3D MORPHOMETRIC CHANGES 1 YEAR AFTER JAW SURGERY

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ABSTRACT

This paper presents image processing methods for the computation of morphometric changes associated with jaw surgery, precisely locating jaw displacements and quantitatively describing the vectors of displacement. The proposed methods rely on a rigid, normalized mutual-information approach to register one image to another on anatomic structures unaltered by surgery in order to evaluate within-subject changes. After registration, the location and magnitude of changes over time are assessed via graphical overlays and calculation of the Euclidean distances between the surfaces. The resulting 3D graphical display of the magnitude of displacements between two segmentations is color-coded. The direction of displacement is shown by the mean vectors of displacement, within lines that graph connecting points of equal values. (NIDCR DE017727-02 and DE005215-26).

1. INTRODUCTION

Exciting advances in 3D image analysis are shedding light on our limited comprehension of jaw deformity corrections. Against the backdrop of the extraordinary developments in imaging, there is a pressing need to ensure that tools emanating from new technologies are applied to clinically relevant questions. Remodeling of the mandibular condyles is necessary after jaw surgery to reposition the mandible. The condyles rotate around their long axis when the maxilla is moved superiorly. When mandibular ramus surgery is used to advance or set back the mandible, the condyle is rotated transversely when the ramus and body fragments are reattached in their new position. Studies using submental vertex cephalograms have documented that 5-10 degree transverse rotations usually occur. This generally does not lead to functional problems, and the amount of apparent rotation decreases over time as remodeling occurs. If the condyles are displaced facially or medially, however, joint pain is likely to occur, and limitation of motion has been observed [1-4].

Until recently, the high radiation needed for spiral computed tomography (CT) made it impossible to use it to follow the sequence of condylar remodeling. Now that cone-beam tomography (CBCT) provides good information with greatly reduced radiation, studies of remodeling are feasible [5-7]. Beginning in early 2004, we have obtained cone beam CT of orthognathic surgery patients prior to and immediately following surgery, and are now collecting CT data at one year following surgery.

A difficult part of using sequential CT to study condylar changes has been the reference system for registration and superimposition of the condyles to demonstrate change. The aim of this study was to investigate positional changes and remodeling 1 year post-surgically at the maxilla, mandibular rami and condyles in groups of patients receiving either maxillary advancement and mandibular setback or maxillary surgery only. We have used well validated methods to register the cranial base structures and display the amount of maxillary and mandibular changes in all planes of space, rather than relying on changes in landmark positions in traditional cephalometric studies.

2. METHODS

Nineteen patients treated at the Dentofacial Deformities Program (7 males and 12 females; 21.6 ± 7.9 y) were recruited for this study. Informed consent was obtained from all subjects and the experimental protocols were approved by the Institutional Review Board. CBCT scans were taken pre-surgery, 1 week post- and 1 year post-orthognathic surgery with the NewTom 9000 (Aperio). Ten patients with various malocclusions underwent maxillary surgery only and eleven patients with Class III malocclusion had both maxillary advancement and mandibular setback.

The image analysis tools applied in this clinical study are modifications of open source, freely available software. The techniques applied to accomplish our aims are summarized on Figure 1, and the common techniques for all aims are the following:

1. *CBCT acquisition*. The imaging protocol used a 70sec head CBCT scanning with a field of view of 230mm x 230mm. Primary reconstruction of the images was done by using the NewTom software immediately after the exposure. All pre-surgery and 1 year post-surgery CBCTs were acquired with the patient in centric occlusion. Splints were not in place at these acquisitions. At 1 week post-surgery, the intermaxillary splints were still in place for all patients.
2. *Conversion to volumetric image format*. This procedure used the Imsel software, a UNC in-house tool developed by Dr. Elizabeth Bullitt to convert the NewTom DICOM files to a format that is readable by the standard imaging processing tools [8].
3. *Construction of 3D models*. Segmentation of anatomic structures was performed with InsightSNAP [8-10]. 3-D virtual models were built from a set of more than 300 axial cross-sectional slices for each image acquisition, after reformatting the voxels for an isotropic of 0.5 x 0.5 x 0.5 mm. After the segmentation with the InsightSNAP tool, a 3D graphical rendering of the volumetric object allowed

navigation between voxels in the volumetric image and the 3D graphics with zooming, rotating and panning. The similarity of the 3D color-coded maps of post-operative changes of 3D models as well as the small surface distance differences of 3D models constructed by three observers show that interobserver variability was negligible. Pre- to post-surgery surface distance measurements differed amongst the three observers by not more than 0.26 mm (maximal error measured as inward displacement at the mandibular rami surface) [8].

4. *Registration and superimposition of 3D models.* A normalized mutual-information based registration approach was used to register one image to another, using a rigid transformation to evaluate within-subject changes. This task was performed using the registration part within the Imagine Pipeline Software developed by Matthieu Jomier at UNC [11]. Our superimposition methods were fully automated, using voxel-wise rigid registration of the cranial base instead of the current standard landmark matching method, which is observer-dependent and highly variable. After the masking out the maxillary and mandibular structures, the registration transform was computed solely on the grey level intensities in the cranial base. Rotation and translation parameters were calculated and then applied to register 3D models. After registration, we assessed the overlay of the 3D models using UNC Software Valmet [11] and MeshValmet. These software packages allow the visual and quantitative assessment of the location and magnitude of changes over time via graphical overlays and calculation of the Euclidean distances between the surfaces of the 3-D models that we compared at two different time points (Figure 2-5, 7-8 show registered 3D models at different time points). The Euclidean distances between the 3D surfaces thereby was computed using closest point correspondence. The resulting 3D graphical display of the structure was color-coded with the regional magnitude of the displacement between two segmentations. Semi-transparency visualizations can be used for the 3D overlays.

3. RESULTS

We evaluated post-surgical changes in the position and contours of the maxilla after LeFort I surgery in 19 patients. The average change from one week to one year post-surgery was -0.88 mm (S.D.=0.21) on maxillary anterior surfaces and -0.90 mm (S.D.=0.13) on lateral surfaces, with a range of -0.60 to -1.53 mm, and -0.65 to -1.15 mm, respectively (Figure 3). The average positional change/remodeling at the condyles was 1.07 mm (SD=0.37, range 0.71-1.58) and 0.77mm (SD=0.09, range 0.59-0.76) for two- and one-jaw surgeries respectively ($p<0.05$)

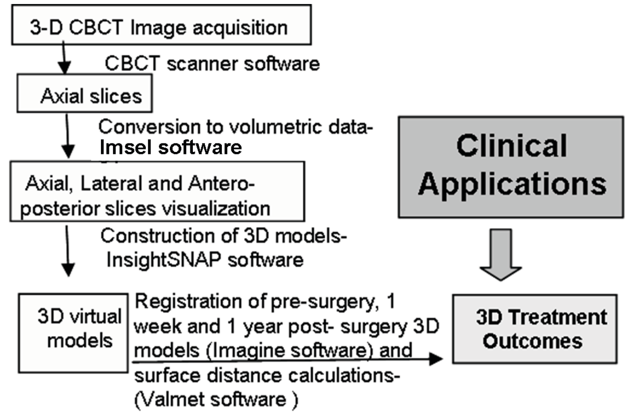

Figure 1. Schematic representation of image analysis methods used in this study.

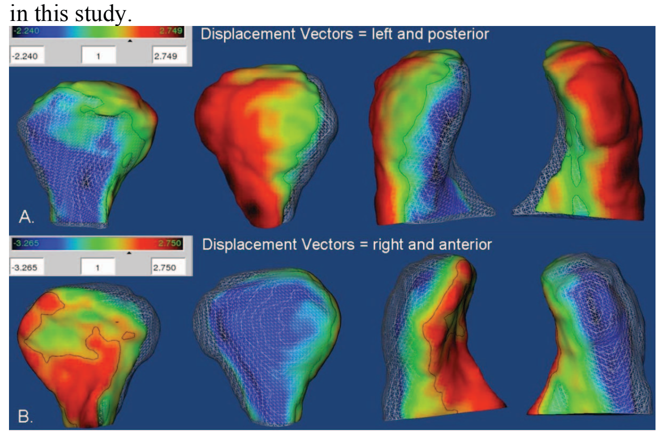

Figure 2. Direction of displacement of an specific anatomic region (left mandibular condyle) is clearly identified with the methods described. A. Color-coded display of displacement with surgery even though the surgeons aim at not displacing the joint; B. Condylar displacement between 1 week and 1 year post-surgery.

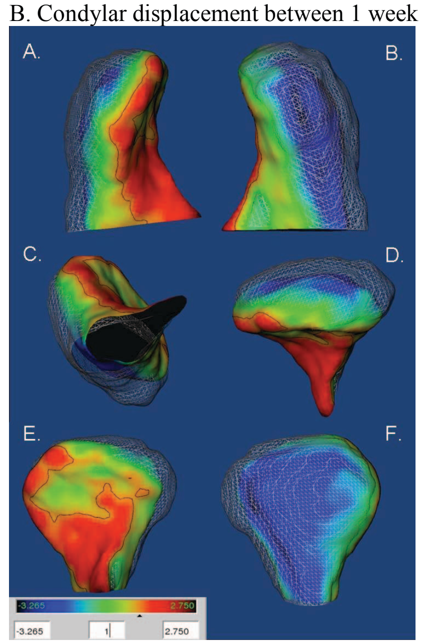

Figure 3. Different views of the color-coded displacement shown in Fig. 2B. A. Right view; B. Left; C. Inferior; D. Superior; E. Anterior; and F. Posterior.

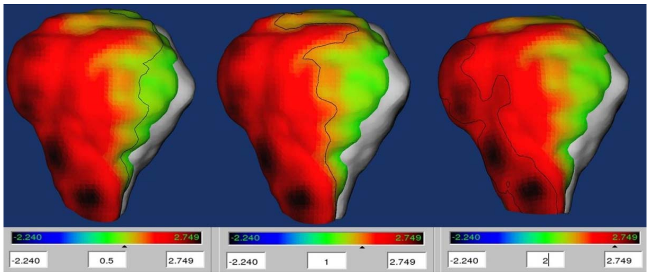

Figure 4. Visualization of different isolines (≥0.5, ≥1 and ≥2mm) of the displacement show in Figure 2A.

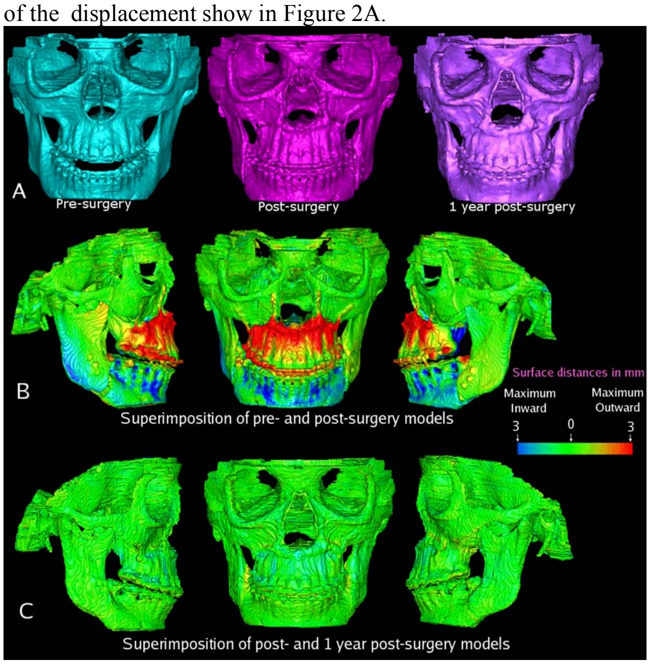

Figure 5- A. Pre-surgery, 1-week post-surgery, and 1-year post-surgery 3D models of patient treated with maxillary advancement and mandibular setback. B, Superimposition of pre-and post-surgery models showing surface distances between 2 models. Surface of cranial base was used for registration. Cranial base color map is *green* (0 mm surface distance), showing adequate match of before and after models for cranial base structures. Note that maxilla was brought forward as shown in *red*. Mandibular setback precisely maintained rami position, sliding mandibular corpus posteriorly, with slight counterclockwise rotation to correct open-bite tendency. C, Surface distances between 1-week and 1-year post-surgery models shows values close to 0 mm and stability of surgical procedures.

All two-jaw surgery patients showed some post-surgical remodeling and positional changes, with anterior rotation of the mandibular rami (mean 1.85mm, SD=0.85, range 0.6-1.45mm), while rami changes in one-jaw surgery groups were in average 0.86mm, SD=0.22,range 0.55-0.9mm (statistically different, p<0.01) (Figures 7 and 8).

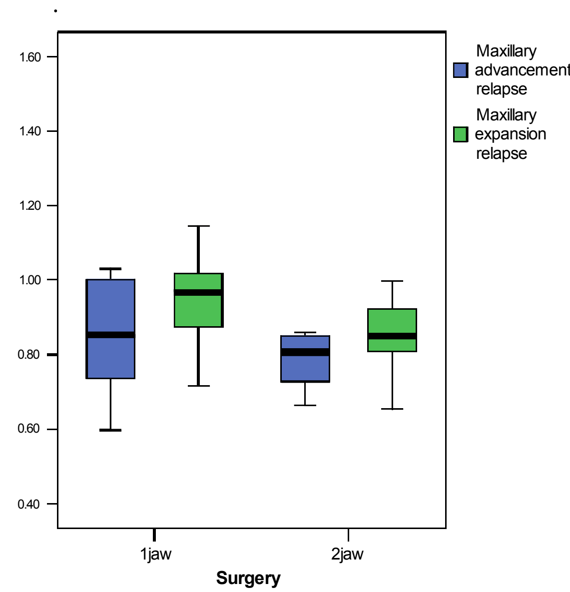

Figure 6. Boxplots showing that the position of the maxilla was quite stable in almost all these patients in both groups.

4. DISCUSSION OF CLINICAL RESULTS

The 3D position of the maxilla was quite stable in almost all these patients where the maxilla was rigidly fixated after surgery and the small changes observed 1 year post-surgery appears to be due mostly to surface remodeling.

As one would expect, when the maxilla is moved surgically and the mandible rotates to a new postural position, only small changes in the condyles are noted. Typically, the average displacement in condylar position is 0.70 mm (S.D.=0.07 mm) and the average surface displacement of the mandibular rami is 0.78 mm (S.D.=0.25mm). Only one subject had a maximum surface distance greater than 2 mm (Figure 7) .

When the mandible is set back surgically in correction of skeletal Class III problems, much greater changes both condylar and ramal are noted. The expected rotation of the condyles is observed post-surgically, and despite the surgeon's best efforts to prevent transverse displacement of the condyles, it can be seen in the superimpositions that small changes (typically less than 2 mm) often occur. One-year post-surgery follow-up has shown that this condylar rotational displacement in the two-jaw group led to adaptive condylar remodeling and positional changes as compared to the one–jaw surgery group.

All two-jaw surgery patients showed backward surface displacement of the mandibular rami pre-surgery is registered and superimposed to 1 week post-surgery models, with a maximum surface distance change ≥2 mm in 8 of 11 subjects. The difference in mean ramus rotation 1 year post-surgery was statistically significant (p<0.01) when we compared the two to one-jaw surgery group.

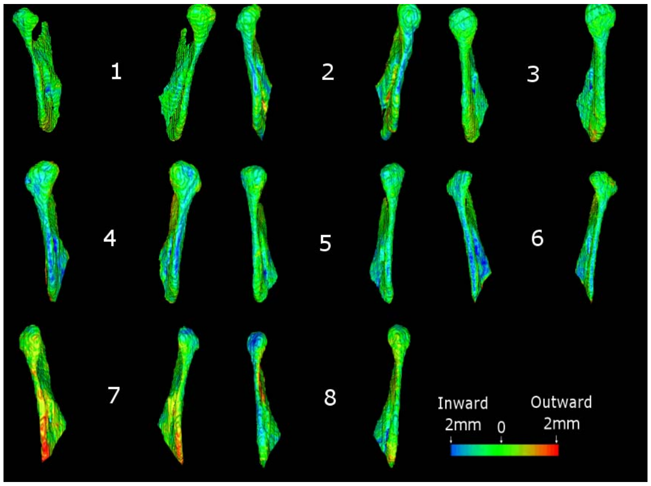

Figure 7. Posterior view of 3D models 1 week post-surgery and 1 year post-surgery for the 8 patients treated with maxillary surgery only.

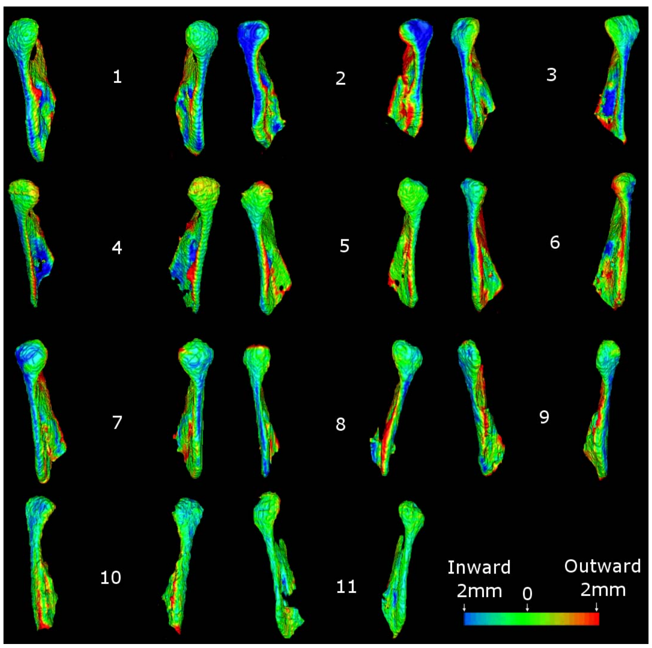

Figure 8. Posterior view of 3D models 1 week post-surgery and 1 year post-surgery for the 11 patients treated with maxillary advancement and mandibular setback.

5. CONCLUSIONS

The application of state-of-art image processing methods allow 3D superimpositions show that the position of the maxilla was quite stable in almost all these patients, with modest changes that appear to be due mostly to surface remodeling.

We conclude that our processing pipeline consisting of a series of mostly in-house developed processing tools can result in appropriate cranial base superimpositions. The color-coded visualization methods can be used to demonstrate small remodeling and positional condylar and ramal changes following surgery. We expect that the pattern of remodeling in the short term can be used as a predictor of long-term change and adaptation. Our data confirm that two-jaw surgery generally results in greater positional and remodeling changes at the condyles and mandibular rami than maxillary surgery only.

6. REFERENCES

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