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Reliability of linear and angular dental measurements with the OrthoMechanics Sequential Analyzer

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Introduction: The aim of this study was to evaluate the reliability of newly developed software in the assessment of orthodontic tooth movement 3 dimensionally. **Methods:** The sample consisted of pretreatment and posttreatment computed tomography scans and plaster dental models of 20 orthodontic patients treated with a hyrax palatal expander as a part of their comprehensive orthodontic treatment. Dental-arch measurements, including arch widths, tooth inclinations, and angulation parameters, were measured on the scans using InvivoDental 3D imaging software (version 5.1; Motionview, Hixson, Tenn). The plaster dental models were laser scanned and superimposed, and measurements were obtained digitally using the new software. Agreement between the digital models and the computed tomography measurements was evaluated with intraclass correlation coefficients, paired *t* tests, and Bland-Altman plots. A *P* value of ≤0.05 was considered statistically significant. **Results:** High agreement, a nonsignificant paired *t* test, and no indication of agreement discrepancies were observed for most of the measured parameters. **Conclusions:** The results confirmed that the new software program offers a reliable tool for dental-arch measurements obtained from 3-dimensional laser-scanned models. (Am J Orthod Dentofacial Orthop 2015;147:264-9)

The assessment of orthodontic tooth movement has always been of great interest to dental clinicians and orthodontists. The magnitude of tooth movement depends mainly on the amount, duration, and direction of the force applied, the conditions of the bones and periodontal tissues, and the moment-to-force ratio.[1] Currently, methods of evaluating orthodontic tooth movement in 3 dimensions include imaging modalities such as cephalograms, computed tomography (CT), and cone-beam CT (CBCT) and the assessment of study models obtained from laser or CT scanning.[2,3] Using either CT or CBCT images not only causes radiation exposure, but also has other limitations when considered for the assessment of orthodontic tooth movement. In addition, the metallic components of the orthodontic appliances in the patient's mouth cause image distortion, which is a major drawback. The literature has also reported many previous attempts to assess tooth movement 3 dimensionally such as 3-dimensional (3D) cephalometric radiographs,[4] 3D occlusograms,[5] infrared photograms,[6] holograms,[7] and stereolithographs.[8] However, most of these attempts proved to be inconvenient for regular or routine use for assessing orthodontic tooth movement.

Digital orthodontic models were introduced with the potential of replacing plaster models as an accurate and efficient patient record. Using digital models facilitates the diagnosis and treatment planning process because they offer clinicians many advantages, such as easy

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Ahmed Ghoneima completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest; he has applied for a patent for this software but reports no other conflicts of interest.
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retrieval and transfer of information; easy manipulation to record measurements of teeth, arch sizes, and dental crowding; accurate diagnostic setups of several extraction patterns; and simple documentation of treatment progress and communications. In addition, it is an integral part of the future "paperless, plasterless office," eliminating the need for storage space and undue office management. Digital models are also used for the production of laboratory appliances and computer-aided bracket placement as well as for virtual treatment simulation.[9-11]

Studies have reported that linear and angular measurements on 3D digital model superimpositions are reliable compared with plaster models.[12-14] The purpose of this study was to test the reliability and validity of newly developed software in the assessment of tooth movement 3 dimensionally. Measurements (tipping, torquing, angular, and linear parameters) obtained digitally with the new software were compared with those obtained from the CT scans.

MATERIAL AND METHODS

The sample for this retrospective study included the pretreatment and posttreatment CT images and the 3D digital maxillary dental models of 20 orthodontic patients with transverse maxillary deficiency. The patients' ages ranged from 8 to 15 years (mean, 12.3 ± 1.9 years). They were treated with rapid maxillary expansion with the hyrax appliance as part of their comprehensive orthodontic treatment. Models included in the study had no gross dental abnormalities or obvious distortions. Models of surgically assisted palatal expansion patients were excluded to be able to use the model's incisive papilla and midpalatal raphe as reference landmarks for superimposing the laser-scanned pretreatment and posttreatment models. We used a sample that was previously collected and approved by the Indiana University institutional review board committee.[15]

Dental models were scanned using an Ortho Insight 3D laser scanner (version 5.1; Motionview, Hixson, Tenn) with scanning resolution set at 20 μ. The scan data of the pretreatment and posttreatment models were exported from the laser scanner in STL format file extension. These files were imported into the OrthoMechanics Sequential Analyzer (OMSA) (US provisional patent application 61/771,328). Pretreatment and posttreatment digital models were superimposed with the OMSA software by registering 2 points on the digital maxillary model; the first point was located at the distal end of the incisive papilla, and the second point was located distal to the first point along the midpalatal raphe. The software was programmed to automatically draw a 3D reference plane on the palatal area for the best-fit superimposition of the digital models (Fig 1).

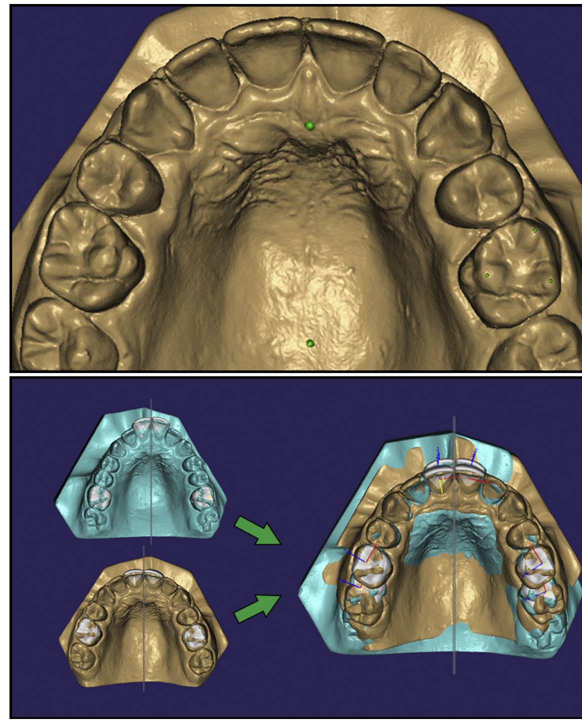

Fig 1. Superimposition of the pretreatment (*blue*) and posttreatment models based on registering 2 points (*green dots*) along the midline of the maxillary dental models. The first point is located at the distal end of the incisive papilla, and the second point is located distal to the first point along the midpalatal raphe.

A spiral CT machine (model X, vision; GE Medical Systems, Milwaukee, Wis) was used to obtain the pretreatment and posttreatment scans immediately after the hyrax appliance was removed. The CT scans were made at 120 kV and 20 mA, with a scanning time of 2 seconds per section. Scan parameters included an A2-90 scanning filter, a 25-cm field of view, and a 0.4-mm voxel size. These DICOM files were imported into the InvivoDental 3D software (version 5.1; Anatomage, San Jose, Calif). After landmark identification, 14 measurements (6 linear, 8 angular) were recorded from both the CT data and the digital models (Table 1). All parameters were measured on both the digital models using the OMSA and the CT images using InvivoDental 3D.

For the software to simulate root position, the outlines of the maxillary central incisor, canine, and first molar crowns were defined and outlined by positioning 3 dots on each tooth crown, and then an avatar (a simulated or virtual tooth and root) was automatically created for the tooth of interest (Fig 2).

Table I. Definitions of linear and angular measurements used in the study

Parameter	*Definition*
R1 torque (°)	Change in maxillary right central incisor labiolingual inclination
R1 tip (°)	Change in maxillary right central incisor mesiodistal angulation
L1 torque (°)	Change in maxillary left central incisor labiolingual inclination
L1 tip (°)	Change in maxillary left central incisor mesiodistal angulation
R6 torque (°)	Change in maxillary right first permanent molar buccolingual inclination
R6 tip (°)	Change in maxillary right first permanent molar mesiodistal angulation
L6 torque (°)	Change in maxillary left first permanent molar buccolingual inclination
L6 tip (°)	Change in maxillary left first permanent molar mesiodistal angulation
R6 translation (mm)	Distance from the maxillary right first permanent molar furcation point to the midpalatal raphe
L6 translation (mm)	Distance from the maxillary left first permanent molar furcation point to the midpalatal raphe
Intercanine width (mm)	Distance between the maxillary right and left canines cusp tips
Intermolar width (mm)	Distance between tips of the mesiobuccal cusps of maxillary right and left first permanent molars

The software was programmed to define a coordinate system related to these teeth guided by the points placed by the operator (S.T.), as explained in the previous step. The software measures the relationship between the tooth coordinates in its pretreatment and posttreatment positions. The coordinate system is composed of the 3 axes of rotation around which a body can rotate in space. The angle difference between the labiolingual and buccolingual axes of the pretreatment and posttreatment avatars is used to describe the change in torque during treatment. The difference in tooth tipping can be described from the angle between the mesiodistal axes before and after treatment. The measured linear and angular changes were recorded in Excel (Microsoft Office; Microsoft, Redmond, Wash) for comparisons with similar measurements taken from the CT images using the Invivo software (Figs 3 and 4).

Measurements on the digital models and the CT images were repeated under the same conditions with a time interval of 1 week. All measurements were made by the same examiner (S.T.). Reliability was estimated as the extent to which the measurements on the digital models and the CT images were repeatable under the same conditions. Validity was considered as the extent to which the measurements on the digital models and the CT images yielded equal results.

Statistical analysis

Statistical analysis was carried out using SPSS software (version 12.0.1; SPSS, Chicago, Ill). Intraobserver reliability was assessed by calculating intraclass correlation coefficients (ICC). Agreement between the digital models and the CT measurements was evaluated using ICC, paired t tests, and Bland-Altman[16] plots. A P value of ≤ 0.05 was considered statistically significant.

RESULTS

The means, standard errors, significant differences as expressed by P values, and levels of agreement between digital model and CT measurements expressed by ICC are presented in Table II. High agreement (ICC >0.9), a nonsignificant paired t test, and no agreement discrepancies were observed for R1 torque, L1 torque, L1 tip, R6 tip, L6 tip, L6 torque, L6 translation, and intercanine pretreatment, intercanine posttreatment, and intermolar posttreatment distances. R1 torque had a high ICC and no significant mean difference, but the Bland-Altman[16] plot showed that the amount of disagreement between the methods was greater for higher measurements. R1 tip was consistently higher for the digital models than for CT, and the discrepancy was greater for higher measurements. R6 torque was consistently lower for the digital models than for CT. R6 tip showed good agreement (ICC = 0.88), with some indication of more disagreement for higher measurements. L6 tip showed moderate agreement (ICC = 0.82), with 1 outlier with great disagreement. R6 translation was generally higher for the digital models than for CT. L6 translation had the lowest agreement among all measurements. Statistically significant differences were detected in R1 tip, R6 torque, R6 translation, and intermolar width; however, these differences are not clinically significant because they were less than 1 mm for the R6 translation and intermolar width, and less than 1° for R1 tip and R6 torque.

DISCUSSION

Assessment of orthodontic tooth movement is an important way to measure the treatment outcomes. The OMSA is a new software program that was developed to help orthodontists in the assessment of tooth movement. The aim is to provide a tool that allows fast and easy evaluation of treatment progress in a 3D manner. Tooth tipping, torquing, and other linear and angular parameters can be measured without exposing the patient to additional radiation and without image

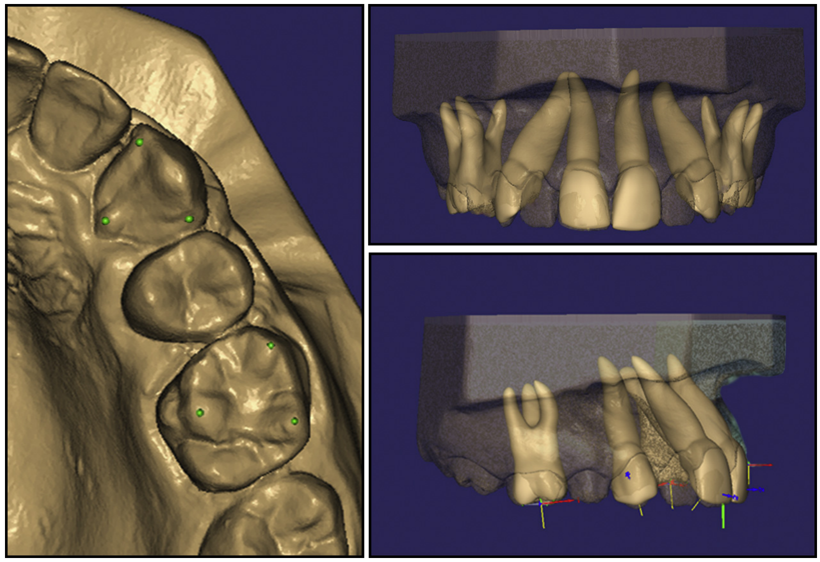

Fig 2. The software calculates the root position by locating certain points (*green dots*) on the tooth crowns defining the outlines of these teeth.

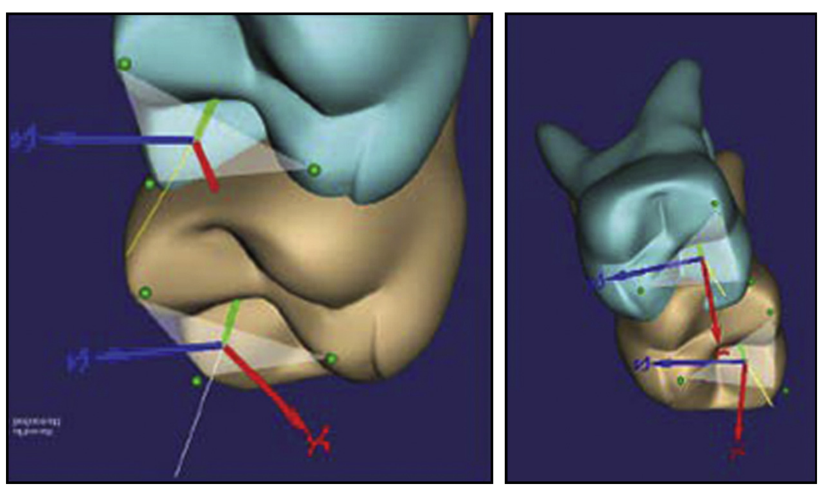

Fig 3. The coordinate system of the pretreatment and posttreatment teeth as defined by the software is used to calculate the differences between pretreatment and posttreatment tooth positions.

distortion when the metallic orthodontic appliances are still fixed in the patient's mouth. This application is intended to provide accurate information for orthodontists and other clinicians that includes but is not limited to 3D superimpositions of pretreatment and posttreatment models, simulation of virtual root positions before and after treatment, evaluation of tooth tipping and torquing before and after treatment, tracking of tooth movements in 4 dimensions throughout treatment, and analyzing the mechanical effects of the orthodontic appliance used on selected teeth. The aim of this study was to test the reliability and validity of the data collected by the new software.

The 3D laser scanners were introduced first for facial measurements and then for dental model analysis.[17,18] A method for measuring 3D tooth movement was developed by Thiruvenkatachari et al.[19] They used a 3D surface laser scanner and superimposed the pretreatment and posttreatment digital models based on regional registrations by selecting a mushroom-shaped area on the palate. They used distances for measuring the achieved tooth movements. The results described

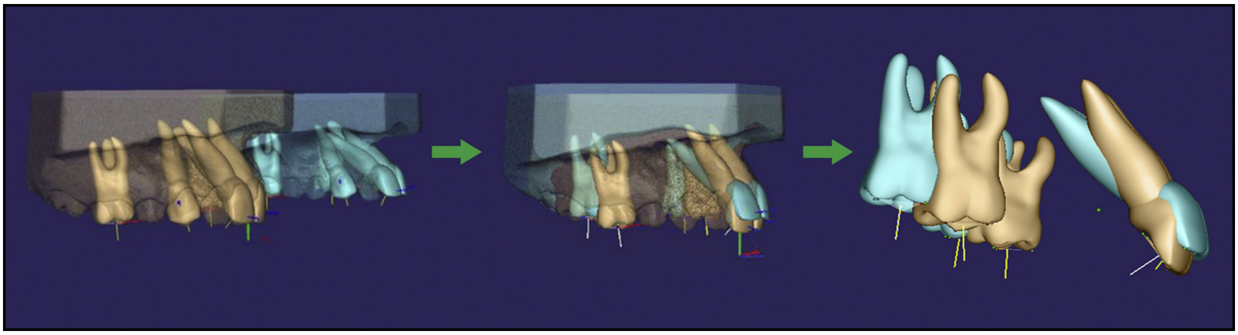

Fig 4. Pretreatment (*blue*) and posttreatment digital model superimpositions. Visualizing the roots allows measuring tooth tip and torque and calculating the changes in tooth movements.

Table II. Means, standard errors, significant differences, and levels of agreement between digital models and CT measurements

	Digital model	CT	Difference					
Parameter	*Mean (SE)*	*Mean (SE)*	*Mean (SE)*	*Min*	*Max*	*P value*	*Within-subject SD*	*ICC*
R1 torque (°)	6.39 (0.96)	6.04 (0.96)	0.35 (0.34)	−2.0	3.9	0.32	1.09	0.94
R1 tip (°)	8.78 (1.21)	7.47 (1.21)	1.31 (0.55)	−3.0	7.0	0.03	1.94	0.87
L1 torque (°)	5.14 (0.79)	4.87 (0.79)	0.27 (0.28)	−2.0	2.5	0.35	0.89	0.94
L1 tip (°)	5.60 (1.03)	5.55 (1.03)	0.05 (0.41)	−2.1	3.8	0.90	1.25	0.93
R6 torque (°)	7.01 (0.85)	7.98 (0.85)	−0.98 (0.35)	−5.5	1.4	0.01	1.29	0.89
R6 tip (°)	4.07 (0.72)	3.58 (0.72)	0.49 (0.35)	−1.7	4.3	0.18	1.13	0.88
L6 torque (°)	9.43 (1.31)	9.23 (1.31)	0.20 (0.44)	−2.9	3.4	0.66	1.38	0.94
L6 tip (°)	3.46 (0.70)	3.25 (0.70)	0.21 (0.42)	−1.9	6.6	0.62	1.31	0.82
R6 translation (mm)	5.49 (0.33)	4.91 (0.33)	0.58 (0.21)	−1.0	2.2	0.01	0.76	0.75
L6 translation (mm)	4.24 (0.33)	4.02 (0.33)	0.22 (0.27)	−2.9	3.0	0.44	0.86	0.67
Intercanine width pre (mm)	30.21 (1.27)	30.22 (1.27)	−0.01 (0.21)	−1.6	1.0	0.97	0.54	0.99
Intercanine width post (mm)	32.72 (1.38)	32.97 (1.37)	−0.25 (0.26)	−2.4	1.0	0.35	0.71	0.99
Intermolar width pre (mm)	45.97 (0.83)	46.63 (0.83)	−0.67 (0.26)	−4.0	1.0	0.02	0.92	0.94
Intermolar width post (mm)	52.65 (1.00)	52.99 (1.00)	−0.35 (0.24)	−3.3	1.4	0.17	0.78	0.97

Min, Minimum; *Max*, maximum; *pre*, pretreatment; *post*, posttreatment.

the measuring validity of the software with respect to linear measurements, but angular measurements were not possible. The algorithm of the OMSA software is considered an improvement because angular measurements can also be assessed. In addition, it represents a method of orthodontic tooth movement assessment in a 3D space including time (fourth dimension), where 6 degrees of freedom (linear and angular parameters) can be measured on the 3D laser scanned models and can also be analyzed over time.

Other studies reported using 3D digitizers that collect 3D data with a stylus tip for analyzing the models.[12,20] This technique provides a method to record 3D measurements of a study model, but it does not offer visualization of the tooth positions in 3D interactive scenes as is the case with this study. Our study showed a real 3D assessment of orthodontic tooth movements in the 3 planes of space where the angular tooth measurements, including inclination and angulation changes, and linear changes were measured and represented in 3D interactive scenes as demonstrated in Figure 4.

A report indicated that the medial rugae are stable reference points to superimpose maxillary models for longitudinal cast analysis.[21] Similarly, in our study, selected palatal areas were scanned, and the incisive papilla and midpalatal raphe were used as landmark volumes to define a reference plane for superimposing the pretreatment and posttreatment digital models.

In this study, dental-arch parameters measured on the CT images of 20 patients, before and after orthodontic treatment with rapid maxillary expansion, were compared with measurements obtained using the OMSA program. The results showed significant agreement in the measurements from the 2 modalities, indicating that the new software used to superimpose fused images from scanned plaster models provides reliable information when compared with the conventional method. However, this method is not indicated for growth, orthopedics, or surgical interventions.

Root angulation is 1 criterion of the American Board of Orthodontics' grading system that is used to assess how well the roots of the teeth have been positioned relative to each other. Although panoramic radiographs are still considered a practical tool for assessing root angulations and root parallelisms before and after treatment, they have many limitations, including image distortions, overlapped teeth, and magnification errors. Furthermore, focal trough errors make panoramic radiographs a questionable tool for assessing root angulations of the anterior teeth. The results of our study showed that OMSA is reliable in terms of visualizing root parallelisms and measuring root tip and torque 3 dimensionally.

The OMSA software was developed to provide a noninvasive, nonradiation exposure method for 3D superimposition of pretreatment and posttreatment models. This project is an initial step toward the validation of 1 application. In this stage, it is considered not technically sensitive. Future proposals lay out a distinct plan to execute the comparative analysis, enhance the software's functionality, and transform the interface into a more user-friendly format.

CONCLUSIONS

These results confirmed that the OMSA software is a reliable tool with regard to dental-arch measurements obtained from 3D laser-scanned models.

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