Three-Dimensional Dynamic Analysis of the Facial Movement Symmetry of Skeletal Class III Patients With Facial Asymmetry

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Purpose: Dynamic asymmetry has not been as rigorously evaluated as static asymmetry for patients with skeletal deformity but could well be even more important. The aim of the present study was to evaluate the dynamic facial movement of Class III patients with facial asymmetry using a 3-dimensional (3D) motion capture system.

Materials and Methods: The present cross-sectional study recruited patients with skeletal Class III malocclusion with and without facial asymmetry. A 3D facial motion capture system was used to record the expression process of a maximal smile. Eleven orofacial landmarks were selected to analyze and calculate the cumulative distance and average speed of each landmark during smiling. The predictor variable was mandibular symmetry. The outcome variables consisted of the measurements of each soft tissue landmark and the absolute differences for the paired landmarks between 2 sides. Other variables consisted of descriptive data, including the age and gender of each patient. The data were analyzed using independent *t* tests and paired *t* tests. Bonferroni's adjustment was used to control for multiple comparisons.

Results: A total of 63 patients were divided into 2 groups, an asymmetric group (n = 46) and a control group (n = 17), according to the degree of skeletal deviation. The difference in the cumulative distance of the bilateral cheilions was statistically significant between the 2 groups ($P = .002$). The difference for the asymmetric and control groups was 2.06 ± 1.78 mm and 1.00 ± 0.79 mm, respectively. In the asymmetric group, a comparison of the deviated side with the nondeviated side revealed statistically significant differences in the magnitude of motion for the cheilion ($P < .01$) and midlateral lower lip ($P < .01$).

Conclusions: The patients with skeletal asymmetry also showed asymmetry in soft tissue functions while smiling. The magnitude of movement in the nondeviated side was greater than that in the deviated side.

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It has been said that one should not judge a book by its cover. However, in our busy modern society, most impressions will occur within the first few seconds of meeting someone. According to Sarver and Jacobson,[1] smile symmetry is one of the esthetic components of dentofacial analyses, and a symmetric smile is considered more attractive.[2] The harmony and symmetry of facial expression can be disturbed by skeletal and occlusal asymmetry, which is the case for many patients with dentofacial deformity.[3] It has been commonly assumed that patients with skeleton asymmetry will also have comparable asymmetric facial movement. However, their relationship has not yet been reported. Based on our clinical experience, patients will tend to become more aware of their expressions after orthognathic surgery. In some cases, their facial expressions have become unbalanced after their skeleton deformity has been corrected. Therefore, it is an important step to record the patients' facial expressions and to compare the differences before and after surgery in the recovery process of dentofacial deformity treatment.

The traditional methods for the study of facial expression have involved photography and videotaping[4] and were mainly based on 2-dimensional images. However, these methods can underestimate the magnitude of facial expressions by 43%.[5] Recently, Popat et al[6,7] and Shujaat et al[8] reported the usage of 3D dynamic motion capture systems using active and passive stereophotogrammetry on facial movement recording, respectively. The technology has been applied in the evaluation process of facial movements for healthy adults and patients with craniofacial deformity, cleft lip and palate, and facial palsy.[9-13] However, few studies have performed a quantitative assessment of the facial movement in patients with skeletal asymmetry.

Therefore, the purpose of the present study was to examine the perioral facial movement characteristics of Class III patients with facial asymmetry using a 3D dynamic motion capture system. The hypothesis was that the patients with skeletal asymmetry will also have asymmetry in soft tissue movement. The specific aims of the present study were *1)* to compare the symmetry in facial movements between Class III patients with and without skeletal deviation; *2)* to estimate the bilateral facial motion differences of patients with facial asymmetry; and *3)* to determine whether the differences in facial movements were associated with the skeletal deviation.

Materials and Methods

STUDY SAMPLE

To address the research purpose, we designed and implemented a cross-sectional study. The study population included all patients with skeletal Class III malocclusion who had been treated at the Department of Oral and Maxillofacial Surgery in Peking University School and Hospital of Stomatology, from January 2019 to April 2019. To be included in the study sample, the patients were required to have no history of facial surgery or paralysis and no currently active orthodontic treatment. The patients were excluded as study subjects if they had experienced facial trauma or infection or had undergone cleft lip/palate, condylar absorption, or previous temporomandibular joint surgery. The institutional review board of the Peking University School of Stomatology (Beijing, China) approved the present study (approval no. PKUSSIRB-201943022), which followed the Declaration of Helsinki on human research. All the participants provided written informed consent.

CONE-BEAM COMPUTED TOMOGRAPHY SCAN AND ANALYSIS

Cone-beam computed tomography scans were taken using an iCAT scanner (NewTom, Verona, Italy). The scanning matrix was 400 $\times$ 400 with a field of view of 15 $\times$ 15 cm and a gray-level depth of 16 bits. The layer thickness was 0.075 mm.

The obtained data were saved in DICOM (Digital Imaging and Communications in Medicine) format and imported into ProPlan CMF, version 1.3, software (Materialise, Oberdorf, Switzerland). For each scan, the following skeleton landmarks were located: sella, nasion, basion, and menton. The midsagittal plane (MSP) was defined as the plane passing through the sella, nasion, and basion.[14,15] The subjects were grouped according to the distance from the menton to the MSP. Of the 63 subjects, 46 had skeletal asymmetry (distance >2 mm) and were included in the asymmetric group, and 17 without asymmetry (distance $\leq$2 mm) were included in the control group.[16] For the asymmetric group, the deviated side was defined as the side that included the menton, and the nondeviated side was the side contralateral to the chin deviation.

3D DYNAMIC MOTION-CAPTURE IMAGING

All the subjects' facial movements were recorded using the 3dMD-Face Dynamic System (3Q Technologies, Atlanta, GA). The system is a noninvasive 3D surface scanner that uses active stereophotogrammetry and random infrared speckle projection to capture both pattern-projected and nonpattern-projected white light images simultaneously.

The subjects were placed in a natural head position, which was fixed with elastics to the head frame (Fig 1). They were asked to perform a maximal smile with their lips closed, which had been regarded as a reproducible smile in previous studies.[17,18] The desired

FIGURE 1. The 3dMD-Face Dynamic System (3Q Technologies, Atlanta, GA) and the fixing head frame.

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facial expression was explained and demonstrated by 1 of us (Z.X.). The facial expression began with the lips pressed together lightly, without any tension in the facial muscles (rest position). The participants were asked to smile maximally with their lips closed, while biting their back teeth together lightly (maximum smile), and then returned to the rest position. The sequence was practiced before image capture to familiarize the subjects with the gestures.

IMAGE ANALYSIS

Three-dimensional measurement of each expression sequence was performed using 3dMDvultus software (3dMD, Atlanta, GA). Five key frames were chosen for the measurements, including the initial frame (rest position), largest frame (maximum smile), quarter frame, half frame, and three-quarter frame.

Eleven landmarks (Table 1, Fig 2), including 4 paired on the left and right sides were manually placed by the examiner (Z.X.) around the subjects' lips for each key frame.[10,19,20] The landmark data were then exported

Table 1. KEY LANDMARKS USED FOR DYNAMIC ANALYSIS

Landmark	Anatomic Location	Abbreviation
1, 3	Alar base	AL
2	Subnasale	SN
4, 8	Cheilion	CH
5, 7	Crista philtri	CPH
9, 11	Midlateral lower lip	MLL
6	Labiale superius	LS
10	Labiale inferius	LI

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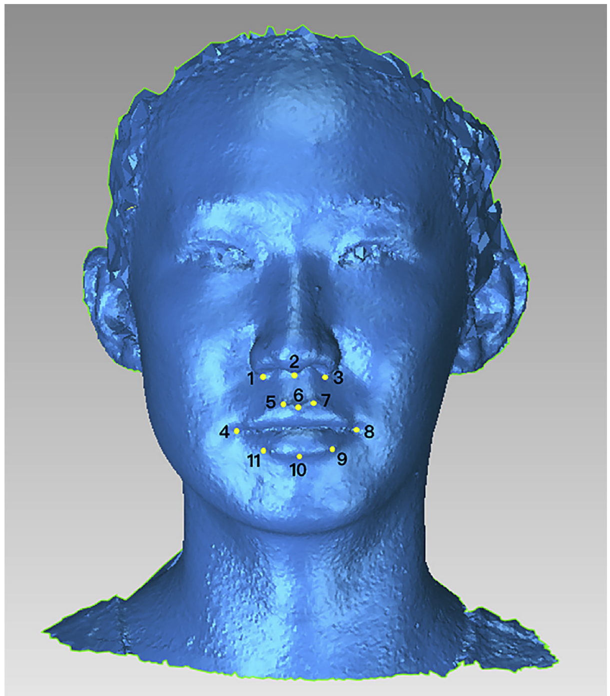

FIGURE 2. The key landmarks used for the dynamic analysis.

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in .txt file format and read into a coding program written in Visual Studio software (Microsoft Visual Studio 2010, Microsoft, Inc, Redmond, WA) for analysis. The cumulative distance (D) and average speed (V) of each landmark from rest to maximum smile were determined. The absolute value difference of the distance and speed (ΔD, ΔV, respectively) of the 4 paired landmarks were also calculated to reflect the asymmetry.

$$\Delta D = |D1 - D2|; \Delta V = |V1 - V2|$$

STUDY VARIABLES

The primary predictor variable for the present study was mandibular symmetry. The primary outcome variable was the dynamic soft tissue measurements. The soft tissue measurements included *1)* the cumulative distance and average speed of each landmark (alar base, cheilion, crista philtri, and midlateral lower lip); and *2)* the absolute value difference between the deviated and nondeviated sides. The third category of variables consisted of descriptive data, including the age and gender of each patient.

STATISTICAL ANALYSIS

The operator reliability for the soft tissue scan measurements was evaluated using intraclass correlation

Table 2. PATIENT DEMOGRAPHICS

Variable	Control Group (n = 17)	Asymmetric Group (n = 46)	*P* Value
Age (yr)	25.1 ± 5.2	23.8 ± 4.8	.365*
Gender			
Male	7	17	
Female	10	29	.759†
Menton deviation (mm)	0.9 ± 0.4	6.6 ± 3.6	< .001‡
Cumulative distance (mm)			
Subnasale	3.88 ± 1.25	3.92 ± 1.14	.919*
Labiale superius	5.71 ± 1.60	6.00 ± 1.81	.560*
Labiale inferius	8.30 ± 3.01	8.56 ± 2.56	.735*

Data presented as mean ± standard deviation.
* Student *t* test.
† χ^2 test.
‡ Mann-Whitney *U* test.

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coefficients. Ten subjects were randomly selected to test for intraoperator and interoperator reliability. Intraoperator reliability was tested by the same operator (Z.X.) who defined the landmarks twice within 1 week. Interoperator reliability was tested by 2 operators (Z.X. and L.W.), who had defined the landmarks at the same time.

Descriptive statistics were used to show the variations in the movement for each group. Independent sample *t* tests were used to compare the differences in the absolute difference of distance and speed for the 4 paired landmarks between the 2 groups after we ascertained the normality using the Shapiro-Wilk test. Paired sample *t* tests were used to compare the differences between the bilateral landmarks in each group. The significance level was set at 5%. The Bonferroni correction was then used for pairwise comparison and was considered significant at $P < .0125$ (α/n; n = 4 comparisons) to control for multiple comparisons. All analyses above were performed using SPSS, version 17.0 (IBM Corp, Armonk, NY).

Results

In accordance with the inclusion and exclusion criteria, we recruited 46 patients (17 men and 29 women; mean age, 23.8 ± 4.8 years) for the asymmetric group and 17 patients (7 men and 10 women; mean age, 25.1 ± 5.2 years) for the control group. A descriptive summary of the 63 patients is presented in Table 1.

The intraoperator reliability coefficients varied from 0.908 to 0.989. The interoperator reliability coefficients ranged from 0.876 to 0.975, confirming that the landmark technique was accurate and reproducible.

The results of the cumulative distance and average speed for each landmark are presented in Tables 2 and 3. The largest landmark displacement for the participants in the control group occurred at the cheilion during smiling (13.82 ± 3.21 mm). The subnasale demonstrated the smallest displacement (3.88 ± 1.25 mm). The displacement and speed results obtained from the smiles of participants of the control group are presented in Figure 3. Similarly, in the asymmetric group, the largest displacement occurred at the cheilion during smiling (14.08 ± 3.49 mm), with the smallest movement on the subnasale (3.92 ± 1.14 mm). The equivalent graphic presentation of the expressions of the asymmetric group are shown in Figure 4.

Combining all landmark pairs, we recorded a significant difference in the ΔD ($P = .002$) and ΔV ($P = .006$) of the cheilion between 2 groups, although no significant differences were found between the groups for the other 3 paired landmarks. In the asymmetric group, the paired landmarks' cumulative distance and average speed in the nondeviated side were all larger than those in the deviated side. The differences were statistically significant for the cheilions and midlateral lower lips on each side ($P < .01$). In the control group, the differences between the 2 sides were not significant (Table 3). The multiple linear regression model for orofacial movement asymmetry is presented in Table 4.

Discussion

The purpose of the present study was to determine the perioral facial movement characteristics of Class III patients with facial asymmetry. We hypothesized that the patients with skeletal asymmetry would have asymmetry in soft tissue functions. Our specific aims

Table 3. COMPARISONS OF MEASUREMENTS AND DIFFERENCES IN 2 SIDES BETWEEN CONTROL AND ASYMMETRIC GROUPS

	Control Group			Asymmetric Group			*P* Value
Variable	Right	Left	Difference*	Deviated	Nondeviated	Difference*	Between Groups†
Alar base							
Distance (mm)	4.99 ± 1.69	4.93 ± 1.28	0.92 ± 0.70	4.82 ± 1.68	4.30 ± 1.56	1.24 ± 1.03	.255
Speed (mm/s)	13.50 ± 4.31	13.40 ± 3.25	2.53 ± 1.95	12.78 ± 4.79	11.44 ± 4.47	3.41 ± 2.96	.259
Cheilion							
Distance (mm)	13.82 ± 3.21	13.76 ± 3.35	1.00 ± 0.79	14.08 ± 3.49	12.89 ± 2.89	2.06 ± 1.78‡	.002‡
Speed (mm/s)	38.04 ± 10.85	37.68 ± 10.44	2.81 ± 2.36	37.67 ± 11.37	34.41 ± 9.48	5.46 ± 4.86‡	.006‡
Crista philtri							
Distance (mm)	6.04 ± 1.58	6.47 ± 2.62	1.37 ± 1.20	6.54 ± 2.28	6.22 ± 1.98	1.26 ± 1.41	.785
Speed (mm/s)	16.57 ± 4.80	17.53 ± 7.12	3.76 ± 3.55	17.35 ± 6.41	16.55 ± 5.72	3.36 ± 3.64	.701
Midlateral lower lip							
Distance (mm)	10.86 ± 2.71	10.78 ± 1.80	1.60 ± 1.64	11.72 ± 3.01	9.94 ± 2.74	2.27 ± 2.20‡	.254
Speed (mm/s)	29.82 ± 8.64	29.67 ± 6.93	4.35 ± 4.46	31.30 ± 9.32	26.42 ± 8.21	6.05 ± 6.01‡	.291

Data presented as mean ± standard deviation; differences reported as absolute values.

* Paired *t* tests were performed for comparisons between the 2 sides in each group.

† Independent *t* tests were performed for comparison of the differences between the control and asymmetric groups.

‡ $P < .0125$ (α was adjusted for multiple comparisons).

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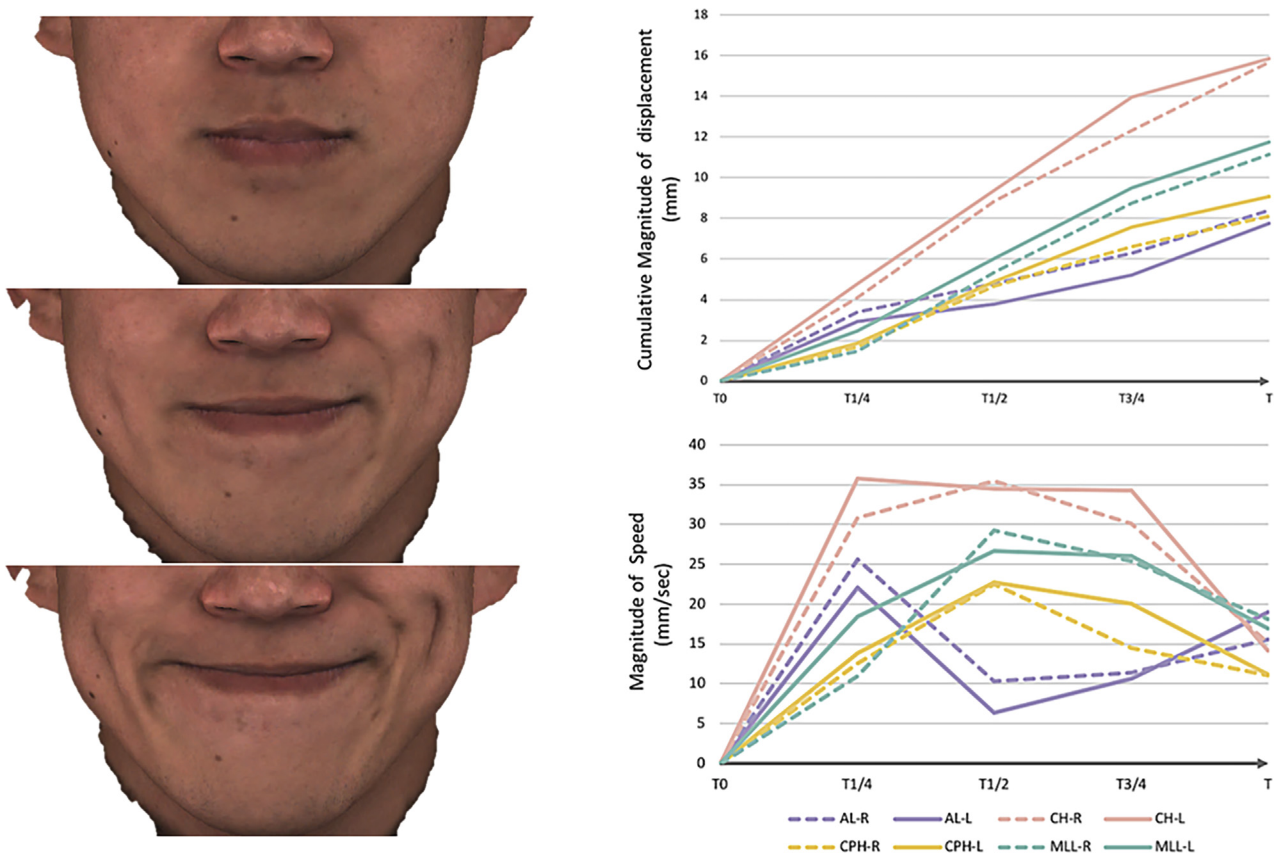

FIGURE 3. Magnitude of cumulative displacement and speed for 1 patient in the control group. Selected contralateral landmarks showing dynamic asymmetry with the subject smiling.

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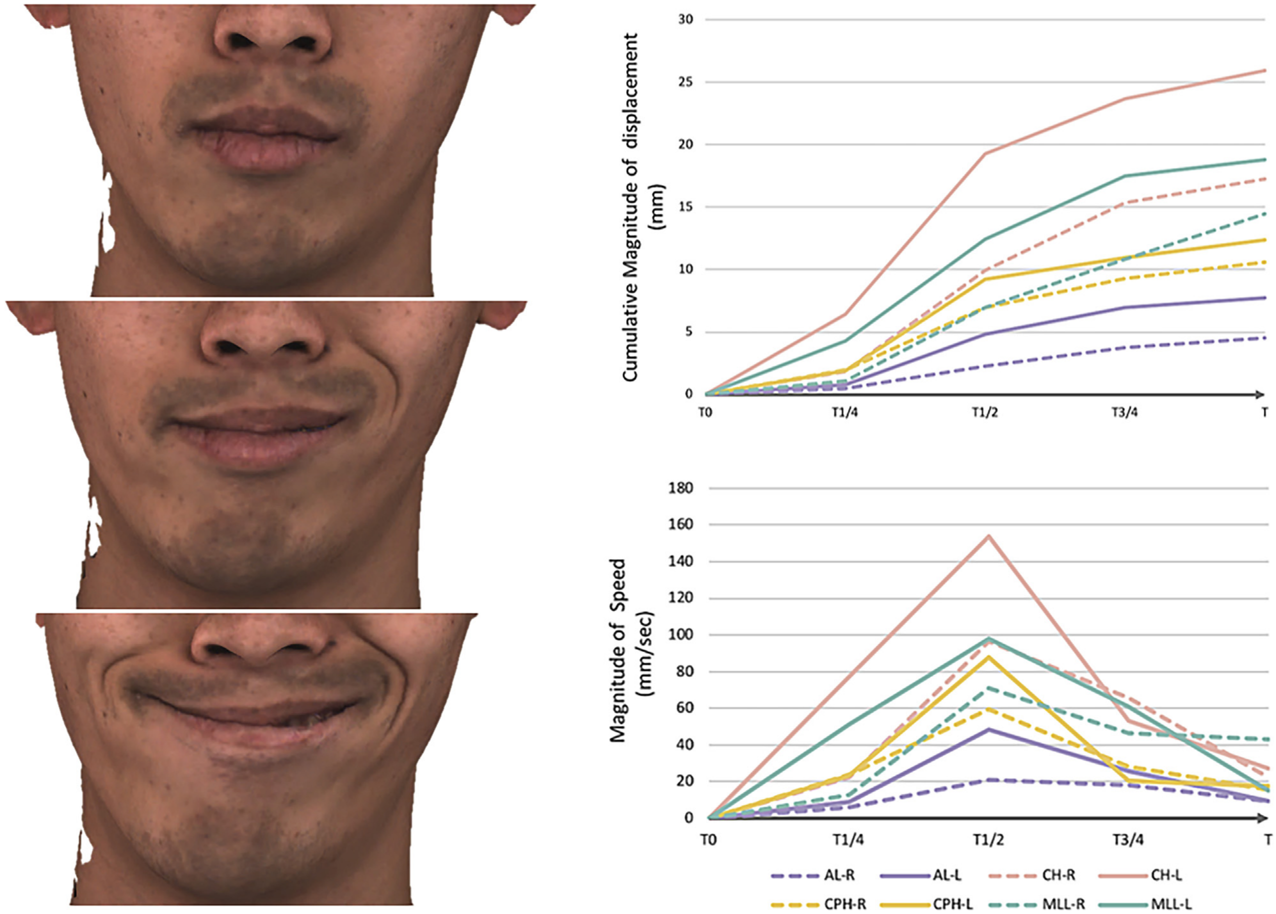

FIGURE 4. Magnitude of cumulative displacement and speed for 1 patient in the asymmetric group. Selected contralateral landmarks showing dynamic asymmetry with the subject smiling.

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were to compare the symmetry in facial movements between Class III patients with and without skeletal deviation; to estimate the bilateral facial motion differences; and to determine whether the differences in facial movements were associated with the skeletal deviation. The main finding of the present study was that the absolute value of the difference of the 2 cheilions, in terms of distance and speed, was significantly larger in the asymmetric group than in the control group. This result is consistent with our hypothesis that patients with skeleton deviation will also have dynamic asymmetry in the motion of the soft tissue.

We also found that in the asymmetric group, both the distance and the speed of the cheilion, midlateral lower lip, and alar base points on the nondeviated side were significantly larger than those on the deviated side. However, the same pattern was not found for the crista philtra point. The large variation between the 2 sides resulted, in part, from the skeletal asymmetry. Soft tissue dynamic function compensation might also have contributed to the muscle movement imbalance. Through muscle balance training, in which the patients adjust the tension of their facial muscles through daily feedback in the mirror, the perioral muscles can establish a dynamic "symmetry" based on the asymmetric skeleton.

Facial expression is dependent on the movement of facial muscles and their relation to the underlying bones.[21] The cheilion is located in the modiolus

Table 4. MULTIPLE LINEAR REGRESSION MODEL FOR OROFACIAL MOVEMENT ASYMMETRY*

Variable	Coefficient (95% CI)	*P* Value
Age	0.02 (−0.07 to 0.11)	.65
Gender	0.11 (−0.74 to 0.95)	.80
Menton deviation	1.08 (0.16 to 2.00)	.02

Abbreviation: CI, confidence interval.

* Orofacial movement asymmetry represented by the cumulative distance difference in the cheilion between the 2 sides.

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area, which has the largest number of perioral muscles involved when smiling (eg, orbicularis oris, levator anguli oris, zygomaticus major, zygomaticus minor, buccinator, risorius). Therefore, consistent with many previous studies,[10,20] the magnitude of the displacement of the cheilion was the largest in both groups. In contrast, the movement of the alar base mainly depends on contraction of the levator labii superioris alaeque nasi, and the movement of the crista philtri depends on the contraction of the levator labii superioris and orbicularis oris. The latter has dermal insertions ~4 to 5 mm lateral from the midline, sparing the central region.[22] Thus, the movement of these 2 points will be relatively small during smiling.

Trotman and Faraway[23] and Nooreyazdan et al[3] used preplaced retroreflective markers with a video-based tracking system to assess the facial expressions of patients with dentofacial deformities. Their findings are consistent with those from our study: facial movements are effected by skeletal malocclusion. Nevertheless, the direct placement of multiple markers on the face before image capture is a major obstacle for the assessment of facial expressions. The placement is time consuming for patients and clinicians and could prevent the patients from producing natural facial expressions.

In the present study, we use a markerless, noninvasive imaging system, capable of 3D soft tissue image capture during facial movements; this is succinct with the latest innovations in this field. The results obtained in the present study have demonstrated the great possibility of muscle compensation in the case of skeleton malformation. The situation will shift gradually after skeletal correction. During this process, the change in the tension and balance of the facial muscles could result in new asymmetry of the perioral movement. Therefore, our further study will focus on the difference between expression asymmetry before and after orthognathic surgery.

The study participants are likely to become candidates for orthognathic surgery, which indicates that the presence of asymmetry during smiling should be considered when developing a diagnosis and treatment plan. Soft tissue dynamic asymmetry while smiling will generally not be correctable by orthognathic surgery alone. Therefore, patients should be aware of the situation before treatment so they will not doubt the efficacy of the treatments or become displeased with the results. This is particularly true because quite a large number of patients with asymmetric smiles might not realize the related soft tissue changes.

In conclusion, using a 3D motion capture system to analyze the dynamics of orofacial movement has provided a novel insight into the differences in facial motion for patients with facial asymmetry. The patients with skeletal asymmetry also had asymmetry in the soft tissue functions while smiling. This issue should be recognized by patients considering orthognathic surgery, so that they can be informed that the condition might not be correctable and that it can affect the final esthetic result. Our further study will focus on the differences between the pre- and postoperative facial expression symmetry.

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