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Research Paper
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Three-dimensional maxillary and mandibular regional superimposition using cone beam computed tomography: a validation study

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Abstract. This study aimed to validate a novel method for fast regional superimposition of cone beam computed tomography (CBCT) scans. The method can be used with smaller field of view scans, thereby allowing for a lower radiation dose. This retrospective study used two dry skulls and secondary data from 15 patients who had more than one scan taken using the same machine. Two observers tested two types of regional voxel-based superimposition: maxillary and mandibular. The registration took 10–15 s. Three-dimensional surface models of the maxillas and mandibles were generated via standardized threshold segmentation, and the accuracy and reproducibility of the superimpositions were assessed using the iterative closest point technique to measure the root mean square (RMS) distance between the images. Five areas were measured and a RMS $\leq$ 0.25 was considered successful. Descriptive statistics and the intra-class correlation coefficient (ICC) were used to compare the intra-observer measurement reproducibility. The ICC was $\geq$0.980 for all of the variables and the highest RMS found was 0.241. The inter-observer reproducibility was assessed case by case and was perfect (RMS 0) for 68% (23 out of 34) of the superimpositions done and not clinically significant (RMS $\leq$ 0.25) for the other 32%. The method is fast, accurate, and reproducible and is an alternative to cranial base superimposition.

Keywords: cone-beam CT; three-dimensional image; 3D image registration; CBCT superimposition; 3D image fusion.

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Cone beam computed tomography (CBCT) has become a very popular diagnostic tool, with several applications in dentistry. One of these is the superimposition of CBCT scans, which has become the state-of-the-art technique for the assessment of treatment outcome, for which CBCT is indicated. It allows clinicians and researchers to better understand the treatment outcomes and improve techniques.

In medical imaging, the process of spatially superimposing three-dimensional

(3D) images is called image superimposition, image registration, or fusion.[1] There are three basic types of superimposition that clinicians need to know: (1) point–landmark-based, (2) surface-based, and (3) voxel-based.[2] The latter and most efficient method compares non-changing reference structures in volumetric data voxel by voxel, does not depend on landmark identification as in the point–landmark-based method, and is not limited by segmentation errors as in surface-based methods.

In orthodontics and oral and maxillofacial surgery, the superimposition of CBCT scans with a large field of view (FOV) has been used to assess orthopedic and surgical outcomes.[3–5] Cevidanes et al. were the first to introduce a voxel-based method for the superimposition of CBCT scans into dentistry; they used the cranial base as the reference to superimpose two or more CBCT scans obtained from non-growing patients.[3] Despite its excellent research application, this method involves the use of different software programs and is time-consuming. Nada et al., using a different software program, tested voxel-based superimposition using either the anterior cranial base or the left zygomatic arch as the reference in non-growing patients.[6] The FOV of the CBCT and the radiation exposure could be reduced slightly with the zygomatic arch superimposition. Despite the good results using each structure as the reference, the method used for each superimposition was also time-consuming (30–40 min).

Most of the studies mentioned above were performed to understand changes in the maxilla and/or the mandible in relation to the cranial base in large FOV scans. There are two problems with this technique: (1) a large FOV is needed to appreciate localized changes in the maxilla and (2) even with a large FOV, the changes in the mandible are not assessed accurately because the mandible can have a different position in each scan. The issue is that a large FOV exposes the patient to a higher radiation dose compared to the use of a medium or small FOV.[7] Therefore, a different method that allows fast, reliable, and accurate 3D regional superimposition of CBCT scans with smaller FOVs and a lower radiation dose is needed.

As stated previously, the voxel-based technique is not new, however superimposition using the maxilla and the mandible as the reference is. Therefore, the aim of this study was to test the accuracy and the reproducibility of a regional superimposition method for the maxilla and mandible in non-growing patients using CBCT.

Materials and methods

Subjects and CBCT scan

The study was approved by the necessary ethics committee. The sample for this retrospective study comprised the CBCT files for two dry skulls obtained from the Oral Diagnostic Science Department of Virginia Commonwealth University and secondary data from 15 patients who had undergone either surgical treatment (coronectomy of wisdom teeth and bone grafts) and/or orthodontic treatment at a private practice. The CBCT scans were taken between April 2009 and March 2015 and the patients ranged in age from 27 to 65 years. All of the patients had either full dentitions or were partially edentulous. Inclusion criteria for the human subjects were (1) non-growing patient, with (2) two CBCT scans (T1 and T2) taken using the same machine and with the same voxel size (0.25 mm). Exclusion criteria were (1) same patient with CBCT scans from different machines, (2) CBCT scans with a different voxel size between T1 and T2.

The dry skulls images were acquired with a Kodak Carestream 9300 (Carestream Health Inc., Rochester, NY, USA) and 13.5 × 17 cm FOV, scan time of 11.3 s, set at 85 kVp, 4 mA, and 0.3-mm voxel size. Two images of each dry skull were taken, modifying its position between T1 and T2. These images were used as a gold standard since there was no bony change between T1 and T2. The patient images were acquired with an i-CAT scanner (Imaging Sciences International LLC, Hatfield, PA, USA) and 16 × 13 cm FOV, scan time of 27 s, set at 120 kVp, 8 mA, and isotropic 0.25-mm voxel size. The DICOM (Digital Imaging and Communication in Medicine) files were imported into OnDemand 3D v1.0.10.5261 (Cybermed Inc., Seoul, Korea). The T2 scan was taken between 4 and 24 months (average 12.3 months) after T1.

3D image processing

A summary of the method is given in Fig. 1. One observer cropped the CBCT files from T1 and T2 to simulate a 10 × 5 cm FOV scan, obtaining a significant amount of the maxillary and mandibular area. The crops were done as shown in Fig. 2; this resulted in a total of four images: T1 mandible, T1 maxilla, T2 mandible, and T2 maxilla. The software used allows the clinician to crop in any dimension, and the inferosuperior crops are done precisely by selecting the number of slices that the user wants to keep. In the present study, 200 slices were used to simulate 5 cm of height (200 × 0.25 mm = 5 cm). The software

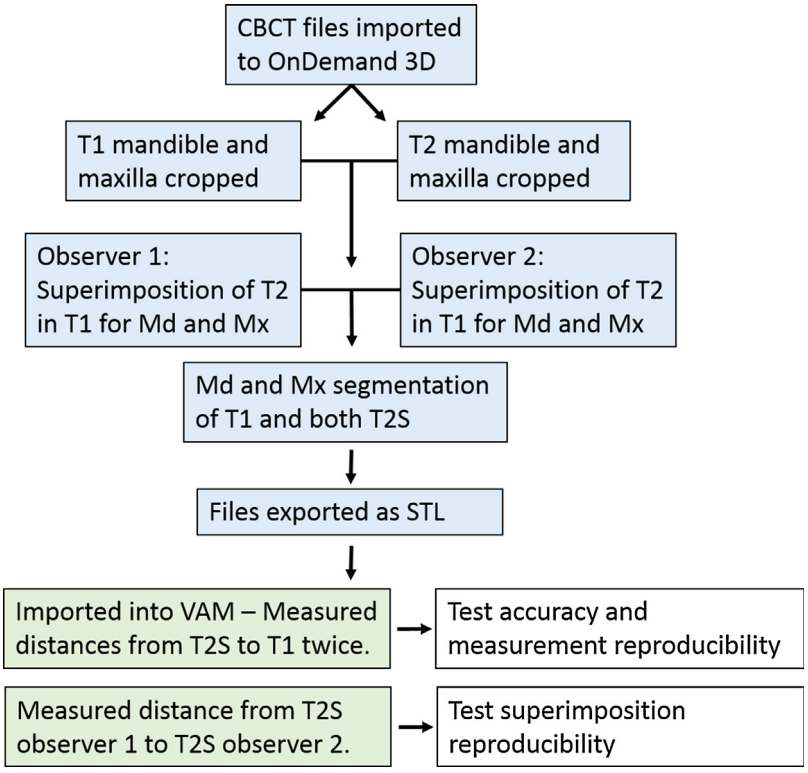

Fig. 1. Flowchart of the method. The blue boxes are steps done using OnDemand 3D and the green boxes are steps done using VAM (Md, mandible; Mx, maxilla; T2S, T2 superimposed).