Int. J. Oral Maxillofac. Surg. 2015; 44: 1188–1196
http://dx.doi.org/10.1016/j.ijom.2015.04.001, available online at http://www.sciencedirect.com

International Journal of Oral & Maxillofacial Surgery

Research Paper
Imaging

Fast three-dimensional superimposition of cone beam computed tomography for orthopaedics and orthognathic surgery evaluation

A. Weissheimer[1], L. M. Menezes[1], L. Koerich[2], J. Pham[3], L. H. S. Cevidanes[4]

[1]Department of Orthodontics, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, RS, Brazil; [2]International Dental Program, Virginia Commonwealth University, Richmond, VA, USA; [3]Advanced Orthodontic Program, Herman Ostrow School of Dentistry, University of Southern California, Los Angeles, CA, USA; [4]Department of Orthodontics at the University of Michigan School of Dentistry, Ann Arbor, MI, USA

A. Weissheimer, L. M. Menezes, L. Koerich, J. Pham, L. H. S. Cevidanes: Fast three-dimensional superimposition of cone beam computed tomography for orthopaedics and orthognathic surgery evaluation. Int. J. Oral Maxillofac. Surg. 2015; 44: 1188–1196.

Abstract. The aim of this study was to validate a method for fast three-dimensional (3D) superimposition of cone beam computed tomography (CBCT) in growing patients and adults (surgical cases). The sample consisted of CBCT scans of 18 patients. For 10 patients, as the gold standard, the spatial position of the pretreatment CBCT was reoriented, saved as a reoriented volume, and then superimposed on the original image. For eight patients, four non-growing and four growing, the pre- and post-treatment scans were superimposed. Fast voxel-based superimposition was performed, with registration at the anterior cranial base. This superimposition process took 10–15 s. The fit of the cranial base superimposition was verified by qualitative visualization of the semi-transparent axial, sagittal, and coronal cross-sectional slices of all corresponding anatomical structures. Virtual 3D surface models of the skull were generated via threshold segmentation, and superimposition errors in the reoriented models and the results of treatment for the treated cases were evaluated by 3D surface distances on colour-coded maps. The superimposition error of the spatial reorientation and for growing and non-growing patients was <0.5 mm, which is acceptable and clinically insignificant. The voxel-based superimposition method evaluated was reproducible in different clinical conditions, rapid, and applicable for research and clinical practice.

Key words: cone-beam computed tomography; voxel-based superimposition; 3D image registration; orthodontic and orthopaedic treatment; orthognathic surgery.

Accepted for publication 6 April 2015
Available online 29 April 2015

Cone beam computed tomography (CBCT) has become a well-established diagnostic tool in dentistry.[1–8] In orthodontics and in oral and maxillofacial surgery, CBCT now allows clinicians to better identify and distinguish treatment outcomes. While two-dimensional (2D) cephalometric superimposition is the conventional method used to evaluate growth and treatment outcomes, improvements in image registration algorithms have made the superimposition of CBCT volumes the state-of-the-art technique for outcomes assessment.

In medical imaging, the process of spatially superimposing three-dimensional (3D) images obtained from different imaging modalities is also called image registration, or fusion.[9] The superimposition of CBCT volumes in 3D space when changes in shape and position of the craniofacial components have occurred over time or with treatment is challenging and requires knowledge of the different types of superimposition. The three basic types of superimposition algorithm are: (1) point landmark-based, (2) surface-based, and (3) voxel-based.[10] The latter, and most efficient method, compares the 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 the surface-based method.

Cevidanes et al.[11] were the first to introduce the voxel-based method for fully automated 3D superimposition of CBCT volumes into dentistry. The method proposed in that study was based on mutual information theory[10] and required the construction of surface models of the reference structure prior to the registration steps. The application of this method in both growing and non-growing subjects has been described in the literature.[4,5,11,12] The drawbacks are that the superimposition process requires several different steps in various software programmes and is time-consuming (45–60 min). In 2010, Choi and Mah[13] introduced a new method for cranial base superimposition that is also voxel-based, but does not require the construction of 3D surface models prior to the registration process. They also added volume and slice visualization capabilities, providing a clinician-friendly user interface. The result was a new software programme (the fusion module of OnDemand3D; Cybermed, Seoul, Korea) that performs CBCT volume superimpositions faster (10–15 s), with fewer steps required. While some research studies[14–16] have applied the superimposition method introduced by Choi and Mah[13] in the OnDemand3D software, there has been no published validation study of this method for fast CBCT volume superimposition in growing patients and adults. There appears to be a lack of scientific evidence regarding the use of this method for fast superimposition of CBCT at the anterior cranial base, especially for the longitudinal assessment of growth and treatment changes in young patients.

The aim of this study was to evaluate a fast method for 3D superimposition of CBCT volumes. Specifically, this study first tested whether there are differences when the same CBCT volumes, with different spatial orientations, are superimposed at the anterior cranial base. Second, this study tested whether there are differences in the anterior cranial base when longitudinal CBCT volumes of growing patients and adults, which also present maxilla–mandibular changes due to growth and/or treatment response, are superimposed at the anterior cranial base.

Methods

This was a retrospective study. Records were obtained from the patient database of the department of orthodontics and included pre-treatment and post-treatment CBCT scans. The sample consisted of the CBCT scans of 18 patients. For 10 patients, as a gold standard, the spatial position of the pretreatment CBCT volume was reoriented, saved as a reoriented volume, and then superimposed on the original image (Fig. 1). For eight patients – four non-growing and four growing – pre- and post-treatment scans were superimposed. The 10 pre-treatment scans (gold standard) were obtained from patients with a mean age of 11.4 ± 1 years. The four non-growing adult patients (mean age 26.3 ± 5.7 years) had CBCT scans taken pre- and 1 year post-orthognathic surgery. The four growing patients (mean age 9.5 ± 1.8 years) had CBCT scans taken pre- and post-treatment with rapid palatal expansion (RPE). The CBCT scans were obtained using an i-CAT scanner (Imaging Sciences International, Hatfield, PA, USA) set at 120 kVp, 8 mA, large field of view, and scan time of 40 s. The images were reconstructed with 0.25-mm slice thickness and exported as Digital Imaging and Communications in Medicine (DICOM) files.[17]

Creating CBCT volumes with different spatial orientations

The DICOM files corresponding to the pre-treatment CBCT scans of the 10 growing patients (gold standard) were imported into OnDemand3D software (version 1.0.9.1451; Cybermed, Seoul, Korea) and organized in the database management module. Each CBCT volume was opened and the patient's head was reoriented in space (translation and rotation) to a different spatial position and data exported in a new DICOM file. Thus, for each original CBCT volume, a second CBCT volume was created with the same voxel size but with different head orientation (Fig. 1A and B). This procedure was performed for all 10 pre-treatment CBCT volumes, creating 10 additional CBCT volumes with different head orientation.

CBCT volume superimposition

For the fully automatic voxel-based rigid registration, the fusion module in OnDemand3D was used. Axial, sagittal, and coronal slice views of the volumes were used to select the anatomical structures of the anterior cranial base in the CBCT volumes (Fig. 2A and B). Next, the OnDemand3D automated registration tool was used to perform the rigid registration (translation and rotation) that optimally aligned the reoriented CBCT volume to the original CBCT volume, using the intensity of the grey levels for each voxel in the anterior cranial base of the two CBCT volumes. The same voxel-based superimposition procedure was used to align pre-treatment and post-treatment CBCT volumes of growing patients subjected to RPE and adults subjected to orthognathic surgery, using the anterior cranial base as reference (Fig. 2C and D). The superimposition process took a total of 10–15 s to complete.

Superimposition assessment

The precision of the OnDemand3D voxel-based superimpositions was verified by quantification of the surface distances using closest-point colour maps on 3D surface models, as done in previous studies for growing patients.[18,19] It was also assessed by qualitative visualization of the semi-transparent axial, sagittal, and coronal cross-sectional slices of all corresponding anatomical structures between the original and reoriented scans, as well as the pre-treatment and post-treatment scans (Figs 3–5). To measure the outcomes of the superimposition, after the registration process, the superimposed CBCT volumes were exported as DICOM files using the OnDemand3D programme and imported into ITK-SNAP software programme (http://www.itksnap.org) for