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Accuracy and reliability of the expected root position setup methodology to evaluate root position during orthodontic treatment

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Introduction: Current methods to evaluate root position either are inaccurate (panoramic radiograph) or expose patients to relatively large amounts of radiation (cone-beam computed tomography [CBCT]). A method to evaluate root position by generating an expected root position (ERP) setup was recently reported but has not been validated. The purpose of this study was to quantitatively assess the accuracy and reliability of the ERP setup with adequate statistical power. **Methods:** This retrospective study included 15 subjects who had completed phase 2 orthodontic treatment. An ERP setup was generated for all patients after treatment. The ERP setup was compared with the posttreatment CBCT scan, which served as the control. The mesiodistal angulation and buccolingual inclination of all teeth in both the ERP setup and the posttreatment CBCT scan were measured and compared. Bland-Altman analysis was used to assess interoperator reliability, intraoperator reliability, and agreement between the ERP setup and the posttreatment CBCT scan. **Results:** Bland-Altman plots showed high interoperator and intraoperator reliabilities. These plots also showed strong agreement between the ERP setup and the posttreatment CBCT scan; 11.8% of teeth measured for mesiodistal angulation and 9.6% of teeth measured for buccolingual inclination were outside the $\pm 2.5^\circ$ range of clinical acceptability. **Conclusions:** We validated that the method to generate an ERP setup to evaluate root position for posttreatment orthodontic assessment is accurate and reliable. (Am J Orthod Dentofacial Orthop 2018;154:583-95)

The objective of orthodontic treatment is to position teeth (crown and root) ideally, in a stable, esthetic, and functional occlusion. The guidelines that orthodontists often follow to achieve this optimal occlusion are Andrews' 6 keys to normal occlusion.[1] Of the 6 keys, 4 (molar relationship, rotations, spaces, and occlusal plane) depend solely on crown position. The other 2 (mesiodistal angulation and buccolingual inclination) depend on both crown and root positions because of variations in crown morphology, inconsistencies in crown-root angulation, and short crown length relative to root length.[2-7]

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Achieving satisfactory root position during orthodontic treatment is essential for optimal restorative treatment, periodontal health, and occlusal function. Previous reports have demonstrated that restorative or periodontal treatment may be compromised if roots of adjacent teeth are positioned too close to one another.[8,9] Root proximity in which the adjacent roots are apart by 1.0 mm or less has been shown to result in poorly shaped gingival embrasures, jeopardized health of the interproximal space, horizontal bone loss, and more rapid periodontal breakdown.[10-15] In addition, accurate root placement and parallelism are important to produce proper occlusal and incisal functions and to distribute occlusal forces.[2,16]

Root position during orthodontic treatment is evaluated through x-rays, most commonly in the form of a panoramic radiograph. A 2008 survey of American orthodontists in the *Journal of Clinical Orthodontics* reported that 67.4% of respondents took progress panoramic radiographs, and 80.1% of respondents took posttreatment panoramic radiographs to monitor and finalize root position.[17] However, panoramic radiographs are not ideal for evaluating root position, since previous studies have determined that they are inaccurate in depicting root position because of distortions and projection effects due to the nonorthogonal x-ray beams directed at the teeth.[18-21] In addition, prior studies have reported that radiographic techniques should be able to evaluate root angulations with an accuracy of 2.5° in either direction to be considered clinically acceptable; yet panoramic radiographs depict 53% to 73% of root angulations outside this clinically acceptable range.[19-22]

Cone-beam computed tomography (CBCT) is another radiographic technique used to assess root position during orthodontic treatment. In contrast to panoramic radiographs, CBCT scans have been reported to accurately evaluate root positions in 3 dimensions and depict dentofacial structures in a 1:1 ratio.[18,23-26] However, compared with panoramic radiographs, CBCT scans expose patients to higher levels of radiation, so multiple CBCT scans for evaluating root position may not be clinically recommended, especially in children.[25-27] Although CBCT technology continues to improve by decreasing the radiation exposure to patients, practitioners are always recommended to follow the ALARA principle and minimize exposing patients to radiation when possible.[28] Therefore, a technique that can accurately evaluate root position in 3 dimensions while also minimizing radiation exposure to patients is desirable.

A new methodology that generates an expected root position (ERP) setup was recently demonstrated to have the potential to evaluate root position at any stage of orthodontic treatment by combining 1 pretreatment CBCT scan with digital scans of teeth.[29-31] This ERP setup is an approximation of the root position at a specific orthodontic stage of interest and has been demonstrated in an ex-vivo typodont model, clinically in 1 subject at posttreatment and in a 5-patient posttreatment pilot study.[29-31] Quantitative analysis of this approach with adequate statistical power and reliability testing was not performed in these previous studies. Thus, the purpose of our study was to quantitatively assess the accuracy and reliability of the ERP setup in a larger sample with adequate statistical power.

MATERIAL AND METHODS

This retrospective study was approved (number 10-00564) by the Committee on Human Research at the University of California at San Francisco. Records for this study were obtained from the patient database of the Division of Orthodontics. The inclusion criteria for this study were those who had completed phase 2 orthodontic treatment and whose records consisted of pretreatment and posttreatment study models and CBCT scans. The exclusion criteria were patients who had extensive restorations covering more than 2 surfaces or had restorations during orthodontic treatment. These criteria also excluded teeth with dilacerated roots and patients with poor CBCT scan resolutions. Based on the previously reported pilot study on this methodology that determined the number of patients needed for adequate statistical power, we selected 15 patients meeting the inclusion and exclusion criteria using convenience sampling.[31]

The Anatomodel 3D modeling service (Anatomage, San Jose, Calif) was used to generate all segmentations of teeth from pretreatment and posttreatment CBCT scans. All CBCT scans were taken 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, 17 × 11 cm field of view, and voxel size of 0.250 mm. An Ortho Insight (MotionView Software, Hixson, Tenn) extraoral laser scanner was used to scan all posttreatment study models. The Ortho Insight software was used to segment, individualize, and export as PLY files the scanned posttreatment crowns. To generate the ERP setup at posttreatment, the individualized pretreatment CBCT teeth obtained from the Anatomodel were superimposed using 3-matic software (version 9.0; Materialise, Leuven, Belgium) onto their respective individualized posttreatment laser scanned crowns (Fig 1). The superimposition was first roughly approximated using an N-points registration function in which 3 matching points were selected on each pretreatment CBCT tooth and its respective posttreatment laser scanned crown. Gross errors in mesiodistal angulation and buccolingual inclination after N-points registration were then corrected by the best judgment of the operator (R.J.L.) to match the alignment of the long axes of the pretreatment CBCT teeth and posttreatment laser scanned crowns through rotation and translation functions. The last step in the superimposition process was to use a global registration function that applied an iterative closest point algorithm.

To quantitatively assess the ERP setup and posttreatment CBCT scan, the mesiodistal angulations and buccolingual inclinations were measured for all teeth in both the ERP setup and the posttreatment CBCT scan. To measure the teeth in the ERP setup, the surface contour of the ERP setup was overlaid onto the CBCT scan in Mimics software (version 16.0; Materialise). The contrast on the CBCT scan was adjusted to create a black background to minimize bias in measurements from the CBCT scan. To find the mesiodistal angulation and buccolingual inclination, the long axis of the tooth was first determined by selecting points for the centers of the crown and root in all 3 dimensions.[32,33] The point