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Functional Outcomes of Cleft Lip Surgery. Part II: Quantification of Nasolabial Movement

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Abstract

Objective—To explore nasolabial movements in participants with repaired cleft lip and palate.

Design—A parallel, three-group, nonrandomized clinical trial.

Subjects—Group 1 = 31 participants with a cleft lip slated for revision surgery (revision), group 2 = 32 participants with a cleft lip who did not have surgery (nonrevision), and group 3 = 37 noncleft control participants.

Methods—Three-dimensional movements were assessed using a video-based tracking system that captured movement of 38 landmarks placed at specific sites on the face during instructed maximum smile, cheek puff, lip purse, mouth opening, and natural smile. Measurements were made at two time points at least 1 week and no greater than 3 months apart. Summary measurements were generated for the magnitude of upper lip, lower lip, and lower jaw movements and the asymmetry of upper lip movement. Separate regression models were fitted to each of the summary measurements.

Results—Lateral movements of the upper lip were greater than vertical movements. Relative to the noncleft group, the revision and nonrevision groups demonstrated 6% to 28% less upper lip movements, with the smiles having the most restriction in movement and greater asymmetry of upper lip movement. Having an alveolar bone graft further increased the asymmetry, while a bilateral cleft lip decreased the asymmetry. Lower jaw movement caused a small increase in upper lip movement.

Conclusions—The objective measurement of movement may be used as an outcome measure for cleft lip surgery.

Keywords

esthetics; facial morphology; lip form; lip function; muscle function

The aim of both primary and secondary (revision) lip surgeries in patients with a cleft lip is to improve the appearance and function of the nasolabial region. Until recently, quantitative

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data on the benefits of primary and secondary lip surgeries have been lacking, and the clinical recommendations for or against revision surgery have necessarily been based on subjective data. Therefore, variable evaluations of lip form and function have been made by operating surgeons (Trotman et al., 2007). Clearly, for some patients, the initial, primary surgical repair of the cleft lip and nose has significant potential for scarring and disfigurement that requires further surgical correction. Patients, their parents, and the operating surgeons must decide whether the benefits of a secondary lip revision following primary correction of a cleft lip outweigh the risks.

In previous studies, objective measures of circumoral soft tissue function including measures of facial movement, lip force, and lip sensation were shown to be successful in quantifying different aspects of circumoral function and were demonstrated to provide functionally relevant outcome criteria to assess the success of both primary and secondary lip revision surgeries (D'Antonio et al., 1994, 1995; Trotman et al., 2000; Essick et al., 2005; Trotman et al., 2005). As a first step toward objectively quantifying function in a large group of subjects, a clinical trial to evaluate the functional outcomes of cleft lip surgery was instituted. The details of the trial are provided in a companion article (Trotman et al., 2007). One aim of this clinical trial was to explore the nasolabial movement in participants with repaired cleft lip and palate. Nasolabial movement was the primary outcome measure of the trial. This aim was accomplished by comparing the nasolabial/facial movement among three groups of participants: (1) a group with repaired cleft lip and palate who were slated to have revision surgery (revision group), (2) a group with repaired cleft lip and palate who did not have revision surgery (nonrevision group), and (3) a noncleft control group (noncleft group). It was hypothesized that the participants with repaired cleft lip and palate would have impairments in the magnitude, direction, and symmetry of nasolabial movement compared with the controls. A second hypothesis was that the movement would be worse the more severe the cleft type; that is, there would be greater impairment for a participant with a bilateral cleft of the lip versus a unilateral cleft lip.

METHOD

Recruitment

The inclusion and exclusion criteria for the participants were as follows.

Inclusion—

- Interest/parent willingness to participate in the study
- Ability to comprehend verbal instructions
- Age range of 5 to 21 years
- For the revision and nonrevision participants, a previously repaired complete unilateral or bilateral cleft lip with or without a cleft palate
- For the revision participants, a recommendation by the surgeon for either a full- or partial-thickness revision surgery of the lip muscles

Exclusion—

- Previous orthognathic surgery
- Diagnosis of a craniofacial anomaly other than cleft lip and palate
- Medical history of diabetes, collagen vascular disease, systemic neurologic impairment, or any medical problem that leads to difficulty with healing

- Mental or hearing impairment to the extent that comprehension or ability to perform the tests was hampered
- For the revision and nonrevision participants, a previous lip revision surgery or other facial soft tissue surgery within 2 years of enrollment in the study

Participants who met the selection criteria were recruited and screened at the University of North Carolina (UNC) Craniofacial Center, the Graduate Orthodontics Clinic, the Pediatric Dentistry Clinic, and the Orthodontic Faculty Practice of UNC. No participant was excluded from participation on the basis of sex, race, or ethnic background. The purpose and protocol of the study was explained to the participants(s) and parent(s), and informed consent and assent was obtained. Consent and HIPAA documents were approved by the School of Dentistry Human Subjects Institutional Review Board.

Tracking System

A video-based tracking system (Motion Analysis; Motion Analysis Corporation, Santa Rosa, CA) was used to measure the circumoral movements of each participant. This system (Fig. 1) tracks retro-reflective markers secured to specific facial landmarks. Thirty-eight hemispherical, retro-reflective markers, each with a diameter of 2 mm, were attached by means of eyelash adhesive to specific sites on the facial skin of each participant (Fig. 2). Each participant then was positioned within the tracking area and instructed to make five maximum facial animations from rest: smile, lip purse, cheek puff, grimace, and mouth opening. The participants also performed a natural smile that was elicited in response to the research assistant's smile. For all animations except the natural smile, the three-dimensional (3D) movement of each marker was captured in real time by the tracking system at a rate of 60 frames per second for 4 seconds. The natural smile was captured at the same rate but for 5 seconds. The different animations served to represent the range of movements expected of the facial soft tissues during expressive behavior. Before data collection, all animations were practiced with each participant. Then, five trials of each animation were recorded for each participant at the same sitting.

The participants in each group were followed longitudinally and tested over a 15-month period. The revision group was tested and movement data recorded at two time points (at approximately 3 months and just before lip revision surgery) and then again at two time points (at approximately 3 and 12 months after surgery). The nonrevision and noncleft groups were tested at similar times to the revision group. The data presented here are the results for the two testing times before surgery and thus represent a baseline comparison of the groups. Data collection and analyses of the results for the longitudinal measures that represent the effects of lip revision surgery on facial movements are ongoing.

Measurement of Facial Movement

For each facial landmark during each of the five replications of the five maximum animations and the natural smile movement, the raw data consisted of a time series of 3D vectors. These vectors were defined by the x, y, and z coordinate data that represented the position in space of each landmark recorded at 1/60 second intervals for 4 seconds during the instructed animations and 5 seconds during the natural smile. Using these raw data, five summary measurements were generated for the participants at each of the two test times: (1) the magnitude of overall upper lip movements, (2) the magnitude of vertical and lateral upper lip movements, (3) the asymmetry of upper lip movements, (4) the magnitude of lower lip movements, and (5) the magnitude of lower jaw movements. The calculations of each of these measurements are described below.

Overall Upper Lip Movements—The overall upper lip summary measurement was based on the change in the distances between eight pairs of landmarks on the upper lip (Fig. 2, landmarks bounded by the solid rectangle on the upper lip). Let $d_{ij}(t)$ be the distance between any two landmarks i and j at time t. Then, the relative change in the distance between these two landmarks from rest for a particular movement is $r_{ij}(t) = [d_{ij}(t)/(d_{ij}(0)] - 1$. This measurement scales out the effect of the resting facial size and shape. The distance change was calculated for all 28 possible pairs of distances of the eight landmarks on the upper lip. Then, the maximum $\max_t |r_{ij}(t)|$ value over time t was computed separately for each of the 28 distances. The summary upper lip movement measurement for the animations and natural smile movement was the average (u) of the logged values of the scaled distances:

$$u = \frac{1}{28} \sum_{\text{upper lip}} \log_e \max_t r_{ij}(t)$$

Vertical and Lateral Upper Lip Movements—To study the directionality of upper lip movement, the magnitude of vertical and lateral movements were calculated. Vertical movement was based on the relative change in distances between all possible pairs of landmarks that were oriented vertically on the upper lip, and the lateral movement was based on the relative change in distances between all possible pairs of landmarks that were oriented laterally or horizontally. Each maximum absolute vertical and horizontal relative change from rest was computed. As in equation 1, the summary measurements were the average of the logged values of the vertical and lateral paired distances, respectively.

Asymmetry of Upper Lip Movement—For each animation and natural smile movement, the average of the relative change in distances between all possible landmarks-pairs for the four landmarks on the right side of the upper lip and then the four landmarks on the left side were calculated (Fig. 2, broken line dividing solid rectangle on the upper lip). Then, the $\log_e$ of the absolute difference in values between the right and left sides of the upper lip was calculated to represent a measurement of asymmetry of movement.

Lower Lip Movement—For the lower lip, a corresponding measurement of movement using the three landmarks on the lower lip (Fig. 2, landmarks bounded by the rectangle on the lower lip) was calculated in a manner similar to that described in equation 1.

Magnitude of Lower Jaw Movement—It was expected that the lower jaw movement could have some effect on the soft tissue movement during the animations and natural smile movements. Also, the movement of the lower jaw during the animations may be altered in the patients with cleft lip to compensate for impaired upper lip movements. The landmark on the midpoint of the lower chin (midchin marker 16; Fig. 2) was paired with the landmark on the nasal bridge (midnose marker 4; Fig. 2), and the change in the distance between these two landmarks was used as a measure of lower jaw movement. The soft tissue in the midchin (landmark) region has been shown to be reasonably stable, and this landmark has been used to represent lower jaw movement (Jemt and Hedegard, 1982). Also, the midnose landmark has minimal movement during the animated movements (Trotman et al., 1996).

Statistical Analysis

Plots for the upper and lower lip overall summary measurements were produced at the two separate time points for each animation and the natural smile movements, respectively. In addition, five separate regression models, each with specific predictor variables, were fitted to each of the five summary measurements. For each model, subject and visit were nested

random effects. For example, upper lip overall movement = participant group + visit + gender + age + bilateral lip + cleft palate + race + maxillary expansion + alveolar bone graft + lower jaw movement.

Lower jaw movement was included as a predictor variable for all the models with the exception of the model for the lower jaw. The levels of the predictor variables were as follows.

Participant group: A three-level factor for noncleft control, nonrevision, and revision (reference level = noncleft control)

Visit: A two-level factor for visit 1 and visit 2 (reference level = visit 1)

Gender: A two-level factor for male and female (reference level = female)

Age: A continuous factor (the effect of 1 additional year)

Bilateral lip: A single factor (no/yes) denoting the absence or presence of a bilateral cleft of the upper lip (reference level = unilateral cleft lip)

Cleft palate: A single factor (no/yes) denoting the absence or presence of a cleft of the secondary palate (reference level = cleft lip)

Race: A four-level factor for Caucasian, Black, Hispanic, and Asian (reference level = Caucasian)

Maxillary expansion: A single factor (no/yes) denoting the absence or presence of a maxillary expansion (reference level = no expansion)

Alveolar bone graft: A single factor (no/yes) denoting the absence or presence of an alveolar bone graft (reference level = no alveolar bone graft)

Lower jaw movement: A continuous variable denoting the amount of lower jaw movement during the animations and natural smile movement (the effect of 1% additional relative movement of the lower jaw)

The variation in movement was given by the standard deviation (SD) of the random effects and was measured as (1) the within-participant variation on making repeated movements at each visit or time point, (2) the among-participant variation at a particular visit or time point, and (3) the variation between visits 1 and 2, that is, between time points.

RESULTS

The final study sample consisted of 37 noncleft, 32 nonrevision, and 31 revision participants. Table 1 gives the mean ages and SDs as well as the gender characteristics of the three groups. There were four bilateral cleft lip participants in the nonrevision group and seven in the revision group. Plots of the descriptive statistics are shown on the Web site http://www.maths.bath.ac.uk/~jjf23/face/. These plots are of the upper and lower lip measurements of movement, respectively, for the different animations of each of the three groups of participants. Clear differences were seen in upper lip movements between the noncleft participants and the participants with a cleft lip during the maximum and natural smile movements. Specifically, during these two movements, the upper lip moved far less for the participants with a cleft lip than for the noncleft individuals. Also, during these two animations, there was a tendency for less variation in movement between the first and second visits for the revision participants compared with the other two groups. For the lower lip, no such differences among the groups were noted during the smile and natural smile animations; however, there was much less movement of the lower lip during the cheek puff animation for the revision participants.

The variation on repeated movements of a participant, variation in movement among participants, and variation in movement between visits for the upper lip of the noncleft, nonrevision, and revision participants are given in Tables 2 to 4, respectively, and similar variations for the asymmetry of movement, lower lip movement, and lower jaw movement of each of the three groups are given in Tables 5 to 7. The variations in movement among the participants were the largest. The variations on repeated movements and between visits were smaller and of similar magnitude. In some instances, these variations were comparable to the differences in movement between the participants with a cleft lip and the noncleft controls.

Upper Lip Overall, Vertical, and Lateral Movement

Tables 8, 10, and 12 give the mean overall, vertical, and lateral upper lip movements at the baseline visit. In general, these mean movements for the revision and nonrevision groups were less than the means for the noncleft group. Also, for all three groups, the mean lateral movements of the upper lip tended to be greater than the vertical movement. A viewer has been created (http://www.maths.bath.ac.uk/~jjf23/face/; see the Appendix for viewer instructions) to view the mean group movements represented in Tables 8, 10, and 12. Tables 9, 11, and 13 display the results for the predictor variables that demonstrated significant effects on the overall, vertical, and lateral movements of the upper lip. The predictor variables of revision and nonrevision represented the movement in these two groups expressed relative to the noncleft group, and the results were presented as percentage differences, with a negative value indicating less movement compared with the noncleft participants and a positive value indicating more movement. For all the facial movements, the revision and nonrevision groups had substantial restriction in overall upper lip movement compared with the noncleft group. This restriction was on the order of 6% to 28% (Table 9), while the restriction for the vertical upper lip movement ranged between 8% and 29% (Table 11) and that for lateral upper lip movement between 12% and 30% (Table 13). In general, there was more restriction in lateral versus vertical movement. For the revision and nonrevision groups, when specific animations were considered, the overall, vertical, and lateral movements were most restricted during the maximum and natural smiles and least restricted during the grimace.

The presence of a bilateral cleft of the upper lip had a major effect on movement. Having a bilateral cleft lip predisposed participants to a further reduction in movement during the smile, natural smile, and lip purse animations. For example, consider the overall natural smile animation in Table 9. The presence of a bilateral cleft resulted in an estimated 25.8% decreased movement compared with the reference level of having a unilateral cleft lip. Obviously, a bilateral cleft of the lip can occur only in the revision and nonrevision groups, and the value of a 25.8% reduction in movement represented the amount of additional reduction in movement (beyond 27.1% for the natural smile of the nonrevision group and 26.4% for the natural smile of the revision group, respectively). This effect was multiplicative, as was the effect of having a maxillary expansion and a bone graft. Those predictors such as age and gender that changed for both the noncleft (control) participants and the participants with a cleft of the lip were not affected by the difference of 25.8% because they were modeled as additive effects, which would affect all the groups equally.

All the other predictor variables had much less of an effect on the upper lip movement. For example, the results showed that there were minimal age changes in movement over the 3-month period, and then only the vertical upper lip movements during the cheek puff and mouth opening animations were affected, with a 0.7% and 2.0% reduction in movement. Gender resulted in a 9.7% and 7.1% reduction in vertical upper lip movement for boys relative to girls during the cheek puff and lip purse animations, respectively. Lower jaw movement had an effect on upper lip movement for all the animations apart from the

grimace. The effect ranged from a 0.9% increase in overall movement for the instructed smile to a 3.3% increase for the natural smile for every percentage increase in lower jaw movement.

Asymmetry of Upper Lip Movement

Tables 14 and 15 give the baseline asymmetry values and the values for significant predictor effects on asymmetry of movement. Because these values were based on the absolute differences between the right and left sides of the upper lip, distinctions as to which side of the upper lip had greater movement could not be made. A value of 0 for this measurement represented perfect symmetry, while increasingly positive values reflected increasing asymmetry of movement. The results demonstrated that the nonrevision and revision participants had greater asymmetry of mean upper lip movement compared to the noncleft participants (Table 14), and this greater asymmetry was significant for all animations (Table 15). The presence of an alveolar bone graft was associated with additional increases in movement asymmetry (40% for the instructed smile and 55% for the natural smile) beyond that due to being in the revision and nonrevision groups, while the presence of a bilateral cleft of the upper lip resulted in a 40% to 50% decrease in movement asymmetry.

Lower Lip Movement

Table 16 gives the results of the mean lower lip movement during the animations, and Table 17 gives the significant effects of the predictor variables on lower lip movement. Only the lower jaw movement had a significant effect on the movement of the lower lip. This effect was present during all the animations except the instructed smile and ranged from a 0.9% increase in movement during the cheek puff animation for each percentage increase in lower jaw movement to a 4.7% increase during the grimace animation.

Lower Jaw Movement

Table 18 gives the results of the mean lower jaw movement during the animations, and Table 19 gives the significant effects of the predictor variables on lower jaw movement. The results show that the lower jaw movement decreased by approximately 20% during the instructed smile for both the non-revision and revision groups. Also, during the lip purse movement, the lower jaw had a 55% increase in movement in participants with a repaired bilateral cleft lip.

DISCUSSION

In this study, circumoral movements were compared among three groups of participants: a group with repaired cleft lip slated to have revision surgery but who had not yet received the surgery, a second group with repaired cleft lip who did not have surgery, and a group of noncleft participants. A finding that was common to all three groups was that the mean lateral movements of the upper lip tended to be slightly greater than the vertical movements, suggesting that lateral lip movements were a greater component of the overall upper lip movement. When compared with the control group, however, a restriction in overall upper lip movement was seen in both the revision and nonrevision groups that affected lateral movement to a greater extent, especially during the cheek puff, lip purse, mouth opening, and grimace animations but less so for the smiles. Restricted movement reflects an altered muscle anatomy and scarring that results from a primary lip repair. In the case of restricted lateral movements, a cleft of the upper lip disrupts the muscle pattern of the orbicularis oris muscle that runs horizontally below, and inserts directly into, the skin overlying the lip. When repaired, scar tissue forms vertically through the muscle to a varying degree depending on the extent of the primary repair. This vertical scar restricts lateral movement. The fact that, during certain animations, the vertical movement capacity in the cleft

participants was not as impaired as the lateral capacity suggests that the strength of the labial muscles oriented in a superior-inferior direction was less compromised than the strength of those muscles oriented lateromedially.

The finding that participants with a bilateral cleft of the upper lip had more severe restriction in upper lip movement as well as more symmetric movement was somewhat intuitive. The surgeries to repair a bilateral cleft lip tend to be more extensive with the possibility of greater scarring and consequent limitations in movement versus the surgeries for a unilateral lip repair. Also, the prolabium in the repaired bilateral cleft lip has little orbicularis oris muscle, a finding that would contribute to tightness and decreased movement in the region. The participants with a bilateral cleft lip were most limited in their movements during the instructed smile, natural smile, and lip purse animations, all of which involved the greatest amount of upper lip movement; however, the more symmetric movement with a bilateral lip was most likely due to the limited movement that allowed little or no expression of asymmetry. Alveolar bone grafting was associated with an increase in movement asymmetry during smiling, which may be related to the effects of further scarring of the region as a consequence of graft. A bone graft restores symmetry and balance to the form of the nasolabal region. This finding suggested that although symmetry in form may have been improved as a result of the bone graft, symmetry in movement was worsened.

Previous studies have demonstrated excessive or different movements of the lower jaw and lower lip regions in participants with repaired cleft lip compared with noncleft control participants. These altered movements appeared to compensate for decreased upper lip movements during specific animations (Trotman et al., 2000). The findings of this study indicated that the internal movements of the lower lip during the animations were normal and that any compensations observed in the lower facial regions that were due solely to the lower lip movements were minor. For the bilateral cleft lip participants, there was greater lower jaw movement during the lip purse animation. During lip purse, perhaps the lack of movement of the repaired bilateral upper lip necessitated greater lower jaw movement to perform the animation. For both the revision and nonrevision participants during the instructed smile, there was little lower jaw movement probably because of the specific instructions given to the participants while performing these animations— participants were instructed to keep their teeth together while making the maximum smile movement. Therefore, lower jaw movement would be minimized.

The variations in the participants' movements were, at times, relatively large, being on the order of the differences between the participants with a repaired cleft lip and the non-cleft controls. Thus, it would be fair to say that the consistency in movement was fairly poor. This poor consistency could have been attributed to the experimental method but was more likely the reality of the situation. In reality, one cannot distinguish reliably a participant with a repaired cleft lip from a control participant with a single movement. Many repeated movements of each animation, as performed in this study, are required.

SUMMARY

Participants with a repaired cleft of the upper lip exhibited less movement when compared with noncleft control participants, but there were no differences in movement for the lower lip measures. Participants with a repaired bilateral cleft of the upper lip moved less than those with a repaired unilateral cleft lip. Lower jaw movement almost always had an effect on the movements of the facial soft tissues. Other than the presence of an alveolar bone graft, gender, race, age, the presence of a cleft palate, and maxillary expansion did not have any effect on facial soft tissue movement. During smiling, however, alveolar bone grafting appeared to be associated with an increase in movement asymmetry. To reliably distinguish

between a participant with a repaired cleft of the upper lip and a control participant, many repeated movements are required.

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APPENDIX

A viewer has been constructed to display the facial movements at any angle. The viewer may be downloaded from http://www.maths.bath.ac.uk/~jjf23/face/. Then go to the appropriate manuscript title and access "Program" and load "Faceexe."

The facial motion program has the following keyboard controls. All show the equivalent of the average movements in the tables: arrow keys rotate the facial views, a shows control average movement, b shows nonrevision average movement, c shows revision average movement, m toggles the animation between smile, cheek puff, lip purse, grimace, mouth open and natural smile; shift > and shift < increase/decrease face size.

How fast the animation displays depends on the computer's hardware and particularly whether a 3D videocard with OpenGL acceleration is installed. This is just a demonstration program. No warranty is given or implied.

FIGURE 1.
Camera arrangements and subject position for facial movement capture (note that markers appear larger than actual size because of light reflection from the cameras).

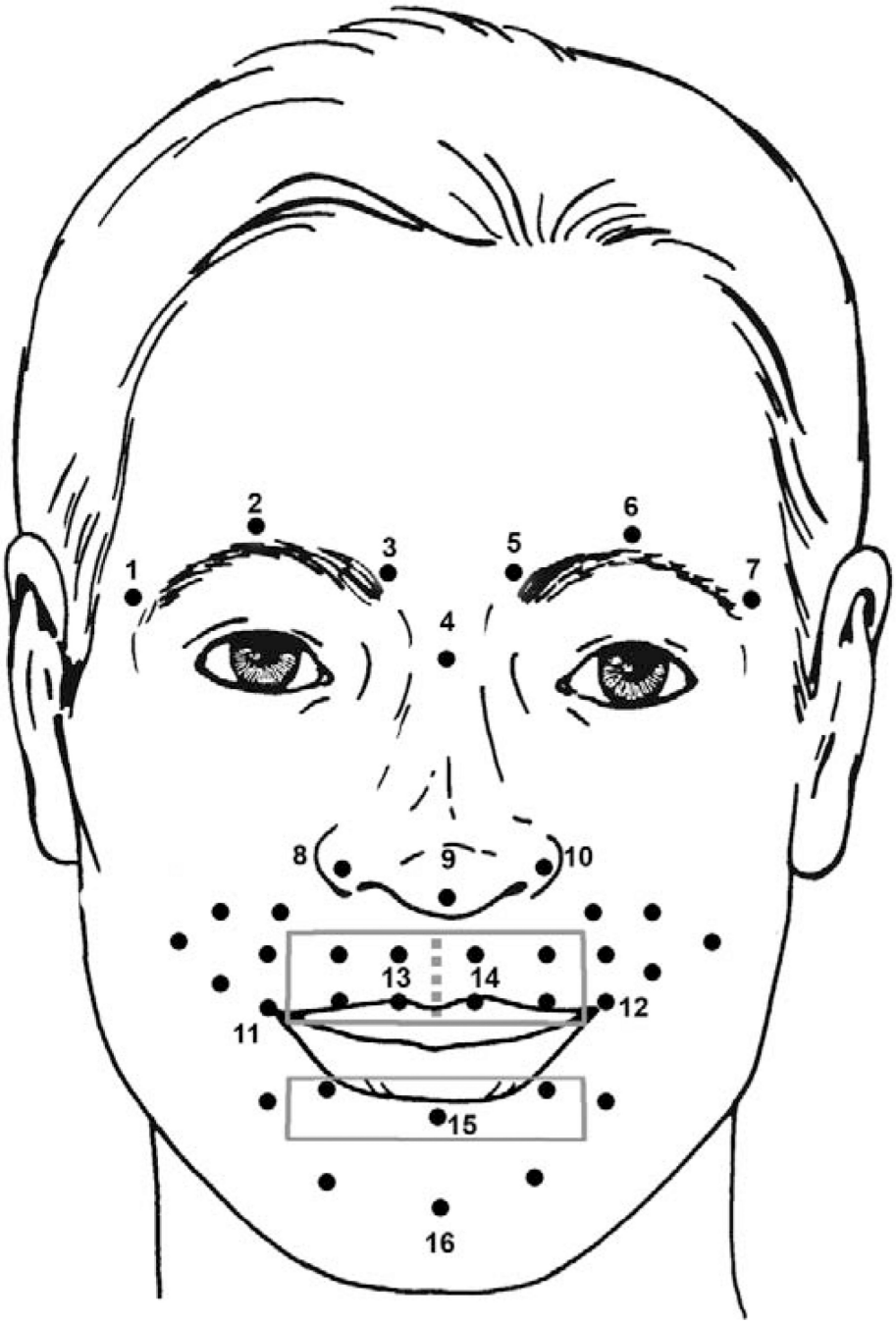

FIGURE 2.

A grid of 38 landmarks on the circumoral region was established relative to the following landmark locations: 1 and 7, right and left lateralciliary points located above most lateral aspect of eyebrows; 2 and 6, right and left superciliary points located above most superior aspect of eyebrows; 3 and 5, right and left interciliary points located above medial aspect of eyebrows; 4, midnose point located on the midline of the nasal bridge in line with medial canthi; 8 and 10, right and left lateral alar points located on lateral alar rims; 9, nasal tip point located on the tip of the nose in the facial midline; 11 and 12, right and left commissure points located on the right and left commissures, respectively; 13 and 14, right

and left upper lip points located on peaks of Cupid’s bow; 15, mid-lower lip point; and 16, midchin point located 2 cm below point 15.

TABLE 1

Sample Size, Mean Age, and Gender Characteristics of the Study Sample

Group	Total n	Mean Age, y	SD, y	Male, n	Female, n
Noncleft	37	13.1	3.6	20	17
Nonrevision	32	12.4	3.3	21	11
Revision	31	12.1	4.0	18	13

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TABLE 2

Percentage Movement Variation in Overall, Vertical, and Lateral Upper Lip Movements for Noncleft Participants

	Variation in Noncleft Movement (%)					
	Cheek Puff	**Lip Purse**	**Mouth Opening**	**Smile**	**Natural Smile**	**Grimace**
Overall upper lip movement						
Repeated movements	13.7	14.0	14.6	9.4	21.0	22.6
Among subjects	22.1	19.9	25.3	18.6	28.0	27.0
Between visits	12.9	13.9	25.5	10.8	13.3	16.5
Upper lip vertical movement						
Repeated movements	13.2	14.7	12.5	9.3	18.2	22.2
Among subjects	14.9	14.7	16.7	15.8	21.2	30.2
Between visits	10.6	12.9	18.9	9.8	14.2	17.9
Upper lip horizontal movement						
Repeated movements	16.5	15.0	16.2	10.7	23.3	27.9
Among subjects	27.9	23.9	29.3	21.4	32.4	27.7
Between visits	15.6	15.5	27.4	12.3	13.8	20.5

TABLE 3

Percentage Movement Variation in Overall, Vertical, and Lateral Upper Lip Movements for Nonrevision Participants

	Variation in Nonrevision Movement (%)					
	Cheek Puff	**Lip Purse**	**Mouth Opening**	**Smile**	**Natural Smile**	**Grimace**
Overall upper lip movement						
Repeated movements	14.4	15.0	20.9	14.0	23.9	22.3
Among subjects	23.2	21.3	36.1	27.8	32.0	27.0
Between visits	13.6	14.9	36.4	16.1	15.2	16.3
Upper lip vertical movement						
Repeated movements	12.5	14.8	15.1	12.3	19.4	22.6
Among subjects	14.1	14.8	20.1	20.9	22.6	30.7
Between visits	10.1	12.9	22.8	12.9	15.1	18.2
Upper lip horizontal movement						
Repeated movements	17.3	16.8	23.8	16.2	27.2	25.9
Among subjects	29.4	26.7	43.0	32.5	37.8	25.7
Between visits	16.5	17.4	40.3	18.7	16.0	19.1

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TABLE 4

Percentage Movement Variation in Overall, Vertical, and Lateral Upper Lip Movements for Revision Participants

	Variation in Revision Movement (%)					
	Cheek Puff	**Lip Purse**	**Mouth Opening**	**Smile**	**Natural Smile**	**Grimace**
Overall upper lip movement						
Repeated movements	15.9	14.4	21.3	13.3	23.3	22.0
Among subjects	25.6	20.3	36.8	26.4	31.2	26.3
Between visits	15.0	14.2	37.1	15.3	14.8	16.1
Upper lip vertical movement						
Repeated movements	13.9	14.2	17.3	11.7	20.2	22.5
Among subjects	15.7	14.2	23.1	19.8	23.6	31.6
Between visits	11.2	12.5	26.1	12.2	15.8	18.1
Upper lip horizontal movement						
Repeated movements	19.1	16.1	23.7	15.6	25.7	24.6
Among subjects	32.4	25.6	42.9	31.3	35.7	24.3
Between visits	18.1	16.7	40.1	18.0	15.2	18.1

TABLE 5

Percentage Variation in Asymmetry of Upper Lip Movement, Percentage Variation in Lower Lip Movements, and Percentage Variation in Lower Jaw Movements for Noncleft Participants During Different Animations

	Variation in Noncleft Movement (%)					
	Cheek Puff	**Lip Purse**	**Mouth Opening**	**Smile**	**Natural Smile**	**Grimace**
Asymmetry of upper lip movement						
Repeated movements	97.2	107.7	89.3	92.0	106.4	110.5
Among subjects	49.7	47.7	50.2	47.7	49.6	48.5
Between visits	41.4	39.3	38.1	49.1	42.5	38.1
Lower lip overall movement						
Repeated movements	19.7	21.4	22.1	14.7	27.7	45.8
Among subjects	18.0	18.8	37.4	19.7	24.7	38.9
Between visits	11.9	16.6	30.7	15.4	21.4	29.3
Lower jaw movement						
Repeated movements	34.3	40.7	9.5	25.9	38.1	29.3
Among subjects	27.4	38.7	12.1	25.8	32.7	31.7
Between visits	24.4	35.4	9.5	23.3	29.2	25.9

TABLE 6

Percentage Variation in Asymmetry of Upper Lip Movement, Percentage Variation in Lower Lip Movements, and Percentage Variation in Lower Jaw Movements for Nonrevision Participants During Different Animations

	Variation in Nonrevision Movement (%)					
	Cheek Puff	**Lip Purse**	**Mouth Opening**	**Smile**	**Natural Smile**	**Grimace**
Asymmetry of upper lip movement						
Repeated movements	75.0	74.4	83.3	41.7	55.3	100.0
Among subjects	38.3	33.0	46.8	17.1	25.8	43.9
Between visits	32.0	23.4	35.5	22.2	22.1	34.5
Lower lip overall movement						
Repeated movements	18.2	19.9	26.8	19.3	27.5	41.8
Among subjects	16.6	17.5	45.3	25.8	24.5	35.1
Between visits	11.0	15.5	37.2	20.2	21.3	26.7
Lower jaw movement						
Repeated movements	29.6	43.3	11.3	36.9	43.0	26.9
Among subjects	23.7	41.1	14.5	35.4	36.9	29.2
Between visits	21.1	37.7	11.3	33.2	33.0	23.8

TABLE 7

Percentage Variation in Asymmetry of Upper Lip Movement, Percentage Variation in Lower Lip Movements, and Percentage Variation in Lower Jaw Movements for Revision Participants During Different Animations

	Variation in Revision Movement (%)					
	Cheek Puff	**Lip Purse**	**Mouth Opening**	**Smile**	**Natural Smile**	**Grimace**
Asymmetry of upper lip movement						
Repeated movements	97.4	107.1	80.7	56.3	91.0	104.1
Among subjects	49.8	47.5	45.4	23.1	42.4	45.7
Between visits	41.5	33.7	34.4	30.0	36.3	35.9
Lower lip overall movement						
Repeated movements	21.9	18.5	30.3	17.7	28.6	36.1
Among subjects	20.0	16.3	51.3	23.7	25.5	30.3
Between visits	13.2	14.4	42.1	18.5	22.1	23.0
Lower jaw movement						
Repeated movements	30.8	39.0	13.0	33.2	46.8	32.6
Among subjects	24.6	37.0	16.7	31.9	40.1	35.4
Between visits	21.9	33.9	13.0	29.9	35.9	28.9

TABLE 8

Baseline Mean Values of Vertical Upper Lip Movement for the Noncleft Control, Nonrevision, and Revision Groups During the Animations and Natural Smile Movements

	Overall Upper Lip Movement					
Group	**Cheek Puff**	**Lip Purse**	**Mouth Opening**	**Instructed Smile**	**Natural Smile**	**Grimace**
Noncleft	12.9	14.2	19.5	26.6	17.4	10.7
Nonrevision	12.1	12.1	16.4	19.3	12.7	11.3
Revision	11.2	12.0	14.0	19.2	12.8	9.2

TABLE 9

Percentage Change in Overall Movement of the Upper Lip Due to the Effects of the Predictors

	Overall Upper Lip Movement					
Predictor	**Cheek Puff**	**Lip Purse**	**Mouth Opening**	**Instructed Smile**	**Natural Smile**	**Grimace**
Nonrevision	−5.9*	−14.8**	−15.5***	−27.5***	−27.1**	4.8
Revision	−13.3**	−15.2***	−27.8***	−27.6***	−26.4***	−14.5**
Visit	−1.5	2.8	−4.7	1.5	3.2	−5.5*
Gender	−5.3	−3.5	−1.5	1.9	−1.3	0.1
Age	−0.9	−0.4	−0.4	0.4	−0.7	0.3
Bilateral lip	−8.3	−16.4*	−11.0	−18.1*	−25.8*	4.0
Cleft palate	0.8	1.7	−8.9	4.5	4.0	−11.5
Race†	−12.7, 3.2, −0.8	−15.5, 4.6, 1.0	25.3, −0.2, −1.0	−7.0, −4.4, −2.3	−6.3, −7.7, 14.2	−15.1, −0.8, 9.7
Expansion	−7.0	−4.9	−15.5	1.9	15.3	−3.2
Bone graft	−5.3	0.0	9.4	−0.9	4.5	−9.4
Lower jaw movement	0.9***	1.3***	1.8***	0.5*	3.3***	1.8***

†First value = Asian, second value = Black, third value = Hispanic.

*$p \leq .05$.

**$p \leq .01$.

***$p \leq .001$.

TABLE 10

Baseline Mean Values of Vertical Upper Lip Movement for the Noncleft Control, Nonrevision, and Revision Groups During the Animations and Natural Smile Movements

	Vertical Upper Lip Movement					
Group	**Cheek Puff**	**Lip Purse**	**Mouth Opening**	**Instructed Smile**	**Natural Smile**	**Grimace**
Noncleft	12.2	11.5	18.8	19.7	13.7	15.6
Nonrevision	12.4	10.5	16.9	14.6	10.5	14.6
Revision	11.0	10.5	14.6	14.0	10.4	13.7

TABLE 11

Percentage Change in Vertical Movement of the Upper Lip Due to the Effects of the Predictors

	Vertical Upper Lip Movement					
Predictor	**Cheek Puff**	**Lip Purse**	**Mouth Opening**	**Instructed Smile**	**Natural Smile**	**Grimace**
Nonrevision	1.6	−8.8*	−10.1***	−25.9***	−23.5**	−5.9**
Revision	−10.3**	−8.8*	−22.3***	−29.0***	−24.1***	−11.7*
Visit	−0.8	2.9	−2.9*	0.7	1.5	5.6
Gender	−9.7**	−7.1*	−2.1	−2.4	−5.9	−6.2
Age	−0.7*	−0.6	−2.0***	0.0	−0.8	−1.9*
Bilateral lip	−11.6	−12.0	−14.7*	−14.7*	−23.1**	14.8
Cleft palate	1.7	1.1	−8.0	4.5	3.9	−19.2*
Race†	1.7, 9.1, 0.8	−0.8, 7.7, 7.7	15.2, 18.6, 2.4	−8.8, 7.7, −0.5	−5.1, −0.1, 7.2	−19.5, 22.7, 17.8
Expansion	−0.1	−0.4	−10.7	4.2	16.3*	−8.8
Bone graft	−4.1	1.5	12.1	0.0	2.7	0.2
Lower jaw movement	1.2***	1.7***	1.9***	0.9***	3.1***	0.2

†First value = Asian, second value = Black, third value = Hispanic.

*$p \leq .05$.

**$p \leq .01$.

***$p \leq .001$.

TABLE 12

Baseline Mean Values of Lateral Upper Lip Movement for the Noncleft Control, Nonrevision, and Revision Groups During the Animations and Natural Smile Movements

	Lateral Upper Lip Movement					
Group	**Cheek Puff**	**Lip Purse**	**Mouth Opening**	**Instructed Smile**	**Natural Smile**	**Grimace**
Noncleft	14.6	16.7	21.4	32.1	20.5	11.3
Nonrevision	12.8	13.6	17.6	23.0	14.4	9.9
Revision	12.1	13.6	15.1	23.4	14.7	8.0

TABLE 13

Percentage Change in Lateral Movement of the Upper Lip Due to the Effects of the Predictors

	Lateral Upper Lip Movement					
Predictor	**Cheek Puff**	**Lip Purse**	**Mouth Opening**	**Instructed Smile**	**Natural Smile**	**Grimace**
Nonrevision	−12.5**	−18.5***	−18.0***	−28.4***	−29.5**	−12.2**
Revision	−17.3**	−18.7***	−29.6***	−27.2***	−28.2**	−29.5***
Visit	−2.2	2.6	−5.2	1.8	3.8	−5.7
Gender	−2.0	−2.5	−0.9	3.9	0.7	1.1
Age	−1.1	−0.3	0.6	0.5	−0.8	0.3
Bilateral lip	−9.0	−19.6*	−9.7	−19.7*	−26.6*	−0.5
Cleft palate	−0.7	1.9	−9.5	4.8	4.6	−1.9
Race†	−20.1, 0.5, −1.4	−21.3, −8.6, −1.7	28.8, −9.6, −2.9	−6.3, −10.2, −4.1	−7.3, −11.2, 16.6	−24.9, −1.8, 22.2
Expansion	−9.0	−7.2	−16.3	0.0	14.0	−5.6
Bone graft	−4.7	−1.4	7.5	−1.3	5.6	−12.2
Lower jaw movement	0.8***	1.0***	1.7***	0.3	3.3***	2.3***

†First value = Asian, second value = Black, third value = Hispanic.

*$p \leq .05$.

**$p \leq .01$.

***$p \leq .001$.

TABLE 14

Baseline Values for Asymmetry of Movement for the Upper Lip of the Noncleft Control, Nonrevision, and Revision Groups During the Animations and Natural Smile Movements

	Asymmetry of Upper Lip Movement					
Group	**Cheek Puff**	**Lip Purse**	**Mouth Opening**	**Instructed Smile**	**Natural Smile**	**Grimace**
Noncleft	1.1	1.1	1.3	1.7	1.2	1.5
Nonrevision	2.6	2.0	4.3	5.3	3.5	2.2
Revision	2.0	1.5	4.2	3.7	2.2	2.0

TABLE 15

Asymmetry of Movement for the Upper Lip Due to the Effects of the Predictors

	Asymmetry of Upper Lip Movement					
Predictor	**Cheek Puff**	**Lip Purse**	**Mouth Opening**	**Instructed Smile**	**Natural Smile**	**Grimace**
Nonrevision	146.7***	81.5***	226.9***	208.3***	185.8***	49.5
Revision	88.2**	34.3**	216.2***	115.1***	76.9**	33.0
Visit	0.2	4.2	−3.5	−9.7	−4.0	−7.3
Gender	−16.2	−12.0	6.8	−7.9	9.1	−6.5
Age	3.5*	3.9	0.8	0.0	−0.1	−3.7*
Bilateral lip	−26.4	−43.4*	−60.4***	−49.1***	−54.8***	−6.6
Cleft palate	−9.1	37.7	−16.9	−10.9	−3.9	−9.8
Race†	−1.9, 7.2, −28.1	18.7, 22.8, −5.9	−36.4, 26.9, −28.6	23.3, −7.5, −1.4	23.0, 10.4, 17.5	−22.3, 30.9, 12.4
Expansion	−2.5	−1.1	10.3	−1.3	−19.6	−3.1
Bone graft	6.4	4.5	29.5	40.3*	55.0*	−5.6
Lower jaw movement	1.3	1.3	1.6***	0.9	3.4**	2.8*

† First value = Asian, second value = Black, third value = Hispanic.

* $p \leq .05$.

** $p \leq .01$.

*** $p \leq .001$.

TABLE 16

Baseline Mean Values of Lower Lip Movement for the Noncleft Control, Nonrevision, and Revision Groups During the Animations and Natural Smile Movements

	Lower Lip Movement					
Group	**Cheek Puff**	**Lip Purse**	**Mouth Opening**	**Instructed Smile**	**Natural Smile**	**Grimace**
Noncleft	17.5	17.8	25.2	37.3	22.0	10.6
Nonrevision	19.0	17.4	20.4	34.1	20.1	11.6
Revision	17.0	16.6	17.9	34.7	22.0	11.1

TABLE 17

Percentage Change in Lower Lip Movement of the Upper Lip Due to the Effects of the Predictors

	Lower Lip Movement					
Predictor	**Cheek Puff**	**Lip Purse**	**Mouth Opening**	**Instructed Smile**	**Natural Smile**	**Grimace**
Nonrevision	8.8	−2.1	−19.2	−8.6	−8.6	9.1
Revision	−2.9	−6.5	−28.8	−7.0	0.2	4.0
Visit	−0.3	2.9	−2.2	2.2	3.6	−6.1
Gender	1.4	−0.9	−1.8	−8.8	−11.6	−10.1
Age	1.2	1.8*	−1.9	−0.9	−1.8	−1.4
Bilateral lip	−2.7	−11.6	29.9	1.5	−8.2	13.3
Cleft palate	3.3	11.7	8.3	−0.4	−0.4	4.1
Race†	−2.9, 2.9, 15.8	−15.7, 1.5, −1.2	35.7, −19.8, −5.8	−18.7, −15.7, −19.4	−4.0, −16.2, 2.1	−26.4, −8.7, −21.7
Expansion	−2.9	1.2	−15.9	4.3	17.2	4.0
Bone graft	−7.3	−8.4	17.0	−3.8	−11.8	−27.1*
Lower jaw movement	0.9***	1.2***	2.2***	0.4	3.7***	4.7***

† First value = Asian, second value = Black, third value = Hispanic.

* $p \leq .05$.

** $p \leq .01$.

*** $p \leq .001$.

TABLE 18

Baseline Mean Values of Lower Jaw Movement for the Noncleft Control, Nonrevision, and Revision Groups During the Animations and Natural Smile Movements

	Lower Jaw Movement					
Group	**Cheek Puff**	**Lip Purse**	**Mouth Opening**	**Instructed Smile**	**Natural Smile**	**Grimace**
Noncleft	8.3	5.3	41.3	6.6	4.1	7.6
Nonrevision	7.8	5.0	40.8	5.3	3.7	7.7
Revision	7.4	5.2	41.3	5.3	3.6	7.6

TABLE 19

Percentage Change in Lower Jaw Movement of the Upper Lip Due to the Effects of the Predictors

	Lower Jaw Movement					
Predictor	**Cheek Puff**	**Lip Purse**	**Mouth Opening**	**Instructed Smile**	**Natural Smile**	**Grimace**
Nonrevision	−6.1	−5.0	−1.1	−19.6**	−8.9	0.1
Revision	−11.2	−1.3	0.1	−20.2**	−12.2	0.4
Visit	−4.2	−7.4	−4.1**	2.0	2.0	−2.7
Gender	0.3	−15.3	−0.8	−9.2	−12.9	6.7
Age	−3.1**	−3.0*	0.8*	−0.1	−2.2	−2.5
Bilateral lip	17.7	55.1*	−2.1	16.0	16.6	11.7
Cleft palate	10.2	−2.0	−5.1	10.2	−1.7	7.6
Race†	−38.3, −9.2, −14.7	5.9, −4.9, −21.6	−20.7, −2.9, −2.1	33.8, 15.6, −5.3	29.2, 9.0, 2.6	−17.9, 1.4, −16.2
Expansion	−10.9	−10.8	5.9	−3.9	7.2	−7.1
Bone graft	13.4	5.9	2.2	−9.1	6.5	3.0
Lower jaw movement	NA	NA	NA	NA	NA	NA

†First value = Asian, second value = Black, third value = Hispanic.

*$p \leq .05$.

**$p \leq .01$.

***$p \leq .001$.