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Accuracy of three-dimensional soft tissue prediction for Le Fort I osteotomy using Dolphin 3D software: a pilot study

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Abstract. Three-dimensional (3D) soft tissue prediction is replacing two-dimensional analysis in planning for orthognathic surgery. The accuracy of different computational models to predict soft tissue changes in 3D, however, is unclear. A retrospective pilot study was implemented to assess the accuracy of Dolphin 3D software in making these predictions. Seven patients who had a single-segment Le Fort I osteotomy and had preoperative (T_0) and >6-month postoperative (T_1) cone beam computed tomography (CBCT) scans and 3D photographs were included. The actual skeletal change was determined by subtracting the T_0 from the T_1 CBCT. 3D photographs were overlaid onto the T_0 CBCT and virtual skeletal movements equivalent to the achieved repositioning were applied using Dolphin 3D planner. A 3D soft tissue prediction (T_P) was generated and differences between the T_P and T_1 images (error) were measured at 14 points and at the nasolabial angle. A mean linear prediction error of 2.91 ± 2.16 mm was found. The mean error at the nasolabial angle was $8.1 \pm 5.6°$. In conclusion, the ability to accurately predict 3D soft tissue changes after Le Fort I osteotomy using Dolphin 3D software is limited.

Key words: 3D prediction; orthognathic surgery; Le Fort I osteotomy; virtual treatment planning.

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Planning for orthognathic surgery has historically been facilitated by two-dimensional (2D) soft tissue prediction of simulated osseous movements.[1] As the availability of cone beam computed tomography (CBCT) and three-dimensional (3D) photography has increased, many software packages have added capability for 3D prediction. The ability to accurately simulate skeletal movements in 3D is invaluable in helping surgeons plan orthognathic procedures, inform patients of the expected results of their operations, and teach trainees.

Current software can reliably simulate hard tissue movements of the maxilla and mandible in 3D.[2] A linear correlation between hard and soft tissue changes has been established in 2D,[3] but these relationships have not been completely determined in 3D. In addition, prior studies of 3D prediction outcomes for orthognathic surgery have not incorporated colorized 3D photographs, an essential component to creating life-like predictions for treatment planning and patient education (Fig. 1).

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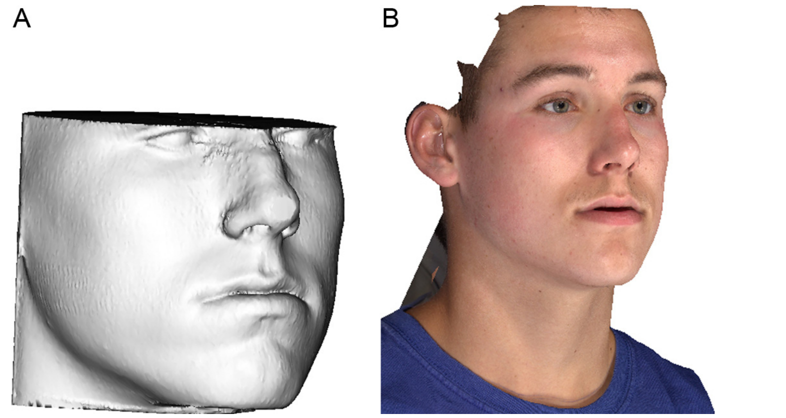

Fig. 1. (A) Soft tissue prediction from the CBCT volume. (B) Soft tissue prediction with 3D photographic overlay onto the CBCT volume.

Three broad categories of computational modelling methods have been applied to facial soft tissue morphing: mass spring model (MSM), finite element model (FEM), and mass tensor model (MTM).[4] Each has advantages and weaknesses, and no method has been accepted as the gold standard. These approaches have been shown to produce soft tissue predictions for orthognathic surgery that are accurate to within 0.27–1.17 mm.[5–8] All of these modelling methods require a large amount of graphics and computational resources and are therefore difficult to apply in real time.

In order to accommodate real-time soft tissue prediction during virtual treatment planning and consultations with patients and families, Dolphin 3D Imaging (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA), the market leader in orthognathic surgical planning, uses a landmark-based photographic morphing algorithm that was developed for 2D prediction and has been extrapolated to 3D. This system requires the user to plot 79 landmarks on the CT volume (42 bony, 37 soft tissue) and generates adjustable curves connecting these points, similar to the tracing of a lateral cephalometric radiograph (Fig. 2).

The purpose of this study was to assess the accuracy of soft tissue prediction for Le Fort I osteotomy (LFI) using Dolphin 3D software. The hypotheses were (1) that Dolphin 3D would produce clinically useful 3D photographic predictions for LFI osteotomies, and (2) that Dolphin 3D would more accurately predict soft tissue changes for midline structures than for lateral facial points because the algorithms for 3D soft tissue morphing are extrapolated from experience with 2D changes in the midline. The specific aim was to measure differences in the predicted 3D soft tissue image compared to the actual result at multiple midline and lateral facial points in a series of patients after LFI osteotomy.

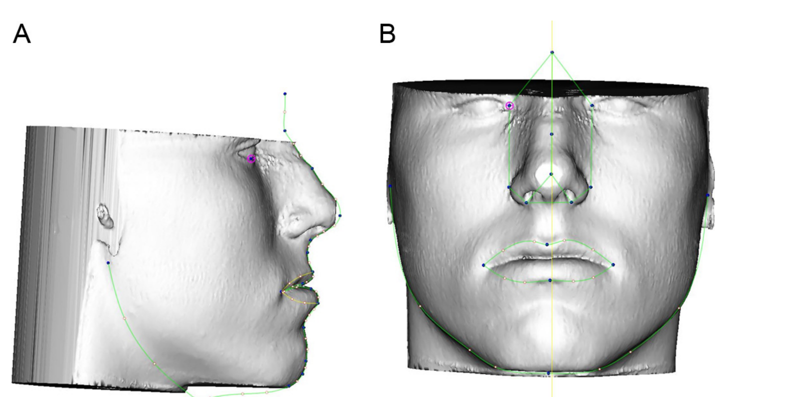

Fig. 2. Method to assign landmarks and adjust morphing curves (green curves) in Dolphin 3D. Blue points are user-defined landmarks and yellow points are positions for adjustment of morphing curves. (A) Lateral view, and (B) frontal view. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Materials and methods

To address the study question, a retrospective case series of patients who had a single-segment LFI osteotomy was implemented. This was designed as a pilot study with strict inclusion criteria in order to test the concept of 3D photographic prediction using Dolphin 3D software. This study was approved by the Institutional Review Board of the Center for Applied Clinical Investigation at Boston Children's Hospital.

Study sample

The study population included patients who had a single-segment LFI osteotomy at Boston Children's Hospital from March 2008 to June 2014. To be included, subjects had to have both preoperative (T_0) and at least 6-month postoperative (T_1) CBCTs and 3D photographs, and had to have completed orthodontic treatment by the time of the T_1 records. Patients were excluded if they had (1) craniofacial anomalies including cleft lip/palate, (2) additional operations at the time of LFI such as malar implants, mandibular or chin osteotomies, (3) multi-segment LFI osteotomies, (4) orthodontic appliances in place at the time of T_1 records, or (5) inadequate records. This study was limited to single-segment LFI osteotomy in order to facilitate the evaluation of soft tissue differences in one facial region without the influence from other osseous changes. All patients underwent pre- and postoperative orthodontic treatment and had fixed orthodontic appliances in place at the time of LFI osteotomy. All T_1 3D photographs were taken after orthodontic appliances had been removed.

Image acquisition and preparation

CBCTs were obtained using either an i-CAT scanner (3D Imaging Systems, Imaging Sciences International Inc., Hatfield, PA, USA) or a Planmeca Promax 3D Max scanner (Planmeca USA, Inc., Roselle, IL, USA), using standard CBCT exposure settings. Prior to obtaining each image, the patients were placed in natural head position and asked to close the teeth and relax the facial muscles. All CBCT volumes were captured from at least the glabella to the hyoid bone.

3D photographs were acquired using a 3D VECTRA M3 imaging system and VECTRA software version 5.5 (Canfield Scientific, Inc., Fairfield, NJ, USA). This system comprises five pod-mounted cameras that are positioned in an arc around