Reproducibility and accuracy of linear measurements on dental models derived from cone-beam computed tomography compared with digital dental casts

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Introduction: The aim of this study was to determine the reproducibility and accuracy of linear measurements on 2 types of dental models derived from cone-beam computed tomography (CBCT) scans: CBCT images, and Anatomodels (InVivoDental, San Jose, Calif); these were compared with digital models generated from dental impressions (Digimodels; Orthoproof, Nieuwegein, The Netherlands). The Digimodels were used as the reference standard. **Methods:** The 3 types of digital models were made from 10 subjects. Four examiners repeated 37 linear tooth and arch measurements 10 times. Paired *t* tests and the intraclass correlation coefficient were performed to determine the reproducibility and accuracy of the measurements. **Results:** The CBCT images showed significantly smaller intraclass correlation coefficient values and larger duplicate measurement errors compared with the corresponding values for Digimodels and Anatomodels. The average difference between measurements on CBCT images and Digimodels ranged from −0.4 to 1.65 mm, with limits of agreement values up to 1.3 mm for crown-width measurements. The average difference between Anatomodels and Digimodels ranged from −0.42 to 0.84 mm with limits of agreement values up to 1.65 mm. **Conclusions:** Statistically significant differences between measurements on Digimodels and Anatomodels, and between Digimodels and CBCT images, were found. Although the mean differences might be clinically acceptable, the random errors were relatively large compared with corresponding measurements reported in the literature for both Anatomodels and CBCT images, and might be clinically important. Therefore, with the CBCT settings used in this study, measurements made directly on CBCT images and Anatomodels are not as accurate as measurements on Digimodels. (Am J Orthod Dentofacial Orthop 2014;146:328-36)

In orthodontics, study model analysis is an essential part of the diagnosis, treatment planning, and evaluation of treatment progress.[1-4] When digitalization was introduced in the orthodontic world, digital models became available to replace traditional plaster casts. The most frequently used method to obtain digital dental models is to digitize plaster models or dental impressions. The technology used to generate digital models from dental models or impressions varies considerably. Orthocad (Cadent, Carlstadt, NJ) uses "destructive scanning" with multiple scans of the plaster model cut in thin slices. Emodels (GeoDigm, Falcon Heights, Minn) scans the surface of a complete plaster model. Impressions can also be scanned directly using cone-beam computed tomography (CBCT) technology (Digimodels; Orthoproof, Nieuwegein, The Netherlands).[5]

Digitized plaster models or digital models derived from dental impressions have been shown to be a valid tool for undertaking simple diagnostic measurements such as tooth size, arch width, overjet, overbite, arch length, and Bolton ratio.[6] In a systematic review, Fleming et al[5] found that overall, the mean differences

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between linear measurements on plaster and digital models were small (0.04-0.4 mm).

Digital dental models provide several advantages over plaster models. Digital models can be stored electronically; this reduces storage space and the risk of damage. Furthermore, digital models can be shared easily over a network.[6,7] A copy of the digital model can be secured at a second site for minimal or no costs. However, computer failure might mean that the models are temporarily or forever inaccessible.[7]

Now, study model analysis can also be performed directly on radiographs, such as CBCT scans, without the need for impressions. Study model analysis can be done directly on the radiograph of the head with dedicated software. For example, Anatomage software (InVivoDental, San José, Calif) can be used to measure the dentition on a CBCT image. The files of a CBCT image can also be sent by e-mail to InVivoDental for segmentation of the dentition to produce digital dental models (Anatomodels). Study model analysis can be done directly on these Anatomodels using the Anatomage measuring tools. The accuracy of linear measurements of the dentition on these Anatomodels for orthodontic purposes has been reported in 4 articles.[8-11] According to these publications, the accuracy of measurements on Anatomodels is related to the voxel size and spatial resolution of the CBCT images. Reduction of the spatial resolution can result in a lower-quality image, more noise and artifacts, and less anatomic information.[12] Spatial resolution is lower at shorter scanning times and larger voxel sizes.[12] Only in 1 study, a shorter scanning time, lower kilovoltage (129 kV), lower milliamperage (47.74 mA), and a voxel size of 0.4 mm were used.[9] In all other studies, a smaller voxel size (0.3 mm) and longer scanning times were applied.[8,10,11] A longer scanning time improves the spatial resolution but also increases the radiation dose.[12]

To our knowledge, no study has compared the accuracy of measurements directly performed on CBCT images (without segmentation of the dentition) with Anatomodels and Digimodels, and only 1 article used CBCT scans with a voxel size of 0.4 mm and shorter scanning time for measuring the dentition. Therefore, the aim of this study was to examine the reproducibility and accuracy of linear measurements on CBCT images and Anatomodels obtained from CBCT images with a relatively large voxel size of 0.4 mm and a relatively short scanning time compared with the reference measurements on Digimodels.

MATERIAL AND METHODS

From the archives of the Department of Orthodontics and Craniofacial Biology of the Radboud University Medical Centre in The Netherlands, pretreatment records were selected of patients who met the following inclusion criteria: (1) impressions to fabricate digital models and a CBCT image obtained on the same day; (2) permanent dentition from left first molar to right first molar in both arches; (3) normal dental crown morphology; (4) no features that would influence crown morphology such as restorations, caries, attrition, or fracture; (5) good-quality digital dental models without irregularities; and (6) the measurements were not compromised by streaking artifacts on the CBCT radiographs, caused by metal restorations or fixed appliances, because these patients had no metal restorations or orthodontic appliances. Twenty-four patients met these inclusion criteria. Ten patients from this group were randomly selected for this study.

The CBCT scans were retrieved from the CBCT database of patients who had combined surgical and orthodontic treatment at the Radboud University Medical Centre. These extended-height scans were used for 3-dimensional planning for the orthognathic surgery. All patients signed the informed consent form for this treatment, including the CBCT documentation. The following settings where used for the i-CAT 3D Imaging System (Imaging Sciences International, Hatfield, Pa): 129 kV, 47.74 mA, 40 seconds with a resolution of 0.4 mm/voxel, and a field of view of 17 cm in diameter and 22 cm in height.

For each patient, 3 types of dental models were analyzed: Digimodels, CBCT images, and Anatomodels. The Digimodels were used as the reference standard. To process the Digimodels (Fig 1), alginate dental impressions (Orthotrace; Cavex Holland BV, Haarlem, The Netherlands) were sent to the OrthoProof company on the same day as the impressions were taken. Within 24 hours, the impressions were scanned with a computed tomography scanner with a voxel size of 0.15 mm (Hytec, Los Alamos, NM). Subsequently, the scanned data were used to fabricate digital models. These Digimodels were imported through the Internet from the OrthoProof Web server into the patient management system at the Radboud University Medical Centre. Study model analysis of the digital dental models was conducted with the Digimodels software.

Alternatively, study model analysis can be carried out directly on the digital image of the dentition on the CBCT image using dedicated software. The DICOM files of the CBCT images were sent by e-mail to the Anatomage company for segmentation of the dentition from the CBCT images to process the digital dental models, which are called Anatomodels. The company uses automatic thresholding logarithms for the segmentation process and does not share information on this rendering process.

Four dental students were trained and calibrated to perform the measurements on the 2 digital models and