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SOFT TISSUE EFFECTS FROM MAXILLOMANDIBULAR ADVANCEMENT WITH COUNTERCLOCKWISE ROTATION

Timothy Yu
University of the Pacific Arthur A. Dugoni School of Dentistry, t_yu9@u.pacific.edu

Audrey Yoon
University of the Pacific Arthur A. Dugoni School of Dentistry, jungdds@gmail.com

Stanley Yung Chuan Liu
Otolaryngology/Head & Neck Surgery (Sleep Surgery) at the Stanford University Medical Center, ycliu@stanford.edu

Heeyeon Suh
University of the Pacific Arthur A. Dugoni School of Dentistry, hsuh1@pacific.edu

Joorok Park
University of the Pacific Arthur A. Dugoni School of Dentistry, jpark3@pacific.edu

See next page for additional authors

Author

Timothy Yu, Audrey Yoon, Stanley Yung Chuan Liu, Heeyeon Suh, Joorok Park, and Heesoo Oh

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by

Timothy Yu

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Timothy Yu

APPROVED BY:

Thesis Advisor: Heesoo Oh, DDS, MSD, Ph.D.

Thesis Committee: Joorok Park, DDS, MSD.

Program Director and Chair: Heesoo Oh, DDS, MSD, Ph.D.

Soft Tissue Effects from Maxillomandibular Advancement with Counterclockwise Rotation

ABSTRACT

Introduction:

The purpose of the study was to evaluate the effects of maxillomandibular advancement (MMA) surgery with counterclockwise rotation on soft tissue oral and nasal structures.

Materials and Methods:

This retrospective study included 34 subjects diagnosed with OSA who underwent MMA at the Stanford Sleep Clinic. Initial (T1) and Final (T2) CBCTs were evaluated and compared for 10 hard tissue and 15 soft tissue measurements. Additionally, the external nasal valve surface area was measured and compared between the two time points. A 3D superimposition was performed and used to evaluate the relative hard and soft tissue movements.

Results:

There was a linear correlation in the advancement of the maxilla to the sagittal movement of the upper lip of 75%, while the mandibular soft tissue moved 91-93% of the mandibular sagittal position. The interalar width and mouth width increased significantly following surgery while the lower vermillion border length decreased significantly. There was a clinically significant increase in the average surface area of the external nasal valve by 28%. No correlations were found between maxillary impaction and soft tissue oral or nasal measurements.

Conclusion:

MMA with CCW results in significant changes to the soft tissue nose and oral region. Soft tissue planning must be considered to maintain desirable esthetics following surgery.

INTRODUCTION

Obstructive sleep apnea (OSA) is a condition characterized by a repeated episode of pharyngeal collapse and increased airflow resistance during sleep. It is estimated to affect between 6-17% of adults in the US, but remains underdiagnosed across the population.[1,2] The first line treatment for OSA is continuous positive airway pressure (CPAP) therapy, though alternative treatments such as oral appliances may also be offered if compliance or tolerance of the device is limited.[3,4]

For patients with an existing dentofacial deformity, severe OSA, or concentric velopharyngeal collapse found on an examination with drug induced sleep endoscopy, maxillomandibular advancement (MMA) surgery is considered.[5] Adjunctive soft tissue procedures, such as UPPP and septoplasty can also be done either before or at the time of surgery.[6] MMA surgery is widely considered the most effective craniofacial surgical technique for adult OSA treatment, with pooled success and cure rates of 86.0% and 43.2%, respectively.[7]

Though the magnitude of advancement of the maxillomandibular complex can vary, the surgeon is limited to maintaining a stable occlusion and balanced esthetic appearance. Altering the occlusal plane through a counterclockwise rotation is a technique used to both maximize facial esthetics and airway space.[5,8] Despite the significant degree of advancement, the facial changes from an MMA with counterclockwise rotation are generally deemed favorable by patients.[9,10]

Previous reports analyzing the soft tissue changes following MMA have generally found an increase in the sagittal dimensions of the lips, cheeks and chin.[11,12] Additionally, studies quantifying soft tissue changes after orthognathic surgery routinely find an increase in alar base width.[12-14] However, there have not been any studies revealing the changes in the nasal valve structures after MMA, which is thought to be a key area of airflow resistance. Furthermore, there are few studies that show the soft tissue changes following an MMA with significant CCW rotation.

The purpose of this study was to analyze the soft tissue changes of the perioral and nasal region and determine the relationship of soft tissue movement relative to skeletal advancement from MMA surgery.

MATERIALS AND METHODS

This was a retrospective study approved by the University of Pacific institutional review board (IRB#16-14). The sample was collected from a single orthodontist (A.Y) who treated the subjects at her private clinic following MMA surgery at Stanford Sleep Surgery from 2014 to 2019 (Fig 1).

Inclusion criteria for the study were the following:

1. Adult patients with documented OSA by attended polysomnography
2. MMA completed by Le Fort 1 and bilateral mandibular sagittal split osteotomies
3. Adequate diagnostic pre- and post-treatment radiographs and documentation

Exclusion criteria for the study were the following:

1. Previous orthognathic surgery
2. Previous maxillofacial surgery, including DOME/SARPE
3. Congenital syndromic craniofacial deformities
4. Poor image quality

MMA Surgical Technique

All surgical procedures were performed or supervised by a single operator (S.L.) at the Stanford Sleep Surgery Clinic. Complete surgical steps was documented along with preoperative planning and postoperative care.[5]

Hard/Soft Tissue Morphological Data

A CBCT scanner (i-CAT FLX, Imaging Sciences, Hatfield, PA) set to a standard setting (300 frames, 120 kVp, 5 mA, 17 x 10 field of view, scanning time of 3.7 s) was used to evaluate the pre- and post- surgical analysis for the MMA subjects in natural head position. Pre-operative (T1) CBCT was acquired within 8 weeks before surgery and a final (T2) CBCT was acquired following completion of orthodontia.

Digital Imaging & Communications in Medicine (DICOM) images were imported into Invivo software (version 6; Anatomage, San Jose, CA) and deidentified for analysis. All scans were oriented to: 1. Axial plane via inferior border of right and left orbits 2. Coronal plane via Frankfort.

Digital Imaging & Communications in Medicine (DICOM) images were imported into Invivo software (version 6; Anatomage, San Jose, CA) and deidentified for analysis. Each image was examined by two judges. After at least three calibration sessions using randomly selected cases, each examiner located landmarks using 3D Analysis feature in Invivo 6.

The CBCTs were oriented prior to landmark location by using three reference planes: (1) Frankfort Horizontal (FH) plane – the primary reference plane that intersects right porion, left porion, and right orbitale; (2) Midsagittal plane – plane passing through nasion and basion and perpendicular to FH plane; and (3) Frontal plane – plane perpendicular to both the FH and midsagittal plane and passing through nasion. A Cartesian coordinate system was constructed based on the three reference planes and the origin was set at nasion.

A total of 42 skeletal and dental landmarks and 36 soft tissue landmarks (Appendix) were identified on the T1 and T2 CBCT images. Landmarks were first located on the 3D volumetric image and were simultaneously displayed in the “Slice locator” view, where the position of the landmark was adjusted in the sagittal, coronal, and axial views. The dual display of the landmark location in the volumetric and cross-sectional views facilitated more precise landmark. The landmark location estimates of two judges were averaged to obtain the x, y, and z coordinates for skeletal and dental landmark. Soft tissue landmarks were evaluated by one examiner and was followed by randomly retracing 7 subjects to test intra-judge reliability. A custom 3D cephalometric analysis was developed, and 10 hard tissue and 15 soft tissue measurements were calculated using the InVivo 3D Analysis tool (Table I).

The external nasal valve was measured by orienting the palatal plane parallel to the horizontal reference plane (Fig2A). In the sagittal section, the horizontal bar is brought superiorly until the nasal aperture is visualized and the first slice in which the external nasal valve was completely surrounded by soft tissue is taken. A best fit line along the lumen of the internal nasal contours was used to measure the surface area of the external nasal valve (Fig 2B).

Upper lip thickness was measured from the middle of the philtrum to the corresponding bone, perpendicular to the soft tissue projection. The lower lip thickness was taken from sublabiale to the tangent line perpendicular to the hard tissue (Fig 2C).

To evaluate the sagittal and vertical movement of the maxilla and mandible from the MMA, a 3D superimposition was performed using the InVivo software through two steps: 1) Registration of matching landmarks on both CBCTs (e.g. Nasion, Right Orbitale, Basion, Right Porion, etc.), then 2) Use of the anterior cranial base as the volume of interest. Axial, sagittal, and coronal slice views of the volumes were used to fine-tune the superimpositions (Fig 2). Once voxel-based superimposition of the T1 and T2 CBCTs was completed, a common coordinate system for both images was established (Fig 3) and displacement in 4 skeletal and 8 soft tissue landmarks were evaluated.

Statistical Analysis

Descriptive statistics were generated to report the mean, standard deviation (SD), and range of the demographic information and skeletal and dental measurements at T1 and T2. Skeletal landmarks were identified by two independent examiners and averaged to determine the measurement. Inter-examiner reliability was provided via intraclass correlation coefficients (ICC).

Paired t-tests were used to evaluate the initial and final skeletal and soft tissue measurements between the two time points. Pearson correlation coefficients were used to determine the strength of association between skeletal and soft tissue relationships. Finally, a stepwise linear regression analysis was used to assess the predictive potential of skeletal measurements to the soft tissue changes. Significance value was set at 0.001.

Statistical values were computed using the Statistical Package for Social Sciences (SPSS) statistical software package (version 12.0; SPSS, Chicago, Ill).

RESULTS

Demographic data of subjects are provided in Table IIa and IIb. There were 34 subjects with moderate to severe OSA included in this study. Twenty-eight subjects were male and 6 were female. The average age at surgery was 35 years with a range of 18-65 years. The average preoperative BMI was 27.49. The mean duration of time in orthodontia before surgery was 6.3 months, while the mean time in orthodontia following surgery was 8.96 months and ranged from 2.13 to 26.23 months. There were 13 subjects who received genioplasty with MMA and 8 who underwent extractions prior to the surgery. Twenty of the subjects were Caucasian, 6 were Asian, and 8 were Hispanic. Finally, the Angle class of the subjects included 22 Class I, 11 Class II, and 2 Class III.

The ICC values for the skeletal and soft tissue measurements averaged 0.93 and 0.94 respectively, indicating excellent reliability.

A summary of the cephalometric measurements is included in Table III. There was a mean sagittal advancement of A point, B point and Pogonion from S-perpendicular of 4.12 ± 2.29 mm, 10.51± 3.63 mm and 14.11 ± 5.39 mm, respectively. There was a superior displacement of A point by 3.81± 3.31 mm, B point by 1.09 ± 3.55 mm, and Pogonion by 2.08 ± 3.66 mm. The MMA surgery resulted in a mean counterclockwise rotation of the occlusal plane, palatal plane, and mandibular plane of 4.13 ± 3.52°, 6.77 ± 3.61°, and 5.07 ± 2.87°, respectively.

There were a number of significant changes in the nasal and oral soft tissue measurements detailed in Table IV. Soft tissue measurements at T2 showed a significant increase in the soft tissue alar width of 3.55 ± 1.53 mm. The alar base width increased by 3.01 ± 3.61 mm and the alar slope angle increased by 11.87 ± 5.32°. There was a decrease in the mean nasolabial angle by 2.54 ± 12.67°, which was not statistically significant. Additionally, there was a slight decrease in the nasal tip angle of 1.79 ± 5.97°. The external nasal valve surface area had a significant increase on the right and left sides of 31.71 ± 26.38 mm^2 and 24.52 ± 21.60 mm^2, respectively, combining for an average increase of 28.12 ± 20.58 mm^2 (Fig 4).

Following the surgery, the oral region showed significant changes in the width of the mouth, which increased by a mean of 1.88 ± 3.25 mm. The lower lip vermillion border decreased significantly by an average of 1.92 ± 1.93 mm. The upper lip thickness showed a significant mean decrease of 1.62 ± 1.6 mm from T1 to T2. The relationship of initial upper and lower lip thickness was compared to the total change in lip thickness following surgery (Fig 6). The findings indicate that subjects with thicker upper lips at T1 had more decrease in upper lip thickness following surgery. In contrast, the thinner the lower lip thickness at T1, the more it had increased following surgery.

Through a 3D volumetric superimposition, the cranial base of T1 and T2 was overlayed and the hard and soft tissue changes were assessed from a common reference point. The 3 hard tissue and 4 soft tissue landmarks were identified in a horizontal and vertical coordinate plane and compared at T1 and T2 (Table IIIa,b). Subnasale, representing the upper lip position, came forward an average of 3.04 mm relative to the mean advancement of 3.98 mm of the maxilla. This resulted in a 76% soft tissue to hard tissue change in the upper lip. In the vertical dimension, the subnasale move superiorly 1.88 mm, relative to the 3.57 mm mean impaction of the maxilla, which represented a 53% soft tissue to hard tissue change. The tip of the nose tracked at 48% of the advancement and 59% of the impaction. Interestingly, the mean relative soft tissue to hard tissue mandibular changes in the group that did not receive a genioglossus advancement with the MMA were greater than those that did. While the group that did not receive a genioglossus advancement had the soft tissue pogonion point move superiorly in the direction of the skeletal changes, those with a genioglossus advancement ended up with the soft tissue pogonion moving inferiorly by a mean of 2.21 mm, though the mean skeletal change was 1.62 mm in the superior direction (Fig7).

Pearson correlations were assessed to determine any significant relationships between the hard and soft tissue movements (Table IVa,b). There were no linear correlations between maxillary impaction and any of the soft tissue measurements. Maxillary advancement was strongly correlated with the sagittal movement of subnasale. Additionally, forward maxillary sagittal movement was correlated with an upward displacement of the nose tip, increase in the upper lip vermillion border length, and decrease in upper lip thickness. A multivariate regression analysis determined the upper lip position is strongly correlated to the advancement of the maxilla, with 70- 80% of change in the upper lip displacement correlated to maxillary advancement (Fig 6). Together, the maxillary advancement and impaction explained 66% of the variation in the upper lip position. Additionally, the mandibular soft tissue at sublabiale and pogonion moved with the skeletal mandibular advancement at a ratio of 0.91-0.93:1 (Fig 5).

DISCUSSION

There is a high degree of variability of individual patient factors which contribute to the soft tissue changes following surgery. These can be divided in to preoperative, perioperative, and postoperative variables.[14] Soft tissue thickness and tone is one of the primary preoperative variables reported to affect the soft to hard tissue relationship, with thinner soft tissues more closely adapting to the hard tissue changes that occur.[15] The findings from this study indicate that the initial upper and lower soft tissue thickness was correlated with either an increase or decrease in the final tissue thickness. On the upper lip, subjects with decreased upper lip thickness did not undergo a significant change following surgery, indicating that the soft tissue followed closely with the skeletal movement. However, those with greater initial upper lip thickness had more of a decrease following MMA surgery, possibly due to the movement of displaceable tissue in the upper lip. These results also indicate that there may be a certain minimum thickness of the upper lip in which additional advancement will not displace the tissue and result in a thinner upper lip contour. In contrast, subjects with a decreased lower lip thickness displayed a positive change following surgery. This is in part due to an alleviation of the lip incompetence caused by a retrognathic mandible in a Class II phenotype. A mandibular advancement with CCW rotation advances the soft tissue B point, thereby increasing the lower lip thickness in subjects with an initial deficiency.

Surgical variables, such as bony recontouring, the magnitude and direction of surgical movement, and surgical closure of soft tissue will affect the final surgical outcome.[14] The MMA procedure starts with a Le Fort osteotomy and is followed by removal of a wedge at the anterior piriform rim. A septoplasty is performed, and the piriform rim and nasal floor are widened. Based on a review of 370 MMA patients from Stanford, 18.7% underwent functional or esthetic nasal surgery within 1.5 years after surgery. The rate decreased to less than 5% in the recent 120 patients with judicious midfacial contouring and intraoperative septoplasty and inferior turbinate reduction.[16]

There is disagreement in the literature as to the effects of recontouring at the anterior nasal spine. Some authors claim that it reduces nasal tip support[17], while others maintain that the piriform aperture and rotation of the palatal plane create the support for the nasal tip.[18] It is not evident from the results of the present study that rotation of the maxillomandibular complex, or more specifically the vertical displacement of the maxilla had any correlation with the displacement of the nasal tip. The correlational analysis determined that maxillary advancement had a more substantial effect on the vertical displacement of the nose tip.

Additionally, the changes in the nasolabial architecture is influenced by the tissue changes of the nose and upper lip. Though the nose tip is displaced forward and upward, the majority of changes of the nasolabial angle appears to come from the advancement of the lip rather than from upturning of the nose.[13] The entire nasolabial complex encounters a counterclockwise rotation following the MMA procedure. It was found that even large maxillary advancements of over 8 mm yielded clinically insignificant changes in the nasolabial angle due to the change in the relationship of the upper lip and nose[14]. The findings of this study confirm that there are minimal changes of the nasolabial angle.

A comparative analysis was performed to determine how the various soft tissue regions respond to the surgical movement. In a previous study, investigators looked at the effects of mandibular advancement on the soft tissue structures. The soft tissue pogonion was shown to have a mean advancement of 100% of the mandibular advancement[19], while Ryckman[20] found 96% hard to soft tissue ratio in the chin. The findings in the present study correspond with the findings in the literature. At soft tissue B point, there was a 93% correlation between hard and soft tissue and the soft tissue pogonion correlated with the hard tissue about 91%. However, a new finding from this study demonstrates the difference in relative hard and soft tissue movement between the group that received a genioglossus advancement and the one that did not. In the group that received a genio advancement, roughly, 80% of the relative soft tissue change was observed compared to 93% in the non genio group. This is perhaps explained by the surgical dissection of the soft tissue during the genioglossus advancement procedure and subsequent reorganization that results in a change of the soft tissue relationship. Additionally, the subjects that were in the genio group did not have a mean change in the face height, measured from nasion to menton, while the non-genio group had a mean reduction of 2.05 mm. The absence of any meaningful reduction in face height may contribute to less soft tissue being projected anteriorly.

A commonly reported finding in the literature is an increase in the greatest alar width of nose that ranged between 1.7-2.5 mm.[12] It is thought the amount of maxillary advancement is correlated to the increase in interalar width[20-21]. In this study, there was a significant increase in the alar width of 3.55 mm and alar base of 3.0 mm. A modest increase in the alar base can be esthetically favorable, particularly in cases of maxillary hypoplasia where the interalar width is narrow. One of the primary benefits of widening the alar width is the subsequent change in the external nasal valve structures, a common site for nasal valve collapse and inciting factor for obstructive events. By widening the alar base, this study demonstrated an appreciable change in the external nasal valve surface area by a mean of 28%. Though this finding has not been directly linked to a reduction in OSA or improvement in NOSE scores, it is well demonstrated the role that expansion of the nasal valve structures has on improving collapsibility of the airway. However, it should be stated that in certain populations, further increasing the alar width can be detrimental to nasal esthetics and must be weighed in to the decision of whether an alar base cinch is to be used to minimize the alar width increase.[22]

The main limitations of the study included a lack of a control group to compare the soft tissue effects from a conventional MMA without significant CCW rotation. Despite the relative abundance of literature on the soft tissue changes following orthognathic surgery, MMA is unique in the magnitude and direction of the underlying skeletal movements. Additionally, the sample size was insufficient to assess any of the soft tissue effects due to sex, ethnicity, and age which are all important contributors to soft tissue variation. Finally, all of the surgeries were performed from a single clinician and the results of the study may not be generalized across all MMA procedures.

MMA surgical planning is a balance between providing the most airway related benefit through advancement of the maxillomandibular complex while minimizing or avoiding facial disharmony. The counterclockwise rotation is a surgical technique to obtain success in OSA treatment without the compromise of disfigurement to facial balance.

CONCLUSIONS

MMA with CCW rotation results in significant changes to the oral and nasal anatomy. The tissue overlying the maxilla and mandible show different relationships in response to skeletal advancement. The nasal anatomy changes significantly by widening of the alar width and rotation in the nasolabial complex. While the upper lip shows a moderate amount of change in response to maxillary advancement, the soft tissue surrounding the mandible follows the hard tissue sagittal movements to a closer degree. Surgical planning should take in to account the soft tissue responses for an esthetic outcome, which is paramount to surgical success.

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Figures/Tables

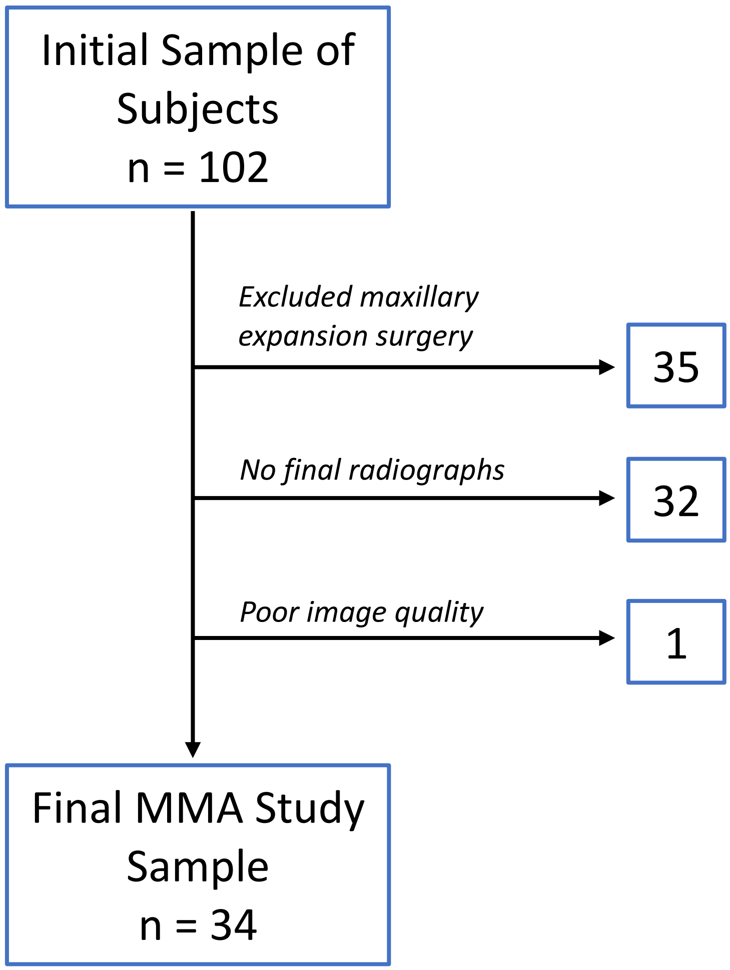

Fig 1. Flow diagram of obtaining final sample

Fig 2. A) The sagittal section is oriented with palatal plane parallel to the horizontal reference plane. B) In the sagittal slice, the horizontal bar is brought superiorly until the nasal aperture is visualized and completely surrounded by soft tissue in the axial slice. C) Upper and lower lip thickness measured from middle of philtrum and soft tissue B point, respectively to tangent line perpendicular to the hard tissue.

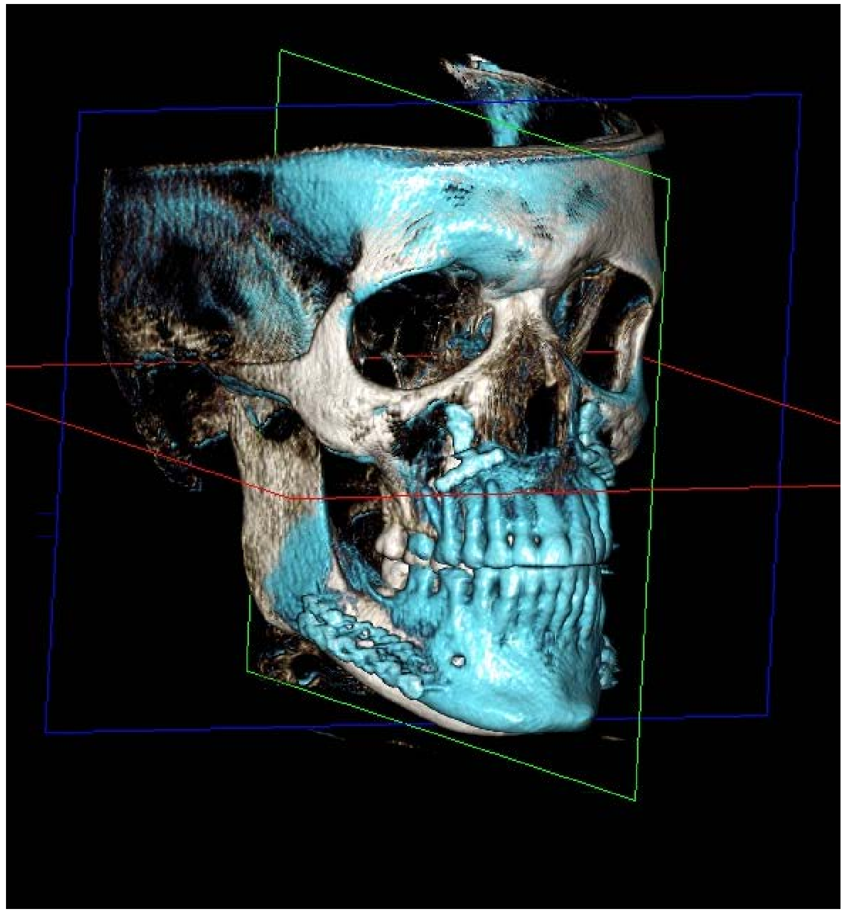

Fig 3. 3D superimposition via registration on cranial base as volume of interest. Common coordinate system was established to determine displacement of hard and soft tissue landmarks.

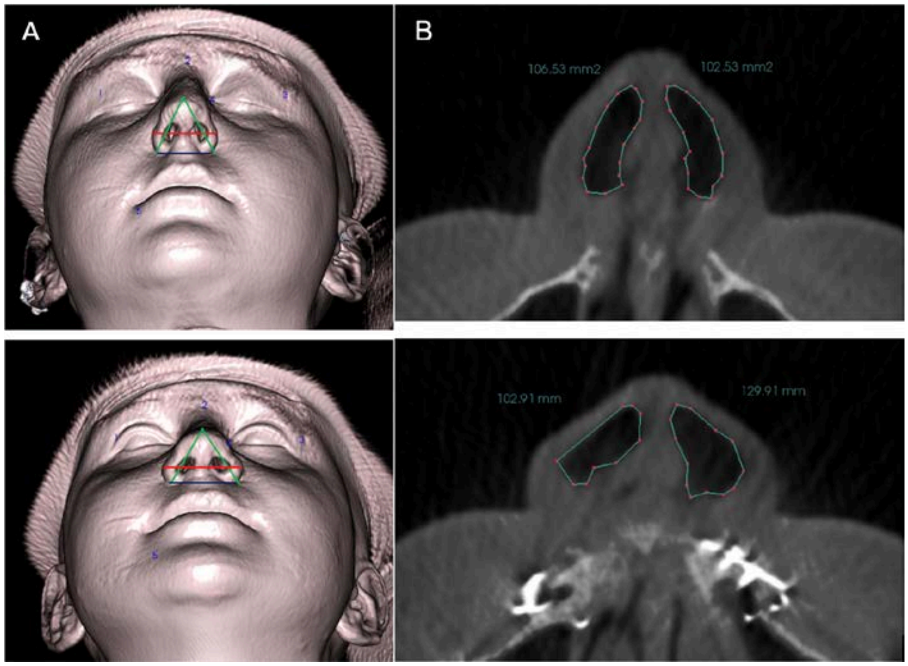

Fig 4. A) Comparison of alar width (red), alar base (blue) and alar tip angle (green) between T1 and T1. B) Comparison of the external nasal aperture in T1 and T2

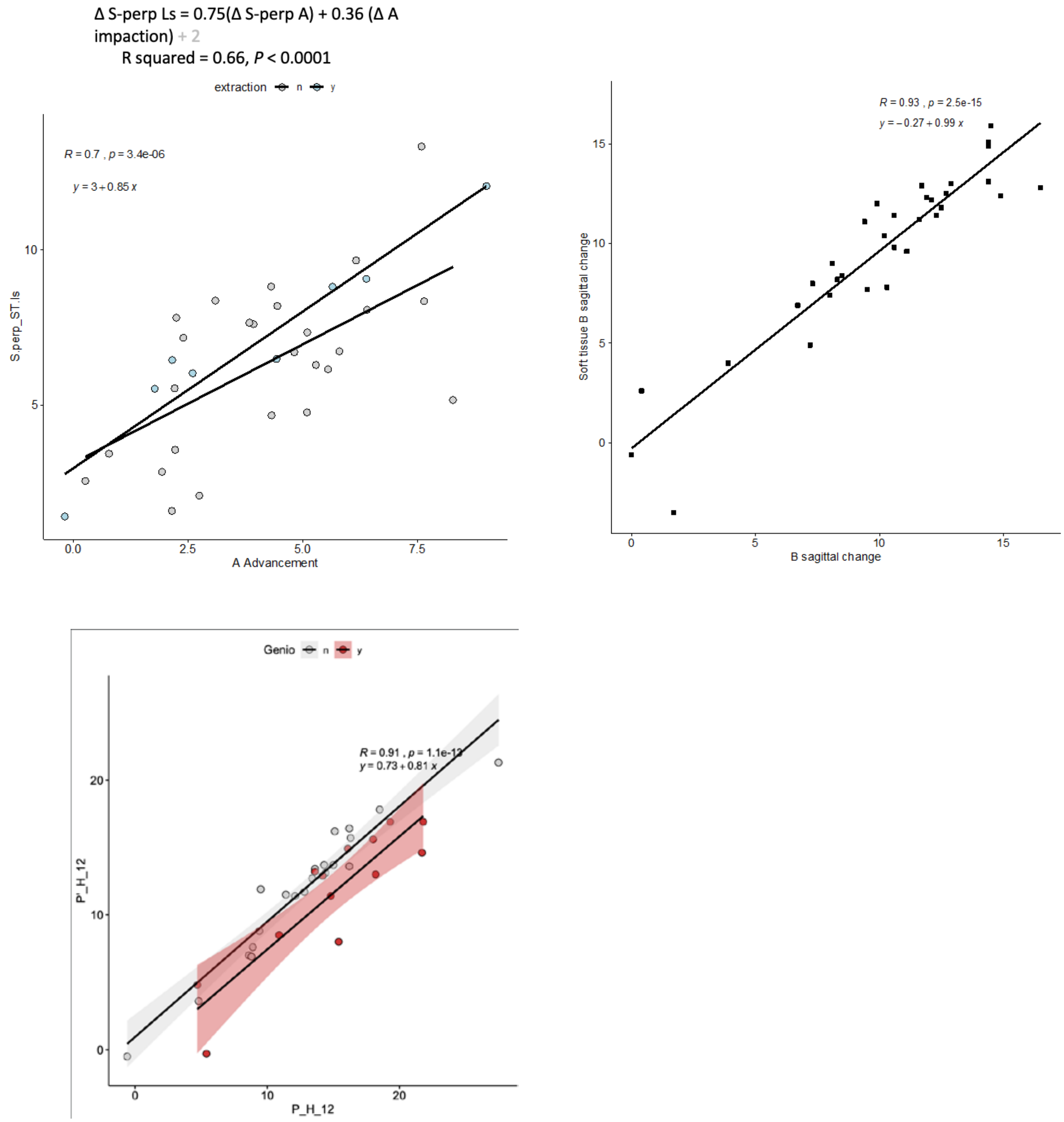

Fig 5. Stepwise linear regression indicating the relationship of maxillary and mandibular advancement on soft tissue position.

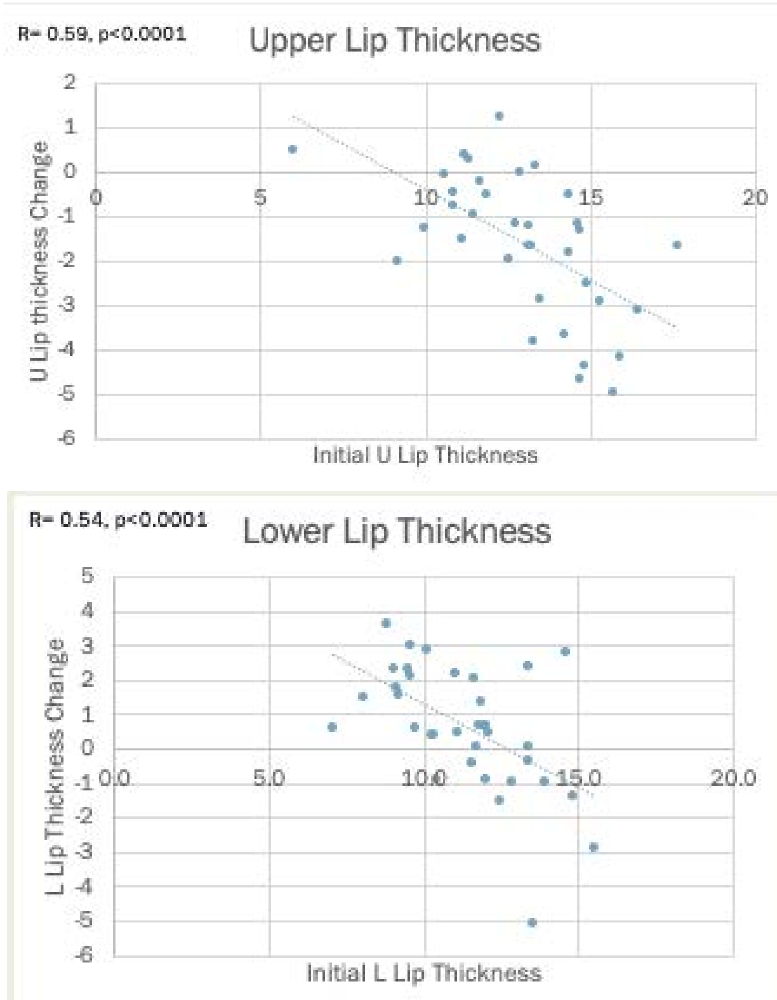

Fig 6. Initial tissue thickness is negatively correlated with the change in soft tissue following surgery.

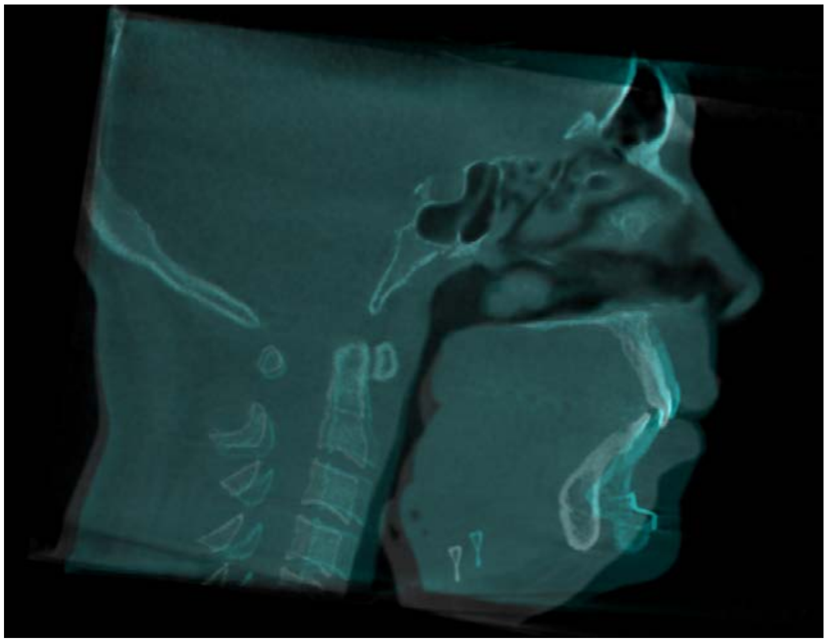

Fig 7. 3D Superimposition of MMA with genio advancement showing the downward vertical displacement of soft tissue pogonion.

Table IA. Soft Tissue Measurements	
Measurement	**Definition**
Alar width	The linear distance between alare to alare
Alar base width	The linear distance between alar curvature to alar curvature
Alar slope angle	The angle formed from alare, pronasale, alare
Nasal tip angle	The angle formed by ST nasion, pronasale, midcolumella, and subnasale
Nasolabial Angle	The angle formed by midcolumella, subnasale, and labrale superiorus
Width of Mouth	The linear distance from chelion to chelion
Upper lip length	The linear distance from labrale superiorus to stomion superiorus
Lower lip length	The linear distance from stomion inferiorus to labrale inferiorus
Upper vermillion border length	The linear distance from labrale superiorus to stomion superiorus
Lower vermillion border length	The linear distance from stomion inferiorus to labrale inferiorus
Mandibular angle width	The linear distance from ST gonion to ST gonion

Table 1bMeasurement
SNA
SNB
ANB
SNPog
S-Perp A point
S-Perp B point
S-Perp Pogonion
FH-Occlusal Plane angle
FH-Palatal Plane angle

Table IIa. Demographic data		
	Mean	Range
Age	38.06	18-65
Initial BMI	27.49	17.4 - 38.7
Total Tx Time (Mo)	15.13	2.75-34.89
Duration Before Surgery (Mo)	6.3	0.62-21.05
Duration After Surgery (Mo)	8.96	2.13-26.23

Table 1Ib. Demographic data	
Sex (M:F)	29: 6
Angle Class (Cl I:II:III)	22:11:02
Extraction (Y:N)	8:27
Genioplasty (Y:N)	11:24

Table III. Cephalometric measurements									
	Pre-surgery (T1) (n=35)			Final (T2) (n=35)			T2-T1		Paired T-test
	mean	sd		mean	sd		mean	sd	*P**
SNA (°)	81.7	3.19		85.49	4.57		3.76	3.16	<0.0001
SNB (°)	76.26	4.47		81.87	4.27		5.67	3.03	<0.0001
ANB (°)	5.53	2.96		4.08	2.4		-1.45	2.17	<0.0001
S.perp_A (mm)	70.2	4.48		74.32	5.2		4.12	2.29	<0.0001
S.perp_B	61.38	8.29		71.89	7.96		10.51	3.63	<0.0001
S.perp_Pog	62.53	9.81		76.64	9.03		14.11	5.39	<0.0001
A_z	-59.93	3.63		-56.12	3.69		-3.81	3.31	<0.0001
B_z	-101.73	6.16		-100.6	6.15		-1.09	3.55	0.0833
Pog_z	-114.32	6.25		-112.3	5.65		-2.08	3.66	0.0023
OC_FH	9.73	5.25		5.6	4.45		-4.13	3.52	<0.0001
PP_FH	0.75	3.74		-7.52	3.66		-6.77	3.61	<0.0001
MP_FH	27.2	6.33		22.13	5.87		-5.07	2.87	<0.0001
S.perp_U1	72.79	5.69		80.94	6.16		8.15	2.96	<0.0001
S.perp_L1	70.3	5.76		78.29	5.75		7.99	2.76	<0.0001
***, paired t-test**									

Table IV. Oral and nasal measurements							
	T1		T2		T2-T1		paired t-test
	mean	sd	mean	sd	mean	sd	P*
External nasal aperture area (R)	128.57	37.92	160.28	45.45	31.71	26.38	<0.0001
External nasal aperture area (L)	130.2	34.45	154.72	40.23	24.52	21.6	<0.0001
External nasal aperture area (avg)	129.38	34.42	157.5	41.17	28.12	20.58	<0.0001
Alar width	36.55	2.91	40.1	3.02	3.55	1.53	<0.0001
Alar base width	32.58	3.47	35.58	3.39	3.01	3.61	<0.0001
Alar slope angle	85.27	11.42	97.13	11.99	11.87	5.32	<0.0001
Nasal tip angle	83.42	8.07	81.63	9.34	-1.79	5.97	0.0946
Nasolabial angle	103.72	10.65	101.18	10.63	-2.54	12.67	0.2583
Width of mouth	47.99	5.08	49.87	5.49	1.88	3.25	0.0017
Upper lip length	8.93	1.64	8.77	1.45	-0.6	2.28	0.13
Lower lip length	7.31	2.47	5.39	1.58	-1.02	2.05	0.006
Upper lip vermillion border	8.93	1.64	8.77	1.45	-0.16	1.38	0.4879
Lower lip vermillion border	7.31	2.47	5.39	1.58	-1.92	1.93	<0.0001
Upper lip thickness	12.96	2.3	11.35	1.88	-1.62	1.6	<0.0001
Lower lip thickness	11.34	2.01	11.97	1.83	0.63	1.8	0.05

Table IIIa. Comparison of skeletal and soft tissue horizontal changes							
Skeletal (N-Perp)	**N**	**Skeletal change**		**Soft tissue (')**	**Soft tissue change**		**Percent of**
		mean	sd		mean	sd	
A_H	35	3.98	2.29	SN_H	3.04	1.94	76
				PrN_H	1.93	2.81	48
B_H	21	10.54	3.95	B'_H	10.43	3.92	99
B (genio)	13	9.19	4.12	B'_H (genio)	8.38	4.66	91
Pog	21	12.68	5.55	Pog'_H	11.79	4.95	93
Pog (genio)	9	16.53	3.74	Pog'_H (genio)	13.16	3.19	80

Table IIIb. Comparison of skeletal and soft tissue vertical changes							
Skeletal (N-Perp)	**N**	**Skeletal change**		**Soft tissue (')**	**Soft tissue change**		**Percent of**
		mean	sd		mean	sd	
A_V	35	-3.57	2.86	SN_V	-1.88	1.28	53
				PrN_V	-2.09	1.39	59
NMe	24	-2.05	2.6				
NMe (genio)	10	0.01	3.56				
B_V	21	-2.32	3.27	B'_V	-4.02	4.17	173
B_V (genio)	13	1.46	3.74	B'_V (genio)	1.67	3.44	114
Pog_V	21	-2.62	3.21	Pog'_V	-2.99	3.22	114
Pog_V (genio)	9	-1.62	3.62	Pog'_V (genio)	2.21	3.62	-136

Table IVa. Pearson correlation Maxillary Impaction		
Measurements	r	p
External nasal valve	0.16	0.357
Alar width	0.19	0.283
Alar base width	0.01	0.968
Nasal base angle	-0.06	0.734
Nasal tip angle	-0.19	0.273
Nasolabial angle	-0.15	0.395
Width of Mouth	-0.05	0.792

Table IVb. Pearson correlation Maxillary Advancement		
Measurements	r	p
Alar width	0.19	0.288
Alar base width	0.11	0.551
Nasal base angle	0.23	0.193
Nose Tip_V	-0.43	0.001
Nasolabial angle	0.22	0.205
Subnasale_H	0.7	<0.0001
Subnasale_V	-0.43	0.01
Upper lip vermillion border	0.49	0.003
Upper Lip Thickness	-0.47	0.005

Appendix

Soft Tissue landmarks

Landmark	**Definition**
Soft tissue nasion	Most concave point between nose and forehead
Pronasale	Most protruded point of nose
Subnasale	Midpoint where the columella base and the upper lip meet
Alare	Most lateral point on the alar contour, if no convexity then the widest part of the nostril
Alar curvature	The base of the ala and the cheek
Subnasale	The point at the deepest curvature on the lateral side of the columella
Subalare	The inner point of the base of the nostrils
Mid Columella	Midpoint of the columella crest at the level of the nostril top points
Labrale Superiorus	The midpoint of the border of the vermillion line
Labrale inferiorus	The midpoint of the border of the vermillion line
Stomion superiorus	Midpoint of the upper border of the upper lip
Stomion inferiorus	Midpoint of the lower border of the lower lip
Chelion	Lateral most point located at the labial commissure
ST Pogonion	The most prominent point of the chin
ST Sublabiale	Posterior midpoint on the labiomental soft tissue contour that defines the border between the lower lip and the chin
ST Subspinale	Deepest concavity anteriorly on the philtrum
ST Gonion	Most lateral point on the soft tissue contour of each mandible (at lower border of mandible) located at the same level as the 3D hard tissue cephalometric gonion landmark