Smile Asymmetry in Patients treated with combined Orthodontics and Orthognathic Surgery

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Abstract

AIM: The aim of this study was to examine the relationship between lip canting and the extent of a smile, both pre- and post-operatively, in patients who were treated with combined orthodontics and orthognathic surgery.
METHODS: This study included 90 clinical photographs of 45 patients smiling, both before and after orthognathic surgery. Facial landmark points were traced to compare pre- and post-operative photographs. The data were used to measure the vertical distance of the lips when smiling – lip elevation and the extent of a smile, both before and after surgery. The correlations among canting, the type of surgery, and Angle class were evaluated by a one-way analysis of variance (ANOVA) and multiple comparisons using the Tamhane post hoc test.
RESULTS: The magnitude of the post-operative extent of a smile was not significantly correlated with lip elevation and changes in lip canting. There were no statistical differences for Angle class I and asymmetric cases, in contrast to Class II and III results regarding the extent of a smile post-operatively. Bimaxillary surgery resulted in significantly broader smiles, and bilateral sagittal split osteotomy resulted in higher lip elevation post-operatively, though not to a significant extent.
CONCLUSION: Soft tissues, particularly the smiling lip line, are affected by orthognathic surgery and skeletal malocclusion. However, further studies will be needed to better assess and study smile dynamics.

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1 Introduction

Most of us start to smile as early as a month after birth, soon after we are able to recognize others' smiles. By about 6 months old, we show a clear preference for looking at faces that have a smile (Gladstone and Parker, 2002).

A smiling face is one of the six universally recognized facial patterns reliably linked to emotional experiences in humans. As the outward or affective expression of happiness, joy, or contentment, "social" smiling is thought to be biologically programmed. It is one of many reciprocal emotional-social behaviors necessary for successful attachment and social development (Gladstone and Parker, 2002). Facial expressions provide perhaps the most effective means of communicating emotion among humans (Etcoff and Magee, 1992; Al-Hiyali et al., 2015).

Culture also shapes the way people express their emotions. Westerners live in individualistic societies and tend to express their emotions explicitly. In contrast, Easterners live in collectivist societies and tend to suppress their emotions to maintain harmony within the group. More importantly, it has recently been shown that culture impacts not only visual perception but also, critically, the extraction of information from faces (Caldara, 2010).

Ekman (1992) states, *"To be happy, smile."* This short sentence highlights well how important the smile is for society and for each human being who pursues happiness as the ultimate life goal.

1.1 The anatomy of a smile

The mouth is the most dynamic element of the face, and the magical effect produced by the beauty of a smile results from the combination of facial harmony and the balanced relationship between healthy teeth and soft tissue.

A smile is an innate, universal, complex movement defined by the elevation of the mouth commissures, viewed from the facial aspect. It results from the interaction of several facial muscles that together produce different positions of the dento-labial structure. A smile is an expression of positive emotions, but it can also be used to mask negative feelings, with its social role being predominant.

A smile primarily manifests itself in the oral region and the eyes (Matthews, 1978). The oral area comprises the upper and lower lips, the corners of the mouth, and the anterior portions of the cheeks. The lips are two highly mobile, fleshy folds surrounding the orifice of the mouth (Matthews, 1978). At rest, the lips have variable anatomy. They may be full or thin, wide or narrow, or short or long, generally in response to genetic factors and the shape of the teeth (Matthews, 1978).

According to Profitt (2013), two types of smiles exist: the posed or social smile and the enjoyment smile (also referred to as the Duchenne smile in research literature). The social smile is reasonably reproducible and is the one presented to the world on a daily basis. The enjoyment smile varies with the displayed emotion.

Currently, the social smile is the focus of orthodontic diagnosis. Machado (2014) describes, based on Rubin (1974), three levels or patterns of the smile (**Figure 1**).

1. The **commissure smile**, or Mona Lisa smile, is commonly performed when people greet each other in social contexts or in unusual locations, such as in an elevator. In this smile, the commissures are pulled upward, showing or not showing the teeth.

2. The **cuspid or social smile**, the second type, is when the upper lip is uniformly

pulled upward, showing the antero-superior teeth, either spontaneously or not. It is widely used in so-called *selfies* on social networks.

3. The **complex smile**, the third smile pattern, is characterized by the movement of the lower lip combined with the broad movement of the upper lip. It is also known as the **spontaneous smile**, often involuntary, which realistically depicts patients' smile design.

Figure 1. Different types of smiles, from left to right: commissure smile, social smile, and spontaneous smile. Source: Machado (2014).

An authentic smile is characterized by the joint action of the zygomatic major muscle and the orbicularis oculi, which raises the eyelid and causes wrinkles on the outer corner of the eye. As the smile expands and approaches laugher the lips separate, the corners of the mouth curve upward, and the teeth are exposed to view. Some people show only the maxillary teeth; others the mandibular teeth; others both. As the angles of the mouth extend and the lips separate, the mesial half of the maxillary first molars and the mandibular second premolars may be exposed (Machado, 2014). Gummy smile is a characteristic of people with hypermobile lips, massive alveolar processes and increased exposition of the gingival tissues.

1.2 Orthodontic and orthognathic surgical treatment plan

Patients seeking orthodontic treatment aim to improve their quality of life, pursuing enhancements in both appearance and functionality. Simultaneously, the primary concerns of patients seeking orthognathic surgery are related to the dysmorphology of facial appearance at rest and during facial expressions (Al-Hiyali et al., 2015).

Occlusal discrepancies require treatment for the preservation of dentition and long-term stable occlusion. While some patients may wish to correct their bite, most seek treatment to enhance their overall appearance, including their dentition, occlusion, smile, and facial aesthetics (Sarver and Jacobson, 2007).

The changes in the approach to orthodontic diagnosis have been gradual but steady over the past two decades (Sarver, 2015). The challenge is to achieve both ideals – occlusion and facial aesthetics. Treating only the occlusion addresses only half of the patient's needs, just as treating only the aesthetic component addresses only half of the patient (Sarver and Jacobson, 2007).

According to Profitt (2013), the soft tissue paradigm posits that the goals and limitations of modern orthodontic and orthognathic treatment are determined by the soft tissues of the face, not solely by the teeth and bones. This statement is evidence that orthodontics is not limited to the Angle classification that dominated the last century. The primary treatment goal nowadays is the management of soft tissue relationships and adaptations, rather than adhering strictly to Angle's ideal occlusion.

Soft tissue changes occur over time, while the skeletal framework may remain reasonably stable after adolescence. Orthodontists usually possess a deep understanding of the comprehensive principles of dental and skeletal development, maturation, and aging, along with other facets of dental practice (Sarver, 2015).

It is essential to remember that facial attractiveness is defined more by the smile than by the soft tissue relationships at rest. For this reason, it is crucial to analyze the characteristics of the smile and consider how the dentition dynamically relates to facial soft tissues, both in motion and at rest (Proffit, Fields, and Sarver, 2013).

1.3 Pre-treatment records

The traditional approach to orthodontic diagnosis and treatment planning, in clinical practice, is based in standard records that include digital photographs, radiographs, and mounted or unmounted plaster or electronic study models (Sarver, Jacobson, 2007).

The photographs that universally are considered standard records include frontal-at-rest, frontal smile, and profile-at-rest images (Sarver, Jacobson, 2007). Although these orientations provide an adequate amount of diagnostic information, they lack dynamism.

Orthognathic surgery requires a broader database of information than the one used for conventional orthodontic treatment. The accepted facial photographic recordings need to include close-up frontal smile, oblique facial smile, close-up oblique smile, and profile smile (Sarver, Jacobson, 2007).

1.4 Facial and dental appearance

A systematic analysis of facial and dental appearance has three major components, that allow an evaluation of each particular patient (**Figure 2**).

1. **Macro-Esthetics – Facial proportions.** Facial proportions in all three planes of space. Examples of macro-esthetic problems to be noted in the first step would include a long face, a short face, lack of chin prominence, asymmetry, mandibular or maxillary deficiency or excess, and other facial features.

2. **Mini-Esthetics – Tooth-Lip Relationships.** The dentition in relation to the face and the smile framework. This includes the display of the teeth at rest, during speech, and on smiling. (Proffit et al., 2013). The smile framework is bordered by the upper and lower lips on smile animation and includes such assessments of excessive gingival display on smile, inadequate gingival display, inappropriate gingival heights, and excessive or deficient buccal corridors (Sarver and Jacobson, 2007).

3. **Micro-Esthetics – Dental appearance.** Micro-esthetics refer to the teeth in relation to each other. This includes assessment of tooth proportions in height and width, gingival shape and contour, black triangular holes, tooth shade, and other dental attributes (Sarver and Jacobson, 2007; Proffit et al., 2013).

1.5 Landmarks of the human face

The analysis of shape is a key part of anatomical research and in the large majority of cases, landmarks provide a standard starting point. However, while the technology of image

Macro-Esthetics	Mini-Esthetics	Micro-Esthetics
Profile	Incisor display	Gingival shape & contour
Vertical proportions	Transverse smile	Emergence profiles
Lip fullness	Smile symmetry	Tooth shade
Chin-nasal Projection	Crowding	Tooth shape
Facial widths	Smile Arc	Black triangular holes

Figure 2. Approach to assessing dentofacial aesthetic analysis. Adapted from Sarver and Jacobson (2007).

capture has developed rapidly and in particular three-dimensional imaging is widely available, the definitions of anatomical landmarks remain rooted in their two-dimensional origins (Katina et al., 2016).

The identification of points that are well-defined and have anatomical meaning allows shape to be characterised in a manner that corresponds across subjects and that therefore provides the basis of subsequent statistical analysis (Katina et al., 2016). Good landmark definitions require the relevant information to be readily identifiable, with good intra- and inter-person reproducibility (Katina et al., 2016).

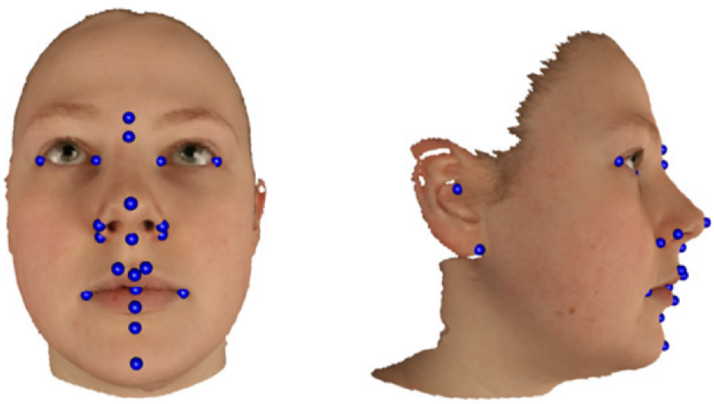

Figure 3. Two facial images show the location of manually identified landmarks. Adapted from Katina et al. (2016).

1.6 Aim of the work

The aim of this work is to test the hypothesis that there is lip canting when smiling after orthognathic surgery in patients with malocclusion along with improvement of their smile magnitude.

2 Methods

Journal articles and clinical case reports published in 4 languages (English, French, Portuguese and Spanish) were searched in PubMed, PMC and Scielo databases using the search terms “orthognathic surgery”, “orthodontics” and “case reports”. A complementary strategy used was to look for the related articles that appeared in the ”similar articles in PubMed” section and in references of selected articles.

In line with the aim of the study, all articles were included that presented photographs of patients smiling before and after combined orthodontic and orthognathic treatment. This applies to case studies as well as clinical trials, cohort studies and case series.

After identifying relevant articles, the following exclusion criteria were applied. Articles pertaining to orthognathic surgery conducted on patients with clefts, syndromes, sequences, or other craniofacial deformities were excluded. Additionally, papers that exclusively involved conservative orthodontic treatment were not considered. Articles lacking photographs of patients smiling or those presenting blurry, low-quality images were excluded. Similarly, articles that obscured the chosen landmarks for this review (e.g., through black rectangles used to protect patient identity) were also excluded. Papers that solely presented patient smiles from an oblique view were likewise excluded. Furthermore, case reports, case series, opinion papers, and titles retrieved from search engines that were deemed irrelevant to this study were excluded.

A total of 59 articles were screened, and abstracts of potentially important articles that fulfilled the inclusion criteria were read. Forty-five papers were finally selected and the full text evaluated. In this study, clinical photographs of patients smiling before and after orthognathic surgery were compared. To achieve this, specific landmark points were traced, as shown in **Figure 4**.

Adobe Illustrator software (Adobe Inc., San Jose, California, U.S.) was used to calibrate the images, ensuring that the preoperative photograph matched the same size as the post-operative one. This calibration was achieved using a standardized ruler created within the software. For this purpose, it was established that line 1 must have the same length in both photographs, meaning that the distance between the exocanthions remained equal.

The Exocanthion Plane (EP) exhibited consistent length in both pre- and postoperative images. To assess lip asymmetry following orthognathic surgery, the vertical distance between the lips during smiling was quantified. This distance represents the shortest perpendicular measurement from the exocanthion plane to the mouth corner (**3a** and **3b** in **Figure 4**) before and after surgery. Canting was defined as the disparity between the vertical distances on the right and left sides.

Lip canting is, then, defined as the absolute value in centimeters of the height difference between cheilion left and cheilion right in relation to the EP. In other words, lip canting is translated by an absolute value of the height difference between the lip elevation on the right side of the face (LER) and the lip elevation on the left side (LEL) of the face, pre- and postoperative.

All measurements were independently verified by the operator for all 45 subjects. The Ear-Eye Line Point (ELP) was not used as a reference line to calibrate the images in Adobe software due to the difficulty in identifying the OI points.

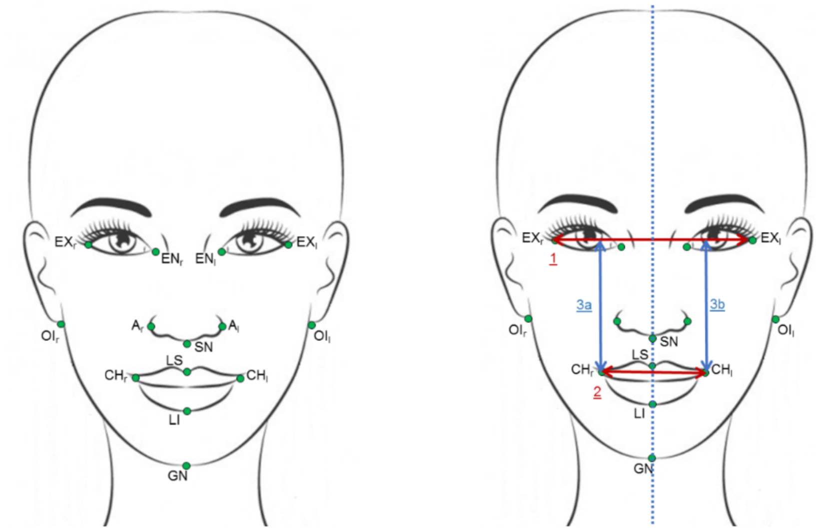

Figure 4. Graphical representation and definitions of used landmarks and measurements. **Left:** [EX] Exocanthion: The soft tissue point located at the outer commisure of each eye fissure (r-right; l-left). [EN] Endocanthion: The soft tissue point located at the inner commisure of each eye fissure (r-right; l-left). [A] Alar: Ridge point on the lateral extension of the nasal cartilage (r-right; l-left). [CH] Cheilion: The point located at each labial comissure (r-right; l-left). [OI] Otobasion inferius: The point of attachment of the ear lobe to the cheek, which determines the lower border of the ear insertion (r-right; l-left). [SN] Subnasale: The point where the nasal septum merges with the upper cutaneous lip in the mid-sagittal plane. [LS] Labiale superius The mid-point of the vermilion line of the upper lip.[LI] Labiale inferius The mid-point of the vermilion line of the lower lip. [GN] Gnathion The most anterior-inferior mid-point of the chin. **Right:** [Midline of the face] Connection between SN+LS+LI+GN points. [Line 1 – Exocanthion plane (EP)] Line connecting the two exocanthion points. [Line 2 – Extent of smile (EOS)] Line connecting the two cheilion points (CH left – CH right). [Line 3a – Lip elevation right (LER)] Perpendicular distance from EP to CH right point. [Line 3b – Lip elevation left (LEL)] Perpendicular distance from EP to CH left point. [Line 4 – Ear lobes plane (ELP)] Line connecting the two inferior ear lobes. [Image source: http://www.freepik.com].

2.1 Statistics

The statistical analysis was performed using IBM SPSS Statistics 21 (IBM Corp., Armonk, NY, USA). Preoperative and postoperative results were compared by Wilcoxon signed-rank test for the Angle Classes and the type of surgery. The correlations among canting, type of surgery and Angle Class were examined by a one-way analysis of variance (ANOVA), using multiple comparisons Tamhane post hoc tests.

The dependent variables studied were length of LER and LEL before orthognathic surgery (preoperative); length of LER and LEL after orthognathic surgery (postoperative) and extent of smile (EOS) pre and post-operative. The independent variables were the Angle class and the type of surgery. The mean and the standard deviation (SD) values were obtained for all the dependent variables. The level of significance was set at 0.05.

3 Results

In this study, a total of 90 photographs were selected and analyzed from a pool of 45 articles. The study included 45 subjects, comprising 28 females and 17 males, with 22 being of Caucasian descent, 12 of Asian descent, and 11 from other ethnic backgrounds.

The 45 patients who underwent combined orthodontic and orthognathic treatment presented a variety of correction challenges. The described surgical procedures encompassed a range of methods, including Le Fort I surgery, bimaxillary jaw surgery, genioplasty, mentoplasty, condylectomy, bilateral sagittal split osteotomy (BSSO), and nasal turbinectomy, among other variations. Among the Angle classification, Class III cases were the most commonly described, with 25 out of the 45 articles focusing on this category. However, all Angle Classes were represented, including asymmetric cases. Additionally, seven patients exhibited anterior open bites.

3.1 Lip asymmetry and extent of smile

The mean lengths for LER and LEL before surgery were 3.39 cm (SD = 0.67) each, and they marginally increased to 3.40 cm for both, with slight differences in the SD values (0.64 for LER and 0.62 for LEL) after surgery (**Table 1**).

The lip canting when smiling (mean ± SD) was 0.16 ± 0.13 for LER (p = 0.852) and 0.15 ± 0.12 for LEL (p = 0.642). For EOS, the mean length before surgery was 3.47 cm (SD = 0.78), and it increased to 3.66 cm (SD = 0.79) after surgery. The EOS measurements, both preoperative (range: 1.95 to 5.80 cm) and postoperative (range: 2.27 to 5.51 cm), are illustrated in **Figure 5**. The extent of smile change was statistically significant different after orthognathic surgery (p = 0.001).

Table 1. Right (LER) and left lip elevation (LEL) measurements as well extent of smile (EOS) pre- and postsurgery.

Measurement (cm)	Mean	SD	p-value[1]
LER pre	3.39	0.67	
LER post	3.40	0.64	
LER canting[2]	0.16	0.13	.856
LEL pre	3.39	0.67	
LEL post	3.40	0.62	
LEL canting[2]	0.15	0.12	.642
EOS pre	3.47	0.78	
EOS post	3.66	0.79	
EOS pre-post[2]	0.28	0.23	.001

[1]Wilcoxon
[2]Absolute values

3.2 Angle Class

No statistically significant differences were observed for Class I and asymmetric Angle Class cases before and after orthognathic surgery across all studied variables (**Table 2**). This implies that there were no discernible variations in lip elevation on either the right or left

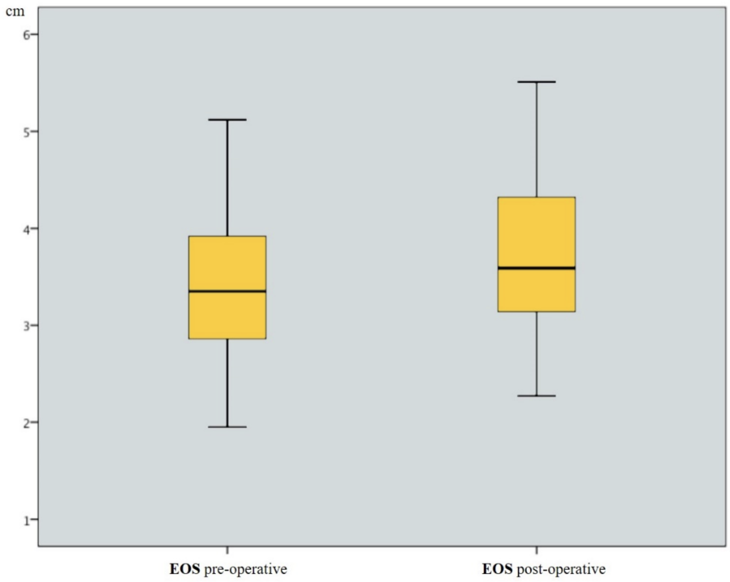

Figure 5. Extent of smile (EOS) change before and after orthognathic surgery.

side (LER or LEL), indicating the absence of canting. Additionally, there were no disparities in EOS between the pre- and post-operative stages.

On the other hand, significant differences were noted for Angle Class II and III cases, specifically with p-values of 0.028 (Class II) and 0.013 (Class III) for the disparity in EOS between post- and preoperative states. For Angle Class II, the mean EOS increased in the post-surgery phase (4.05 ± 0.96), compared to the pre-surgery measurement (3.78 ± 1.09). Similarly, for Angle Class III, the mean EOS exhibited an increase from 3.46 ± 0.66 pre-surgery to 3.65 ± 0.73 post-surgery. Regarding canting, no meaningful differences were observed in the mean values for both classes. A detailed examination of **Table 2** reveals that the values are closely aligned for the dependent variables when comparing pre- and post-surgery measurements, particularly for p-values greater than 0.05.

Table 2. Right (LER) and left lip elevation (LEL) measurements (cm) as well extent of smile (EOS) pre- and postsurgery according to Angle Class.

		pre	post	p-value
Class I	LER	3.10 ± 0.75	3.01 ± 0.78	.172
	LEL	3.11 ± 0.73	3.07 ± 0.69	.753
	EOS	3.15 ± 0.85	3.25 ± 0.78	.249
Class II	LER	3.75 ± 0.78	3.74 ± 0.68	.878
	LEL	3.74 ± 0.79	3.72 ± 0.69	.678
	EOS	3.78 ± 1.09	4.05 ± 0.96	**.028**
Class III	LER	3.36 ± 0.61	3.38 ± 0.58	.764
	LEL	3.35 ± 0.60	3.38 ± 0.57	.415
	EOS	3.46 ± 0.66	3.65 ± 0.73	**.013**
Asym.	LER	3.16 ± 0.34	3.22 ± 0.42	.465
	LEL	3.13 ± 0.45	3.23 ± 0.48	.465
	EOS	3.23 ± 0.44	3.38 ± 0.33	.465

3.3 Type of surgery

Following similar analysis, we can observe in **Table 3** that there is a statistically significant difference in the EOS after Le Fort I ($p = 0.018$) and bimaxillary surgery ($p = 0.024$). This means patients subjected to these two types of surgery presented a broader smile postoperative as the EOS mean increased from 3.32 cm to 3.62 ± 0.93 in the case of Le Fort I surgery and from 3.49 ± 0.74 to 3.66 ± 0.78 in the case of bimaxillary surgery. For BSSO, combined bimaxillary and genioplasty surgery and other non-specified types of orthognathic surgery there were no significant differences ($p > 0.05$) neither for LER or LEL nor for the EOS, pre and post-surgery.

The exception was the lower LEL on patients treated with bimaxillary surgery combined with genioplasty. The mean decreased from 3.58 ± 0.84 to 3.48 ± 0.81 which means that in these particular cases, lip canting of the left mouth commissure when smiling was verified with a smaller lip elevation ($p = 0.043$).

In BSSO there is a trend nearly significant ($p = 0.068$) in the difference of LER and LEL, before and after surgery (**Table 3**). It is observed a higher lip elevation post-surgery for both sides as the mean increases from 3.14 ± 0.43 to 3.35 ± 0.31 on the right and from 3.13 ± 0.37 to 3.32 ± 0.29 on the left. However, no significant difference in EOS post-surgery ($p = 0.144$).

In bimaxillary surgery there is a reverse effect compared to BSSO. Whereas BSSO showed nearly significant differences in lip elevation post-surgery but no difference in EOS, patients treated with bimaxillary surgery showed no higher lip elevation but a significant broader smile after surgery ($p = 0.024$).

Table 3. Right (LER) and left lip elevation (LEL) measurements (cm) as well extent of smile (EOS) pre- and postsurgery according to type of surgery.

		pre	post	p-value
Not described	LER	3.32 ± 0.57	3.36 ± 0.64	.735
	LEL	3.29 ± 0.58	3.32 ± 0.59	.612
	EOS	3.49 ± 0.72	3.79 ± 0.72	.063
Le Fort I	LER	3.27 ± 0.78	3.22 ± 0.82	.484
	LEL	3.23 ± 0.76	3.22 ± 0.74	.624
	EOS	3.32 ± 0.96	3.62 ± 0.93	.018
BSSO	LER	3.14 ± 0.43	3.35 ± 0.31	.068
	LEL	3.13 ± 0.37	3.32 ± 0.29	.068
	EOS	3.32 ± 0.38	3.72 ± 0.46	.144
Bimax	LER	3.48 ± 0.67	3.46 ± 0.60	.862
	LEL	3.47 ± 0.67	3.49 ± 0.60	.570
	EOS	3.49 ± 0.74	3.66 ± 0.78	.024
Bimax + Genio	LER	3.52 ± 0.81	3.47 ± 0.79	.204
	LEL	3.58 ± 0.84	3.48 ± 0.81	.043
	EOS	3.61 ± 1.07	3.54 ± 1.01	.398

3.4 Multiple comparisons test

The one-way ANOVA with the Tamhane Post Hoc test revealed no statistically significant difference in canting for either LER or LEL concerning the type of surgery. This suggests that there was no observable change in either higher or lower lip elevation after orthognathic surgery.

Despite the absence of a relationship with the type of surgery, the ANOVA Tamhane post hoc test indicated a significant correlation between canting on the right side and Angle Class (**Table 4**). Specifically, the mean difference in canting on the right between Class III cases and asymmetric cases is statistically significant ($p < 0.05$). Class III cases exhibited a mean canting on the right side 0.32 cm higher than asymmetric cases ($p = 0.015$).

The remaining multiple comparisons between Angle classes were not significant ($p > 0.05$), implying that equal means were not rejected. There was no difference in canting on the right side for Class I and II. The ANOVA Tamhane post hoc test for canting on the left revealed a non-significant relation ($p > 0.05$) for all Angle Classes. Consequently, there was no statistically significant difference in canting on the left for the studied Angle Classes.

Table 4. Multiple comparisons table between canting on the right and Angle Class (ANOVA post hoc Tamhane test). [n.s.] not significant.

Angle Class (i)	Angle Class (j)	i-j	Sig.	95CI Lo	95CI Up
I	II	.200	n.s.	-.69	1.09
	III	.180	n.s.	-.70	1.06
	Asym.	.500	n.s.	-.44	1.44
II	I	-.200	n.s.	-1.09	.69
	III	-.020	n.s.	-.56	.52
	Asym.	.300	n.s.	-.21	.81
III	I	-.180	n.s.	-1.06	.70
	II	.020	n.s.	-.52	.56
	Asym.	.320	**.015**	.05	.59
Asym.	I	-.500	n.s.	-1.44	.44
	II	-.300	n.s.	-.81	.21
	III	-.320	**.015**	-.59	-.05

4 Discussion

Facial expressions have an impact on the diagnosis of facial soft tissue disabilities, planning of the surgical procedure for correction of the skeletal deformities and evaluation of the surgical outcomes, consequently, the assessment of the facial expressions dynamics before orthognathic surgery is very important for the orthodontists and the oral surgeons.

The present investigation objective focused on testing the hypothesis that there is lip canting when smiling after orthognathic surgery in patients with malocclusion along with improvement of their smile magnitude.

The lip canting when smiling was 0.16 ± 0.13 for LER ($p = 0.852$) and 0.15 ± 0.12 for LEL ($p = 0.642$). Despite the presence of some cases exhibiting postoperative lip canting, the results did not reach statistical significance. Notably, the mean values of lip canting on both the right and left sides were smaller than 0.20 cm, which in itself represents a limitation of this study.

It is visible on **Figures 6** and **7** that there were no marked changes on lip canting, in general, before (LER and LEL pre) and after (LER and LEL post) orthognathic surgery as the lines in the graphics remain close together.

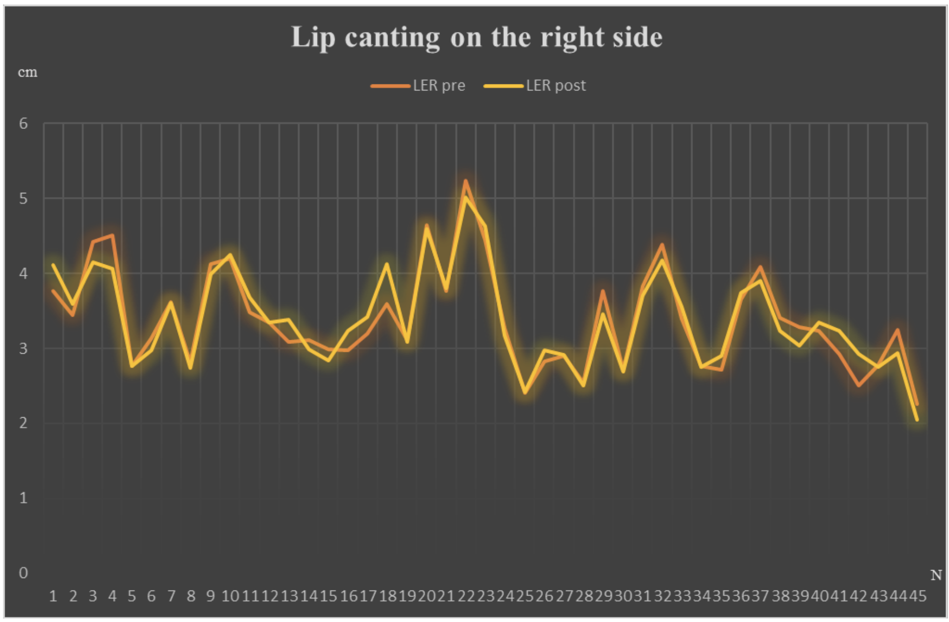

Figure 6. Right lip elevation in cm in pre- and post-operative images for the 45 subjects.

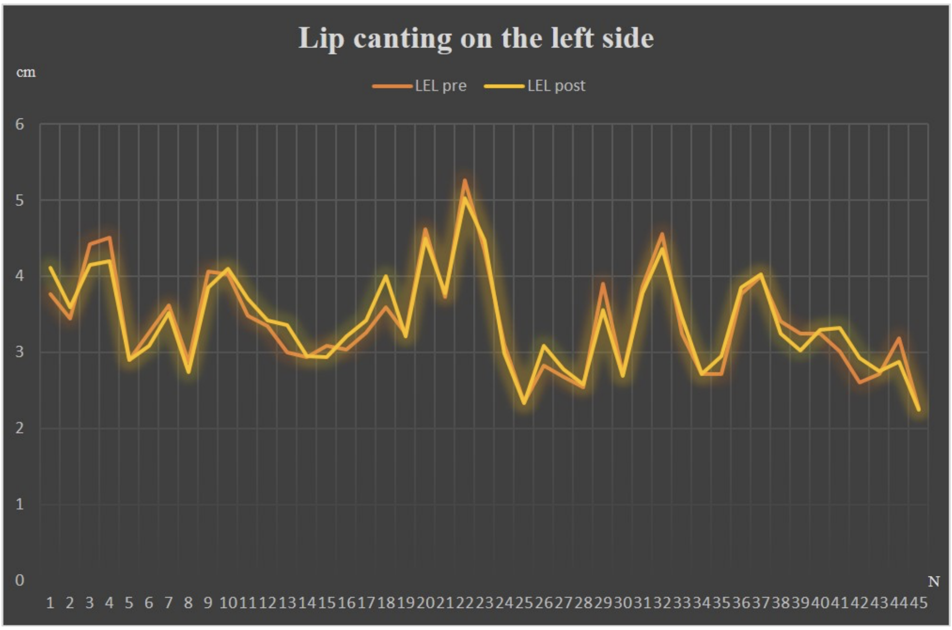

Figure 7. Left lip elevation in cm in pre- and post-operative images for the 45 subjects.

Observing both graphics, the patients 3 and 4 of the study had the biggest evidence of reduction of the LER and LEL after surgery. Both were open bite cases, subject 3 had a Class II subject 4 a Class III malocclusion both treated with Le Fort I and BSSO. Similar results were reported in a study by Al-Hiyali et al. (2015), which concluded that the magnitude of facial expressions decreased after Le Fort I osteotomy. Their conclusion is in agreement with the results for lip elevation for bimaxillary surgery when compared with BSSO. The first evidences lesser lip elevation than BSSO, which can be explained by the complications associated with Le Fort I (commonly performed when a bimaxillary surgery is described), that include occasional direct or indirect damage to facial nerves.

Le Fort I osteotomy induces changes in the maxillary teeth, buccal mucosa, palatal mucosa, and facial skin sensation (Kim, 2017). While skin sensation tends to recover over time even after direct damage to the sensory nerves, it may not completely recover to the condition that was present before surgery (Al-Din et al., 1996). In the last authors mentioned study, none of the patients returned to preoperative level considering the buccal mucosa fine touch sensation.

Furthermore, the null hypothesis is accepted concerning lip canting. There was no lip canting when smiling after orthognathic surgery. Contrastingly, the EOS postoperative presented a statistically significant change ($p < 0.05$) which means the null hypothesis for EOS is rejected, patients showed a broader smile after combined orthodontics and orthognathic surgery. The increase in the EOS is supported by a systematic review by Hunt et al. (2001) that indicates that patients who undergo orthognathic treatment have improved psychosocial benefits, such as better social functioning, social adjustment, self-confidence, self-concept, body image, emotional stability, self-esteem, facial-attractiveness image, positive life changes, and reduced anxiety (Song and Yap, 2017). However, the authors admitted that the level of scientific evidence to support these conclusions is not strong, as they resulted from uncontrolled prospective and retrospective studies (Song and Yap, 2017). Nevertheless, it can be correlated an improvement of the smile magnitude after orthognathic surgery and the patient satisfaction with the results.

Additionally, it can be stated by the results that not only the psychosocial benefits effects the smile, also the type of orthognathic surgery. Bimaxillary surgeries presented broader smiles ($p = 0.024$) than BSSO ($p = 0.144$), clarifying one of the research questions. Another particular finding of interest is demonstrated by Yuki et al. (2007) respecting culture influence on face analysis. The authors were the first to show that people from different cultures tend to weight facial cues differently when interpreting emotional expressions. Researchers have noted that cultures of individualism or independence emphasize the direct and explicit expression of emotions (Yuki et al., 2007).

In fact, in Western cultures, where people tend to have an independent self-control, denying the expression and experience of feelings is often equated with denying one's true self (Heine et al., 1999). Your sentence is well-structured, but I would make a slight adjustment for clarity:

By contrast, in East Asian countries such as Japan, China, and Korea, where people tend to be more collectivistic and interdependent, it is more important for emotional expressions to be controlled and subdued. A relative absence of affect is considered crucial for maintaining harmonious relationships (Heine et al., 1999). This cultural difference on expression emotions and interpreting them could have affected not only the EOS and lip canting of the patients before the camera, pre- and post-operative, as well as the author work on tracing the 90 pictures of this study. It is important to remember the heterogeneity of the sample, with 12 Asians, 22 Caucasians and 11 other ethnicities, not having specific information on how the photographs were taken.

In addition, smiling and frowning both involve the combined contraction of two groups of muscles: the zygomatic major (around the mouth) and the orbicularis oculi (around the eyes). A true smile or *Duchenne smile* involves the contraction of the orbicularis oculi muscles around the eyes, while other types of *fake smiles* (smiles that do not indicate genuine happiness involve only the zygomatic major muscles but not the orbicularis oculi (Ekman, 1992). Enjoyment smiles can be distinguished from other forms of smiling by the action of certain other muscles, by the extent of bilateral symmetry, and by the timing of the smile (Ekman, 1992).

The established protocol based on clinical photographs where the landmarks focused essentially on the exocanthions (left and right) and the cheilions (left and right) is, then, directly influenced by the smile captured at a certain moment, in an *artificial* environment for having a genuine smile expression from each patient. It is a very important limitation of this study that represents a direct influence on the results obtained on lip elevation on both sides (resulting or not in lip canting) and on EOS. Besides, smiling is not a static phenomenon (Kang et al., 2016), condition that interferes in the results obtained.

The increase in the EOS values for the class II and III patients could be explained by the type of surgical procedures needed to correct these facial deformities. In skeletal class I cases the orthognathic surgery is performed basically to correct open bites, through rotations of the jaws or segments of the jaws, so the soft tissues are not affected. This is in agreement with the results as LER, LEL and EOS for Class I, meaning there were no statistically differences before and after orthognathic surgery for the evaluated features.

Surgical treatment of class II and III cases include advancement and/or setback of the maxilla and/or the mandible and these bone movements have an effect on the soft tissues which, in this study, resulted in a significative broader smile (increase of EOS, $p < 0.05$). According to the study of Freudlsperger et al. (2017), the change in lip cant is not fully responsive to the hard tissue movement. A correction of the occlusal plane of one degree resulted in a correction of the lip cant of only 0.372 degrees. In line with Jung et al. (2009), as movement of the hard tissue cannot produce a positional change in the soft tissue as 1:1 ratio, owing to the influence of skin and muscles. These studies are congruent with the results as LER and LEL showed no statistical differences before and after orthognathic surgery, for any of the surgeries evaluated.

Rubio-Palau et al. (2016) refer that the behaviour of the soft tissues after a bone movement is very unpredictable because of its different components and status. The response depends on the skin, fat tissue, or muscle and can be very different in every patient. So, virtual surgery may be helpful to simulate the result after surgery but regarding the soft tissues, only approximate results can be expected.

Regarding the type of orthognathic surgery realized, Le Fort I and bimaxillary surgery presented a statistically significant difference in the EOS ($p < 0.05$) but no important lip canting postoperative. These results oppose the study of Al-Hiyali A et al. (2015), which justified the reduction of lip movements magnitude in Le Fort I with the stretch of the muscle attachments after the maxillary block is advanced. This difference may reside in the fact that, for many of the 45 patients analysed, the orthognathic surgery performed was a combination of different surgical procedures. Sixteen patients in the present study also had BSSO or genioplasty or both combined with Le Fort I osteotomy. These distinct combined surgical techniques may also have affected the results obtained for BSSO and bimaxillary surgery with genioplasty.

4.1 Improvement of the research protocol used

Hereafter, to develop this study, a standardized method must be a priority. It should begin by establishing an agreement with a Faculty of Dental Medicine or another educational institution in the field of Dental Medicine or specialized Orthodontics. This will significantly reduce intraoperator error in clinical pictures by ensuring that photographs are consistently taken by the same professional, from the same distance to the patient, and with pre-defined positions. The quality of the acquired images will also be more controlled and homogeneous.

Various strategies have been established to assess facial expressions. Photography and videotaping are 2-dimensional methods that underestimate the magnitude of facial expressions by 43% (Gross et al., 1996). Measuring lip smile from 2D photographs is inaccurate and does not represent the three dimensional (3D) nature of this facial expression (Kang, 2016). The small number of landmarks to describe facial movements limits the comprehensiveness of the analysis and the interpretation of the results. Other researches assessed facial expressions using 3D statistic imaging-based systems which do not record the direction, speed and pattern of facial movements, limiting the robustness of the analysis (Al-Hiyali et al., 2015).

Freudlsperger et al. (2017) used a combination between 3D photogrammetry, that offers the advantages of natural colour and texture information but excludes data about the underlying facial bone, and 3D Cone Beam computed tomography (CBCT), an effective tool to analyse the hard and soft tissue changes after orthognathic surgery.

Additionally, if we consider the application of multiple markers on a patient's face, it is relevant to remember that it can vary between imaging sessions, which introduces inaccuracies into the assessment. It is time consuming for the clinician, requires cooperation from the patient and could prevent the achievement of the natural smile of the patient (Al-Hiyali et al., 2015).

In resume, an alliance of 2D photographs, 3D CBCT images, 3D software and video records can help analysing more trustworthy the dynamics of a smile, guiding the studies to more faithful, statistically significant results.

4.2 Limitations

Along with the previous limitations already mentioned, there were some others in the design of this study as follows: lower quality of the photographs then desired, a limited sample size, lack of a control group, surgeries performed by diverse medical teams, the need of long-term established follow-up of the smile pattern (six months and one year later). Hence, an improvement of this research protocol is needed.

Conclusions

This study indicates that the magnitude of the post-operative extent of the smile was not significantly correlated with changes in canting. Postoperative smiles appeared broader than the preoperative ones for bimaxillary surgeries. Bilateral sagittal split osteotomy showed a higher lip elevation postoperatively on both sides, nearly reaching statistical significance. Class I cases, which mostly involved open bites, showed no change in lip elevation and extent of the smile after orthognathic surgery. These findings suggest that facial movements, particularly in soft tissues, are affected by orthognathic surgery and skeletal malocclusion. Despite the above limitations, this study underscores the importance of investigating smile dynamics and evaluating the impact of orthognathic surgery on the symmetry and magnitude of the smile, not only on orthodontic malocclusion. This is recognized as an important factor for patient psychosocial satisfaction with the final result.

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Ethical approval

No ethical approval was required for this study as it did not involve human participants, animal subjects, or sensitive data. This study falls under the category of data collection without participant identification.

Authors' contributions

The author(s) declare that all the criteria for authorship designated by the International Committee of Medical Journal Editors have been met. More specifically, these are: (a) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (b) Drafting the work or revising it critically for important intellectual content; AND (c) Final approval of the version to be published; AND (d) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests

The author(s) declare that there are no competing interests related to this work.

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