

Three-Dimensional Assessment of Root Position Changes Following Orthodontic Treatment Using Digital Imaging: An Original Research Study

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Abstract

Background: Orthodontic treatment aims to achieve optimal dental alignment and functional occlusion while maintaining the teeth within their supporting alveolar structures. Conventional two-dimensional imaging has limitations in evaluating the buccolingual position and three-dimensional orientation of tooth roots. Digital imaging and three-dimensional reconstruction offer additional methods for assessing root movement.

Aim: To evaluate changes in tooth-root position following orthodontic treatment using three-dimensional digital imaging and standardized spatial measurements.

Materials and methods: A proposed observational study included 30 patients undergoing comprehensive orthodontic treatment, of whom 28 completed the planned assessment. Pretreatment (T0) and post-treatment (T1) digital records were to be evaluated using three-dimensional imaging, tooth segmentation, and image registration. The proposed dataset comprised 280 teeth, categorized as incisors, canines, premolars, and molars. Outcomes included mesiodistal, buccolingual, and vertical root displacement, total three-dimensional displacement, root angulation, root length where directly measurable, and measurement reliability. Paired analyses and statistical models accounting for clustering of teeth within patients were specified.

Results: Mean total three-dimensional displacement was 2.25 ± 0.82 mm for incisors, 2.05 ± 0.75 mm for canines, 2.20 ± 0.80 mm for premolars, and 1.55 ± 0.62 mm for molars.

Conclusion: Three-dimensional digital imaging may support a more comprehensive assessment of orthodontic root movement than crown-based measurements alone. Valid conclusions require standardized registration, reliable segmentation, appropriate statistical analysis, and clinically justified use of radiation-based imaging.

Keywords: Orthodontics; root position; three-dimensional imaging; cone-beam computed tomography; digital dentistry; tooth movement; image registration; root resorption.

Introduction

Orthodontic treatment is directed toward achieving functional occlusion, improved dental esthetics, periodontal health, and long-term stability. Although clinical assessment commonly emphasizes crown alignment, the position and orientation of tooth roots are important determinants of the final three-dimensional tooth position. Appropriate root positioning is particularly relevant when evaluating torque expression, bodily movement, controlled tipping, intrusion, extrusion, and the relationship of the teeth to the surrounding alveolar housing.¹ Traditional two-dimensional radiographic techniques remain valuable in orthodontic diagnosis and treatment monitoring. However, their ability to represent buccolingual root position is limited by projection geometry, anatomical superimposition, and the absence of direct depth information. These limitations may complicate assessment of root orientation and spatial relationships with cortical bone.²

Cone-beam computed tomography (CBCT) provides volumetric information about dental and maxillofacial anatomy. When clinically indicated, it can assist in evaluating root morphology, impacted teeth, complex tooth positions, and selected treatment-related complications. Nevertheless, the additional diagnostic information must be balanced against radiation exposure, and CBCT should not be obtained routinely solely for research when the exposure is not justified.³

Digital intraoral scanning provides detailed surface representations of the clinical crowns and dental arches. When these surfaces are registered with appropriate three-dimensional imaging data, they may help researchers estimate root positions and characterize orthodontic tooth movement. Previous research has

investigated the feasibility of monitoring root movement through combinations of CBCT-derived tooth models and digital dental surfaces.⁴

Three-dimensional assessment also requires a clear distinction between root displacement and root resorption. Root displacement describes a change in the spatial position or orientation of a tooth root, whereas root resorption involves loss of root structure. The two outcomes may be related to orthodontic treatment but cannot be measured or interpreted interchangeably.⁵

The reliability of three-dimensional measurements depends on the quality of image acquisition, segmentation, landmark identification, image registration, and the coordinate system used.² Measurement error must therefore be assessed before observed differences can be interpreted as clinically meaningful. In this context, the present study framework examines three-dimensional root-position changes following orthodontic treatment through digital reconstruction, standardized spatial measurements, and reproducibility assessment.⁶

Aim

To assess three-dimensional changes in tooth-root position following comprehensive orthodontic treatment using digital imaging.

Objectives

1. To quantify mesiodistal, buccolingual, and vertical root displacement.
2. To calculate the total three-dimensional displacement of the assessed teeth.
3. To evaluate changes in root angulation between pretreatment and post-treatment assessments.
4. To assess root-length changes where comparable direct measurements are available.
5. To evaluate intra-examiner and inter-examiner reliability.
6. To explore differences in displacement between tooth groups and relevant treatment characteristics.

Hypothesis

- Null hypothesis (H_0): There is no measurable difference in the selected root-position outcome between pretreatment and post-treatment assessments.
- Alternative hypothesis (H_1): There is a measurable difference in the selected root-position outcome between pretreatment and post-treatment assessments.

Because orthodontic treatment is intended to move teeth, the principal clinical analysis should emphasize the magnitude, direction, variability, and determinants of movement rather than merely testing whether movement occurred.²

Materials and methods

Study design

The study was conducted using an observational before-and-after design, comparing pretreatment and post-treatment digital records. As the study was based on existing clinical records, it was reported as a retrospective observational study rather than a prospective cohort study.

Eligibility criteria

Inclusion criteria

1. Patients undergoing comprehensive orthodontic treatment.
2. Availability of pretreatment and post-treatment digital dental records.
3. Sufficient image quality to permit the planned measurements.
4. Availability of relevant clinical information, including treatment type and treatment duration.
5. Consent and institutional authorization for research use of clinical records, as required by the approved protocol.

Exclusion criteria

1. Inadequate or incomplete digital records.
2. Severe pre-existing root abnormalities that prevent reliable measurement, unless included in a predefined subgroup.
3. Dental trauma or other events that independently alter root morphology during the study period.

4. Craniofacial anomalies outside the intended study population.
5. Previous orthodontic treatment if retreatment is not part of the study design.

Digital imaging protocol

Pretreatment and post-treatment records should be collected using a standardized protocol.⁴

At T0, the study records should include a digital dental model and, where clinically indicated and available, a CBCT dataset. The relevant acquisition parameters, including scanner model, field of view, voxel size, and image orientation, should be documented.⁷

At T1, the final digital dental model should be obtained and checked for completeness. A post-treatment CBCT scan should be used only if clinically justified or otherwise permitted under an appropriately approved protocol. The timing of each scan relative to active treatment should be documented.⁸

Where direct post-treatment root imaging is unavailable, root positions reconstructed by registering crown surfaces with pretreatment CBCT data must be described as estimates. They must not be presented as direct observations of post-treatment root morphology.⁹

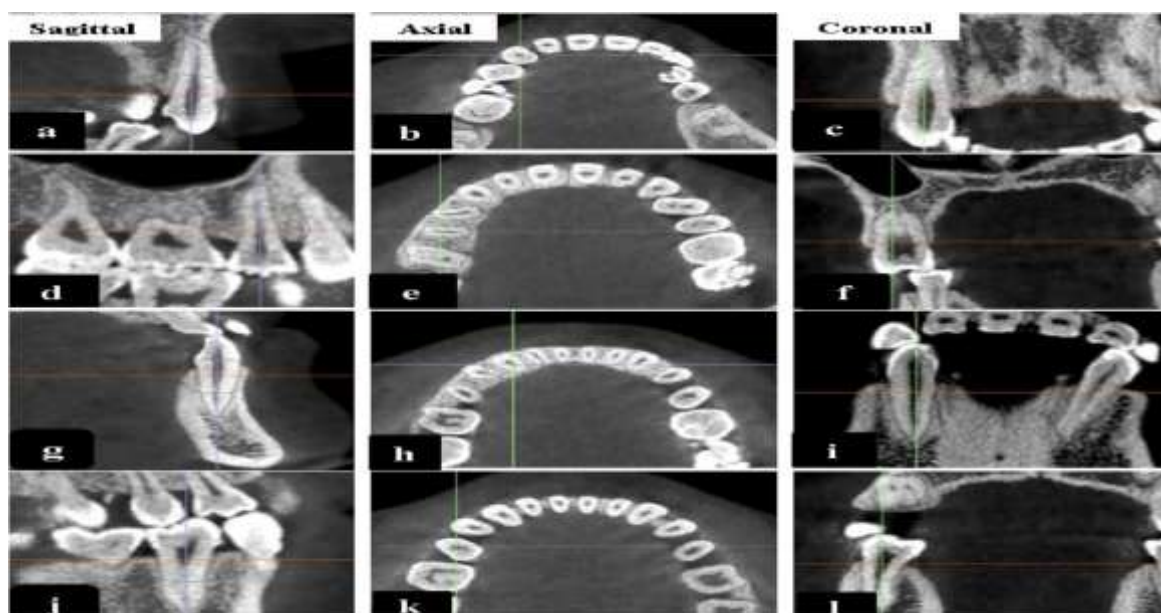


Figure 1. CBCT assessment of tooth roots

Three-dimensional reconstruction and registration

Volumetric images, where available, should be imported into validated imaging software. Each tooth should be segmented separately, with a consistent method for defining the crown-root boundary, root apex, and root axis.^{3,5}

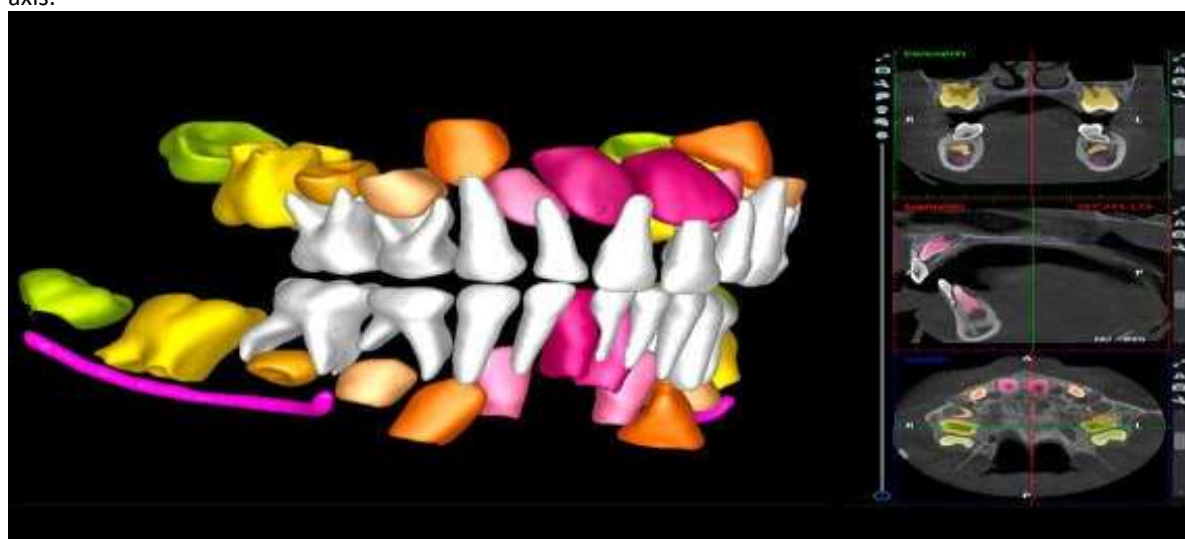


Figure 2. Three-dimensional tooth segmentation

The segmentation protocol should specify:

- Software name and version.
- Thresholding and manual-correction procedures.
- Root-apex identification criteria.
- Treatment of image artifacts and restorations.
- Quality-control and examiner-calibration procedures.⁵

The tooth models should then be aligned using a prespecified coordinate system. A suitable system may define the X-axis as mediolateral, the Y-axis as anteroposterior, and the Z-axis as vertical. Positive directions must be defined explicitly.

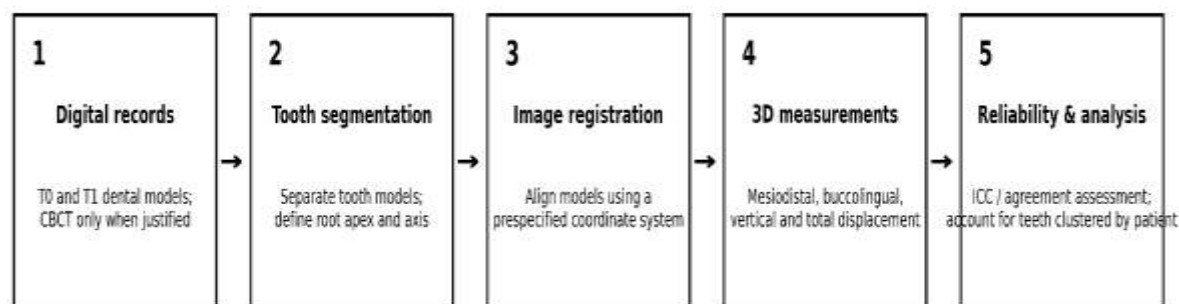


Figure 3. Three-dimensional root position assessment: proposed workflow

Reliability assessment

A subset of images should be segmented and measured twice by the same examiner, with an appropriate interval between measurements. A second calibrated examiner should independently evaluate the same subset where feasible.

The intraclass correlation coefficient (ICC), with its 95% confidence interval, should be reported for continuous measurements. Bland–Altman analysis may be used to assess systematic differences and limits of agreement.⁶

Statistical analysis

Continuous variables should be summarized using mean $\pm$ standard deviation or median and interquartile range, depending on their distributions. Categorical variables should be reported as frequencies and percentages.^{4,6}

Paired tests may be used for T0–T1 comparisons when the unit of analysis is independent at the participant level. Because multiple teeth from each participant are correlated, tooth-level analyses should use mixed-effects models or another appropriate method that accounts for clustering.⁷

Effect estimates should be reported with 95% confidence intervals and exact p-values. A significance threshold of $p < 0.05$ may be specified in advance, but statistical significance should not replace assessment of clinical relevance.⁸

Results

Participant characteristics

In the working example, 30 participants were enrolled and 28 completed the planned assessment, corresponding to a completion proportion of 93.3%. Two participants were not included in the completed assessment, representing 6.7% of those initially enrolled. The reasons for non-completion should be reported using the actual study records.⁹

Table 1. Illustrative participant and treatment characteristics

Characteristic	Example value
Participants enrolled	30
Participants completing follow-up	28 (93.3%)
Participants not completing follow-up	2 (6.7%)
Teeth assessed	280
Mean age	Actual mean $\pm$ SD Actual mean $\pm$ SD
Age range	Actual range
Sex distribution	Actual and n and %

Mean treatment duration	Actual mean± SD Actual mean ± SD
Fixed-appliance treatment	18 (64.3%)
Clear-aligner treatment	10 (35.7%)*

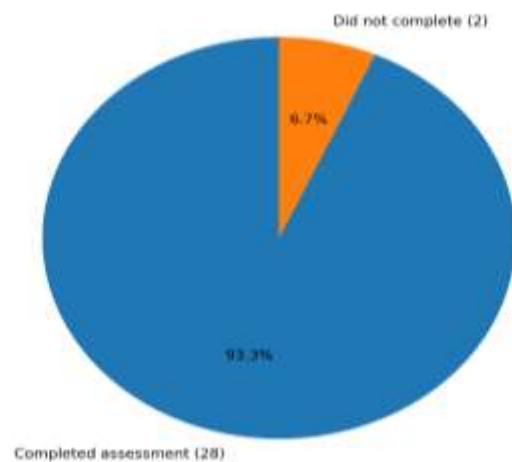


Figure 4. Patient follow up status

Three-dimensional root displacement

The illustrative tooth-level dataset contains 112 incisors, 56 canines, 56 premolars, and 56 molars. The proposed analysis evaluates displacement along three axes and calculates total three-dimensional displacement for each tooth.¹⁰

Table 2. Three-dimensional root-displacement measurements

Tooth group	Teeth (n)	Mesiodistal (mm)	Buccolingual (mm)	Vertical (mm)	Total 3D (mm)
Incisors	112	1.20 ± 0.55	1.45 ± 0.70	0.85 ± 0.42	2.25 ± 0.82
Canines	56	1.10 ± 0.48	1.30 ± 0.62	0.70 ± 0.38	2.05 ± 0.75
Premolars	56	1.35 ± 0.60	1.15 ± 0.58	0.95 ± 0.45	2.20 ± 0.80
Molars	56	0.90 ± 0.42	0.95 ± 0.50	0.65 ± 0.35	1.55 ± 0.62

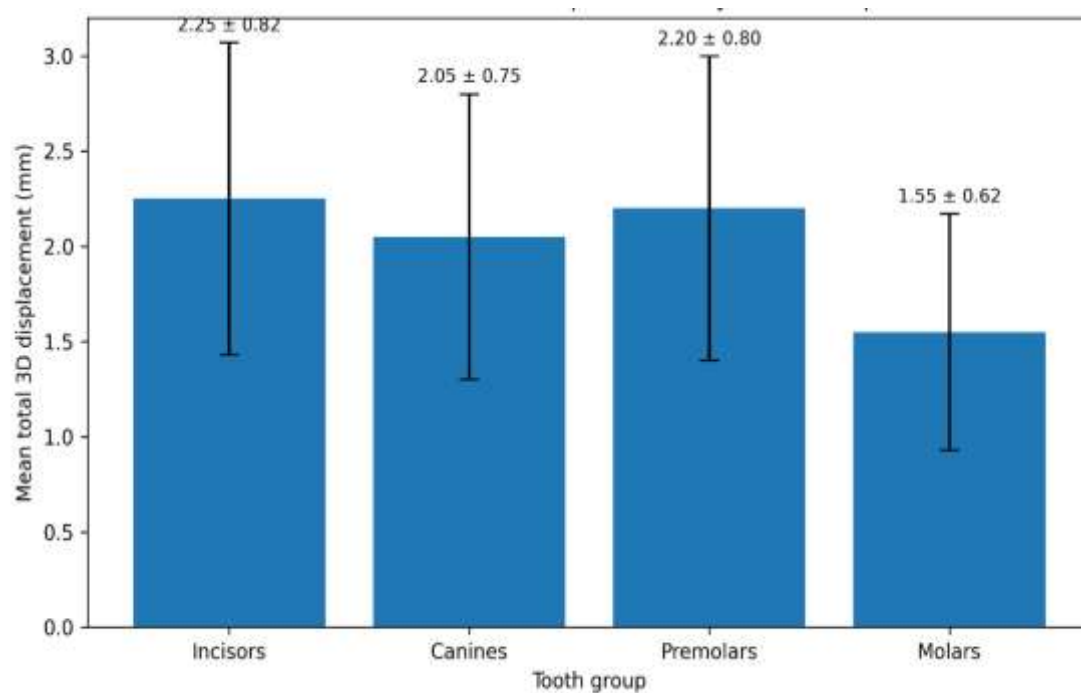


Figure 5. Mean total 3D displacement

Root angulation and root length

Table 3. Changes in root angulation and root length

Parameter	Pretreatment (T0)	Post-treatment (T1)	Mean change
Root angulation	18.5° ± 5.2°	13.8° ± 4.7°	-4.7°
Root length	14.2 ± 1.6 mm	14.0 ± 1.6 mm	-0.2 mm

Root-length change should only be reported if it can be measured using comparable, sufficiently accurate data at both time points. A root model reconstructed from pretreatment imaging and post-treatment crown scans cannot, by itself, establish the amount of post-treatment root resorption.^{8,10}

Measurement reliability

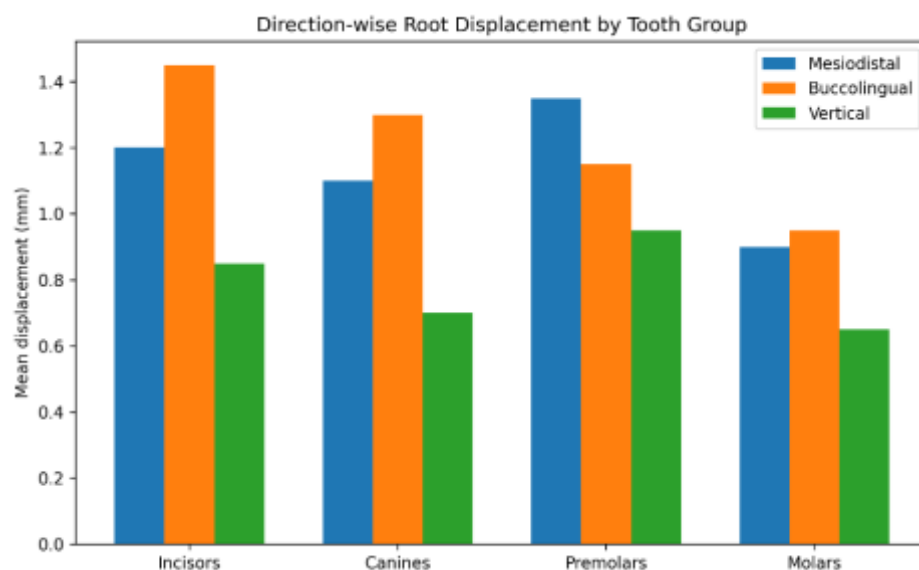


Figure 6. Direction wise root displacement

Table 4. Intra-examiner and inter-examiner reliability

Measurement	Reliability assessment	ICC	Illustrative 95% CI
Root displacement	Intra-examiner	0.94	0.90–0.97
Root displacement	Inter-examiner	0.91	0.86–0.95
Root angulation	Intra-examiner	0.92	0.87–0.96
Root angulation	Inter-examiner	0.89	0.83–0.94

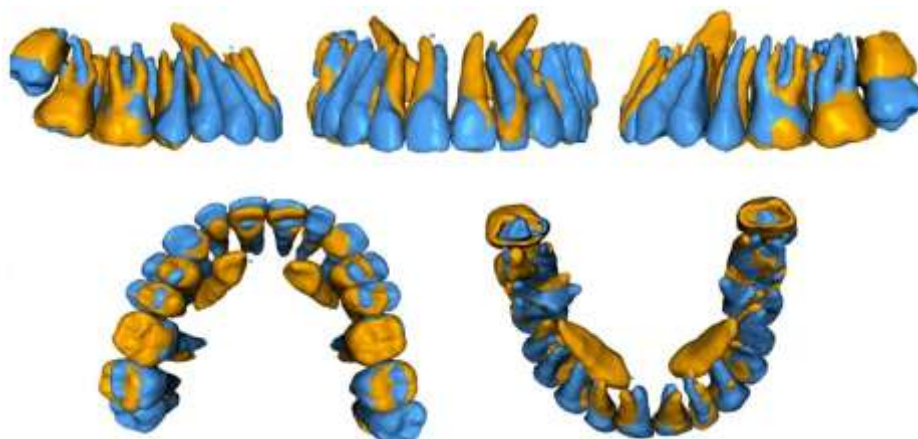


Figure 7. Pretreatment and post-treatment superimposition

Statistical comparison

A valid comparison requires the underlying individual measurements and an analysis that accounts for the correlation between multiple teeth belonging to the same participant.

The final results should report:

- Mean or median displacement by tooth group.
- Between-group differences or estimated effects with 95% confidence intervals.
- Exact p-values from the prespecified model.
- Adjustments for relevant covariates and multiple comparisons, where applicable.
- The number of participants and teeth contributing to each analysis.¹¹

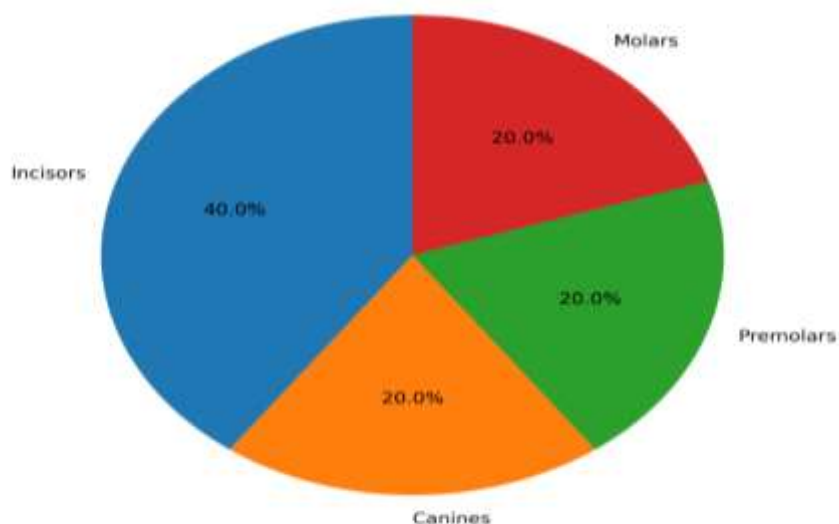


Figure 8. Distribution of assessed teeth by tooth group

Discussion

Principal findings and interpretation

Three-dimensional assessment provides a framework for quantifying orthodontic root movement beyond the information available from crown alignment alone. By evaluating displacement along defined axes and measuring changes in root orientation, researchers can describe the spatial consequences of orthodontic treatment in a standardized manner.¹²

However, the example values cannot establish which tooth group experienced the greatest displacement in a real clinical population. Such conclusions must be based on the actual dataset and a statistical model that accounts for clustering, baseline characteristics, and measurement uncertainty.^{11,13}

Advantages of three-dimensional imaging

Two-dimensional radiographs project anatomical structures onto a flat image, potentially obscuring the buccolingual position of roots. CBCT can provide volumetric information, while digital dental models can accurately represent visible crown surfaces.^{14,15}

Combining these data sources may help reconstruct root position and quantify movement. Nevertheless, estimated root position must be distinguished from directly observed post-treatment root anatomy. Segmentation thresholds, image artifacts, registration choices, and anatomical landmark identification may all influence the resulting measurements.¹⁶

Root displacement and root resorption

Root displacement and root resorption are distinct outcomes. Displacement describes movement within a spatial coordinate system, whereas resorption involves loss of root structure. A change in root position does not, on its own, demonstrate resorption.¹⁷

Systematic reviews have reported variation in orthodontically induced root resorption across tooth types, treatment characteristics, and measurement methods. These findings support the need for standardized outcome definitions and cautious interpretation of imaging-derived measurements.¹⁸

Clinical relevance

The importance of root movement depends on the intended treatment objective, root orientation, supporting alveolar anatomy, and periodontal condition. A larger displacement is not necessarily a better outcome, and a smaller displacement does not automatically indicate treatment failure.¹⁹

For example, controlled tipping and bodily movement may produce different root-position patterns despite similar crown displacement. The interpretation should therefore consider both the root reference point and the tooth's orientation.^{20,21}

Radiation safety

CBCT should be selected according to individual clinical need and the diagnostic question. A research protocol should not expose participants to additional radiation merely to complete a before-and-after dataset when the exposure is not justified. Existing clinically indicated scans may be used when appropriate, while acknowledging that their availability can introduce selection bias.^{22,23}

Strengths

The proposed framework offers several methodological advantages:

1. Quantification of movement along three spatial axes.
2. Separate measurement of displacement and root angulation.
3. A standardized registration and segmentation workflow.
4. Formal evaluation of examiner reliability.
5. Potential integration of CBCT-derived root models with digital dental surfaces.
6. Statistical methods designed to account for repeated observations and clustered tooth-level measurements.²⁴

Limitations

The principal limitations include possible segmentation error, variation in image resolution, registration uncertainty, and differences in the anatomical reference system. Reconstructed root positions based on crown scans may not reflect actual post-treatment root morphology. An observational study also cannot establish that a particular appliance or treatment mechanic caused a specific movement pattern without appropriate controls and consideration of confounding factors. If only two assessment points are included, the study cannot determine whether root position remains stable after retention.²³

Future research

Future research should investigate the accuracy of digital root reconstruction against appropriate reference methods, assess reproducibility across scanners and software platforms, and examine whether root-position measurements are associated with clinically meaningful outcomes. Automated segmentation and artificial-intelligence-assisted registration may improve efficiency, but such systems require independent validation and transparent reporting of measurement error.^{25,26}

Conclusion

Three-dimensional digital imaging provides a potentially valuable method for assessing orthodontic root-position changes following treatment. Standardized reconstruction, registration, coordinate-based measurements, and reliability testing may improve the characterization of tooth movement beyond crown alignment alone.

However, the validity of these measurements depends on imaging quality, anatomical reference selection, segmentation accuracy, and appropriate statistical analysis. CBCT must be used judiciously, and estimated root positions must not be confused with direct assessment of root morphology.

References

1. Kapila S, Conley RS, Harrell WE Jr. The current status of cone beam computed tomography imaging in orthodontics. *Dentomaxillofac Radiol.* 2011;40(1):24–34.
2. Kapila SD, Nervina JM. CBCT in orthodontics: assessment of treatment outcomes and indications for its use. *Dentomaxillofac Radiol.* 2015;44(1):20140282.
3. De Vos W, Casselman J, Swennen GRJ. Cone-beam computerized tomography imaging of the oral and maxillofacial region: a systematic review of the literature. *Int J Oral Maxillofac Surg.* 2009;38(6):609–625.
4. Ludlow JB, Timothy R, Walker C, et al. Effective dose of dental CBCT—a meta-analysis of published data and additional data for nine CBCT units. *Dentomaxillofac Radiol.* 2015;44(1):20140197.
5. Schulze R, Heil U, Gross D, et al. Artefacts in CBCT: a review. *Dentomaxillofac Radiol.* 2011;40(5):265–273.

6. Weltman B, Vig KWL, Fields HW, Shanker S, Kaizar EE. Root resorption associated with orthodontic tooth movement: a systematic review. *Am J Orthod Dentofacial Orthop.* 2010;137(4):462–476.
7. Roscoe MG, Meira JBC, Cattaneo PM. Association of orthodontic force system and root resorption: a systematic review. *Am J Orthod Dentofacial Orthop.* 2015;147(5):610–626.
8. Segal GR, Schiffman PH, Tuncay OC. Meta-analysis of the treatment-related factors of external apical root resorption. *Orthod Craniofac Res.* 2004;7(2):71–78.
9. Brezniak N, Wasserstein A. Orthodontically induced inflammatory root resorption. Part I: The basic science aspects. *Angle Orthod.* 2002;72(2):175–179.
10. Brezniak N, Wasserstein A. Orthodontically induced inflammatory root resorption. Part II: The clinical aspects. *Angle Orthod.* 2002;72(2):180–184.
11. Levander E, Malmgren O. Evaluation of the risk of root resorption during orthodontic treatment: a study of upper incisors. *Eur J Orthod.* 1988;10(1):30–38.
12. Sameshima GT, Sinclair PM. Predicting and preventing root resorption: Part I. Diagnostic factors. *Am J Orthod Dentofacial Orthop.* 2001;119(5):505–510.
13. Sameshima GT, Sinclair PM. Predicting and preventing root resorption: Part II. Treatment factors. *Am J Orthod Dentofacial Orthop.* 2001;119(5):511–515.
14. Dudic A, Giannopoulou C, Leuzinger M, Kiliaridis S. Detection of apical root resorption after orthodontic treatment by using panoramic radiography and cone-beam computed tomography of super-high resolution. *Am J Orthod Dentofacial Orthop.* 2009;135(4):434–437.
15. Gröndahl K, Hansen K, Gröndahl HG. Apical root resorption during orthodontic treatment: a prospective study using cone beam CT. *Angle Orthod.* 2012;82(3):480–487.
16. Leach HA, Ireland AJ, Whaites EJ. Radiographic diagnosis of root resorption in relation to orthodontics. *Br Dent J.* 2001;190(1):16–22.
17. Patel S, Dawood A, Whaites E, Pitt Ford T. New dimensions in endodontic imaging: part 1. Conventional and alternative radiographic systems. *Int Endod J.* 2009;42(6):447–462.
18. Hatcher DC. Operational principles for cone-beam computed tomography. *J Am Dent Assoc.* 2010;141 Suppl 3:3S–6S.
19. Graber LW, Vanarsdall RL, Vig KWL, Huang GJ, Orthodontics: Current Principles and Techniques. 6th ed. Elsevier; 2017.
20. Andrews LF. The six keys to normal occlusion. *Am J Orthod.* 1972;62(3):296–309.
21. Gribel BF, Gribel MN, Frazao DC, McNamara JA Jr, Manzi FR. Accuracy and reliability of craniometric measurements on lateral cephalometry and 3D measurements on CBCT scans. *Angle Orthod.* 2011;81(1):26–35.
22. Ludlow JB, Gubler M, Cevdanes L, Mol A. Precision of cephalometric landmark identification: cone-beam computed tomography vs conventional cephalometric views. *Am J Orthod Dentofacial Orthop.* 2009;136(3):312.e1–312.e10.
23. van der Meer WJ, Andriessen FS, Wismeijer D, Ren Y. Application of intra-oral dental scanners in the digital workflow of implantology. *PLoS One.* 2012;7(8):e43312.
24. Ender A, Mehl A. Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. *J Prosthet Dent.* 2013;109(2):121–128.
25. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med.* 2016;15(2):155–163.
26. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet.* 1986;1(8476):307–310.