TITLE PAGE:

Three-dimensional prediction of roots position through Cone-Beam Computed Tomography scans-digital model superimposition: a novel method

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been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the [Version of Record](#). Please cite this article as [doi: 10.1111/ocr.12252](#)

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Number of words for the abstract: 231

Number of words for the manuscript: 3025

ACKNOWLEDGMENTS

We would like to express sincere gratitude to Ass. Prof. Dalstra Michel and Mr. Decesari Davide for their sincere commitment, and great support with software programs.

DISCLOSURE STATEMENT:

All authors (both the corresponding author and co-authors) disclose any potential sources of conflict of interest.

ABSTRACT AND KEYWORDS:

Objectives: To introduce a new, fast, reliable, and free from software-related bias method to predict three-dimensionally the root position and angulation during and after orthodontic treatment. The final goal is to keep to a minimum the use of ionizing radiation by eliminating the necessity of multiple radiation exposure for checking root alignment.

Setting and Sample Population: Pre- and post-treatment digital models and CBCT scans from a patient were retrieved.

Material and Methods: The post-treatment digital model (post-model) was set as the reference; pre- and post-treatment CBCT scans were pre-aligned to the post-model with a point set registration; iterative closest point algorithm was then employed for final adjustments. The accuracy of the proposed method was assessed by comparing the average distance between the expected root position setup with the true position of the roots, as from the post-treatment CBCT.

Results: After crown superimposition, 3D color maps showed that the accuracy of the root prediction was below 0.1 mm.

Conclusion: The proposed digital workflow allows to predict in an accurate and truly three-dimensional way the final position of roots, when an initial CBCT is available, without the need of an extra X-ray examination for the patient at the end of treatment. The limitation of the exposure to mid- and post- treatment x-rays is in accordance with the ALARA (As Low As Reasonably Achievable) principle and it is even more relevant in growing patients.

KEYWORDS:

CBCT, intra-oral scans, image segmentation, orthodontics, three-dimensional imaging

Short Title:

Three-dimensional prediction of roots position

Article type : Original Article

TITLE:

Three-dimensional prediction of roots position through Cone-Beam Computed Tomography scans-digital model superimposition: a novel method

INTRODUCTION

In orthodontics, clinicians require several radiographic examinations for three-dimensional monitoring of root movement during treatment and/or after treatment completion (ectopic/impacted teeth, critical tooth movements in periodontally compromised patients, surgical patients): indeed, risk of relapse, periodontal damage, fenestration and dehiscences may be influenced by improper root positions.^{1,2}

The visualization of initial and final root position represents a key factor for planning a successful treatment, preventing adverse consequences and improving the long-term stability of clinical outcomes.^{3,4}

Owing to the geometric distortion and magnification artifacts in orthopantomography (OTP), cone-beam computed tomographic (CBCT) examinations are best suited for assessing root angulation and parallelism.⁵⁻⁷

Lee et al. have validated two protocols of integration of pre-treatment CBCT teeth into post-treatment model, in order to predict the root position.^{8,9}

These procedures still encounter some difficulties during the data segmentation and fusion; issues in this methodology may be found at operator-related and software-related levels:

- 1) the threshold segmentation of each tooth from the body structures, as the author reported, is quite time-consuming for a daily use in a clinical setting; moreover, a time-lasting process

should be prone to affect the operator burden-to-fatigue, leading to stress-related segmentation bias;¹⁰

- 2) manual adjustments are required to refine CBCT segmentation and minimize the amount of bone surrounding the root, again introducing bias related to operators' experience;
- 3) cutting tools create a rough separation between crown and root portions, leading to cementum-enamel junction inconsistencies between different teeth.

In order to solve the above-mentioned limitations, this study aims to validate a new direct protocol to merge three-dimensional (3D) data from CBCT scans with digital models, which allows to predict root positions during and at the end of treatment without the use of extra radiation.

MATERIALS AND METHODS

Data collection

A post-treatment digital model (post-model), a pre-treatment CBCT scan (pre-CBCT) and a post-treatment CBCT scan (post-CBCT) scans of a patient were retrieved from the database of the Section of Orthodontics of XXXXX. All data were anonymized.

Trios Color® intraoral scanner (3Shape Dental Systems, Copenhagen, Denmark) was used to scan digitally the maxillary and mandibular arches, resulting in a stereolithography file (STL) of the post-model crowns of the patient's teeth in high resolution.

CBCT-scans had been carried out following the protocol approved by the Radiological Department, XXXX.

The patient chosen was a 20 years-old girl with a skeletal open bite and facial asymmetry; a large field of view CBCT-scan (18 x 16 cm) was available at T0, before undergoing bimaxillary surgery, and at T1, after surgical intervention. All CBCT-scans were acquired using the NewTom 5G (QR, Verona, Italy) with the following acquisition parameters: 3-7 mA, 110 kV, 18s scanning time, 360° rotation angle, 360 projections. The CBCT-images were reconstructed with a 0.30 mm isotropic voxel dimension.

Data preparation

The CBCT-scans were exported in the DICOM format and imported into Amira® software (version 5.2.2; Mercury Computer Systems, Inc., Chelmsford, USA).

After applying the appropriate threshold value (1350-3790 for the pre-CBCT and 980-2870 for the post-CBCT) and adjusting color balance, the relevant structures (i.e. roots and crowns) were rightmosty outlined on all the XY (sagittal) view of CBCT (supplementary figure 1). Then, the “magic wand” tool was used to refine the manual thresholding, by using an algorithm that looks at

the gradient of the neighboring voxels. All the slices were thus interpolated, and a “mask” of the tooth was generated (supplementary figure 2). Finally, the “mask” was converted to a 3D object, with the help of the marching cubes algorithm. (supplementary figure 3).

Each tooth isolated from the pre-CBCT scans was individually exported using the STL file format, in order to be superimposed independently onto the post-model, whereas post-CBCT maxillary and mandibular arches were saved as two single entities, in order to maintain the post-treatment arch forms.

The post-model was imported into OnyxCeph[®] software (version 3.2.36; Image Instruments GmbH, Chemnitz, Germany) where the crowns were separated from the gingiva; maxillary and mandibular dental arches were exported as independent STL files.

Integration of the CBCT roots into the post-model

We set the post-model as a fixed entity of the 3D registration, and the pre-CBCT single teeth were superimposed on it. The Geomagic[®] software (version 2014; 3D Systems, Rock Hill, SC, USA) was used to overlay the crowns created using the CBCT data were matched to the crowns of the digital model through a biphasic sequential registration procedure.

Three points on each pre-CBCT and post-cast crown were selected to perform a pre-alignment of the STL files; then, an iterative closest point registration (best-fit method) to bring the isolated pre-CBCT crowns close to the digital model was applied.¹¹ Roots are carried along with the pre-CBCT crowns and merged with post-cast model. The virtual model resulting from pre-CBCT/post-model superimposition represents the “expected root position” (ERP) setup; it is defined as a prediction of the three-dimensional position of the roots after the orthodontic treatment. Then, maxillary and mandibular post-CBCT arches were pre-registered separately on their corresponding post-model, using a 5-points protocol as proposed by De Waard et al.;¹² iterative closest point algorithm was applied to finalize the 3D objects registration.

The virtual model resulting from superimposing and combining the post-CBCT and the post-model represents the “true root position” (TRP) setup, as the post-CBCT depicts the three-dimensional position of the roots (Figure 1).

Accuracy of the method

A 3D color map was used to visualize magnitude of movement at any location between two given 3D surface models. The maximum critical distance between the 3D objects was set at ± 0.5 mm, considering that the two most common voxel sizes used for orthodontic CBCT scans are between 0.3 and 0.4 mm, thus resulting in a spatial resolution of about 0.7 mm.¹³

In order to assess the accuracy of the iterative closest point superimposition, color maps were generated to visualize the distribution and the extent of the changes occurred between:

- pre-CBCT/post-model
- post-CBCT/post-model
- ERP/TRP (Figure 2)

The ERP and TRP .stl files were then imported into Mimics[®] software (version 21.0; Materialise, Leuven, Belgium) to calculate angular distances between ERP and TRP. Reference landmarks in linear measurements were identified on the root apices of incisors and canines; the buccal root was evaluated for premolars, the palatal root for maxillary molars, and the distal root for lower molars. Center of the angle between the root apices of the ERP and the TRP was identified on the crown of the post-model: it was located on the mesial incisal edge of incisors, on the zenith of the vestibular cusp of canines and premolars, on the zenith of the mesial cusp of maxillary molars, and on the zenith of the distal cusp of mandibular molars.

Reliability

All procedures were repeated twice by two operators, with an interval of at least two weeks between the measurements. The two investigators, previously calibrated for segmentation and STL registration, starting from the same data source and setting (i.e. same computer, same monitor, same protocol), generated different 3D models.

The technical error of the method(s) was calculated for both the intra- and inter- operator agreement using the Dahlberg's formula ($s = \sqrt{\sum d^2 / 2n}$, where d = difference between repeated measurements).¹⁴ Bland-Altman plot was applied to evaluate the mean difference distribution.¹⁵ All calculations were performed using SPSS (version 24.0; IBM Corp., Armonk, NY, USA).

RESULTS

On average, the accuracy of the registration pre-CBCT/post-model showed a mean displacement below 0.2 mm (Table 1); the accuracy of the registration post-CBCT/post-model showed a mean displacement below 0.7 mm (Table 2); the accuracy of the method from direct superimposition of the ERP setup on the TRP showed a mean displacement below 0.1 mm (Table 3).

Angular distances between the pre- and post-CBCT showed an average error of 2.09°. (Supplementary Table 1)

Regarding the reliability of the method, the error calculated from the Dahlberg formula was 0.06 for both intra- and inter-operator agreement (Table 3). The Bland-Altman plots showed good reliability of the method and no systematic errors both for the intra- and for inter-operator comparison were detected (Figures 3A and 3B).

DISCUSSION

Digital models are becoming the gold standard for measuring tooth size, arch width and length, occlusal and irregularity indices, and Bolton ratio;¹⁶ however, root position cannot be accurately assumed from crown inclination in a clinical situation.¹⁷

To identify three-dimensionally the root position before treatment, CBCT seems to be the method of choice, and this constitutes the rationale for its use in orthodontic treatment planning of complex cases. For example, in order to assess accurately the position and inclination of impacted teeth in relation to the neighboring roots and the alveolar bone boundaries, this 3D radiographic approach represents the key to ascertain treatment prognosis.¹⁸ With the development of the computer-aided technology, the digital set-up allows the dentist to determine the final position of the crowns before the treatment starts.¹⁹ As a consequence, this give the unprecedented opportunity, of paramount importance, to determine before treatment start the final position of the roots.

Clinicians often require multiple CBCTs for monitoring and determining the final root position in complex cases; however, due to ethical implications, the justification of such radiation dose has been a matter of constant discussion, especially in a pediatric population.²⁰

The present novel approach opens the doors to clinical scenarios for cases where a pre-operative CBCT radiograph is still mandatory (e.g. impacted and ectopic teeth, critical tooth movements in periodontally compromised patients, surgery first cases) but progress and post-treatment OTP and/or CBCT scans could be avoided.²¹⁻²³ Type and amount of tooth movement could be carefully planned by clinicians taking in consideration both the position of the roots of contiguous teeth as well as the thickness and the morphology of the alveolar bone envelop.²⁴⁻²⁶

Direct superimposition between ERP and TRP was tested to be accurate through the color maps and demonstrated a clinically acceptable level of agreement. The average angular error was 2.09°, which is below the clinical minimum detectable angle of the human eye.²⁷ The proposed method achieves a similar or better level of precision as compared to what has been reported by other studies.^{8,9}

Strenghts and limitations of the method

Segmentation: the innovation of the proposed method lies in the ability to obtain a semi-automatic segmentation, avoiding the need of manual adjustments or post-processing tools

(smoothing, wrapping, triangle reduction) that may be time-consuming and cause further distortions of the actual roots' anatomy.^{8,9}

Integration of CBCT into digital model: the segmentation of the crowns on the digital model prior to the 3D objects registration allows an easier surface fitting, without the need of selecting the crown portion of each tooth.

3D comparison: the avoidance of the manual separation through the cutting tools of the crown from the root portion of CBCT teeth, as proposed by Lee,⁹ limits the manual operation of adding or subtracting tooth structure, which might result in discrepancies at the cementum-enamel junction level.

In the present study, the evaluation of the accuracy of segmentation was tested on the crown of the teeth; indeed, further studies are needed to create a ground truth image for segmentation of the roots in digital image processing.

Even though the present method has proven to be accurate and feasible, it is not completely artifact-free, since some manual steps are still needed in the digital workflow: CBCT and model segmentation, 3D objects registration and comparison.^{8,9,27} Moreover, this method requires a steep learning curve: assuming that the clinician has some knowledge in 3D image processing, 2-3 hours are necessary to get familiar with software packages, although to reach an expert level takes considerably longer.

In a research environment, the abovementioned approach has endless potential for construction of 3D anatomical model and morphometric analysis, yet for a clinical use, costs of software, computer system requirements, and time, represent major disadvantages of these technologies.^{28,29} The whole procedure (i.e. from segmentation to integration into digital cast, including 3D comparison) takes approximately 30 minutes per tooth to be completed; however, the first two steps that are needed in a routine workflow will take less than half this time with the nowadays state-of-art tools.

Thus, in order to make this methodology applicable in a clinical context, a user-friendly interface, allowing also non-experienced operators to perform quick and reliable manipulation of digital data, is needed.³⁰

CONCLUSION

The integration of CBCTs scans into digital models has the potential to have a clinical impact in respect to ionizing radiation exposure: it provides a framework to achieve precise 3D simulation of

root alignment and position during and after orthodontic treatment yet eliminating the necessity of multiple radiation exposures. This radiation reduction to the patient, yet maintaining or even improving the level of precision and accuracy in the treatment, supports the concept of moving from "As Low As Reasonably Achievable" (ALARA) to "As Low As Diagnostically Acceptable" (ALADA).^{31,32}

REFERENCES:

1. Bert JD. Differential diagnosis and treatment of root angulation problems. *Dent Clin North Am.* 1981;25(1):85-93.
2. Van Elslande D, Heo G, Flores-Mir C, Carey J, Major PW. Accuracy of mesiodistal root angulation projected by cone-beam computed tomographic panoramic-like images. *Am J Orthod Dentofacial Orthop.* 2010;137(4 Suppl):S94-99.
3. Mills JR. The long-term results of the proclination of lower incisors. *Br Dent J.* 1966;120(8):355-363.
4. 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(6):442-451.
5. 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(1):93-99.
6. Owens AM, Johal A. Near-end of treatment panoramic radiograph in the assessment of mesiodistal root angulation. *Angle Orthod.* 2008;78(3):475-481.

7. Peck JL, Sameshima GT, Miller A, Worth P, Hatcher DC. Mesiodistal root angulation using panoramic and cone beam CT. *Angle Orthod*. 2007;77(2):206-213.
8. Lee RJ, Pham J, Choy M, 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(3):399-409.
9. Lee RJ, Weissheimer A, Pham J, et al. Three-dimensional monitoring of root movement during orthodontic treatment. *Am J Orthod Dentofacial Orthop*. 2015;147(1):132-142.
10. Lin HH, Chiang WC, Lo LJ, Sheng-Pin Hsu S, Wang CH, Wan SY. Artifact-resistant superimposition of digital dental models and cone-beam computed tomography images. *J Oral Maxillofac Surg*. 2013;71(11):1933-1947.
11. Park TJ, Lee SH, Lee KS. A method for mandibular dental arch superimposition using 3D cone beam CT and orthodontic 3D digital model. *Korean J Orthod*. 2012;42(4):169-181.
12. de Waard O, Rangel FA, Fudalej PS, Bronkhorst EM, Kuijpers-Jagtman AM, Breuning KH. Reproducibility and accuracy of linear measurements on dental models derived from cone-beam computed tomography compared with digital dental casts. *Am J Orthod Dentofacial Orthop*. 2014;146(3):328-336.
13. Cattaneo PM, Treccani M, Carlsson K, et al. Transversal maxillary dento-alveolar changes in patients treated with active and passive self-ligating brackets: a randomized clinical trial using CBCT-scans and digital models. *Orthod Craniofac Res*. 2011;14(4):222-233.
14. Springate SD. The effect of sample size and bias on the reliability of estimates of error: a comparative study of Dahlberg's formula. *Eur J Orthod*. 2012;34(2):158-163.
15. Donatelli RE, Lee SJ. How to report reliability in orthodontic research: Part 2. *Am J Orthod Dentofacial Orthop*. 2013;144(2):315-318.
16. Fleming PS, Marinho V, Johal A. Orthodontic measurements on digital study models compared with plaster models: a systematic review. *Orthod Craniofac Res*. 2011;14(1):1-16.
17. Carlsson R, Ronnerman A. Crown-root angles of upper central incisors. *Am J Orthod*. 1973;64(2):147-154.
18. Tong H, Kwon D, Shi J, Sakai N, Enciso R, Sameshima GT. Mesiodistal angulation and faciolingual inclination of each whole tooth in 3-dimensional space in patients with near-normal occlusion. *Am J Orthod Dentofacial Orthop*. 2012;141(5):604-617.
19. Grauer D, Proffit WR. Accuracy in tooth positioning with a fully customized lingual orthodontic appliance. *Am J Orthod Dentofacial Orthop*. 2011;140(3):433-443.
20. 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.

21. Garib DG, Calil LR, Leal CR, Janson G. Is there a consensus for CBCT use in Orthodontics? *Dental Press J Orthod*. 2014;19(5):136-149.
22. Yeo BR, Han JJ, Jung S, Park HJ, Oh HK, Kook MS. Horizontal changes of the proximal mandibular segment after mandibular setback surgery using 3-dimensional computed tomography data. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2018;125(1):14-19.
23. 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(5):640 e641-645.
24. Miresmaeili A, Basafa M, Mahvelati Shamsabadi R, Farhadian N, Moghymbeigi A, Mollabashi V. Treatment decision analysis for palatally-displaced canines based on orthodontists' opinion and CBCT. *Int Orthod*. 2017;15(4):625-639.
25. SD K. *Cone Beam Computed Tomography in Orthodontics: indications, insights, and innovations*. 1 ed. Ames, Iowa: John Wiley & Sons, Inc.; 2014.
26. Shewinvanakitkul W, Hans MG, Narendran S, Martin Palomo J. Measuring buccolingual inclination of mandibular canines and first molars using CBCT. *Orthod Craniofac Res*. 2011;14(3):168-174.
27. Moesi B, Dyer F, Benson PE. Roth versus MBT: does bracket prescription have an effect on the subjective outcome of pre-adjusted edgewise treatment? *Eur J Orthod*. 2013;35(2):236-43.
28. Lee RJ, Pham J, Weissheimer A, Tong H. Generating an Ideal Virtual Setup with Three-Dimensional Crowns and Roots. *J Clin Orthod*. 2015;49(11):696-700.
29. Martin CM, Roach VA, Nguyen N, Rice CL, Wilson TD. Comparison of 3D reconstructive technologies used for morphometric research and the translation of knowledge using a decision matrix. *Anat Sci Educ*. 2013;6(6):393-403.
30. Xi T, Schreurs R, Heerink WJ, Berge SJ, Maal TJ. A novel region-growing based semi-automatic segmentation protocol for three-dimensional condylar reconstruction using cone beam computed tomography (CBCT). *PLoS One*. 2014;9(11):e111126.
31. Jaju PP, Jaju SP. Cone-beam computed tomography: Time to move from ALARA to ALADA. *Imaging Sci Dent*. 2015;45(4):263-265.
32. Kapila SD, Nervina JM. CBCT in orthodontics: assessment of treatment outcomes and indications for its use. *Dentomaxillofac Radiol*. 2015;44(1):20140282.

FIGURE LEGENDS:

Figure 1. Superimposition process used to generate expected root position (ERP = yellow), true root position (TRP = green) and to compare them.

Figure 2. Color maps showing 3D displacements between: A) pre-CBCT and post-model; B) post-CBCT and post-model; C) ERP and TRP.

Red indicates outward displacement of ERP in relation to TRP, blue indicates inward displacement, an absence of displacement is indicated by the green color code.

Figure 3. Bland-Altman plots showing: A) intra-operator agreement; B) inter-operator agreement.

Supplementary figure 1. After threshold segmentation, the relevant structures (i.e. roots and crowns) are rightmosty outlined on all the XY (sagittal) view of CBCT.

Supplementary figure 2. Interpolation of all the slices generates a mask of the tooth (red).

Supplementary figure 3. The mask is converted to a 3D object.

TABLES:

Table 1. Mean Euclidean distances between pre-CBCT and post-model.

Tooth	I Operator		II Operator	
	T ₀	T ₁	T ₀	T ₁
	(mm)	(mm)	(mm)	(mm)
MAXILLA				
Central incisors	-0,15	-0,10	-0,12	-0,18
Lateral incisors	-0,15	-0,04	-0,22	-0,12
Canines	-0,26	-0,03	-0,16	-0,05
First premolars	-0,07	-0,04	-0,02	0,13
Second premolars	-0,14	0,00	-0,06	-0,04
First molars	-0,09	-0,06	-0,05	-0,14
Second molars	-0,05	0,03	0,01	-0,12
MANDIBLE				
Central incisors	-0,22	-0,27	-0,21	-0,24
Lateral incisors	-0,21	-0,27	-0,20	-0,25
Canines	-0,17	-0,23	-0,20	-0,21
First premolars	-0,08	-0,08	-0,14	-0,21

Second premolars	-0,14	-0,12	-0,25	-0,30
First molars	-0,04	-0,07	-0,09	-0,22
Second molars	0,01	0,09	0,02	-0,14
MEAN	-0,13	-0,08	-0,12	-0,17
SD	0,09	0,12	0,10	0,10
DAHLBERG				
Intra-operator	0,09			0,09
Inter-operator		0,06		

T₀: first set of measurements

T₁: second set of measurements (after two weeks)

MEAN: average

Table 2. Mean Euclidean distances between post-CBCT and post-model.

Arch	I Operator		II Operator	
	T ₀	T ₁	T ₀	T ₁
	(mm)	(mm)	(mm)	(mm)
Maxilla	-0,59	-0,59	-0,60	-0,58
Mandible	-0,65	-0,66	-0,66	-0,66
MEAN	-0,62	-0,62	-0,63	-0,62
SD	0,05	0,05	0,04	0,05
DAHLBERG				
Intra-operator	0,00		0,01	
Inter-operator	0,01			

T₀: first set of measurements

T₁: second set of measurements (after two weeks)

MEAN: average

Table 3. Mean Euclidean (ME) distances, Maximum distances and Standard Deviation (SD) of ME distances between ERP and TRP.

Tooth	Mean Euclidean distances				Maximum distances				Standard Deviation of ME distances			
	I Operator		II Operator		I Operator		II Operator		I Operator		II Operator	
	T ₀	T ₁	T ₀	T ₁	Max	Min	Max	Min	T ₀	T ₁	T ₀	T ₁
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
MAXILLA												
Central incisors	-0,04	-0,05	0,01	-0,09	1,74	-1,85	1,18	-1,23	0,22	0,81	0,32	0,45
Lateral incisors	0,08	-0,04	0,11	0,07	1,94	-1,82	1,30	-1,53	0,77	0,66	0,63	0,43
Canines	0,05	0,03	-0,01	-0,01	1,05	-1,36	1,28	-1,25	0,41	0,30	0,46	0,49
First premolars	0,10	0,01	0,10	0,01	1,60	-1,23	1,48	-1,41	0,60	0,41	0,72	0,29
Second premolars	0,08	-0,01	0,02	-0,01	1,05	-1,59	1,78	-1,24	0,36	0,33	0,39	0,49
First molars	-0,04	0,01	-0,00	-0,03	1,07	-1,58	1,22	-1,77	0,24	0,24	0,30	0,20
Second molars	-0,06	0,02	-0,04	-0,05	1,44	-1,54	2,11	-2,40	0,28	0,28	0,45	0,46
MANDIBLE												
Central incisors	0,04	0,06	-0,04	-0,04	0,90	-1,18	0,99	-1,69	0,57	0,20	0,73	0,28
Lateral incisors	0,03	0,02	0,07	-0,05	1,14	-1,30	1,43	-1,74	0,67	0,27	0,47	0,52
Canines	0,05	-0,03	0,09	0,04	1,67	-1,67	1,12	-1,56	0,71	0,50	0,70	0,41
First premolars	0,08	0,09	0,01	0,04	1,17	-1,24	1,86	-2,10	0,27	0,39	0,77	0,76
Second premolars	-0,03	-0,07	0,07	-0,03	0,89	-1,03	1,18	-1,03	0,31	0,23	0,38	0,24
First molars	0,08	0,02	-0,01	0,00	1,04	-1,52	1,95	-2,50	0,32	0,31	0,40	0,47
Second molars	-0,01	-0,01	-0,14	-0,05	0,87	-2,13	1,91	-1,96	0,51	0,30	0,47	0,54
MEAN	0,03	0,01	0,01	-0,01	1,25	-1,50	1,49	-1,67	0,45	0,38	0,52	0,42
SD	0,08	0,06	0,10	0,08	0,35	0,30	0,36	0,44				
DAHLBERG												
Intra-operator	0,06		0,06		0,23		0,24					
Inter-operator	0,06				0,23							

T₀: first set of measurements

T₁: second set of measurements (after two weeks)

MEAN: average

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Title:

Three-dimensional prediction of roots position through cone-beam computed tomography scans-digital model superimposition: A novel method

Date:

2019-02-01

Citation:

Staderini, E., Guglielmi, F., Cornelis, M. A. & Cattaneo, P. M. (2019). Three-dimensional prediction of roots position through cone-beam computed tomography scans-digital model superimposition: A novel method. ORTHODONTICS & CRANIOFACIAL RESEARCH, 22 (1), pp.16-23. <https://doi.org/10.1111/ocr.12252>.

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