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A systematic review on soft-to-hard tissue ratios in orthognathic surgery part I: Maxillary repositioning osteotomy

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ABSTRACT

Introduction: Changes occurring in facial soft tissues after orthognathic surgery have been studied over the past 45 years. In this systematic review, we analyzed soft-to-hard tissue ratios regarding maxillary repositioning surgery.
Methods: We searched major online databases according to the guidelines of the CONSORT/QUORUM flowchart, and selected studies based on their inclusion and exclusion criteria.
Results: Our search identified 27 articles, and 10 additional articles were found in the reference sections. Of these, six were evidence level IIIb, three were evidence level IIb, and the rest were evidence level IV. Only three articles were prospective. A high variability of soft-to-hard tissue ratios regarding Le Fort I surgery seemed to vanish if data were stratified according to confounding factors. With the available data, a ratio of 0.6:1 (labrale superius to upper incisor tip) could be used in Le Fort I advancement surgery if alar base cinch suture is not performed, and a ratio of 0.9:1 if it is performed.
Conclusion: Although there are many publications on soft tissue changes after orthognathic surgery, more prospective studies are needed that stratify by confounding factors such as type of osteotomy technique, magnitude of the movement, age, sex, race, quantity, and quality of the soft tissues.

1. Introduction

Classically, the goal of orthognathic surgery has been to achieve a good occlusion by means of a set of osteotomies and placement of the segments in a position that guarantees optimal function. However, patient concern regarding the facial esthetic results of the orthognathic/orthofacial procedure is increasing, and most patients have high expectations regarding outcomes. After the maxilla has undergone osteotomy and mobilization, the segment(s) can be moved in three directions, and the soft tissues will move according to certain ratios. Each ratio explains how much a certain landmark of soft tissue will move in relation to the movement of a certain landmark of hard tissue. For example, a ratio of 0.5:1 between subnasale and point "A" means that for each 1 mm of anterior movement of bony point A, the subnasale will advance (or follow) only 0.5 mm. Thus, the knowledge of how soft tissue moves in relation to hard tissue may provide better profile predictions, which may in turn improve patient and clinician communication in the frame of an orthognathic/orthofacial procedure. The problem remaining is that this ratio is an average, and the standard deviations are very large.

In this systematic review, all data concerning soft-to-hard tissue ratios after orthognathic surgery regarding maxillary procedures have been compiled and analyzed, except for bimaxillary surgery. The movements in the three dimensions for maxillary surgery were accounted for, and they comprise advancement (protrusion), setback (retrusion), extrusion, intrusion, and widening (expansion).

2. Material and methods

2.1. Literature search

The systematic literature search [displayed as a QUOROM-flow diagram (Moher et al., 1999) in Fig. 1] was initiated with the assistance of the Unika Library Service from the University of Navarre (Clínica Universitaria de Navarra, Pamplona, Spain). This service allowed the authors (JSMM and WV) to use Pubmed Central, ProQuest Dissertations and Theses, Science Citation Index,

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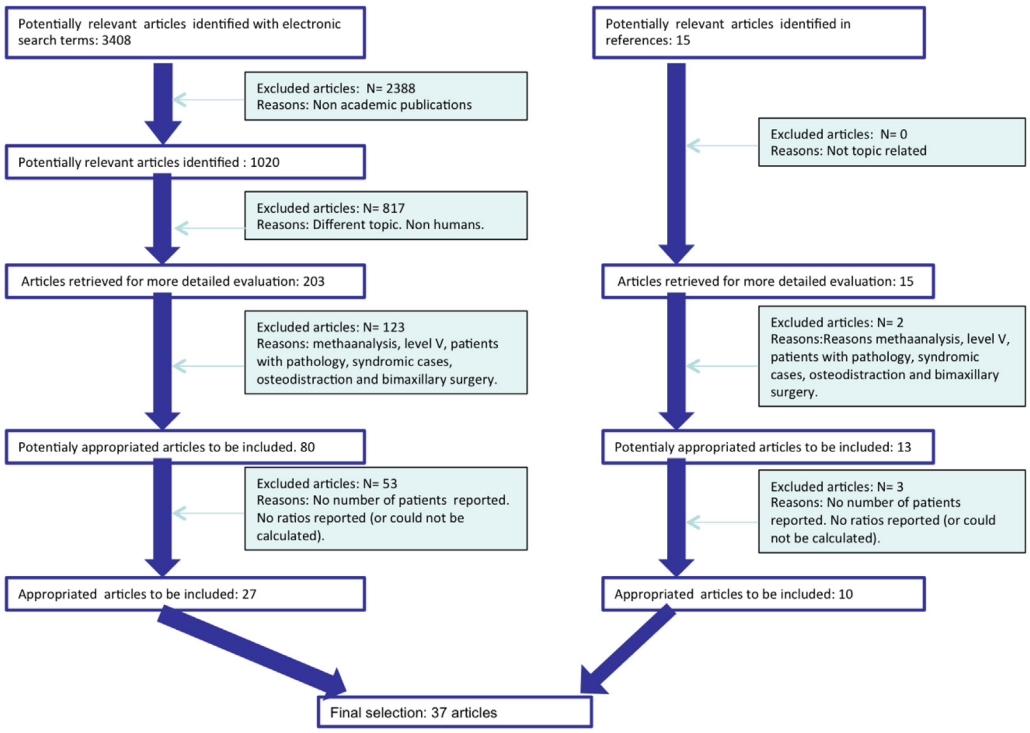

Fig. 1. QUOROM-flow diagram (Moher et al, 1999). The column on the left indicates the search of articles identified by electronic way; the column on the right indicates the search of articles identified using the references of the articles previously chosen in the left column. The final selection includes the sum of the articles chosen at the bottom of the right and left column. Abbreviations: N (number of studies).

Elsevier Science Direct Complete, Highwire Press, Springer Standard Collection, SAGE Premier 2011, DOAJ Directory of Open Access Journals, Sweetswise, Free E-Journals, Ovid Lippincott Williams & Wilkins Total Access Collection, Wiley Online Library Journals, and Cochrane Plus databases. The heading sequence {"Soft Tissue" OR "Nasolabial"} AND {["Maxillary" OR "Le Fort I"] AND ["Advancement" OR "Retrusion" OR "Setback" OR "Impaction" OR "Intrusion" OR "Superior Repositioning" OR "Downgrafting" OR "Inferior Repositioning" OR "Expansion" OR "Widening" OR "SARPE" OR "Narrowing"]} was selected. Our initial search returned 3408 published articles. Our inclusion criteria mandated only academic publications, and the number of articles decreased to 1020. No articles were excluded by means of their language. Articles discussing non-human research were excluded, and 203 potential articles were found. Articles about syndromic cases, osteodistraction, or bimaxillary surgery were excluded, such that only 80 articles remained. Of these, only 27 fulfilled inclusion criteria 3 and 4 and exclusion criteria 4 and 6 (see selection criteria). To complete the search, we also reviewed the references for each selected publication. Based on this, an additional 15 articles were found, but only 10 of these fulfilled the inclusion and exclusion criteria. Ultimately, a total of 37 articles were included in this systematic review.

2.2. Selection criteria

The following inclusion criteria used to select potential articles from the published abstract results included: 1) only human patients; 2) a group of patients who underwent monomaxillary surgery; 3) the number of patients was cited; and 4) at least one soft-to-hard tissue ratio was quantified or could be calculated from the data included in the article. We did not specify a minimum number of patients that must be included in each study given the lack of studies in some of the movements.

The exclusion criteria were as follows: 1) non-syndromic patients (i.e., cleft lip, alveolus and palate, Pierre Robin sequence); 2) unrelated disease (i.e., oncologic or traumatic cases); 3) monomaxillary cases; 4) systematic reviews or meta-analyses; 5) use of distraction techniques (except for maxillary expansion); or 6) level of evidence V. Some studies compared soft tissue changes after maxillary advancement in both non-cleft and cleft patients, but only the data regarding non-cleft patients were included in this article (Willmar, 1974; Dann et al., 1976; Freihofer, 1977; Araujo et al., 1978).

The articles that met the inclusion or exclusion criteria were divided into five groups according to the type of surgery performed for maxillary advancement. A total of three articles included in the maxillary advancement section were also included in the maxillary impaction surgery; however, two different groups were used in each study for each movement (Mansour et al., 1983; Rosen, 1988; Rosenberg et al., 2002).

The authors of the study contacted Dr. Del Santo to retrieve more information about the study by Del Santo et al., 2004, which was generously shared.

2.3. Data extraction

The following data were extracted from the full-text articles: a) features of the group [i.e., the number of patients, gender, age (years), race, and pre-operative soft tissue thickness (in mm)]; b) features of the study [i.e., follow-up time (months), direction of analysis (prospective vs. retrospective), randomization, level of evidence, and method of analysis (i.e., lateral radiographs, cone-beam)]; c) features of the operation [i.e., the type of surgery used for a certain bony movement, added orthognathic and/or facial procedures, use of bone graft, use of implants, amount of movement in mm (mm), removal of anterior nasal spine, use of an alar cinch suture, use of V–Y lip closure, subspinal osteotomy, and type

Table 1
Maxillary advancement.

Author	Year	N	F–U (m)	Direc study	LOE	Maxillary movements	Additional surgery	Fix	Cinch	V–Y	Rem. ANS	Magnitude of advancement	Sex[a]	Age (years)	Ra-ce	Meas	Horizontal reference line
Willmar[c]	1974	67	12	Retr	IV	Le Fort I adv	Only Le Fort	WF	NR	NR	NR	NR	NR	NR	NR	Cef	Sella-Nasion
Araujo et al.[c]	1978	13	28	Retr	IIIB	Le Fort I	5 pts bone graft	WF	NR	NR	NR	6 mm	NR	26 (17–41)	NR	Cef	Sella-Nasion
Dann et al. [c]	1976	6	6	Retr	IV	Le Fort I adv	Only Le Fort	WF	NR	NR	NR	NR	NS	NS	NR	Cef	NR
Freihofer[c]	1977	25	6	Retr	IV	Le Fort I adv and 1 mm downgr	Only Le Fort	WF	NR	NR	10 pts yes	6.2 mm from A	NR	NR	NR	Cef	Sella-Nasion
Engel et al.	1979	19	2	Retr	IV	AMxSO (8 pts), Le Fort I (11 pts)	Only Le Fort	WF	No	No	NR	NR	4	26.4 ± 9.9	NR	Cef	Frankfort
Teuscher and Sailer	1982	16	12	Retr	IV	Le Fort I adv	Only Le Fort	WF	NR	NR	NR	7.1	NR	27	NR	Cef	Frankfort
Mansour et al.	1983	7	6	Retr	IV	Le Fort I adv	Only Le Fort	NR	NR	No	NR	NR	NR	[b]	NR	Cef	Constructed frankfort hizontal, 7 degrees from Sella-Nasion
Bundgaard et al.	1986	16	12	Retr	IV	Le Fort I adv and impa	Only Le Fort	NR	NR	NR	NR	NR	5	14.6–34.4	NR	Cef	Frankfort
Carlotti et al.	1986	25	8.8	Retr	IV	Le Fort I adv	Only Le Fort	NR	Yes	Yes	NR	5.5 mm U1 adv	NR	21	NR	Cef	Cranial base line of Delaire
Rosen	1988	30	9.8	Retr	IV	Le Fort I adv + impa (11 pts) + ext (5 pts)	Only Le Fort	NR	No	No	No	7 mm; 4–11	NS	NS	Ca	Cef	Sella-Nasion
Stella et al.	1989	21	6	Retr	IIIB	Le Fort I adv. Two groups based on more or less movement	Only Le Fort	NR	No	No	NR	6 ± 2.4	NR	>16	NR	Cef	Frankfort
Hack et al.	1993	25	13.2	Retr	IV	Le Fort I adv (+ impa)	13 pts BSSO adv or genio	NR	NR	NR	NR	2.72 from A, 1.28 vert from Sn	NR	NR	NR	Cef	X-axis
Hui et al.[c]	1994	25	2	Retr	IV	Le Fort I adv (± segment)	12 pts BSSO	NR	NR	NR	NR	NR	12	21.6	As	Cef	NR
Van Butsele et al.	1995	24	15	Retr	IV	Le Fort I adv	Only Le Fort	WF/RIF	Yes	Yes	NR	5.7 from U1 0.12 vert from U1	NR	21.4 ± 6.8	NR	Cef	Frankfort
Brooks et al.	2001	57	15.5	Retr	IV	Le Fort I segment 4 pieces, adv + impa	70% pts mand proc, 45% pts genio	RIF	Yes	Yes	NR	NR	15	27.5	NR	Cef	X-axis
Rosenberg et al.	2002	9	12	Retr	IV	Le Fort I adv; Le Fort I adv + impa	Only Le Fort	RIF	No	Yes	No	2.6 mm from A	NS	NS	NR	Cef	X-axis 7 degrees from Sella-Nasion
Del Santo et al.	2004	19	12	Retr	IV	Le Fort I adv	Only Le Fort	NR	**Yes**	**No**	NR	NR	10	19–42	Ca	Cef	Frankfort
Peled et al.	2004	18	6	Retr	IIIB	Le Fort I adv	Only Le Fort	RIF	Yes	[d]	NR	4.6 mm from A	NR	NR	NR	Cef	NR
		17	6	Retr	IIIB	Le Fort I adv	Only Le Fort	RIF	Yes	Yes	NR	5.2 mm from A	NR	NR	NR	Cef	
Alonso	2007	18	12	Retr	IV	Le Fort I adv + impa	Only Le Fort	RIF	No	Yes	No	NR	7	27.3	Ca	Cef	X-axis
Nkenke et al.	2008	20	6	Pros	IIB	Le Fort I adv	Only Le Fort	RIF	NR	NR	NR	5.3 ± 2.1	10	33.9 ± 14.9	NR	Optical 3D scan	X-axis
McCollum et al.	2009	26	16	Retr	IIIB	Le Fort I adv	6 pts BSSO setback, 4 pts reduction genio, 3 pts combination of both	RIF	No	[d]	Yes	NR	10	22.1 (for women 25)	NR	Cef	X-axis

Abbreviations: N (number of patients), F–U (follow-up period), m (months), Direc study (time direction of the study), LOE (level of evidence),Fix (type of fixation), Cinch (whether alar cinch suture was used or not), V–Y (whether lip V–Y closure was used or not), Rem ANS (whether removal of anterior nasal spine was performed or not), Mesas (method used for measurement), Retr (retrospective), Pros (prospective), pts (patients), adv (advancement), downgr (downgrafting), impa (impaction), segment (segmentation), BSSO (bilateral sagital split osteotomy), genio (genioplasty), mand proc (mandibular procedures), NR (not reported), NS (not stratified according to the different subgroups of patients), WF (wire fixation), RIF (rigid internal fixation), mm (millimeters), A (point A), U1 (upper incisor tip point), Sn (subnasale point), vert (vertically) Ca (Caucassian ethnicity), As (Asian ethnicity), Cef (lateral cephalometry), 3D (three dimensional).

[a] Number of male patients.

[b] ≥18 males and ≥15 females.

[c] Only the patients without cleft lip/palate have been included.

[d] 2 groups: one with VY closure and another one without.

of osteosynthesis]; and d) features of the analysis (i.e., use of x-rays, cone-beam computed tomography, laser scan or optic scan, and horizontal line of reference in cephalometry).

To assess the methodological soundness of each article, a quality evaluation was performed using the Level of Evidence (LOE) scale according to the 2011 Oxford Center for Evidence-Based Medicine LOE (Howick et al., 2011) recommendations. The quality was categorized from level I to level IV. Level V studies were not included in the article.

3. Results

Soft-to-hard tissue ratios were recorded in maxillary advancement surgery, maxillary setback, inferior repositioning of the maxilla, superior repositioning of the maxilla, and maxillary expansion (Tables 1–5). Unfortunately, articles alluding to soft-to-hard tissue ratios after maxillary narrowing were not found. We obtained a total of 37 articles, of which six were LOE IIIb, three were LOE IIb, and the rest were LOE IV. Only three articles were prospective in nature.

3.1. Maxillary advancement

We found a total of 21 studies reporting soft-to-hard tissue ratios related to Le Fort I advancement (Table 1). One article was prospective, one article was LOE IIb, and three articles were LOE IIIb. The amount of advancement ranged from 2.72 mm to 7.1 mm (mean: 5.3 mm). Labrale superior (Ls) was the most used soft tissue landmark for the evaluation of soft tissue changes after Le Fort I advancement, and is reported in 17 studies. Ls movement was mainly correlated with upper incisor tip (U1) movement in 15 studies, and only incidentally with Point A (A), Prosthion (Pr), or anterior aspect of upper incisor (Ua). No studies used anterior nasal spine (ANS) as a bony landmark to predict Ls movements. This suggests that Ls is a good candidate for comparisons among groups.

After Le Fort I advancement of the maxilla, Ls followed the hard tissue with ratios ranging from 0.4:1 to 0.95:1 (Table 6). If nasal cinch suture and V–Y lip plasty were not performed, this ratio ranged from 0.4:1 and 0.80:1 (mean: 0.57:1) (Willmar, 1974; Dann et al., 1976; Freihofer, 1977; Araujo et al., 1978; Engel et al., 1979; Teuscher and Sailer, 1982; Rosen, 1988; Hack et al., 1993; Hui et al., 1994; Del Santo et al., 2004). In contrast, the ratio ranged from 0.56:1 to 0.78:1 (mean: 0.66:1) if only V–Y was performed (no cinch) (Rosenberg et al., 2002; Alonso, 2007; McCollum et al., 2009). Although McCollum et al. (2009) found no difference between V–Y and no V–Y closure, stomion superius (Sto^s) moved forward 24% more than did Ls when a V–Y closure was performed, which appears to indicate that the amount of vermilion exposed was increased because of the V–Y closure. Nasal cinch suture along with V–Y plasty also showed higher ratios, which ranged from 0.9:1 to 0.95:1 (Carlotti et al., 1986; Brooks et al., 2001; Peled et al., 2004). Although cinch without V–Y had no significant differences in one study (0.9:1 with V–Y vs. 0.87:1 without V–Y) (Peled et al., 2004), Del Santo et al. (2004) found a ratio of only 0.6:1.

Sto^s moves upwards when a maxillary advancement is performed, which is probably due to stretching of the lip. This movement must to be taken into account and added to the total amount of upper incisor that will be exposed with the lips at rest or while smiling. After a Le Fort I advancement, Sto^s followed U1 at a ratio ranging between −0.12:1and −0.33:1 (Bundgaard et al., 1986; Van Butsele et al., 1995; Rosenberg et al., 2002; McCollum et al., 2009). McCollum et al. (2009) found that this ratio became −0.26:1 without V–Y closure and that the ratio decreased to −0.12:1 when V–Y was performed, suggesting that V–Y ensured that the lip did not shorten. Similarly, Van Butsele et al. (1995) and Rosenberg et al. (2002) found a Sto^s:U1 ratio of −0.30:1 and −0.33:1, respectively, when cinch and V–Y were performed.

Other soft tissue landmarks are important when it comes to Le Fort I advancement. Movement of the superior labial sulcus (Sls), also named "soft A" (A'), was described in eight studies. U1 has typically been the hard-tissue landmark correlated with the movement of Sls, followed by point A, Pr, and Ua. Soft-to-hard ratios have ranged from 0.32:1 to 0.93:1; however, despite this variability, when no cinch or V–Y were performed, the ratios ranged from 0.39 to 0.66 (mean: 0.52:1) (Mansour et al., 1983; Hack et al., 1993; Hui et al., 1994). When V–Y was performed alone, the ratios ranged from 0.69:1 to 0.74:1 (Alonso, 2007; McCollum et al., 2009), and when V–Y and cinch were performed together, the ratios ranged from 0.78:1 to 0.93:1. This suggests that cinch and V–Y have a similar effect both in Ls and Sls landmarks.

As for the subnasale (Sn) landmark, the ratio of the horizontal movement of the A-point and the Sn landmark has been the most investigated. A large amount of variability has been found, with ratios ranging from 0.06:1 to 0.86:1. When no cinch or V–Y was performed, ratios ranged from 0.06 to 0.51 (mean: 0.33:1) (Freihofer, 1977; Engel et al., 1979; Mansour et al., 1983; Rosen, 1988; Hack et al., 1993; Hui et al., 1994). When V–Y was performed, this ratio ranged from 0.56 to 0.64 (Rosenberg et al., 2002; McCollum et al., 2009), and when cinch was added to VY closure,

Table 2
Maxillary retrusion.

Author	Year	N	F–U (m)	Direc study	LOE	Technique	Additional surgery	Fix	Cinch	V–Y	Rem ANS	Magnitude of movement	Sex[a]	Age (years)	Race	Meas
Ayoub et al.	1991	10	6	Retr	IV	AMxSO	None	NR	NR	NR	NR	−4.7 mm	2	17–23	NR	Cef
Pan et al.	1997	15	24	Retr	IV	AMxSO	None	NR	NR	NR	NR	NR	5	20–30	As	Cef
Shawky and El-Ghareeb	2012	22	6	Retr	IV	AMxSO	None	RIF L[b]	NR	Yes	Yes	−6.2 mm	NR	17–35	Ca	CBCT
Chouet-Girard and Mercier	2003	11	12	Retr	IV	Le Fort I TPR	3 pts BSSO adv, 3 genio adv	RIF L[b]	NR	NR	NR	−4.5 mm retrusion, −4.7 mm intrusion	NR	25.9	NR	Cef

Negative sign means a backward movement.
Abbreviations: Meas (method used for measurement), AMxSO (anterior maxillary subapical osteotomy) TPR (total posterior repositioning), N (number of patients), F–U (follow-up period), m (months), Direc study (time direction of the study), LOE (level of evidence), Fix (type of fixation), Cinch (whether alar cinch suture was used or not), V–Y (whether lip V–Y closure was used or not), Rem ANS (whether removal of anterior nasal spine was performed or not), Retr (retrospective), pts (patients), adv (advancement), BSSO (bilateral sagittal split osteotomy), genio (genioplasty), NR (not reported), RIF (rigid internal fixation), mm (millimeters), Ca (Caucassian ethnicity), As (Asian ethnicity), Cef (lateral cephalometry), CBCT (cone-beam computerized tomography).
[a] Number of male patients.
[b] L-shaped plates with four holes.

Table 3
Maxillary extrusion.

Author	Year	N	F–U (m)	Direc study	LOE	Technique	Additional surgery	Fix	Cinch	V–Y	Bone graft	Magnitude of movement	Sex[a]	Age (years)	Race	Meas
Lecointre	1997	5	10	Retr	IV	Le Fort I extrusion.	3 pts BSSO adv and 1 genio vertical augmentation	RIF L[b]	Yes	NR	No	3 mm–7 mm downwards	2	30 (19–30)	NR	Cef

Abbreviations: Meas (method used for measurement), N (number of patients), F–U (follow-up period), m (months), Direc study (time direction of the study), LOE (level of evidence), Fix (type of fixation), Cinch (whether alar cinch suture was used or not), V–Y (whether lip V–Y closure was used or not), bone graft (whether bony material was grafted in the gap or not), Retr (retrospective), pts (patients), adv (advancement), BSSO (bilateral sagital split osteotomy), genio (genioplasty), NR (not reported), RIF (rigid internal fixation), mm (millimeters), Cef (lateral cephalometry).
[a] Number of male patients.
[b] L-shaped plates with four holes.

the ratios ranged from 0.67 to 0.86 (Carlotti et al., 1986; Brooks et al., 2001).

Pronasale (Pn) is the most anterior point of the nose in the sagittal plane, and its movement has been mostly correlated to point A, ANS, Ua, and U1. Ratios for Pn have ranged from 0.14 to 0.34, and they did not seem to vary according to the presence of V–Y (Freihofer, 1977; Engel et al., 1979; Teuscher and Sailer, 1982; Mansour et al., 1983; Hui et al., 1994; Rosenberg et al., 2002; McCollum et al., 2009). Only two studies specify if ANS was removed or not, and they showed a Pn:A ratio of 0.17 when ANS was removed (McCollum et al., 2009), and 0.25 and 0.34 when the ANS was not removed (Freihofer, 1977; Rosenberg et al., 2002). Pn also moved upwards when advancing the maxilla in a ratio of 0.29:1 (Rosenberg et al., 2002), which appears to indicate a slight upward movement of the tip of the nose. Nevertheless, Mommaerts et al. (2000) found that advancing piriform aperture, and not nasal spine, was responsible for the increase in nasal tip projection after Le Fort I advancement.

3.2. Maxillary setback

Maxillary retrusion (or setback) was first performed by Hullihen (1849) by means of segmental osteotomies in the anterior region of the mandible. Anterior maxillary segmental osteotomy (AMxSO) is performed after extraction of two premolars and is indicated for the correction of isolated premaxillary protrusions or dento-alveolar protrusion with proclined incisors, with a molar Class I or II occlusion. However, the first report of a total maxillary setback osteotomy (TMSO) was presented by Colantino and Dudley (1970). Although not broadly used by surgeons, TMSO can achieve very satisfactory results in some rare cases of Class II occlusion, with vertical abnormalities of the upper jaw (which an AMxSO is not able to correct), marked maxillary prognathism, and especially an acute nasolabial angle. Most of the time, AMxSO is chosen instead of TMSO in Class II cases, but the main reason may be the limited knowledge and practice of TMSO which most of the time requires the removal of the maxillary tuberosity and inferior resection of the pterygoid process.

All studies identified here were LOE IV and retrospective (Table 2), and only one study reported soft-to-hard tissue ratios after TMSO (Table 7). Chouet-Girard and Mercier (2003) found that Ls followed U1 at a ratio of −0.6:1 and a mean opening of the nasolabial angle of 9° (mean setback movement of −4.1 mm). They also found that Sls moved backwards 8% of the movement of point A and that Pn did not suffer any significant movement.

As for AMxSO (without concomitant mandibular surgery), a total of three studies (Ayoub et al., 1991; Pan et al., 1997; Shawky and El-Ghareeb, 2012) were identified (Table 7). These demonstrated that Ls:U1 ratios ranged from −0.53:1 to −0.75:1 (mean: −63.5:1). As for Sls, only Pan et al. (1997) reported an Sls:A ratio of −0.63:1. Thus, it appears that the data for AMxSO are consistent with TMSO.

3.3. Maxillary extrusion

Maxillary extrusion, also called inferior maxillary repositioning (IMR), can be indicated in cases of a short face syndrome. IMR can be associated with anterior movement of the maxilla, clockwise rotation of the maxillary complex, and chin extrusion. When a Le Fort I osteotomy is performed, the resulting gap can be filled with a bone graft or hydroxyapatite, or it can be left open. Only one study (Tables 3 and 8) reported quantitative data regarding soft-to-hard tissue ratios after maxillary extrusion/downgrafting. Lecointre (1997) reported a ratio of 0.9:1 (Me':Me) after IMR, but the sample size was only five patients, of whom three underwent bilateral sagittal split osteotomy advancement and just one underwent extrusion genioplasty. Bone graft was not used to fill the gap in these patients, and the amount of extrusion ranged from 3 to 7 mm. More studies are needed in order to study the effect of IMR in soft tissues. Van Butsele et al. (1995) found that Sto^{s} followed U1 at a ratio of 0.25:1 either for superior or inferior repositioning of the maxilla. However, they did not specify a ratio for IMR alone.

3.4. Maxillary intrusion

Maxillary intrusion, also called maxillary impaction or superior maxillary repositioning (SMR), was performed for the first time by Converse in 1952 to treat patients with open bite by means of posterior intrusion. SMR can be performed anteriorly in cases of "long face syndrome" with excessive prominence of the maxilla and gummy smile. All studies we found regarding SMR were LOE IV and retrospective (Table 4). Specifically, a total of eight studies reporting soft-to-hard tissue ratios after maxillary impaction with mandibular autorotation were found (Table 9), of which only four focused on maxillary ratios. The resultant clinical predictions that may be considered as vertical movements of the maxilla were combined with antero-posterior movements. Sto^{s} followed the hard tissue movement at ratios between 0.32:1 and 0.42:1 (mean of 0.38:1) (Radney and Jacobs, 1981; Mansour et al., 1983; Rosen, 1988). However, Rosenberg et al. (2002) found that the movement slightly lengthened the lip in impaction cases. In the vertical plane, Pn and Sn followed Pr at a ratio of 0.15 and 0.28, respectively (Mansour et al., 1983). Radney and Jacobs (1981) and Mansour et al. (1983) found that Sls followed either point A or Pr at a ratio of 0.25:1 and 0.26:1, respectively, and that Ls followed either U1 or Pr at a ratio of 0.30:1 and 0.31:1, respectively.

If only maxillary intrusion is performed, the mandible can autorotate to a new occlusion, and soft tissues will follow the hard tissues according to certain ratios. Ratios of vertical movements for the Labrale inferior (Li) have ranged from −0.85:1 to −1.48:1. For example, Mansour et al. (1983) reported that the lower lip seemed to shorten slightly in the vertical plane, responding by −0.93:1 relative to the movement of the lower incisor, with a high correlation ($r = 0.86$). However, Ksiezycki-Ostoya et al. (2009) found that the lower lip lengthened by an average of 1.56 mm after mandibular autorotation, with Li following L1 vertically at a ratio of −1.3:1

Table 4
Maxillary intrusion.

Author	Year	N	F–U (m)	Direc tudy	LOE	Technique	Additional surgery	Fix	Cinch	V–Y	Rem ANS	Magnitude of movement	Sex[a]	Age (years)	Race	Meas
Schendel et al.	1976	24	29	Retr	IV	Le Fort I impa (11 pts) and simultaneous anterior and posterior maxillary osteotomies (13 pts)	14 pts did not have mandibular surgery	NR	NR	NR	NR	−5.5 mm from first upper molar and −5.69 mm from upper incisor.	NR	20 (13–33)	NR	Cef and computerized model of walker
Radney and Jacobs	1981	10	6	Retr	IV	Le Fort I impa ± setback	Only Le Fort	NR	NR	NR	NR	Not clear	1	27.3 (52–16)	Ca	Cef
Mansour et al.	1983	14	6	Retr	IV	Le fort I impa	Only Le Fort	NR	NR	No	NR	NR	NR	>18 men and >15 women	NR	Cef
Sakima and Sachdeva	1987	20	12	Retr	IV	Le Fort I impa	Only Le Fort	NR	NR	NR	NR	NR	NS	NS	As	Cef
Rosen	1988	23	9.8	Retr	IV	Le Fort I impa and adv	Only Le Fort	NR	No	No	No	−6 mm (mean); −3 mm to −10 mm	NS	NS	Ca	Cef
Rosenberg et al.	2002	11	12	Retr	IV	Le Fort I impa	Only Le Fort	RIF	No	Yes	No	−5.5 mm from A	NS	NS	NR	Cef
		14	12	Retr	IV	Le Fort I post impa	Only Le Fort	RIF	No	Yes	No	−4.4 mm from PNS; −0.8 mm from A	NS	NS	NR	Cef
Steinhäuser et al.	2008	42	NR	Retr	IV	Le Fort I with post impa (21 pts), with post imp and ant subsidence (13 pts) and parallel impa (8 pts)	Only Le Fort	NR	NR	NR	NR	−4.6 mm from PNS; −0.9 mm from ANS	10	20 (18–55)	NR	Cef
Ksiezycki-Ostoya et al.	2009	22	15	Retr	IV	Le Fort I impa	6 pts had adv genio[b]	NR	NR	NR	NR	NR	NR	26.4 (15–45)	NR	Cef

Abbreviations: N (number of patients), F–U (follow-up period), m (months), Direc study (time direction of the study), LOE (level of evidence), Fix (type of fixation), Cinch (whether alar cinch suture was used or not), V–Y (whether lip V–Y closure was used or not), Rem ANS (whether removal of anterior nasal spine was performed or not), Meas (method used for measurement), Retr (retrospective), pts (patients), adv (advancement), impa (impaction), post (posterior), genio (genioplasty), NR (not reported), NS (not stratified according to the different subgroups of patients), RIF (rigid internal fixation), mm (millimeters), A (point A), ANS (anterior nasal spine), PNS (posterior nasal spine), Ca (Caucassian ethnicity), As (Asian ethnicity), Cef (lateral cephalometry).
[a] Number of male patients.
[b] Analyzed as an independent group.

[coefficient of determination (R^2): 50%]. Sakima and Sachdeva (1987) demonstrated similar findings, with an Li:Me ratio of −1.48:1. However, Steinhäuser et al. (2008) found that Li followed L1 at a ratio of 0.85:1. In the horizontal plane, Li appeared to follow L1 at a ratio between 0.52:1 and 1:1 (Mansour et al., 1983; Ksiezycki-Ostoya et al., 2009; Steinhäuser et al., 2008).

The Mentolabial fold (Mlf) followed point B vertically at a ratio between −0.7:1 and −1.05:1 and horizontally between 0.61 and 1:1 (Radney and Jacobs, 1981; Mansour et al., 1983; Sakima and Sachdeva, 1987; Steinhäuser et al., 2008). Furthermore, soft pogonion (Pg') followed hard pogonion (Pg) in the vertical plane at a ratio of −0.7:1 (Steinhäuser et al., 2008) and followed gnathion (Gn) at a ratio of −0.8:1 (Ksiezycki-Ostoya et al., 2009). Horizontally, Pg':Pg ranged from 0.86:1 to 1:1 (Radney and Jacobs, 1981; Mansour et al., 1983; Van Butsele et al., 1995; Steinhäuser et al., 2008).

Steinhäuser et al. (2008) demonstrated that the amount of mandibular autorotation correlates with the extent of maxillary impaction. For instance, the Pg advanced 100% in the group that had the maxillae impacted in parallel (same amount of impaction in either ANS or PNS). In the group with posterior impaction of the maxilla with anterior subsidence, Pg advanced 50% of the impaction, and in the group with only posterior impaction, Pg advanced 80% of the impaction. Ksiezycki-Ostoya et al. (2009) found that hard tissue Gn was the most reliable predictor of the soft-tissue chin response in the horizontal plane of space (R^2 = 94%), with Gn' following Gn at a ratio of 0.94:1. Soft menton (Me') followed hard menton (Me) at ratios that have ranging between −1:1 and −1.2:1

Table 5
Maxillary expansion.

Author	Year	N	F–U (m)	Direc study	LOE	Technique	Additional	Fixation	Magnitude of movement	Sex[a]	Age (years)	Race	Meas
Berger et al.	1999	24	12	Retr	IIIB	Le Fort I + Hyrax	Only exp	NR	5 mm exp	12	19.3	NR	Photos
	1999	20	12	Retr	IIIB	Hyrax Alone	Only exp	NR	4 mm exp	11	8.6	NR	Photos
Ramieri et al	2008	18	12	Pros	IIB	Le Fort I + TPD Mommaerts[b]	Only exp	RIF	6.1 mm from molar to molar[c]	4	24 (18–35)	Ca	Laser scanning and 3D morphometry
Nada et al.	2013	15	22	Pros	IIB	Le Fort I + TPD Mommaerts[b]	Only exp	RIF	NR	7	30 ± 10	NR	CBCT
	2013	25	22	Pros	IIB	Le Fort I + Hyrax	Only exp	NR	NR	6	25.4 ± 9	NR	CBCT

Abbreviations: N (number of patients), F–U (follow-up period), m (months), Direc study (time direction of the study), LOE (level of evidence), Fix (type of fixation), Meas (method used for measurement), Retr (retrospective), Pros (prospective), pts (patients), exp (expansion), NR (not reported), RIF (rigid internal fixation), mm (millimeters), Ca (Caucassian ethnicity), Cef (lateral cephalometry).
[a] Number of male patients.
[b] Trans palatal distractor, Mommaerts type.
[c] From first upper molar of one side to first upper molar of the other side.

Table 6
Soft to hard tissue ratios for maxillary advancement.

Authors	Surgical Technique	Additional	Pn/ ANS (x)	Pn/ ANS (y)	Pn/A (x)	Pn/U_a (x)	Pn/U_1 (x)	Pn/U_1 (y)	Sn/ ANS (x)	Sn/ ANS (y)	Sn/A (x)	Sn/A (y)	Sn/U_a (x)	Sn/U_1 (y)	Sls/A (x)	Sls/A (y)	Sls/Pr (x)	Sls/Pr (y)	Sls/U_a (x)	Sls/U_1 (x)	Sls/U_1 (y)	Ls/A (x)	Ls/ Pr (x)	Ls/U_a (x)	Ls/U_1 (x)	Ls/U_1 (y)	Sts/U_1 (x)	Sts/U1 (y)
Willmar[a]	Le Fort I adv	Only Le Fort																							53			
Araujo et al.	Le Fort I	5 pts bone graft																							40			
Dann et al.[a]	Le Fort I adv	Only Le Fort																							53	30		
Freihofer[a]	Le Fort I adv and 1 mm downgr	Only Le Fort			25[b]						50														57			
Engel et al.	AMxSO (8 pts), Le Fort I (11 pts)	Only Le Fort			20						37											58						
Teuscher and Sailer	Le Fort I adv	Only Le Fort			22																				63			
Mansour et al.	Le Fort I adv	Only Le Fort				17							24						52					62				
Bundgaard	Le Fort I adv and impa	Only Le Fort			13																				50			
Carlotti et al.	Le Fort I adv	Only Le Fort																		78					90			
Rosen	Le Fort I adv + impa (11 pts) + ext (5 pts)	Only Le Fort									51														82			
Stella et al.	Le Fort I adv	Only Le Fort									46																	
Hack et al.	Le Fort I adv (+ impa)	13 pts BSSO adv or genio							36		24				32		37			39		64	69		60			
Hui et al.[a]	Le Fort I adv (± segment)	12 pts BSSO	6	13	7		14		6	12	6	10			14	20				51	24	15	27		54	29	51	
Van Butsele et al.	Le Fort I adv	Only Le Fort																										30
Brooks et al.	Le Fort I segment 4 pieces, adv + impa	70% pts mand proc 45% pts genio							68	92	86	90			90	86	96	95		93	93				95	96		
Rosenberg et al.	Le Fort I adv; Le Fort I adv + impa	Only Le Fort			34			29			64			38											65	33		33
Del Santo et al.	Le Fort I adv	Only Le Fort																				60						
Peled et al.	Le Fort I adv	18 pts without V−Y closure																							87			
	Le Fort I adv	17 pts with V−Y closure																							90			
Alonso	Le Fort I adv + impa	Only Le Fort													74	75									78	78		
Nkenke	Le Fort I adv	Only Le Fort																							80			
McCollum et al.	Le Fort I adv	11 pts with V−Y closure	33		17	25					56		52						69						55		56	20
		15 pts without V−Y closure																							57			
		10 pts with lip thickness <15 mm									79														75			
		16 pts with lip thickness >15 mm									21														25			

The numbers in the table are in %.
Abbreviations: Pn (pronasale), Subnasale (Sn), ANS (anterior nasal spine), Ua (anterior aspect of first upper incisor), U1 (tip of first upper incisor), A (point A), Sls (superior labial sulcus), Pr (prosthion), Ls (labrale superius), Sts (stomion superius), x (x-axis), y (y-axis), adv (advancement), impa (impaction), ext (extrusion), downgr (downgrafting), pts (patients), BSSO (bilateral sagital split osteotomy), mm (millimeters), segment (segmentation), mand proc (mandibular procedure), genio (genioplasty), AMxSO (anterior maxillary subapical osteotomy).
[a] Only non cleft-lip/palate patients have been taken into account.
[b] For greater movements 2:7; for lesser movements 2:9.

Table 7
Soft to hard tissue ratios for maxillary setback.

Authors	Technique	Additional procedures	Pn/A (x)	Sn/A (x)	Sls/A (x)	Ls/U1 (x)
Ayoub et al.	AMxSO	None				60
Pan et al.	AMxSO	None			63	75
Shawky and El-Ghareeb	AMxSO	None				53
Chouet-Girard and Mercier	Le Fort I total posterior repositioning	3 pts BSSO adv, 3 genio adv	0	8		**60**

The numbers in the table are in %.
Abbreviations: Pn (pronasale), Sn (subnasale), U1 (tip of first upper incisor), A (point A), Ls (labrale superius), Sts (stomion superius), x (x-axis), y (y-axis), AMxSO (anterior maxillary subapical osteotomy), pts (patients), BSSO (bilateral sagital split osteotomy), adv (advancement), genio (genioplasty).

in the vertical plane (Mansour et al., 1983; Ksiezycki-Ostoya et al., 2009). This passive soft-tissue response may be explained by the fact that no muscular detachment had been effected in the lower lip and soft tissue chin region during the maxillary surgery.

3.5. Maxillary expansion

Maxillary expansion has long been used for correcting maxillary compression and can be performed via orthopedic, orthodontic, or surgically-assisted techniques. A total of three studies were identified, of which two had a LOE IIB and one had a LOE IIIB (Table 5). In two of these studies, we calculated the ratios based on the data in the study (Table 10). Berger et al. (1999) studied the soft tissue changes associated with orthopedic or surgically-assisted maxillary expansion (SARME) by means of frontal photographic analysis. After 1 year of follow-up in SARME patients, their results showed a significant increase in the nasal width (2.0 mm after 5 mm of transverse expansion). In addition, the interalar width (Al_r–Al_l) increased following transverse expansion increase [measured as the distance between the mesial cuspid of the upper first molars (6–6)] at a ratio of 0.4:1. Ramieri et al. (2008) had similar findings with an (Al_r–Al_l):(6–6) ratio of 0.32:1 and an absolute increase in Al_r–Al_l by 14 mm at 1-year follow-up. These authors also found an increase in cheilion–cheilion (Ch_r–Ch_l) of 1.6 mm, which represented a (Ch_r–Ch_l):(6–6) ratio of 0.26:1. However, this change was not statistically significant. Nada et al. (2013) showed that the cheek region had an increase in transversal length of 1.66 mm. The cheek region followed the alveolar expansion at a ratio of 0.32:1. Cheek landmark (Ck) was defined at the intersection between a line parallel to the midline of the face starting from exocanthion and crossing a line passing from Ch_l to Ch_r. Changes in the central part of the upper lip consisted of a retraction that followed the retraction or remodeling in the middle alveolar region of the maxilla at a ratio of 0.88:1.

Table 8
Soft to hard tissue ratios for maxillary extrusion.

Authors	Technique	Additional procedures	Me'/Me (y)
Lecointre	Le Fort I extrusion, no bone graft in the gap	3BSSO adv and 1 genio vertical augm	90

The numbers in the table are in %.
Abbreviations: Pn (pronasale), Sn (subnasale), Me'(soft menton), Me (bony menton), y (y-axis), BSSO (bilateral sagital split osteotomy), adv (advancement), genio (genioplasty), augm (augmentation).

Table 9
Soft to hard tissue ratios for maxillary impaction.

Authors	Technique	Additional procedures	Pn/ ANS (y)	Pn/Pr (y)	Sn/Pr (y)	Sls/A (x)	Sls/A (y)	Sls/Pr (y)	Sls/U_a (x)	Ls/A (y)	Ls/Pr (y)	Ls/U_a (x)	Ls/U_l (x)	Ls/U_l (y)	Sts/A (y)	Sts/Pr (y)	Sts /Ua (y)	Sts/U1 (y)	Sto^i/L1 (y)	Li/L1 (x)	Li/L1 (y)	Mlf/L1 (x)	Mlf/B (y)	Pg/ Pg (x)	Pg/ Pg (y)	Gn'/ Gn (x)	Gn'/ Gn (y)	Me'/ Me (x)	Me'/ Me (y)
Schendel et al.	Le Fort I impa (11 pts) and simultaneous ant and post maxillary osteotomies (13 pts)	14 pts did not have mand proc											76	31										100					
Radney and Jacobs	Le Fort I impa ± setback	Only Le Fort	20				25						67	30				40											
Mansour et al.	Le fort I impa	Only Le Fort		15	28			26	76		31	89				37	37	42	93	75		90		86				120
Sakima and Sachdeva	Le Fort I impa	Only Le Fort																40			100				100				
Rosen	Le Fort I impa and adv	Only Le Fort																32											
Rosenberg et al.	Le Fort I impa	Only Le Fort													133														
	Le Fort I post impa	Only Le Fort								123					112														
Steinhäuser	Le Fort I with post impa (21 pts), with post imp and ant subsidence (13 pts) and parallel impa (8 pts)	Only Le Fort				28														44	72	58	56	78	49		80	60	
Ksiezycki-Ostoya et al.	Le Fort I impa	6 pts had adv genio																		100	150					90	90		100

The numbers in the table are in %.
Abbreviations: Pn (pronasale), Subnasale (Sn), ANS (anterior nasal spine), Ua (anterior aspect of first upper incisor), U1 (tip of first upper incisor), A (point A), Sls (superior labial sulcus), Pr (prosthion), Ls (labrale superius), Sts (stomion superius), Sto^i (stomion inferius), Li (labrale inferius), L_1 (tip of first lower incisor) mlf (mentolabial fold /soft B), B (bony point B), Pg (bony pogonion), Pg(soft pogonion), Gn (bony gnathion), Gń(soft gnathion), Me (bony menton), Mé (soft menton), x (x-axis), y (y-axis), adv (advancement), impa (impaction), pts (patients), mand proc (mandibular procedure), genio (genioplasty), post (posterior), ant (anterior).

Table 10
Max expansion.

Authors	Technique	Additional procedures	Al–al/6–6	Ch–ch/6–6	Ck–ck/6–6	Ls/U1 (x)
Berger et al.	Le Fort I + Hyrax	Only exp	40			
	Hyrax Alone	Only exp	32			
Ramieri et al.	Le Fort I + TPD Mommaerts[a]	Only exp	32	26		
Nada	Le Fort I + TPD Mommaerts[a]	Only exp			32	−88
	Le Fort I + Hyrax	Only exp			32	−88

The numbers in the table are in %.
Abbreviations: al–al (right to left alare distance), ch–ch (right to left cheilion distance), ck (rigtht to left cheek distance), (tip of first upper incisor), Ls (labrale superius), Sts (stomion superius), x (x-axis), y (y-axis), adv (advancement), impa (impaction), ext (extrusion), downgr (downgrafting), pts (patients), BSSO (bilateral sagital split osteotomy), mm (millimeters), segment (segmentation), mand proc (mandibular procedure), genio (genioplasty), AMxSO (anterior maxillary subapical osteotomy), exp (expansion), NC (not calculated).
[a] Trans palatal distractor, Mommaerts type (Surgi-Tec, Gent, Belgium).

4. Discussion

When people are asked to evaluate the esthetics of lateral photographs of post-operative patients who have undergone orthognathic surgery, they put more emphasis on the lips and give more cursory attention to the nose or the chin (Burcal et al., 1987). This means that the correct placement of the upper lip is of great importance and is one of the reasons why soft-to-hard tissue ratios regarding maxillary surgery have mainly focused on the Ls landmark. Several factors can lead to variability in the values of soft-to-hard tissue ratios regarding Ls after maxillary surgery. The use of the V–Y closure and nasal cinch suture proposed by Collins and Epker (1982) has already been discussed and can explain an important part of this variability. In summary, V–Y lip closure increases the Ls:U1 ratio only slightly, whereas cinch suture seems to increase the ratio at a 0.80:1 value.

Nevertheless, other factors can also contribute to the variability of soft-to-hard tissue ratios after Le Fort I surgery. For example, the pre-operative soft tissue thickness can lead to significantly different soft-to-hard tissue ratios after Le Fort I surgery, as stated by several authors (Freihofer, 1977; Stella et al., 1989; McCollum et al., 2009). Freihofer (1977) found that patients with lips thicker than 19 mm recorded a ratio of movement of Ls to upper incisor tip of 0.5:1. In patients with lips thinner than 16 mm, a ratio of 0.78:1 was found. This suggested that thinner lips follow the bony movements better than thicker lips. Stella et al. (1989) supported these findings when comparing thin- and thick-lip patients. They reported ratios at the Sn:A point of 0.5:1 in a group of thin-lip patients and of 0.3:1 in a thick-lip group, considering 12–17 mm a thin lip and everything above 17 mm a thick lip. These findings were significantly different. McCollum et al. (2009) also found a notable difference between thin- and thick-lip patients. In the cases of patients with thin lips, Sn advanced at a ratio of 0.79:1 to A-point movement, whereas the ratio for the thick-lip group was 0.22:1. However defining the normal thickness of the lip as 14.5–17.5 mm, Louis et al. (2001) could not find any difference in response between normal and thick lips. Similarly, Rosen (1988) could not demonstrate any statistically significant correlation in their sample of patients presenting with either thin or thick lips. As for maxillary setback surgery, lip thickness appeared to have no consequence on the relationship between bony tissues and changes in soft tissues after TMSO (Streater et al., 1988).

The magnitude of skeletal repositioning has also been analyzed to assess its implication in the values of soft-to-hard tissue ratios after Le Fort I advancement. Freihofer (1977) compared the eight greatest and the eight smallest advancements of the maxilla after Le Fort I surgery, and the results showed only slightly better ratios for greater movements at Pn (0.22:1 and 0.28:1, respectively). Stella et al. (1989) also investigated the correlation of the amount of maxillary advancement to the bony-to-soft tissue changes post-operatively. The patients were divided into two groups, the first one with a movement of less than 5 mm and the second one with a movement more than 5 mm. These authors found that the correlation coefficient for the first group was 0.54, which indicates a mediocre relationship between the magnitude of maxillary advancement and change in Sn. In the second group, however, the correlation coefficient was 0.22, demonstrating an extremely poor relationship between the magnitude of maxillary advancement and changes in Sn. For a given amount of advancement it was not possible to predict the soft tissue changes. The theories proposed to explain this unpredictability are that the bulk of a thick upper lip might absorb a large amount of the forward movement of the maxilla, thus reducing the amount of soft tissue change or that there is a pocket of air present between the maxillary dentoalveolar structures and the upper lip labial mucosa in the more severe cases of maxillary retrognathia, and the movement of the maxilla into this space might not be noticeable in the soft tissue until the dentoalveolar unit makes contact with the labial mucosa.

The fact that the soft-to-hard tissue movements are expressed in mean ratios can lead to lower correlations. Studies that rely on mean values do not explain individual variation and it has only been through the inclusion of many variables in the analyses that stronger correlations have been identified (Pospisil, 1987). Veltkamp et al. (2002) showed that the inclusion of up to five different variables into a multiple regression equation improved the correlation significantly. Likewise, nine studies have included linear or multiple regression equations for assessing soft-to-hard tissue movements after Le Fort I surgery (Engel et al., 1979; Mansour et al., 1983; Bundgaard et al., 1986; Hui et al., 1994; Van Butsele et al., 1995; Brooks et al., 2001; Rosenberg et al., 2002; McCollum et al., 2009; Ksiezycki-Ostoya et al., 2009). Of these, Engel et al. (1979) were the first authors to use multiple regression to analyze soft-to-hard tissue movement, and found that it could be used to predict vertical as well as horizontal coordinate changes for each of the soft tissue points. Taking into account the thickness of the upper lip to explain Le Fort I intrusion or extrusion, Van Butsele et al. (1995) also used multiple linear regression analysis combining the effects of horizontal and vertical maxillary movements. However, these authors found that the introduction of the third variable did not result in a better explanation of the dependent variable since R^2 square hardly increased. Lastly, Rosenberg et al. (2002) used multiple regression analysis for a group of patients that simultaneously underwent both maxillary advancement and impaction. They found that for horizontal movements of the maxilla, Sto^s and Ls followed the bony tissue to a lesser degree than did the vertical hard tissue movement.

It is still difficult to determine if there is a difference between soft-to-hard tissue ratios when bimaxillary or monomaxillary surgery is performed. Pospisil (1987) found that prediction errors were more likely to occur in the bimaxillary osteotomy group than in the

monomaxillary one. Moreover, prediction programs for bimaxillary surgery seem to be less predictable than those for monomaxillary surgery (Kaiapatur and Flores-Mir, 2009). The soft tissue response has been reported to be similar for single and double jaw surgeries (with maxillary advancement) with Ls:U1 ratios of 0.9:1 (Jensen et al., 1992) and 0.96:1 (Conley and Boyd, 2007) when cinch and V–Y closure were performed. Values of 0.80:1 were also seen when only V–Y was performed (Louis et al., 2001), which are higher than the values reported in monomaxillary surgery. However, Baik and Kim (2010) found Ls:U1 ratios of only 0.33:1 and 0.34:1 after bimaxillary surgery with and without genioplasty, respectively. The patients were analyzed with 3-dimensional laser scanning and the correlation between soft and hard tissue movement was statistically significant. TMSO along with mandibular advancement (Schouman et al., 2010) has demonstrated ratios similar to those reported by Chouet-Girard and Mercier (2003), with an Ls:U1 ratio of −0.64:1.

Cleft lip/palate patients appear to display lower Ls:U1 ratios compared to normal patients, with a range of 0.19:1 to 0.66:1 (mean: 0.48:1) (Willmar, 1974; Lines and Steinhauser, 1974; Dann et al., 1976; Freihofer, 1977; Jensen et al., 1992; Ewing and Ross, 1993; Hui et al., 1994; Al-Waheidi et al., 1998). Hui et al. (1994), however, found that the level of correlation was stronger in the horizontal lip response (Ls:U1) of the cleft group ($r = 0.84$) compared with non-cleft patients ($r = 0.64$). However, ratios found in the 1970s are, in general, lower than the ones reported in the 1990s. This could be explained by the fact that different surgical techniques have been used. Furthermore, a different pattern of ratio "ranges" appears to emerge in cleft patients. Freihofer (1977) noticed that the pattern of decreasing ratios from labrale superius to subnasale was reversed, and the highest ratio was at the level of subnasale.

Other factors that may the variability of the values of soft-to-hard tissue ratios are related to the accuracy of cephalometric prediction of soft tissue changes. Trpkova et al. (1997) showed that the accuracy of cephalometric prediction is affected by several method-related factors, such as the anatomic complexity and superimposition of hard and soft tissues, density and sharpness of the image, observer's experience when locating a particular landmark, and precise definition and location of a landmark.

Although age, gender, and race may play a role in the variability of soft-to-hard tissue ratios after maxillary surgery, there is a lack of data concerning these factors. Hui et al. (1994) found similar ratios in the Japanese population than the ones classically found in Caucasians. Differences between male and female responses have been analyzed in mandibular setback surgery, but not in maxillary advancement, with a soft tissue movement in response to skeletal repositioning being greater in females than in males (Kolokitha and Chatzistavrou, 2012).

As for nasal and midfacial changes after Le Fort I surgery, Sn and Pn landmarks have been analyzed by several authors, as discussed in the previous section. However, ratios regarding the transverse axis after Le Fort I advancement have yet to be reported. Westermark et al. (1991) stated that Le Fort I advancement and impaction increases alar width in 4.6% and 6.9% with and without cinch suture, respectively. Guymon et al. (1988) found greater differences, with a 2.9% increase in alar width with suture cinch and 10.75% without. Westermark et al. (1991) found that Le Fort I advancement also increased the nasolabial angle and tended to increase anterior and superior projection of the nasal tip. These authors also found that the alar base suture cinch reduced alar flaring, added an increase in nasolabial angle, and did not significantly influence nasal tip projection. However, Muradin et al. (2012) conducted a prospective study in which patients with cinch and V–Y closure were compared with a control group with a simple mucosal closure and found no difference regarding the horizontal excursions of alare between both groups. Other authors found a 1.35°–1.5° nasolabial angle increase for every 1 mm of advancement (Westermark et al., 1991; Vasudsavan et al., 2012). After maxillary advancement, the alar-midfacial region showed both regions of volume increase (about 5 cm^3) and volume decrease (from 5 cm^3 to about 1 cm^3) (Nkenke et al., 2008). Midfacial soft tissue changes after maxillary impaction have also been reported. As for maxillary impaction, a widening of the greatest alar width and alar base width, shortening of columella height, and nasal tip protrusion have been reported (Betts and Fonseca, 1989). However, maxillary impaction analysis of 36 long-term patient records showed that the soft tissue changes were minimal (increases in alar base width and shortening of lip length) and that they returned to their pre-operative measurements in the long-term analysis (Sarver and Weissman, 1991). Midfacial soft tissue changes are different between one side and the other when occlusal canting is corrected by leveling Le Fort I impaction, with more redundant soft tissue in the nasolabial groove as determined by superimposition of cone-beam computed tomography volumes (Hwang et al., 2012).

5. Conclusion

Soft tissue changes after monomaxillary surgery have been analyzed since 1973, when Dann and Bell published the first article on this topic. Of the studies we reviewed in this report, 56% involved maxillary advancement, 21% maxillary intrusion, 19% maxillary setback, and 8% and 2% maxillary expansion and extrusion, respectively. Maxillary extrusion is a common procedure in maxillofacial surgery, and much has been written regarding the stability of the results; however, there is still a need for an analysis of soft-to-hard tissue ratios. More prospective studies with a higher level of evidence are required. Also, more studies that stratify by confounding factors such as the magnitude of movement, alar cinch and or V–Y closure, subspinal osteotomy (Mommaerts et al., 1997), bimaxillary/monomaxillary surgery, age, sex, race, quality and quantity of the soft tissues, and possibly method of osteosynthesis are still needed.

Conflict of interest

None.

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