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Title: Immediate effects of rapid maxillary expansion on the naso-maxillary facial soft tissue using 3D stereophotogrammetry.

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Keywords: 3D imaging, stereophotogrammetry, rapid maxillary expansion, facial, soft tissue, rapid palatal expansion.

Short Title: Immediate 3D facial soft tissue effects of RME.

Abstract

Background: Rapid maxillary expansion (RME) is used to expand the narrow maxilla. Dental and skeletal affects have previously been reported but few studies have reported on the overlying soft tissue changes. This study reports on the immediate effects RME on the naso-maxillary facial soft tissue using 3D stereophotogrammetry.

Methods: Fourteen patients requiring upper arch expansion using RME as part of their full comprehensive orthodontic plan were recruited. Cone beam CT scans and stereophotogrammetry images were taken for each patient; pre-RME activation (T_0) and immediately post-RME expansion (T_1). Based on twenty-three landmarks, 13 linear and 3 angular measurements were made from each of the stereophotogrammetry images. A linear measurement at ANS was taken from each CBCT image. Using a Wilcoxon signed rank test, the pre-RME and post-RME measurements were compared.

Results: The mean separation of the anterior nasal spine was 3.8mm ± 1.2mm. The largest median increase was in nasal base width (1.6mm), which was statistically significant ($p=0.001$). Changes in the nasal dorsum height, nasal tip protrusion, philtrum width, and upper lip length were not statistically significant ($p<0.05$). No significant differences were observed in the nostril linear measurements, expect for columella width ($p=0.009$). Naso-labial angle decreased but was not statistically significant ($p=0.276$). The only statically significant angular change was an increase in the nasal tip displacement angle ($p=0.001$).

Conclusion: Rapid maxillary expansion produces subtle changes in the naso-maxillary soft tissue complex. There is an increase in nasal base width, retraction and flattening of the nasal tip. These changes are small, less than 2mm and variable between patients.

Keywords: 3D imaging, stereophotogrammetry, rapid maxillary expansion, facial, soft tissue, rapid palatal expansion

Introduction

Rapid maxillary expansion (RME) has been advocated to increase the transverse width of a narrow maxilla. The expansion facilitates posterior crossbite correction, relief of crowding, increase in airway dimensions and has been used in conjunction with facemask therapy to facilitate maxillary advancement.[1-3] The dental and skeletal effects of RME are well documented in the literature. The main skeletal effects produce separation of the mid-palatal suture, more anteriorly then posteriorly, with vertical expansion extending to varying levels. The expansion is often pyramidal in shape with the greatest expansion around the region of the nasal aperture.[4-8] Studies based on two-dimensional lateral cephalograms have shown that the maxilla displaces downwards and forwards to a varying degree following RME treatment.[9] One of the most noticeable dental effects during RME activation is a diastema between the upper central incisors but tipping of the maxillary posterior teeth and alveolar processes laterally have also been reported.[9-12]

Since the maxillary bones contribute significantly to nasal cavity's anatomical structure, the effects of RME are not just limited to the maxilla but extend to the surrounding nasal structures.[13-16] Conventional tomography has been used to evaluate volume changes in the nasal cavity after RME.[15, 17] These authors reported that the internal area and volume increased significantly throughout the nasal cavity. These changes, together with the maxillary advancement, may produce clinically significant changes in the morphology of the naso-maxillary soft tissue.

The potential effects of RME may not be limited to skeletal and dental changes but may be expected to affect the overlying soft tissue; in particular around the nasal soft tissue. Most of the studies carried out to quantify the effect of RME on soft tissue have utilised two-dimensional techniques, including lateral cephalograms[18] and frontal photographic views or by physical direct measurements.[19, 20] Measuring three-dimensional changes from a frontal profile photograph will have inherent errors whilst directly measuring changes in nasal width using calipers is clinically difficult with landmark identification and soft tissue distortion being a problem. A more recent study has used cone beam CT to evaluate the changes in the naso-maxillary complex associated with two types of maxillary expanders.[16] However, non-invasive methods of capturing the 3D soft tissue based on stereophotogrammetry are available which have been validated and used for analysis of facial morphology.[21, 22]

The aim of the study was to investigate the immediate three-dimensional effects of rapid maxillary expansion on the naso-labial soft tissue using 3D stereophotogrammetry. The underlying hard tissue effects of RME of this group of patients have previously been reported.[23] The null hypothesis was that there is no difference in linear and angular measurements of the naso-labial soft tissue pre and post RME.

Materials and Methods

Following ethical approval from the West of Scotland Research Ethics Committee (REC reference number: 09/S0709/40), patients were recruited from the Orthodontic Department of the Victoria Hospital, Kirkcaldy, Scotland, U.K.

Patients were recruited on their need for upper arch expansion as part of their full comprehensive orthodontic plan; either for unilateral or bilateral posterior crossbite correction and / or relief of crowding. All patients went onto receive full comprehensive orthodontic treatment. Written consent was obtained from each patient and parent or guardian for participation in the study.

The sample size was based on a clinically significant difference of 3mm in soft tissue change[25] with a standard deviation of 1.13mm (6) a power of 0.90, and alpha of 0.05. The calculated sample size was 14 subjects.

Clinical protocol

For each patient, a medical and dental history, intraoral and extraoral photographs and dental casts were taken prior to placement of the appliance. No additional plane film radiographs were taken.

Following upper and lower alginate impressions, a cast cap fixed split acrylic design RME appliance with a Hyrax screw (Forestadent, Germany) was constructed. This was cemented in situ with glass ionomer cement (AquaCem®, Dentsply, Germany) by a single experienced Orthodontic Consultant (JMcD).

Data collection

For all scans, subjects were seated with their Frankfort plane parallel to the floor by a single experienced Consultant Orthodontist (BK). An initial pre-treatment, prior to activation (T_0), CBCT scan was taken (i-CAT, Imaging Sciences

International, Hatfield, Pa). The scan was performed at 120kV, 18.45 mAS, for 20 seconds with a 0.4mm voxel resolution with a field of view from the supra-orbital ridge to the upper occlusal plane. The image files from the CBCT images were stored in DICOM format (Digital Imaging and Communications in Medicine) and a 3D rendered model built using Maxilim (MEDICIM, Mechelen, Belgium) based on the default threshold values. The methodology of data capture and virtual 3D model visualisation has previously been described in detail.[23]

Immediately following the CBCT scan, a 3D stereophotogrammetry image was taken using a Di3D system (Di3D, Dimensional Imaging, Hilington Park, Glasgow, UK). Prior to image capture the system was calibrated according the manufactures instructions. For all captures, subjects were seated directly in front of the camera system, after removal of any spectacles and jewelry. Each subject was captured in natural head position and rest position.

The parent was instructed to activate the appliance a quarter turn (0.25mm) twice a day. The patients were reviewed regularly and expansion was stopped when the palatal cusp of the upper molars was touching the buccal cusp of the lower molars.[23] At this point a second CBCT scan and 3D stereophotogrammetry image was taken (T_1) using the same protocol as T_0.

Twenty-three landmarks (9 bilateral and 5 individual) were used (Table 1 and Figure 1) to measure 13 linear and 3 angular measurements directly from each of the stereophotogrammetry images, Table 2.

Table 1 Landmark definitions (* Indicates bilateral left & right landmarks).

Landmark	Definition
Glabella (G)	The most prominent midline point between the eyebrows, identical to bony glabella on the frontal bone.
Nasion (N)	The point in the midline of both the nasal root and the nasofrontal suture, always above the line that connects the two inner canthi, identical to bony nasion.
Endocanthion (Enc)*	The point at the inner commissure of the eye fissure, located lateral to the bony landmark used in cephalometry.
Exocanthion (Exc)*	The point at the outer commissure of the eye fissure, located slightly medial to bony exocanthion.
Alar curvature (or alar crest)(Ac)*	The most lateral point in the curved base line of each ala, indicating the facial insertion of the nasal wingbase.
Alare (Al)*	The most lateral point on each alar contour.
Pronasale (Prn)	The most protruded point of the apex nasi identified in lateral view of the rest position of the head.
Subnasale (Sn)	The midpoint of the angle at the columella base where the lower border of the nasal septum and surface of the upper lip meet; not identical to the bony point ANS or nasospinale.
Subnasale' (sn)*	The point on each side of the columella at its thinnest part.
Columella (C)*	The highest point on each columella where the nostril starts to curve laterally.
Alare' Inner (al'i)*	The point on the inner aspect of each ala at its thinnest part.
Subalare (sbal)*	The point at the lower limit of each alar base where it disappears into the skin of the upper lip.
Crista philtri (Cph)*	The point at each crossing of the vermilion line and the elevated margin of the philtrum. Or the point on each elevated margin of the philtrum just above the vermilion border.
Labrale superius (Ls)	The midpoint of the upper vermilion line.

Table 2 Naso-labial measurements and their landmarks.

Region	Linear measurement	Landmarks
Linear		
Nose		
	Nasal base width	AcR-AcL
	Alar cartilage width	AlR-AlL
	Right alar length	AcR-Prn
	Left alar length	AcL-Prn
	Nasal dorsum length	N-Prn
	Nasal tip protrusion	Sn-Prn
Nostrils		
	Right nostril long axis	sbalR-cR
	Left nostril long axis	sbalL-cL
	Right nostril width	snR-aliR
	Left nostril width	snL-aliL
	Columella width	snR-snL
Upper Lip		
	Philtrum width	CphR-CphL
	Upper cutaneous lip height	Ls-Sn
Angular		
	Nasal tip angle	AcR-Prn-AcL
	Nasolabial angle	Prn-Sn-Ls
	Nasal tip horizontal displacement angle	N-Prn-Sn

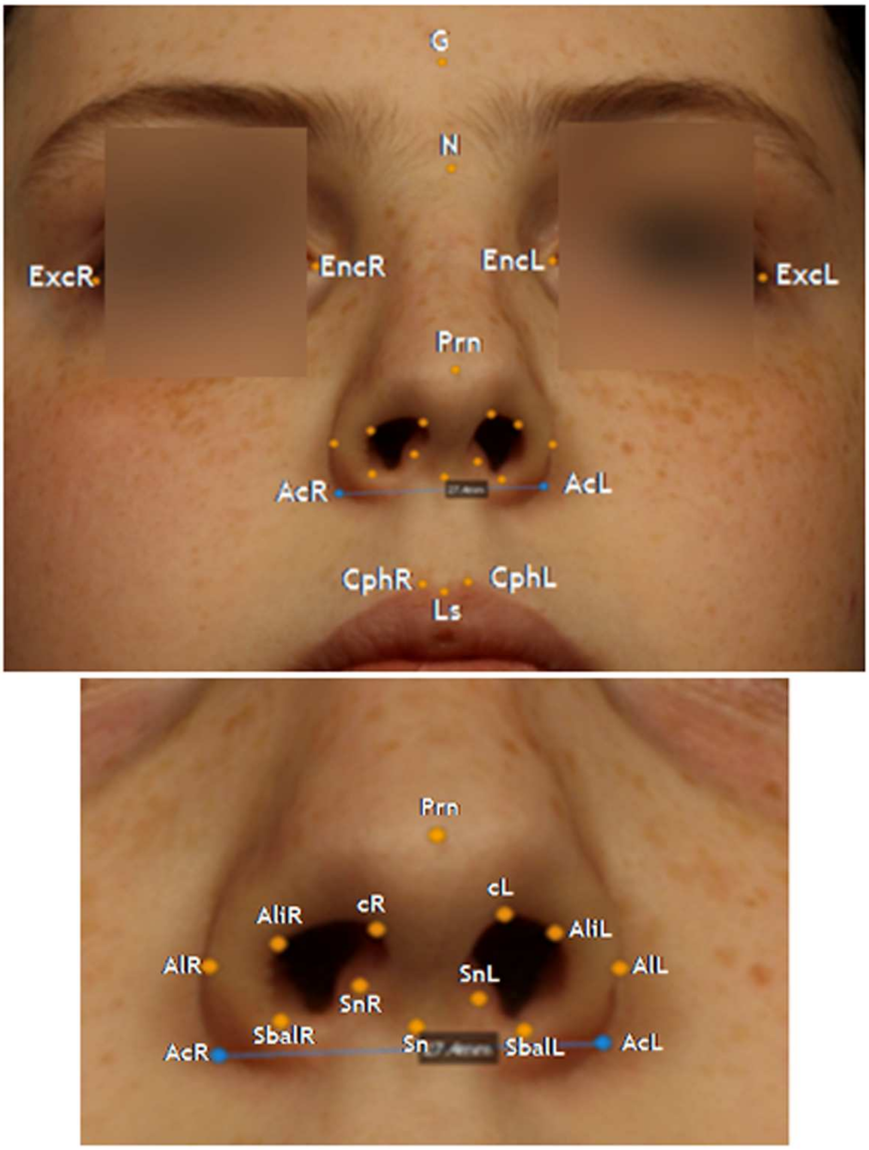

Figure 1 Facial and nasal landmarks.

Two landmarks and one linear measurement were taken from each CBCT image. The landmarks were the most anterior points on the right and left anterior nasal spines. The distance between them was the defined as the anterior nasal spine width (ANSW), Figure 2.

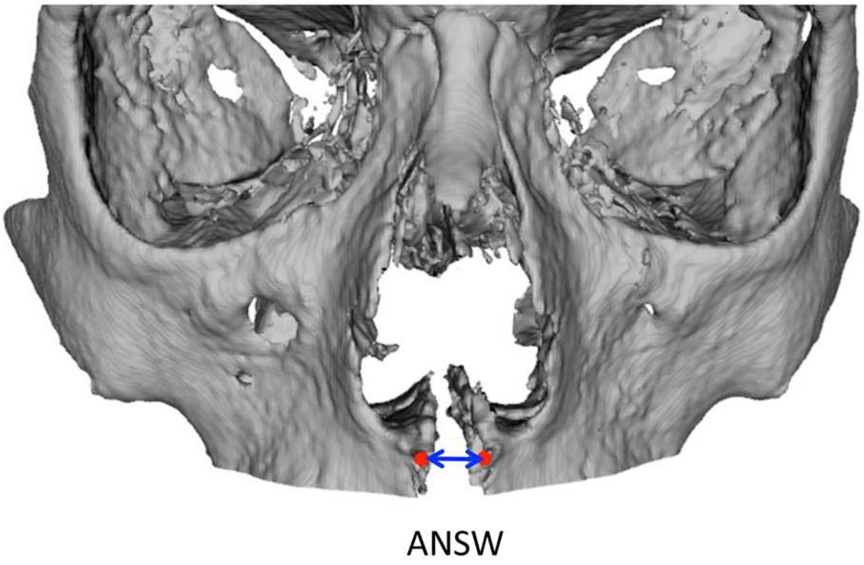

Figure 2 Anterior nasal spine width (ANSW). Defined as the distance between the most anterior points on the right and left anterior nasal spines.

Statistical Analysis

The reproducibility of the landmark placement error was assessed. All the images were landmarked on two separate occasions, one week apart, by the same operator. The data was used to determine intra-examiner systemic and random error according to Houston.[24] Systemic error was assessed using a Student's *t*-test and random error was examined using correlation coefficient.

The pre-RME (T_0) and post-RME (T_1) linear and angular measurements were compared. Significant differences ($P<0.05$) were tested using a Wilcoxon signed rank test. Pearson correlation coefficient was used to test the relationship between the ANSW changes and the overlying soft tissue nasal base width changes.

Results

No systemic errors were observed ($p>0.1$). All coefficients of reliability were above 90%. Landmark identification error was 0.3mm ± 0.2mm for all the landmarks.

In total fourteen patients (7 males, 7 females; mean age 12.6 ± 1.8 years) were recruited. The mean separation of the anterior nasal spine for this group of patients was 3.8 ± 1.2mm.[23]

All transverse linear nasal soft tissue measurements increased following RME. The largest median increase in width was seen in the nasal base width (1.6 mm), which was statistically significant ($p=0.001$), Table 3. The nasal dorsum height (N-Prn) and nasal tip protrusion (Sn-Prn) both increased as a result of RME (0.2mm) but were not statistically significant ($p<0.05$). No significant differences were observed in the nostril linear measurements, expect for columella width, which increased by a median distance of 0.5mm; this was statistically significant ($p=0.009$).

Naso-labial angle (Prn-Sn-Ls) decreased following RME expansion by 1.1^{o}, however this was not statistically significant ($p=0.276$). The only statically significant change was seen with the nasal tip displacement angle (AcR-Prn-AcL), which had a median increase of 3.4^{o}; this was statistically significant ($p=0.001$). The nasal tip angle (N-Prn-Sn), increased by 0.6mm, which was not statistically significant ($p=0.407$).

Table 3 Transverse linear soft tissue measurement changes and angular changes after RME expansion in the naso-labial complex.

Measurement	Post RME – Pre RME	Median 95% Confidence Interval		P-value[1]
	Median (mm)	Lower limit (mm)	Upper limit (mm)	
Nasal linear measurements				
AcR-AcL	1.6	1.0	2.2	0.001*
AlR-AlL	0.4	-0.1	0.9	0.09
AcR-Prn	0.2	-0.3	0.6	0.463
AcL-Prn	0.1	-0.1	0.4	0.366
N-Prn	0.2	-0.3	0.9	0.776
Sn-Prn	0.2	-0.4	0.7	0.535
Nasal angular measurements				
N-Prn-Sn	0.6	-0.7	2.0	0.407
Prn-Sn-Ls	-1.1	-3.0	1.1	0.276
AcR-Prn-AcL	3.4	1.9	4.8	0.001*
Nostril linear measurements				
SbalR-cR	0.0	-0.3	0.2	0.850
SbalL-cL	-0.2	-0.3	0.3	0.523
SnR-ALiR	0.0	-0.4	0.3	0.962
SnL-ALiL	-0.1	-0.4	0.2	0.679
SnR-SnL	0.5	0.2	0.9	0.009*
Upper lip linear measurements				
CphR-CphL	0.3	-0.1	0.7	0.113
Ls-Sn	-0.1	-0.5	0.3	0.758

*Statistically significant result Wilcoxon’s signed rank rest result ($p<0.05$).

The philtrum width (CphR-CphL) increased by 0.3mm, whilst the length of the upper lip (Ls-Sn) decreased by 0.1mm; neither was statistically significant ($p<0.05$).

The Pearson's correlation showed a positive correlation between ANSW and nasal base width soft tissue change ($r=0.62$); the correlation was statistically significant ($p=0.016$), Figure 3. On average 47% ± 22% of the ANSW increase translates into an increase in soft tissue nasal base width.

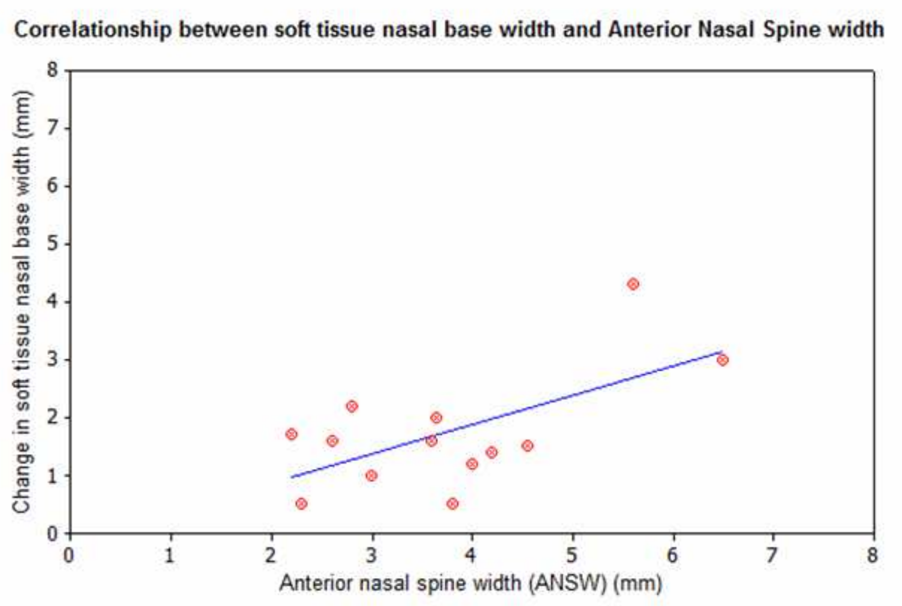

Figure 3 Correlation coefficient graph between soft tissue nasal base width and Anterior Nasal Spine width (ANSW).

Discussion

Subjects that had a deficiency in maxillary arch width with unilateral or bilateral posterior cross-bite were recruited and treated with RME. The study was controlled through the application of inclusion and exclusion criteria. The power calculation had determined that a minimum of 14 subjects were required.

The 3D soft tissue landmarks and measurements used in the present study were decided by the reproducibility of landmark identification and the landmarks and measurements recorded in previous studies.[26] Fourteen facial soft tissue landmarks (9 paired and 5 unpaired), thirteen measurements and three angles were chosen for the facial soft tissue analysis. These measurements were chosen to cover the area of the face which was anticipated to change during RME treatment i.e. the naso-labial region.

In the present study all transverse linear measurements in the nasal region; nasal base width (AcR-AcL) and alar cartridge width (AlR-AlL) increased in width, as did left and right alar length (AcR-Prn, AcL-Prn). The largest median increase in width was seen in nasal base width 1.6mm. This was statistically significant (p=0.001) but may not be clinically significant; however the upper 95% confidence limit of 2.2mm may indicate a trend towards clinical significance in the larger population. Similar results were found with previous studies using direct clinical measurements and 2D photographs.[20, 27] The present study highlights the subtle changes of widening of the soft tissue nasal base and flattening of the nose as seen by an increase in nasal tip horizontal displacement angle (AcR-Prn-AcL) following RME.

Berger (19) found an increase of 1.2mm in nasal base width for an average of 4mm appliance expansion, which is similar to the present study but was based on 2D photographs. However the actual skeletal expansion at the level of the base of nose was not known since no radiographs were taken. Instead the author's related soft tissue changes to appliance expansion assumed all the expansion produced within the appliance had been translated into skeletal change, which may not the case.

A recent cone beam CT study comparing two types of RME found an increase in anterior nasal floor width of 1.43mm with banded RME and 1.36mm increase with bonded RME for an average of 6mm to 10mm of appliance expansion.[16] Again highlighting the fact that appliance expansion is not a valid measure of the skeletal changes produced by the appliance. A further issue of the study was that changes in the hard and soft tissue nasal width measurements were made 6 months following RME and may have been affected by growth, relapse or both. No measurement error study was reported.

Johnson[20] used direct measurements with an average of 7mm of appliance expansion and found less than 1.5mm change in nasal base and alar cartilage width. As with Berger[19] appliance expansion was used to represent skeletal change. A serious drawback of direct soft tissue measurements is the distortion of the area to be measured during landmark identification. Silva Filho[27] used subjective assessment on 2D photographs and concluded that RME does not lead to changes in nasal morphology. The present study was able to determine the direct relationship of the underlying hard tissue changes with the overlying soft tissue based on the known hard tissue changes of this group of patients, rather than relying on appliance expansion measurements.[23]

The present study found no significant differences in the nostril measurements, except for columella width (SnR-SnL) which increased by 0.5mm, following RME. This was statistically significant ($p=0.009$) but not clinically significant i.e. not greater than 3mm.

Naso-labial angle decreased following RME expansion by 1.1° in this study; however this was not clinically or statistically significant ($p=0.276$). This finding is not in agreement with a previous study which reported an increase of 5.4° ($p=0.50$) in the naso-labial angle (18). However, Karaman[18] used lateral cephalograms to measure the effects of RME on soft tissues and there was no mention of the amount of appliance expansion. Interestingly a meta-analysis of the immediate dental and skeletal effects of RME treatment found that changes in the anteroposterior angulation of the maxillary incisors and of the maxilla were not significant.[28] Therefore no change in the overlying soft tissue would be expected.

The relationship between hard tissue and soft tissue is complex. This is due to the inherent variability in the response to RME for each patient but will also be dependant on the site of measurement. RME produces pyramidal expansion, with the greatest transverse expansion at the ANS, therefore measurements of the adjacent alar base displacement, i.e. nasal base width, should be the greatest. The results in this study demonstrate that the changes in soft tissue nasal base width at the level of the anterior nasal spine follow the changes in ANSW in a consistent manner but with variation between patients.

Approximately half of the ANS separation is translated into soft tissue nasal base width increase in this group of patients.[23]

This study quantifies the immediate naso-labial soft tissue changes following RME and so growth will not be a confounding factor; it does not however take into account the long term effects of RME or the effects of relapse.

Conclusions

This study has quantified the subtle changes expected to the naso-labial soft tissue complex following RME. There is an increase in nasal base width, retraction of the nasal tip and flattening of the nasal tip. These changes are small and variable between patients hence it would make prediction of naso-labial soft tissue changes following RME difficult.

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