Do Vertical Soft Tissue and Actual Bony Landmarks Correlate in Le Fort I Orthognathic Surgery?

Cynthia J. Tsay, MPhil, [*] *Rajendra Sawh-Martinez, MD, MHS,* [†] *Karl Bruckman, MD, DDS,* [‡] *Anamika Veeramani, BS,* [§] *and Derek Steinbacher, DMD, MD* [‖]

Purpose: Vertical changes in Le Fort I orthognathic surgery are critical to the overall esthetic result. Three-dimensional planning enables vertical measurements from the rendered computed tomographic (CT) scan, but intraoperative points are ascribed partially from soft tissues landmarks. This study compared intraoperative soft tissue vertical measurements with pre- and postoperative CT-based values and attempted to validate intraoperative soft tissue landmarks for vertical positioning.

Materials and Methods: In this retrospective single-cohort study, the authors examined orthognathic procedures performed by a single surgeon at their institution. Patients were excluded if measurements or pre- and postoperative CT scans were lacking. Demographic information and soft tissue perioperative data were tabulated. Clinical vertical measurements included the left medial canthus to the central incisor, the left medial canthus to the left canine, and the right medial canthus to the right canine. Bone measurements were calculated using pre- and postoperative cone-beam CT scans for the same clinical landmarks. Statistical analysis, including paired Student *t* test, was performed using SPSS.

Results: Forty-two patients were identified (mean age, 23 yr; 57% female). The change in pre- and postoperative measurements was analyzed. There was no significant difference in the absolute value pre- and postoperatively between the 2 modalities ($P < .2, .1, .1$), but there was a significant difference between bony and soft tissue measurements ($P < .01$). Subset analysis showed differences in postoperative values between Class II and III cases.

Conclusions: These results show a nonlinear but predictable relation between intraoperative soft tissue (medial canthi and maxillary dentition) and CT-measured bony vertical measurements. Understanding this relation enables effective use of intraoperative measurements to reproducibly achieve the desired bony vertical position and allows adjustments to be made to optimize esthetics.

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[*]Resident Physician, Department of Internal Medicine, Yale School of Medicine, New Haven, CT.

[†]Craniomaxillofacial Surgery Fellow and Instructor, Section of Plastic and Reconstructive Surgery, Department of Surgery, Yale School of Medicine, New Haven, CT.

[‡]Craniomaxillofacial Surgery Fellow and Instructor, Section of Plastic and Reconstructive Surgery, Department of Surgery, Yale School of Medicine, New Haven, CT.

[§]Researcher, Yale Plastic and Reconstructive Surgery, Department of Surgery, Yale School of Medicine, New Haven, CT.

[‖]Director of Craniomaxillofacial Surgery; Plastic Surgery; Chief of Oral and Maxillofacial Surgery, Yale School of Medicine, New Haven, CT.

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Address correspondence and reprint requests to Dr Steinbacher: Craniomaxillofacial Surgery, Yale University School of Medicine, 330 Cedar Street, 3rd Floor, New Haven, CT 06520; e-mail: derek.steinbacher@gmail.com

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The Le Fort maxillary osteotomy is a surgical procedure used to alter facial balance and maxillomandibular function. Since the early 20th century, the Le Fort procedure has been widely used by surgeons because of its long-term efficacy and low complication rates.[1,2]

Discrepancies in sagittal positioning are most often emphasized in analysis and treatment. Three-dimensional (3D) positioning of the maxilla intraoperatively, involving vertical movement, is instrumental to achieving optimal esthetic and functional outcomes. Prior studies have shown that a 1-to-1 relation between soft tissue and bony maxillary vertical measurements does not exist.

Precise 3D bony positioning as part of the preoperative planning process has been shown to improve technical accuracy in addition to decreasing intraoperative time.[3] Previous studies and case reports examining the role of virtual surgical planning and computer-assisted design have found that the technology, whether using optically scanned 3D data or medical computed tomographic (CT) or cone-beam CT scans, helps to predict 3D outcomes with high accuracy.[4,5] In addition, in analysis of postoperative assessment, several studies have found that when superimposing virtual surgical plans with postoperative scans, the plans are an accurate predictor of esthetic surgical outcomes.[6] This is important in improving surgical outcomes, because it has been shown that using vertical measurements (as opposed to horizontal measurements) for surgical landmarks is crucial in assessing facial shape and symmetry and in obtaining the desired esthetic result.[7,8]

The vertical position of the maxilla is frequently adjusted intraoperatively, sometimes veering off from the preoperatively planned bony movements, to optimize esthetics relative to the bone, lip, and tooth relation. Thus, the purpose of this study was to determine whether there was a predictable relation between intraoperative soft tissue vertical measurements and pre- and postoperative bony CT-based values. The authors hypothesized that a nonlinear relation exists between these values and that soft tissue measurements can be used as an adjunct to predict the degree of vertical bony change. The specific aims of the study were *1)* to measure bony CT vertical measurements from pre- and postoperative scans, *2)* to compare these values with intraoperative soft tissue measurements, and *3)* to identify whether there was a predictable relation between these 2 values.

Materials and Methods

STUDY DESIGN AND SAMPLE

To address the research purpose, the authors designed and implemented a retrospective chart review of prospectively collected data, which received institutional review board approval (HIC number 110100793). The study population was composed of all patients presenting to the authors' large academic center for evaluation and management of dentofacial abnormalities from 2012 through 2014. To be included in the study sample, patients had to have at least 1 year of postoperative follow-up, pre- and postoperative cone-beam CT imaging, and intraoperative soft tissue measurements. Patients were excluded as study subjects if intraoperative measurements or pre- and postoperative CT scans were not available.

VARIABLES

The primary predictor variables for this study were intraoperative soft tissue measurements. The primary outcome variable was the bony CT-based vertical measurements. The vertical measurements included the distances between the following landmarks: the left medial canthus to the central incisor (LMC-CI), the left medial canthus to the left canine (LMC-LC), and the right medical canthus to the right canine (RMC-RC). Perioperative soft tissue measurements were performed using a caliper at the start and end of the procedure. Bony measurements were calculated, post hoc, from pre- and postoperative cone-beam CT scans using the ruler tool within the Synapse PACS imaging software (Fujifilm, Valhalla, NY) from the dacryon to the incisal tooth edge. The third category of variables consisted of descriptive data, including age at the time of the procedure, gender, type of preoperative orthodontic device, and class of malocclusion (I, neutral occlusion; II, distal occlusion or retrognathism; III, mesial occlusion or prognathism).

DATA COLLECTION METHODS

The same landmarks as described earlier for the soft tissue measurements were used in the bony CT measurements. Two individuals independently performed all measurements and each calculated a single set of measurements for the preoperative and postoperative CT scans.

DATA ANALYSES

The absolute value of the difference between the pre- and postoperative vertical measurements was calculated and compared to determine the relation between the intraoperative (canthi to maxillary tooth) and CT-determined bony landmarks. Linear regression was used to determine the correlation between CT and intraoperative measurements. Impaction and disimpaction ratios and malocclusion class were calculated between bony CT and intraoperative soft tissue values. Statistical analyses, including paired-sample t tests, were performed using SPSS (IBM Corp, Armonk, NY). Statistical significance was set at a P value less than .05.

Results

The study sample was composed of 42 patients and 168 sets of measurements were analyzed. Patients' mean age was 23 years, 57% were female, and 76% had wire braces versus clear aligners. Malocclusion was classified as I in 3 patients, II in 10 patients, and III in 29 patients.

Average vertical measurements (LMC-CI, LMC-LC, and RMC-RC) for preoperative soft tissue were 64.4 ± 5.5, 61.0 ± 5.2, and 60.9 ± 5.3 mm and postoperative values were 66.4 ± 5.8, 62.6 ± 5.3, and 62.4 ± 5.3 mm. Bony preoperative measurements were 84.2 ± 7.4, 82.6 ± 7.2, and 82.4 ± 6.8 mm and postoperative measurements were 84.6 ± 8.4, 83.6 ± 8.3, and 83.8 ± 8.4 mm. Stratification of vertical measurements based on malocclusion class showed a larger change in patients with a Class III malocclusion in the intraoperative measurements compared with patients with a Class I or II malocclusion (Table 1). However, this trend was not reflected on the pre- versus postoperative bony cone-beam CT scans (Table 2).

A correlation analysis was carried out on the intraoperative vertical measurements by comparing them with pre- and postoperative measurements. The differences between preoperative and postoperative soft tissue vertical measurements were 2.76 ± 1.9 mm for LMC-CI, 2.59 ± 1.9 mm for LMC-LC, and 2.65 ± 2.2 mm for RMC-RC. For the bony CT vertical measurements, the differences were 2.74 ± 2.2, 2.52 ± 2.2, and 3.18 ± 2.5 mm (Table 3). The ratios between the soft tissue and CT measurements were 1.00 (P = .98), 1.02 (P = .89), and 0.83 (P = .38). Correlation coefficients between CT and intraoperative soft tissue measurements for a linear model were 0.46 for LMC-CI, 0.59 for LMC-LC, and 0.62 for RMC-RC.

The intraoperative vertical measurement differences (preoperative vs postoperative) for patients undergoing impaction were 1.66 ± 1.8 mm for LMC-CI, 1.22 ± 1.1 mm for LMC-LC, and 1.39 ± 1.3 mm for RMC-RC. Changes in vertical measurements for bony values were 2.61 ± 2.5, 2.40 ± 2.1, and 2.70 ± 2.6 mm. The ratios of soft tissue to CT measurements were 0.63 (P = .30), 0.51 (P = .10), and 0.52 (P = .12; Table 4). For patients undergoing disimpaction, the soft tissue values were 3.38 ± 1.8, 3.70 ± 1.3, and 3.40 ± 2.3 mm and CT bony measurements were 2.28 ± 2.1, 2.58 ± 2.3, and 3.45 ± 2.5 mm. The ratios were 1.21 (P = .30), 1.43 (P = .10), and 0.98 (P = .12; Table 5).

Discussion

The purpose of this study was to evaluate the relation of pre- and postoperative CT bony movements to intraoperative pre- and postoperative soft tissue landmarks in Le Fort I maxillary repositioning. The vertical position of the maxilla is often adjusted intraoperatively to achieve the best esthetic appearance relative to bone, lip, and tooth relations, and the authors sought to determine how accurate the pre- and postoperative CT bony measurements were compared with those taken intraoperatively based on soft tissue landmarks. Although the relation between CT and soft tissue landmarks was not linear, a relation exists to guide correction of the vertical position.

Proper vertical repositioning of the maxilla is critical to achieving the best esthetic outcome. Incisor display is cosmetically important and relies on the transfer of a preoperative plan intraoperatively. At the beginning of the procedure, a baseline or starting point must be recorded, and then, before fixating the maxilla in its new position, new measurements are obtained to ensure the desired vertical goals are met (or an iatrogenic cant or malposition is created). Esthetic judgment is permitted to provide more or less maxillary anterior tooth show, depending on the goals. The preoperative plan, in the coronal plane with vertical adjustments, is bony and based on the orbital

Table 1. AVERAGE SOFT TISSUE VERTICAL PRE- AND POSTOPERATIVE MEASUREMENTS BY CLASS

	Class I	Class II	Class III
Soft tissue preoperative measurements			
LMC-CI	63.7 ± 3.9	65.3 ± 7.1	64.2 ± 5.6
LMC-LC	60.1 ± 5.7	61.2 ± 6.6	61.0 ± 4.8
RMC-RC	60.3 ± 5.5	60.2 ± 6.4	61.2 ± 5.1
Soft tissue postoperative measurements			
LMC-CI	63.5 ± 5.9	65.3 ± 7.1	67.1 ± 5.4
LMC-LC	60.8 ± 5.3	61.2 ± 6.5	63.6 ± 4.9
RMC-RC	60.8 ± 5.0	61.2 ± 6.7	63.0 ± 4.9

Note: The largest pre- to postoperative changes appeared to be in Class III.

Abbreviations: LMC-CI, left medial canthus to central incisor; LMC-LC, left medial canthus to left canine; RMC-RC, right medical canthus to right canine.

Table 2. AVERAGE BONY CT VERTICAL PRE- AND POSTOPERATIVE MEASUREMENTS BY CLASS

	Class I	Class II	Class III
Bony CT preoperative measurements			
LMC-CI	79.3 ± 8.3	83.5 ± 7.5	84.9 ± 7.4
LMC-LC	82.0 ± 7.2	81.6 ± 7.6	82.9 ± 7.3
RMC-RC	82.3 ± 8.1	80.9 ± 7.1	82.9 ± 6.8
Bony CT postoperative measurements			
LMC-CI	78.3 ± 10.8	86.9 ± 12.0	84.5 ± 6.6
LMC-LC	80.1 ± 9.5	85.6 ± 12.5	83.2 ± 6.3
RMC-RC	80.5 ± 10.3	85.4 ± 13.3	83.6 ± 6.0

Note: The largest pre- to postoperative changes appeared to be in Class II.

Abbreviations: CT, computed tomographic; LMC-CI, left medial canthus to central incisor; LMC-LC, left medial canthus to left canine; RMC-RC, right medical canthus to right canine.

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position relative to the maxillary anterior teeth. However, intraoperatively, a soft tissue landmark (medial canthus) is used to measure to this distance.

Optimization of esthetic results in orthognathic surgery varies by surgeon but proper maxillomandibular complex positioning and intraoperative measurements from the medial canthus have been shown to be important metrics to ensure translation of the proper vertical position and lip positioning. Vertical cephalometric measurements also are critical to avoid cant creation and malocclusion.[9] The most used technique for achieving the desired intraoperative vertical positioning of the upper jaw includes the use of external reference points; however, inaccuracies with this method can occur.[10] Inaccuracies in the differences between planned and actual measurements in maxillary surgery is due primarily to the difference in measurements between reference lines compared with changes at the level of dentition.[11,12]

Another reason is that surgeons fail to acknowledge the triangulation effect as a result of horizontal or transverse movements of the maxilla when considering vertical measurements. Because of the triangulation effect, to properly maintain the level of the dental landmark, the distance between the external reference point (medial canthus) and the tooth (canine or incisor) is actually represented by the hypotenuse of a right triangle rather than a purely vertical measurement.[10] This could explain the larger change in vertical measurements in patients with Class III (prognathic) occlusions given that maxillary advancement is necessary in these cases. Some have reported the use of vertical guides in conjunction with splints using computer-assisted surgical simulation.[10,13-16] The future, with custom-printed Le Fort cutting guides and plates that predetermine vertical positioning, might make intraoperative vertical measurements less critical. However, the onus will be placed on fastidious preoperative planning, and the locked-in vertical position prevents intraoperative esthetic judgments based on the incisal display to be altered or manipulated.

Facial asymmetry is dependent on not only bony landmarks but also soft tissue changes. Even with advanced imaging techniques, such as 3D CT facial imaging, deviations in the calculation of bony landmarks varies depending on the methods for establishing reference planes.[17] Intraoperative vertical measurements from soft tissue to bony teeth landmarks correlate closely with the actual bone position, although the relation is not always predictable. External reference points using the nasion or medial canthal region

Table 3. PRE- TO POSTOPERATIVE CT VERSUS PRE- TO POSTOPERATIVE SOFT TISSUE MEASUREMENTS

	Soft Tissues	CT	Ratio	*P* Value
LMC-CI	2.76 ± 1.9	2.74 ± 2.2	1.00	.98
LMC-LC	2.59 ± 1.9	2.52 ± 2.2	1.02	.89
RMC-RC	2.65 ± 2.2	3.18 ± 2.5	0.83	.38

Note: This table presents the difference between pre- and postoperative vertical measurements depending on the modality and relative ratios of soft tissue to bony CT measurements. None of these values were statistically significant.

Abbreviations: CT, computed tomographic; LMC-CI, left medial canthus to central incisor; LMC-LC, left medial canthus to left canine; RMC-RC, right medical canthus to right canine.

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Table 4. IMPACTION RATIOS FOR SOFT TISSUE TO BONY CT MEASUREMENTS

	Soft Tissues	CT	Ratio	*P* Value
LMC-CI	1.66 ± 1.8	2.61 ± 2.5	0.63	.3
LMC-LC	1.22 ± 1.1	2.40 ± 2.1	0.51	.1
RMC-RC	1.39 ± 1.3	2.70 ± 2.6	0.52	.12

Note: None of the ratios were statistically significant.

Abbreviations: CT, computed tomographic; LMC-CI, left medial canthus to central incisor; LMC-LC, left medial canthus to left canine; RMC-RC, right medical canthus to right canine.

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have been validated as reproducible points of reference for intraoperative vertical measurements in orthognathic surgery.[15,16,18-20]

The present study corroborates intraoperative measurements as a valid and predictable method for vertical maxillary positioning. The results show that there is a nonlinear relation between soft tissue intraoperative values and the actual bony change that results. This is important to recognize because the amount of bony change planned during virtual surgical planning might depict a 2-mm change from the infraorbital line, but this does not correlate exactly with the intraoperative measurement changes for the medial canthal to incisor. The intraoperative measurements are a guide, and their change is important to ensure a cant is corrected or not created. Esthetic judgment is still necessary when establishing the maxillary, lip, and tooth relations. A previous study reported a predictable ratio of soft to hard tissue in advancement during certain orthognathic procedures, including genioplasty, osseous chin recontouring, and alloplastic chin augmentation.[21] Using radiographic and real-time intraoperative vertical measurements could be obviated with increased acceptance and usage of 3D custom maxillary plates. However, the ability to predict the interface between the soft tissue and bone remains paramount. The present study sheds light on this and could help in the improvement of predictive and simulation software related to bone, lip, and tooth vertical positioning.

Table 5. DISIMPACTION RATIOS FOR SOFT TISSUE TO BONY CT MEASUREMENTS

	Soft Tissues	CT	Ratio	*P* Value
LMC-CI	3.38 ± 1.8	2.82 ± 2.1	1.21	.3
LMC-LC	3.70 ± 1.3	2.58 ± 2.3	1.43	.1
RMC-RC	3.40 ± 2.3	3.45 ± 2.5	0.98	.12

Note: None of the ratios were statistically significant.

Abbreviations: CT, computed tomographic; LMC-CI, left medial canthus to central incisor; LMC-LC, left medial canthus to left canine; RMC-RC, right medical canthus to right canine.

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Limitations of this study relate to inherent measurement error, location of bony landmarks, and accuracy of intraoperative measurements. However, a single surgeon took and recorded all intraoperative measurements and the post hoc CT analysis was standardized and shown to exhibit good inter-rater reliability. Future studies will build on these data to further elucidate the relation between soft tissue and bony measurements in Le Fort I vertical repositioning. Stratification of results based on 3D movements and long-term follow-up also will be implemented to further corroborate this correlation. The correlation of the predicted bony to soft tissue measurements with the esthetic outcome, on a standardized rubric by blinded graders, would shed light on the importance of the vertical position on overall esthetic outcomes.

Proper vertical Le Fort I positioning is important to achieve the desired esthetic result in orthognathic surgery. The present results show a nonlinear but predictable relation between intraoperative (canthi and maxillary dental) and actual bony vertical measurements. Understanding this relation enables the effective use of intraoperative measurements to reproducibly achieve the desired bony vertical position.

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