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The novel use of three-dimensional surface models to quantify and visualise the immediate changes of the mid-facial skeleton following rapid maxillary expansion

S.C. Ong, B.S. Khambay, J.P. McDonald, D.L. Cross, L.M. Brocklebank, X. Ju*

Dental School, School of Medicine, College of Medical, Veterinary and Life Sciences, University of Glasgow, UK

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ABSTRACT

Background: The transverse skeletal effects of rapid maxillary expansion (RME) have previously been assessed using cone-beam CT (CBCT). However, to date the majority of studies assess the changes based on two-dimensional slice images, which under utilises the three-dimensional (3D) data captured. This study optimizes the volumetric CBCT data by generating 3D rendered surface models to quantity and visualize the immediate 3D changes of the mid-facial bone surfaces following RME.

Methods: The sample consisted of 14 patients who required RME prior to fixed appliances. Pretreatment (T_0) and immediate post expansion (T_1) CBCT images were taken. Following superimposition the mid face was divided into six anatomical regions. A one-sample *t*-test was used to determine if the differences between the two surfaces were significantly $\geq$0.5 mm.

Findings: All regions showed a change following RME $\geq$ 0.5 mm. The maxillary and nasal bones showed 2.3 mm and 2.4 mm expansion respectively, followed by the zygomatic bones (1.4 mm), 2 cases showing asymmetric expansion.

Conclusions: The use of 3D surface rendered models allows quantification and visualisation of 3D changes in the mid-facial skeleton at anatomical sites distant of RME activation. Following activation there can be a pan mid-facial expansion, including not only the maxilla but also the nasal lateral bones and zygomas. The response was highly variable and asymmetric expansion can occur.

Introduction

Rapid Maxillary Expansion (RME) is undertaken to increase the width of the maxillary dental arch at both a dental and skeletal level to relieve crowding and correct buccal crossbites. Analysis of the transverse skeletal and dental effects of RME in growing patients have previously been conducted using study models, two-dimensional imaging,[1–13] and more recently three-dimensional (3D) imaging based on computed tomographic (CT) data.[14–20]

* *Corresponding author*. Pediatric Dentistry and Orthodontics, Faculty of Dentistry, The University of Hong Kong, Hong Kong. Tel.: +852 2859 0260.
E-mail address: bkhambay@hku.hk (B.S. Khambay).

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The use of low dose Cone Beam CT (CBCT) and software originating from computer aided design and computer aided manufacture (CAD/CAM) has allowed capture, visualisation, manipulation and analysis of anatomical structures in 3D. Numerous studies to date using CBCT scans to assess RME changes have only analysed the 2D slice data (axial, coronal and sagittal slices) and ultimately have not utilised the 3D data to its full potential. Only one study, a case presentation of only two patients, has used 3D reconstructed rendered surface models to visualize the 3D effect of RME.[21]

A change in position of a single point in two or three-dimensional space cannot fully describe the entire 3D positional change of a structure. The displacement of several landmarks on the structure would allow for a more representative analysis of change. This theory can be taken one step further by combining hundreds of points together and creating a “surface mesh” representing the surface of an entire anatomical structure. The change in position of all the linked surface points or mesh can be represented as a change colour, an error map, or numerically as changes in Euclidian distances of all the points making up the surface mesh.

A novel method to assess RME effects has recently been described which measures the changes in widths of the circumaxillary sutures as an indication of bone displacement, again based on the slice data.[22] However, due to the complex interactions of the sutures the actual 3D changes of the adjoining bone surface may be difficult to determine and visualise. The true 3D effects of RME can only be determined by assessing the positional changes of the bone surfaces. The outcome measure can be based on both colour error maps and as changes in the Euclidian distance between the closest-point between the two 3D models surface triangles at two different time points.[23]

Using the 3D rendered surface model this study proposes to determine the immediate three-dimensional changes of the mid-facial bone surfaces i.e. nasal, maxillary and zygomatic bones due to rapid maxillary expansion based on low dose cone-beam computed tomography (CBCT). The null hypothesis is that there is no change in the 3D hard tissue surface of the mid-facial bones following RME, i.e. the mean difference between the bone surface was not different to 0.5 mm.

Materials and methods

The sample size calculation was based upon previous estimates of RME suture separation[22] and indicated that 14 patients were needed to detect a difference of $\geq$0.5 mm, SD = 0.7 mm, $\alpha = 0.05$, $\beta = 0.8$.

Ethical approval was obtained from the Dental Ethics Committee of North Glasgow University Hospitals NHS Trust. Patients were recruited from the Orthodontic Department of the Victoria Hospital, Kirkcaldy, Fife, Scotland, U.K. The patients were initially referred to the Department by General Dental Practitioners, Medical Practitioners or Hospital Specialists. Written consent was obtained from each patient and parent or guardian for participation in the study. The inclusion criteria were as follows; patients under 16 years of age with good oral hygiene, constricted maxillary arch with unilateral or bilateral posterior crossbite which required correction/treatment as part of a comprehensive orthodontic plan and erupting maxillary permanent canines. Following RME all patients went on to receive upper and lower fixed appliances. No previous tonsillar, nasal or adenoid surgery or craniofacial deformity. Patients were excluded if they were above 16 years of age, had previous or actual periodontal disease or orthodontic treatment.

Upper and lower dental impressions of each patient were taken using alginate (XantALGIN® select, Heraeus, Germany) and plaster models produced (Sherahard-rock, John-Winters, Halifax). The RME appliance was a cast cap fixed split acrylic appliance with the active expansion produced by a Hyrax screw (Forestadent, Germany). The cast cap splint was constructed of a silver-copper alloy (SP70, Skillbond, England) with full tooth coverage from the first molar to the canines. The RME appliance was cemented in-situ with glass ionomer cement (AquaCem®, Dentsply, Germany) within 1 week of the impression being taken to ensure an accurate fit. All clinical treatments were undertaken by a single experienced Orthodontic Consultant (JMcD).

Prior to activation an initial pre-treatment (T_0) CBCT scan was taken (i-CAT, Imaging Sciences International, Hatfield, Pa) by a single trained radiographer. Each patient was positioned by a single experienced Consultant Orthodontist (BK). For all scans, subjects were seated with their Frankfort plane parallel to the floor. Each patient was scanned at 120 kV, 18.45 mAS, for 20 s with a 0.4 mm voxel resolution. To further minimise radiation exposure the field of view was adjusted to image only from the supra-orbital ridge to the upper occlusal plane for each patient. The data files for the CBCT images were stored in DICOM format (Digital Imaging and Communications in Medicine). No additional plan film radiographs were taken.

The appliance was activated by the parent and the patients were reviewed regularly during active expansion. The regime used was a quarter turn (0.25 mm) twice a day until the palatal cusp of the upper molars was touching the buccal cusp of the lower molars. Once this point had been reached a second CBCT scan was taken (T_1) using the same protocol as for the initial CBCT scan.

3D image construction and analysis

The DICOM slice data were converted into 3D volumetric images using Maxilim software (MEDICIM, Mechelen, Belgium) installed on a personal computer (Dell Optiplex 745, Intel Duo Core processor). The process involved importing the DICOM slice files from iCAT into Maxilim, and thresholding the hard tissues for each patient at the default value before building a 3D volumetric skull model. Following 3D volumetric image construction, each image was exported as an Stereolithography (STL) file which produced surface mesh images of the 3D volumetric data (Fig. 1(a)).

The T_0 and T_1 STL file produced by Maxilim software for each patient was imported into a CAD/CAM mesh editing software VRMesh software (VirtualGrid, Seattle City, WA, USA) installed on a personal computer (Dell XPS 710, Intel Quad Core processor).

The T_0 and T_1 STL skull images were superimposed and aligned using an “intermediate template” of the same patients posterior cranial base (Fig. 1(b)) and checked for accuracy (Fig. 1(c)). Following superimposition (Fig. 1(d)) the image was