical decisions regarding root position, the ERP setup does not replace midtreatment radiographs or final radiographs.

Table II. Intermethod reliability between the midtreatment CBCT scan and ERP setup

	Kappa (95% CI)		
Tooth group	*ERP/CBCT Set 1*	*ERP/CBCT Set 2*	*CBCT Set 1/CBCT Set 2*
Maxillary molars	0.70 (0.54-0.87)	0.69 (0.52-0.86)	0.76 (0.60-0.92)
Maxillary premolars	0.71 (0.57-0.85)	0.75 (0.63-0.87)	0.66 (0.52-0.81)
Maxillary canines	0.76 (0.58-0.94)	0.70 (0.51-0.88)	0.88 (0.76-1.01)
Maxillary incisors	0.74 (0.62-0.86)	0.78 (0.67-0.89)	0.90 (0.82-0.98)
Mandibular molars	0.72 (0.54-0.91)	0.69 (0.51-0.87)	0.68 (0.49-0.86)
Mandibular premolars	0.78 (0.67-0.88)	0.80 (0.70-0.90)	0.72 (0.60-0.83)
Mandibular canines	0.71 (0.40-1.02)	0.64 (0.32-0.96)	0.52 (0.15-0.88)
Mandibular incisors	0.79 (0.67-0.91)	0.73 (0.59-0.87)	0.75 (0.61-0.88)

Table III. Sensitivity, specificity, PPV, and NPV of the CBCT scan compared with the ERP setup

	Sensitivity (95% CI)	*Specificity (95% CI)*	*PPV (95% CI)*	*NPV (95% CI)*
ERP/CBCT Set 1				
Maxillary molars	0.79 (0.54-0.93)	0.95 (0.90-0.98)	0.68 (0.45-0.85)	0.97 (0.92-0.99)
Maxillary premolars	0.88 (0.69-0.97)	0.90 (0.82-0.95)	0.68 (0.49-0.82)	0.97 (0.91-0.99)
Maxillary canines	0.80 (0.51-0.95)	0.95 (0.86-0.99)	0.80 (0.51-0.95)	0.95 (0.86-0.99)
Maxillary incisors	0.84 (0.67-0.93)	0.92 (0.85-0.96)	0.76 (0.59-0.87)	0.95 (0.89-0.98)
Mandibular molars	0.80 (0.51-0.95)	0.97 (0.92-0.99)	0.71 (0.44-0.89)	0.98 (0.94-0.99)
Mandibular premolars	0.90 (0.76-0.97)	0.89 (0.81-0.94)	0.77 (0.62-0.87)	0.96 (0.89-0.99)
Mandibular canines	0.80 (0.30-0.99)	0.97 (0.90-0.99)	0.67 (0.24-0.94)	0.99 (0.92-0.99)
Mandibular incisors	0.82 (0.62-0.93)	0.96 (0.91-0.99)	0.82 (0.62-0.93)	0.96 (0.91-0.99)
ERP/CBCT Set 2				
Maxillary molars	0.74 (0.49-0.90)	0.96 (0.91-0.98)	0.70 (0.46-0.87)	0.96 (0.91-0.99)
Maxillary premolars	0.81 (0.64-0.91)	0.93 (0.85-0.97)	0.81 (0.64-0.91)	0.93 (0.85-0.97)
Maxillary canines	0.88 (0.60-0.98)	0.89 (0.78-0.95)	0.67 (0.43-0.85)	0.97 (0.87-0.99)
Maxillary incisors	0.86 (0.70-0.95)	0.93 (0.87-0.97)	0.80 (0.64-0.90)	0.96 (0.90-0.98)
Mandibular molars	0.72 (0.46-0.89)	0.96 (0.92-0.99)	0.72 (0.46-0.89)	0.96 (0.92-0.99)
Mandibular premolars	0.85 (0.71-0.93)	0.93 (0.85-0.97)	0.85 (0.71-0.93)	0.93 (0.85-0.97)
Mandibular canines	0.80 (0.30-0.99)	0.96 (0.88-0.99)	0.57 (0.20-0.88)	0.99 (0.92-0.99)
Mandibular incisors	0.79 (0.59-0.91)	0.95 (0.89-0.98)	0.76 (0.56-0.89)	0.95 (0.90-0.98)
CBCT Set 1/CBCT Set 2				
Maxillary molars	0.84 (0.60-0.96)	0.98 (0.93-0.99)	0.84 (0.60-0.96)	0.98 (0.93-0.99)
Maxillary premolars	0.88 (0.69-0.97)	0.87 (0.79-0.93)	0.62 (0.45-0.77)	0.97 (0.91-0.99)
Maxillary canines	0.94 (0.68-0.99)	0.97 (0.88-0.99)	0.88 (0.62-0.98)	0.98 (0.90-0.99)
Maxillary incisors	0.92 (0.77-0.98)	0.98 (0.92-0.99)	0.92 (0.77-0.98)	0.98 (0.92-0.99)
Mandibular molars	0.80 (0.51-0.95)	0.96 (0.91-0.98)	0.67 (0.41-0.86)	0.98 (0.93-0.99)
Mandibular premolars	0.88 (0.73-0.95)	0.89 (0.81-0.94)	0.77 (0.62-0.87)	0.95 (0.88-0.98)
Mandibular canines	0.80 (0.30-0.99)	0.99 (0.92-0.99)	0.80 (0.30-0.99)	0.99 (0.92-0.99)
Mandibular incisors	0.79 (0.59-0.91)	0.95 (0.90-0.98)	0.79 (0.59-0.91)	0.95 (0.90-0.98)

A midtreatment and final radiograph would still be clinically recommended during orthodontic treatment to monitor root resorption and pathologic conditions. The benefit of using the ERP setup is that it allows for evaluation of root position at any appointment during orthodontic treatment rather than only at an appointment in which a radiograph is taken. In addition, an option to reduce radiation exposure could be through the use of the ERP setup plus midtreatment periapical (PA) radiographs, instead of a midtreatment CBCT scan, to locally monitor root resorption. Because the teeth most susceptible to root resorption are maxillary and mandibular incisors, use of PA radiographs localized to only these teeth would result in an effective dose of <10 μSV, which is significantly lower than the effective dose of a small field of view midtreatment CBCT scan (reported to range between 5 and 652 μSV, with a mean of 84 μSV).[37-39] However, this option has significant limitations because root resorption will only be monitored on specific teeth, pathologic condition will not be monitored, and PA radiographs are not as accurate as CBCT scans in evaluating root resorption.

A further application of this approach is that the ERP setup could be used to verify root position before placing temporary skeletal anchorage devices, or to verify adequate space for a dental implant before debonding appliances. In these 2 applications, only a partial ERP setup in the region of interest for the temporary skeletal anchorage devices or dental implants would be necessary.

The long setup time is the primary limitation for clinical use of ERP and resulted in a retrospective study using a small sample size. In addition, the infrequent acquisition of midtreatment CBCT scans in conjunction with a midtreatment study model in the UCSF orthodontic clinic limited the available sample size. A prospective study may be feasible in the future, when the method to generate an ERP setup is more time efficient. Improvements in CBCT technology, intraoral scanners, and image processing software will likely make this approach feasible for clinical use in the near future. Third-party vendors, which were used in this study, now offer services to segment teeth from the pretreatment CBCT scan, which was previously the most time-consuming step of generating an ERP setup. Although this study obtained digital models of the crowns via extraoral laser scan of the study models at midtreatment because of the available records, use of an intraoral scanner would likely be more accurate and time efficient. Intraoral scanners stitch the dentition together using superimposition algorithms, so it is feasible in the near future that intraoral scanners may incorporate the segmented pretreatment CBCT teeth obtained from a third party and superimpose these pretreatment CBCT teeth onto the intraoral scan, generating real-time ERP setups.

Another limitation of the ERP setup is that it relies on accurate crown superimposition of the pretreatment CBCT teeth onto the digital model. Thus, any factor that would result in poor segmentation of the CBCT tooth, such as a large restoration or poor CBCT scan resolution, would decrease the accuracy of the crown superimposition. In addition, any modification to the crown after the pretreatment CBCT scan would result in a difference in crown anatomy between the pretreatment CBCT tooth and the current digital model, yielding an inaccurate crown superimposition and ERP setup.

CONCLUSION

Substantial agreement in intermethod reliability was found between the midtreatment ERP setup and CBCT scan. Calculations for sensitivity, specificity, PPV, and NPV indicated the satisfactory diagnostic reliability of the ERP setup. Thus, this study demonstrated that the ERP setup, when compared with the gold standard CBCT scan, was diagnostically reliable in making clinical decisions regarding root position at midtreatment. A small field-of-view pretreatment CBCT scan may be used to generate the ERP setup to reduce radiation exposure to the patient.

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REFERENCES

1. Andrews LF. The six keys to normal occlusion. Am J Orthod 1972; 62:296-309.
2. Balut N, Klapper L, Sandrik J, Bowman D. Variations in bracket placement in the preadjusted orthodontic appliance. Am J Orthod Dentofacial Orthop 1992;102:62-7.
3. Miethke RR. Third order tooth movements with straight wire appliances. Influence of vestibular tooth crown morphology in the vertical plane. J Orofac Orthop 1997;58:186-97.
4. Miethke RR, Melsen B. Effect of variation in tooth morphology and bracket position on first and third order correction with preadjusted appliances. Am J Orthod Dentofacial Orthop 1999;116: 329-35.
5. Germane N, Bentley BE Jr, Isaacson RJ. Three biologic variables modifying faciolingual tooth angulation by straight-wire appliances. Am J Orthod Dentofacial Orthop 1989;96:312-9.
6. Carlsson R, Rönnerman A. Crown-root angles of upper central incisors. Am J Orthod 1973;64:147-54.
7. Bryant RM, Sadowsky PL, Hazelrig JB. Variability in three morphologic features of the permanent maxillary central incisor. Am J Orthod 1984;86:25-32.
8. Dewel BF. Clinical observations on the axial inclination of teeth. Am J Orthod 1949;35:98-115.
9. Vermylen K, De Quincey GN, van 't Hof MA, Wolffe GN, Renggli HH. Classification, reproducibility and prevalence of root proximity in periodontal patients. J Clin Periodontol 2005;32: 254-9.
10. Vermylen K, De Quincey GN, Wolffe GN, van 't Hof MA, Renggli HH. Root proximity as a risk marker for periodontal disease: a case-control study. J Clin Periodontol 2005;32:260-5.
11. Olsen CT, Ammons WF, van Belle G. A longitudinal study comparing apically repositioned flaps, with and without osseous surgery. Int J Periodontics Restorative Dent 1985;5:10-33.
12. Waerhaug J. Eruption of teeth into crowded position, loss of attachment, and downgrowth of subgingival plaque. Am J Orthod 1980;78:453-9.
13. Nevins M. Interproximal periodontal disease—the embrasure as an etiologic factor. Int J Periodontics Restorative Dent 1982;2:8-27.
14. Klassman B, Zucker HW. Treatment of a periodontal defect resulting from improper tooth alignment and local factors. J Periodontol 1969;40:401-3.
15. Ritchey B, Orban B. The crests of the interdental alveolar septa. J Periodontol 1953;24:75-87.
16. Akiyoshi M, Mori K. Marginal periodontitis: a histological study of the incipient stage. J Periodontol 1967;38:45-52.
17. Sondhi A. The implications of bracket selection and bracket placement on finishing details. Semin Orthod 2003;9:155-64.
18. Carlson SK, Johnson E. Bracket positioning and resets: five steps to align crowns and roots consistently. Am J Orthod Dentofacial Orthop 2001;119:76-80.

19. Keim RG, Gottlieb EL, Vogels DS 3rd, Vogels PB. 2014 JCO study of orthodontic diagnosis and treatment procedures, part 1: results and trends. J Clin Orthod 2014;48:607-30.
20. Lagravère MO, Carey J, Toogood RW, Major PW. Three-dimensional accuracy of measurements made with software on cone-beam computed tomography images. Am J Orthod Dentofacial Orthop 2008;134:112-6.
21. Mckee IW, Glover KE, Williamson PC, Lam EW, Heo G, Major PW. The effect of vertical and horizontal head positioning in panoramic radiography on mesiodistal tooth angulations. Angle Orthod 2001; 71:442-51.
22. Garcia-Figueroa MA, Raboud DW, Lam EW, Heo G, Major PW. Effect of buccolingual root angulation on the mesiodistal angulation shown on panoramic radiographs. Am J Orthod Dentofacial Orthop 2008;134:93-9.
23. Owens AM, Johal A. Near-end of treatment panoramic radiograph in the assessment of mesiodistal root angulation. Angle Orthod 2008;78:475-81.
24. Casko JS, Vaden JL, Kokich VG, Damone J, James RD, Cangialosi TJ, et al. Objective grading system for dental casts and panoramic radiographs. Am J Orthod Dentofacial Orthop 1998;114:589-99.
25. Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). Dentomaxillofac Radiol 2004;33:291-4.
26. Hutchinson SY. Cone beam computed tomography panoramic images vs. traditional panoramic radiographs. Am J Orthod Dentofacial Orthop 2005;128:550.
27. Ludlow JB, Davies-Ludlow LE, Brooks SL, Howerton WB. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. Dentomaxillofac Radiol 2006; 35:219-26.
28. Brooks SL. CBCT dosimetry: orthodontic considerations. Semin Orthod 2009;15:14-8.
29. Silva MA, Wolf U, Heinicke F, Bumann A, Visser H, Hirsch E. Cone-beam computed tomography for routine orthodontic treatment planning: a radiation dose evaluation. Am J Orthod Dentofacial Orthop 2008;133:640.e1-5.
30. Mah JK, Huang JC, Choo H. Practical applications of cone-beam computed tomography in orthodontics. J Am Dent Assoc 2010; 141(Suppl 3):7S-13S.
31. Lee RJ, Pham J, Choy M, Weissheimer A, Dougherty HL Jr, Sameshima GT, et al. Monitoring of typodont root movement via crown superimposition of single cone-beam computed tomography and consecutive intraoral scans. Am J Orthod Dentofacial Orthop 2014;145:399-409.
32. Lee RJ, Weissheimer A, Pham J, Go L, de Menezes LM, Redmond WR, et al. Three-dimensional monitoring of root movement during orthodontic treatment. Am J Orthod Dentofacial Orthop 2015;147:132-42.
33. Lee RJ, Pi S, Park J, Nelson G, Hatcher D, Oberoi S. Three-dimensional evaluation of root position at the reset appointment without radiographs: a proof-of-concept study. Prog Orthod 2018;19:15.
34. Lee RJ, Pi S, Park J, Devgon D, Nelson G, Hatcher D, et al. Accuracy and reliability of the expected root position setup methodology to evaluate root position during orthodontic treatment. Am J Orthod Dentofacial Orthop 2018;154:583-95.
35. Lee R, Park J, Pi S, Nelson G, Hatcher D, Oberoi S. Accuracy of the expected root position setup to monitor root angulations and inclinations during orthodontic treatment: a pilot study. J Indian Orthod Soc 2018;52:44.
36. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74.
37. Pandis N, Nasika M, Polychronopoulou A, Eliades T. External apical root resorption in patients treated with conventional and self-ligating brackets. Am J Orthod Dentofacial Orthop 2008;134: 646-51.
38. Ludlow JB, Davies-Ludlow LE, White SC. Patient risk related to common dental radiographic examinations: the impact of 2007 International Commission on Radiological Protection recommendations regarding dose calculation. J Am Dent Assoc 2008;139: 1237-43.
39. Ludlow JB, Timothy R, Walker C, Hunter R, Benavides E, Samuelson DB, et al. Effective dose of dental CBCT-a metaanalysis of published data and additional data for nine CBCT units. Dentomaxillofacial Radiol 2015;44:20140197.