In the Eye of the Beholder: Changes in Perceived Emotion Expression after Smile Reanimation

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Background: Tools to quantify layperson assessments of facial palsy are lacking. In this study, artificial intelligence was applied to develop a proxy for layperson assessments, and compare sensitivity to existing outcome measures.

Methods: Artificially intelligent emotion detection software was used to develop the emotionality quotient. The emotionality quotient was defined as the percentage probability of perceived joy over the percentage probability of perceived negative emotions during smiling, as predicted by the software. The emotionality quotient was used to analyze the emotionality of voluntary smiles of normal subjects and unilateral facial palsy patients before and after smile reanimation. The emotionality quotient was compared to oral commissure excursion and layperson assessments of facial palsy patients.

Results: In voluntary smiles of 10 normal subjects, 100 percent joy and no negative emotion was detected (interquartile ranges, 0/1). Median preoperative emotionality quotient of 30 facial palsy patients was 15/−60 (interquartile range, 73/62). Postoperatively, median emotionality quotient was 84/0 (interquartile range, 28/5). In 134 smile reanimation patients, no correlation was found between postoperative oral commissure excursion and emotionality quotient score. However, in 61 preoperative patients, a moderate correlation was found between layperson-assessed disfigurement and negative emotion perception (correlation coefficient, 0.516; $p < 0.001$).

Conclusions: Computer vision artificial intelligence software detected less joy and more negative emotion in smiles of facial palsy patients compared with normal subjects. Following smile reanimation, significantly more joy and less negative emotion were detected. The emotionality quotient was correlated with layperson assessments. The simplicity, sensitivity, and objectivity of the emotionality quotient render it an attractive tool to serve as a potential proxy for layperson assessment, an ideal outcome measure in facial palsy. (*Plast. Reconstr. Surg.* 144: 457, 2019.)

CLINICAL QUESTION/LEVEL OF EVIDENCE: Diagnostic, IV.

Smiling is a highly effective means of nonverbal communication,[1,2] and inability to smile has a profoundly negative impact on quality of life, being the dominant problem reported by facial palsy patients and their families.[3,4] For

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facial reanimation surgeons, the most challenging reconstructive goal is for the patient to appear normal in the eye of the naive observer. Despite the multiple outcome measures available in facial reanimation surgery, none has gained widespread acceptance, and it is impractical to perform layperson assessments routinely in clinical practice. An extremely welcome tool would be an assay that predicts the layperson interpretation of facial expressions in facial palsy.

A method of quantifying normal facial expressions, the Facial Action Coding System, was developed by analyzing the contributions from discrete facial muscle groups (known as action units).[5,6] Joy is composed of bilateral lip corner pull, cheek raise, and lid tighten; disgust is upper lip raise, wrinkled nose, and cheek raise; and contempt is a variant of disgust, also known as a smirk.[7,8] [**See Appendix, Supplemental Digital Content 1**, which shows muscle action units (*AU*) relevant to the facial expressions associated with smiling. *FACS*, Facial Action Coding System. (Excerpt taken from Ekman P, Friesen WV. *Facial Action Coding System: A Technique for the Measurement of Facial Movement.* Palo, Alto, Calif: Consulting Psychologists Press; 1978), ***http://links.lww.com/PRS/D582***.] Although clearly a useful tool, Facial Action Coding System analysis requires a high degree of training, is time-consuming, and has only moderate interrater reliability.[9]

Recent advances in artificial intelligence have enabled automatic detection of facial movements, and machine learning has trained models to predict perceived expression of standardized emotion categories.[10] Freely available, facial recognition and emotion detection software has been developed from 5 million videos of normal subjects from 75 countries, resulting in over 2 billion facial frames in which Facial Action Coding System action units were expertly recognized and labeled.[11–15] These data have enabled automatic analysis of the phenomenon known as emotionality, the *observable* behavioral and physiologic component of emotion.[16] One must recognize that facial movement analysis alone, without contextual information, is unable to determine the true or *felt* emotional state of an individual.[17] Therefore, computer vision software may only predict *perceived* emotion or, in the case of voluntary facial movements, emotion that is being *communicated*.

The aim of this study was to leverage recent advances in artificial intelligence software to develop the emotionality quotient, a novel, objective, automated emotion-detection tool in facial palsy. The emotionality quotient was used to characterize the *perceived* emotionality of smiling in normal subjects and in facial palsy patients before and after smile reanimation with gracilis functional free muscle transfer. Only voluntary smile frames were analyzed where, by definition, the subject was trying to communicate joy. Spontaneous smiling was not assessed. A further aim was to validate the emotionality quotient by comparison with oral commissure excursion and layperson assessments of facial disfigurement.

PATIENTS AND METHODS

This study was approved by the Massachusetts Eye and Ear Infirmary Institutional review board. Written consent was obtained from all patients, before their inclusion in this study.

Freely available, proprietary software (Affdex; Affectiva, Boston, Mass.) was used to analyze photographs and videos of smiles, generating percentage probabilities of perceived joy, contempt, and disgust (Fig. 1). Postprocessing of data was performed with MATLAB (MathWorks, Natick, Mass.). A descriptive means of reporting relative probabilities, known as the emotionality quotient, was defined as the percentage probability of perceived joy (range, 0 to 100 percent) over the percentage probability of perceived negative emotions (contempt or disgust; range, −100 to 0 percent) during smiling, as predicted by computer vision software. The higher probability between contempt and disgust was selected, as similar action units evoke these expressions. The change in emotionality quotient after an intervention, known as emotionality quotient delta, was defined as the sum of the percentage change in both joy and negative emotion perception, comparing postoperative to preoperative scores (Fig. 2). The maximum possible improvement in emotionality quotient delta is 200 percent.

Range of Emotionality Quotient Scores in Normal, Flaccid Facial Palsy, and Nonflaccid Facial Palsy Patients

To quantify the range of perceived emotion in unilateral facial palsy patients, we analyzed maximal voluntary smile efforts in flaccid and nonflaccid facial palsy patients, and used normal subjects as controls (Fig. 1). Bilateral facial palsy patients were excluded. Flaccid facial palsy was defined by a complete absence of facial movement on the affected side of the face for at least 18 months. Nonflaccid facial palsy was defined as all other cases of facial palsy where there had been some improvement in facial animation on the affected side, with or without synkinesis.

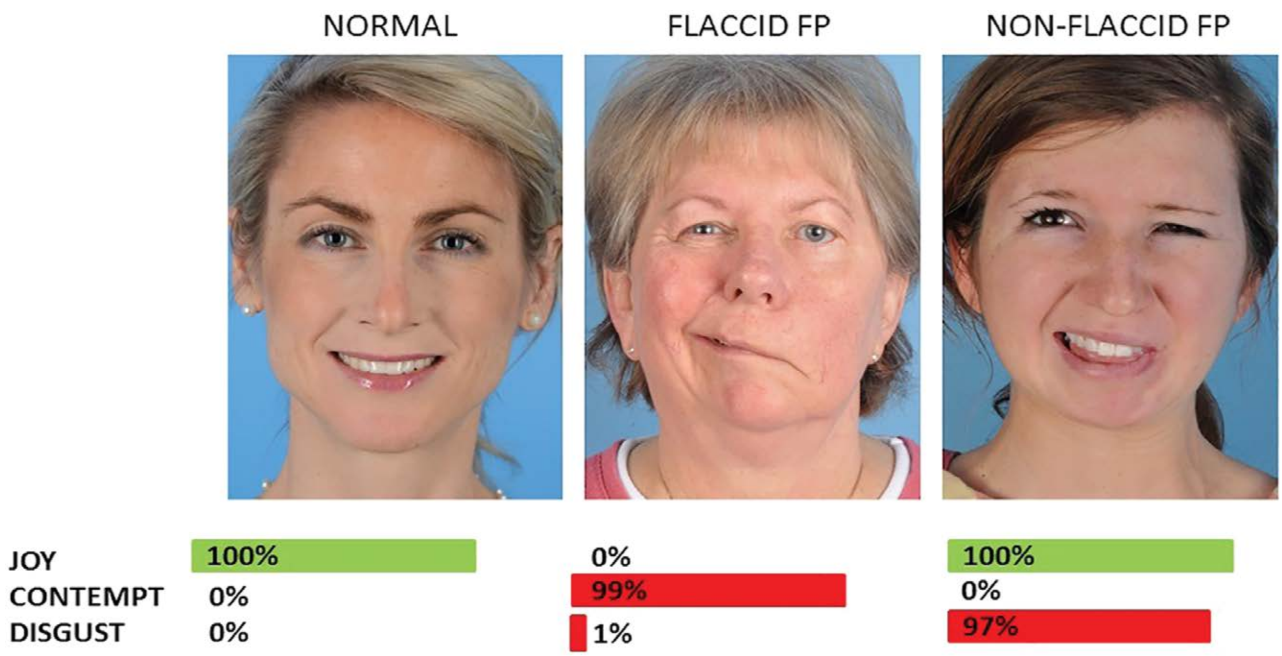

Fig. 1. Maximal smile efforts in (*left*) a normal subject (high levels of joy and no negative emotion are perceived), (*center*) a patient with flaccid facial palsy (no joy and high levels of contempt are perceived), and (*right*) a patient with nonflaccid facial palsy (high levels of joy and disgust are perceived). Both flaccid and nonflaccid patients are affected on their left sides. *FP*, facial palsy.

Emotionality Quotient Sensitivity to Change and Reliability

Paired preoperative and postoperative smiles of randomly selected gracilis functional free muscle transfer smile reanimation cases were analyzed to determine the reliability and sensitivity to change of emotionality quotient (Table 1). Selected cases were screened to ensure they included equal numbers of flaccid and nonflaccid facial palsy, and cases driven by cross-face nerve graft, nerve-to-masseter, and combined innervation techniques. Reliability was assessed by analyzing the same photographs on multiple occasions.

Comparison of Oral Commissure Excursion to the Emotionality Quotient

To determine the relationship between the emotionality quotient and oral commissure excursion, we reviewed all gracilis functional free muscle transfer smile reanimation cases performed at our institution between 2006 and 2016. Cases were excluded from analysis if preoperative or postoperative images were unavailable or if the algorithm failed to detect the face (e.g., because of a cropped border of the face). Cause, preoperative facial nerve status (i.e., flaccid or nonflaccid), and innervation pattern of the gracilis were recorded (Table 2). Commissure excursion was measured from postoperative voluntary smile and rest photographs using an automated photographic measurement tool, known as Emotrics.[18,19] The Emotrics application automatically calculated pixel distance from the point where the facial midline crossed the lower lip to the oral commissure on the affected side. This value was scaled to iris diameter to give an output in millimeters.[18,19] Negative values were recorded if the affected side oral commissure moved toward the facial midline during smiling.

Comparison of Layperson-Assessed Disfigurement to the Emotionality Quotient

To establish the relationship between the emotionality quotient and layperson assessment of facial palsy, we compared emotionality quotient scores to a validated method of quantifying layperson assessment of disfigurement in unilateral facial palsy. Thanks to generous collaborators, we were able to analyze exactly the same voluntary smile videos that had been shown to 593 laypersons at the 2016 Minnesota State Fair.[20] Sixty-one videos of preoperative, unilateral facial palsy patients were selected from a larger population of 500 patient videos provided by the Massachusetts Eye and Ear Infirmary to encompass the complete spectrum of eFACE total scores (range, 40 to 98) and patient ages (range, 18 to 84 years).[20] Laypersons ranked disfigurement of facial palsy patients during smiling on a Likert scale from 0 to 10 (with 0 being no disfigurement and 10 being maximal

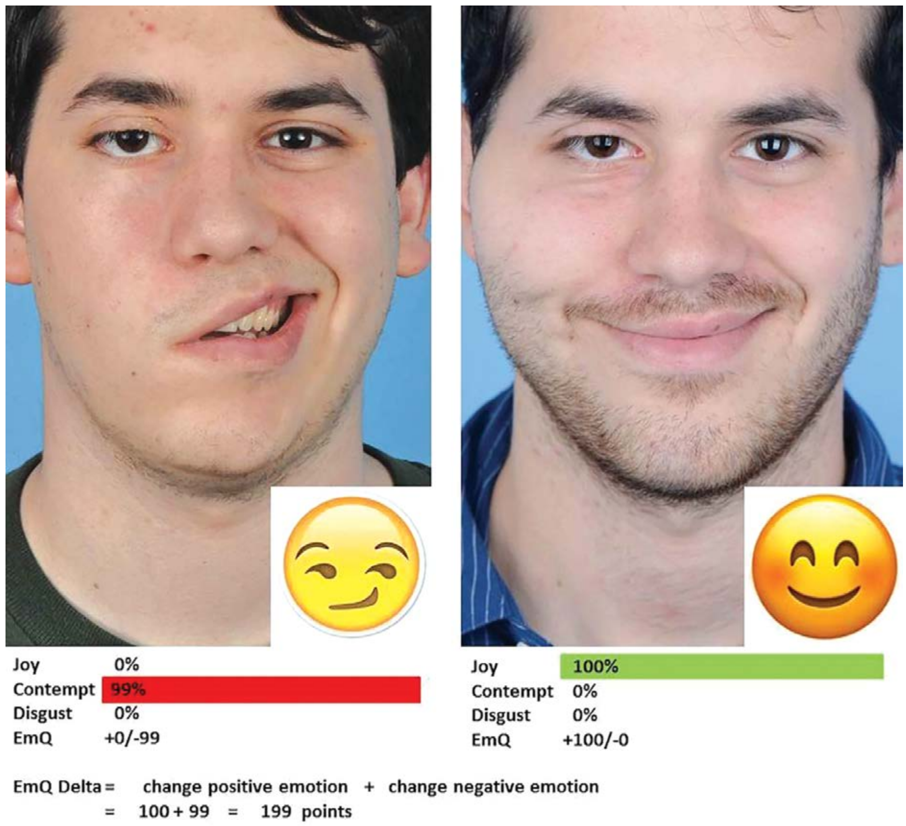

Fig. 2. Maximal smile efforts. (*Left*) Preoperative flaccid facial palsy and (*right*) postoperative outcome of smile reanimation with gracilis functional free tissue muscle transfer. Preoperatively, 0 percent perceived joy and 99 percent perceived contempt, and so the emotionality quotient was +0/−99. Postoperatively, 100 percent perceived joy and 0 percent perceived contempt, and so the emotionality quotient was reversed to +100/−0. The emotionality quotient delta is the sum of the improvements in probabilities of both joy and negative emotion perception: emotionality quotient delta = 100-point improvement (joy) + 99-point reduction (negative emotion) = 199 points. This patient had longstanding right unilateral flaccid facial palsy after vestibular schwannoma resection corrected by gracilis functional free muscle transfer dually innervated by the masseteric nerve and a long cross-face nerve graft. Postoperative photograph was taken after 1.6 years. *EmQ*, emotionality quotient; *Preop*, preoperative; *Postop*, postoperative.

disfigurement). The Likert scale was normalized to range from 0 to 100, so that a mean value of layperson assessments could be calculated for each patient. Finally, we compared mean layperson-assessed disfigurement with the probability of perceived joy and perceived negative emotion for each patient.

Statistical Analysis

Descriptive data were presented as numbers, frequencies, medians, interquartile ranges (the difference between the 25th and 75th percentiles), and means and standard deviations. Nonparametric tests were used for statistical comparison of perceived emotion between preoperative and postoperative data (Wilcoxon signed ranks test) and flaccid and nonflaccid patients (Mann-Whitney *U* test) attributable to nonnormality of the data. Correlations were tested using the Spearman rank correlation. An alpha of 0.05 was selected, and all statistical tests were performed using IBM SPSS Version 25 (IBM Corp., Armonk, N.Y.).

RESULTS

Range of Emotionality Quotient Scores in Normal, Flaccid Facial Palsy, and Nonflaccid Facial Palsy Patients

In maximal effort smiles of normal subjects ($n = 10$), 100 percent joy was perceived and almost

Table 1. Demographic Data, Cause, and Innervation Pattern of Two Representative Groups of Facial Palsy

	FFP	NFFP
No.	15	15
Mean age ± SD, yr	41.5 ± 17.4	37.1 ± 14.7
Sex		
Male	6	3
Female	9	12
Cause		
Vestibular schwannoma	4	4
Temporal bone fracture	—	3
Trauma	—	3
Brainstem hemangioma	2	-
Iatrogenic injury	1	1
Medulloblastoma	1	1
Other	7	3
Innervation source		
Nerve to masseter	5	5
Cross-face nerve graft	5	5
Dually innervated	5	5

FFP, flaccid facial palsy; NFFP, nonflaccid facial palsy.

Table 2. Demographic Data, Cause, and Innervation Pattern of All Patients Analyzed Preoperatively and Postoperatively Who Underwent Gracilis Free Functional Muscle Transfer

Characteristic	Value (%)
No. of gracilis patients analyzed	134
Mean age ± SD, yr	41.3 ± 18.1
Sex	
Male	48
Female	86
Cause	
Vestibular schwannoma	25 (18.7)
Central nervous system lesion	25 (18.7)
Benign tumor	15 (11.2)
Congenital	14 (10.4)
Bell palsy	13 (9.7)
Head and neck cancer	13 (9.7)
Trauma	13 (9.7)
Other	16 (11.9)
Innervation source	
Nerve to masseter	69
Cross-face nerve graft	55
Dually innervated	10

no negative expression was detected, as anticipated. Median emotionality quotient was +100/0 (interquartile range, 0/1) (Fig. 1). In maximal effort smiles of flaccid facial palsy patients ($n = 15$), a median 0 percent joy was perceived and there was a median 75 percent probability of negative emotion perception. Median emotionality quotient score in flaccid facial palsy was 0/−75 (interquartile range, 0/47). In maximal effort smiles of nonflaccid facial palsy patients ($n = 15$), there was a median 63 percent probability that joy was perceived and a 16 percent probability of negative emotion perception. Median emotionality quotient score in nonflaccid facial palsy was 63/−16 (interquartile range, 62/57). This result indicates that, preoperatively, the software was 63 percent more likely to perceive joy in smiles of nonflaccid facial palsy patients than in flaccid facial palsy patients ($p < 0.001$).

Emotionality Quotient Sensitivity to Change and Reliability

In postoperative maximal effort smiles of flaccid facial palsy patients ($n = 15$), the median emotionality quotient score was +84/0 (interquartile range, 26/5), compared to preoperative score of 0/−75 (interquartile range, 0/47). After smile reanimation surgery, the perceived probability of joy expression increased by 84 percent (interquartile range, 92 percent; $p = 0.002$) and negative emotion perception diminished by 73 percent (interquartile range, 51 percent; $p < 0.001$). The median emotionality quotient delta of gracilis functional free muscle transfer smile reanimation in flaccid facial palsy was 144 percent (interquartile range, 122 percent) (Figs. 3 and 4). (**See Video, Supplemental Digital Content 2**, which shows preoperative and postoperative maximal smile efforts in a flaccid facial palsy patient with graphic representations of automated output of the emotion detection software, ***http://links.lww.com/PRS/D583***. **See Video, Supplemental Digital Content 3**, which shows preoperative and postoperative maximal smile efforts in a flaccid facial palsy patient with graphic representations of automated output of the emotion detection software, ***http://links.lww.com/PRS/D584***.) In postoperative maximal effort smiles of nonflaccid facial palsy patients ($n = 15$), the median emotionality quotient score was +85/0 (interquartile range, 33/6), compared with a preoperative score of +63/16 (interquartile range, 62/57). Perceived joy was not significantly increased in the nonflaccid facial palsy group (median, 2 percent; interquartile range, 36 percent; $p = 0.194$). However, a small yet significant reduction in perceived negative emotion was demonstrated (9 percent; interquartile range, 54 percent; $p = 0.004$). The median emotionality quotient delta of gracilis functional free muscle transfer smile reanimation in nonflaccid facial palsy patients was 35 percent (interquartile range, 69 percent). [**See Figure, Supplemental Digital Content 4**, which shows (*above*) preoperative and postoperative maximal smile efforts in a nonflaccid facial palsy patient. (*Below*) Graphic representations of automated output of the emotion-detection software from a video of the following sequence: rest, smile, rest, smile, rest. (*Below, left*) Preoperatively, no joy was detected and a

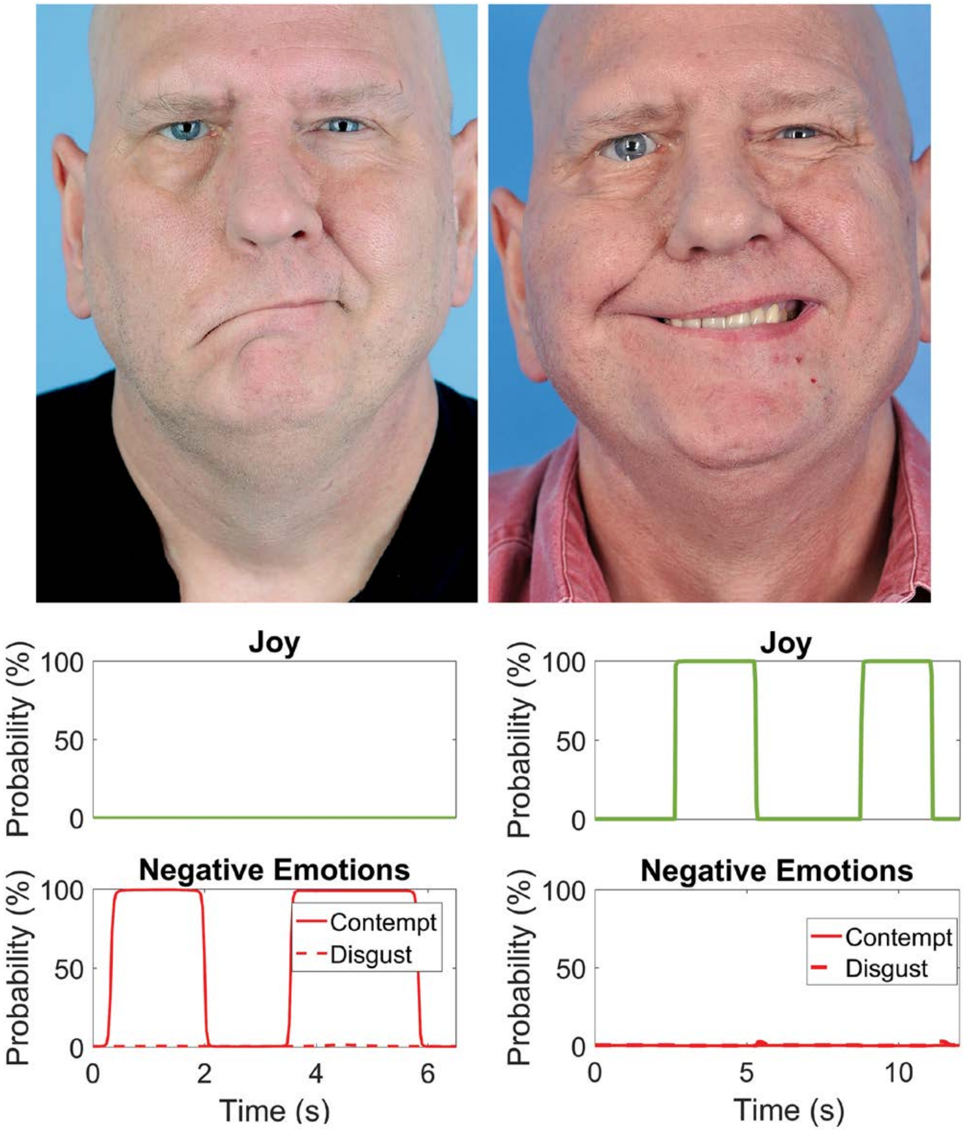

Fig. 3. (*Above*) Preoperative and postoperative maximal smile efforts in a flaccid facial palsy patient. (*Below*) Graphic representations of automated output of the emotion-detection software from a video of the following sequence: rest, smile, rest, smile, rest. (*Below*, *left*) Preoperatively, no joy was detected and considerable contempt was detected during smile efforts. (*Below*, *right*) Postoperatively, this was corrected. This patient had longstanding right unilateral flaccid facial palsy after resection of a cholesteatoma corrected by gracilis functional free muscle transfer innervated by the masseteric nerve. He also underwent static facial suspension with two ribbons of fascia lata. The postoperative photograph was taken after 1.4 years.

mean of 32 percent contempt was detected during smile efforts. (*Below, right*) Postoperatively, 92 percent joy was detected and no negative emotion was detected. This patient had a temporal bone fracture and developed right facial nerve palsy with subsequent panfacial synkinesis. She underwent two-stage gracilis functional free muscle transfer innervated by a cross-face nerve graft 3 years after her injury. She had no static suspensions. The postoperative photograph was taken after 0.6 years, ***http://links.lww.com/PRS/D587***. **See Video, Supplemental Digital Content 5**, which shows preoperative and postoperative maximal smile efforts in a nonflaccid facial palsy patient with graphic representations of automated output of the emotion-detection software, ***http://links.lww.com/PRS/D589***.] Every time the algorithm was presented with the same photograph, it produced the same numerical output. The emotionality quotient was highly reliable.

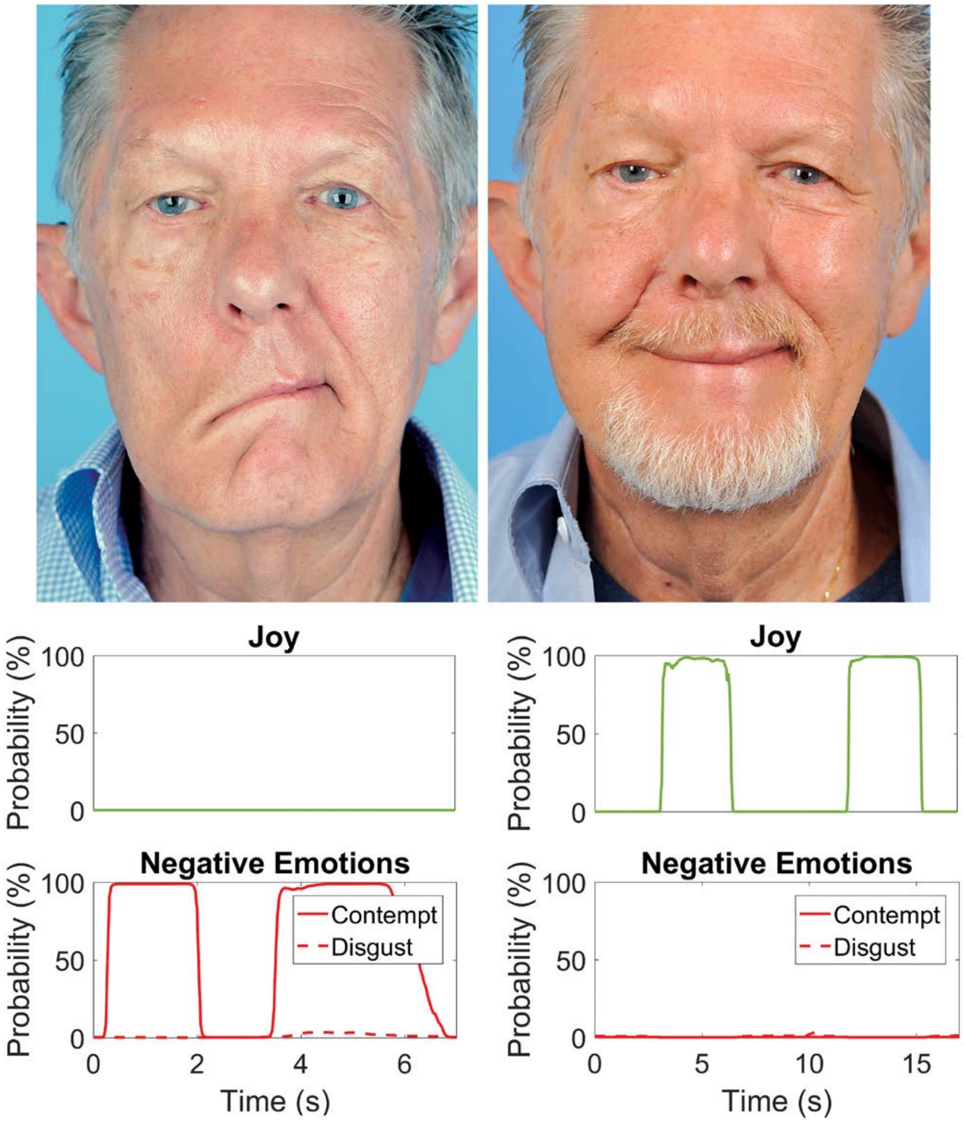

Fig. 4. (*Above*) Preoperative and postoperative maximal smile efforts in a flaccid facial palsy patient. (*Below*) Graphic representations of automated output of the emotion-detection software from a video of the following sequence: rest, smile, rest, smile, rest. (*Below*, *left*) Preoperatively, no joy was detected and considerable contempt was detected during smile efforts. (*Below*, *right*) Postoperatively, this was corrected. This patient had longstanding right unilateral flaccid facial palsy after superficial parotidectomy for an inconclusive parotid mass corrected by gracilis functional free muscle transfer innervated by the masseteric nerve. He also underwent two ribbon static facial suspension with two ribbons of fascia lata. Postoperative photograph was taken after 0.8 year.

Comparison of Oral Commissure Excursion to the Emotionality Quotient

Of 223 gracilis functional free muscle transfer patients reviewed, 134 met criteria for inclusion. No correlation was found between commissure excursion and the probability of joy perception ($p = 0.433$) or negative emotion perception ($p = 0.527$) (Fig. 5). No correlation was found even when analyzing flaccid and nonflaccid facial palsy separately (data not shown). Several patients with less than 3-mm commissure excursion were perceived to express considerable levels of joy. [**See Figure, Supplemental Digital Content 6**, which shows rest and voluntary smile photographs of a patient postoperatively with discordant perceived joy expression and oral commissure excursion. (*Above*) This patient generated −3.3 mm of oral commissure excursion during voluntary smiling

Video 1. Supplemental Digital Content 2 shows preoperative and postoperative maximal smile efforts in a flaccid facial palsy patient with graphic representations of automated output of the emotion detection software, ***http://links.lww.com/PRS/D583***.

Video 2. Supplemental Digital Content 3 shows preoperative and postoperative maximal smile efforts in a flaccid facial palsy patient with graphic representations of automated output of the emotion detection software, ***http://links.lww.com/PRS/D584***.

Video 3. Supplemental Digital Content 5 shows preoperative and postoperative maximal smile efforts in a nonflaccid facial palsy patient with graphic representations of automated output of the emotion-detection software, ***http://links.lww.com/PRS/D589***.

Video 4. Supplemental Digital Content 7 shows two postoperative patients with discordant perceived joy expression and oral commissure excursion. Video refers to Video 1, Supplemental Digital Content 2, and Video 2, Supplemental Digital Content 3, ***http://links.lww.com/PRS/D593***.

(i.e., oral commissure moves toward the midline during smiling), but the probability of perceived joy from voluntary smiling was 62 percent. This patient had a right vestibular schwannoma and insidious loss of right facial function. He underwent facial reanimation with gracilis functional free muscle transfer innervated by the masseteric nerve. He also had two ribbons of fascia lata to correct his nasolabial fold position and nasal valve position. The postoperative photograph was taken after 0.6 year. (*Below*) Graphic representations of automated output of the emotion-detection software from a video of the following sequence: rest, smile, rest, smile, rest, ***http://links.lww.com/PRS/D592***. **See Video, Supplemental Digital Content 7**, which shows two postoperative patients with discordant perceived joy expression and oral commissure excursion. Video refers to **Video 1, Supplemental Digital Content 2**, and **Video 2, Supplemental Digital Content 3**, ***http://links.lww.com/PRS/D593***.] Furthermore, three of 11 patients (27 percent) with good commissure excursion (between 10 and 15 mm) demonstrated minimal probability of joy perception. [**See Figure, Supplemental Digital Content 8**, which shows rest and voluntary smile photographs of a patient postoperatively with discordant perceived joy expression and oral commissure excursion. (*Above*) This patient generated 11-mm oral commissure excursion during voluntary smiling, but the probability of perceived joy was 0 percent. This patient had facial nerve schwannoma that was resected, leading to right flaccid facial palsy. He underwent facial reanimation with gracilis functional free muscle transfer innervated by the masseteric nerve and a cross-face nerve graft in a dual-innervation pattern. He also had nasal valve correction with a band of fascia lata. The postoperative photograph was taken after 0.8 year. (*Below*) Graphic representations of automated output of the emotion detection software from a video of the following sequence: rest, smile, rest, smile, rest, ***http://links.lww.com/PRS/D595***.]

Comparison of Layperson Assessment of Disfigurement to the Emotionality Quotient

In videos of smile efforts of a spectrum of facial palsy patients (n = 61), mean layperson-assessed disfigurement scores showed a positive correlation with perceived negative emotion (correlation coefficient, 0.516; $p < 0.001$) and a negative correlation with perceived joy (correlation coefficient, −0.452; $p < 0.001$) (Fig. 6).

DISCUSSION

Despite decades of effort, many measures used to assess facial palsy rehabilitation outcomes remain prone to bias and error.[21] Moreover, measures not developed for the purpose of quantifying success after smile reanimation surgery remain insensitive to outcomes of these procedures.[22] Presently, many authors report success after smile reanimation surgery according to clinician-graded scales of success.[23–26] The Terzis and Noah scale, a five-point Likert scale ranging from poor to excellent, is unreliable, insensitive, and prone to confirmation bias.[22] It is also commonplace to quantify successful outcomes using oral commissure excursion, as measured by

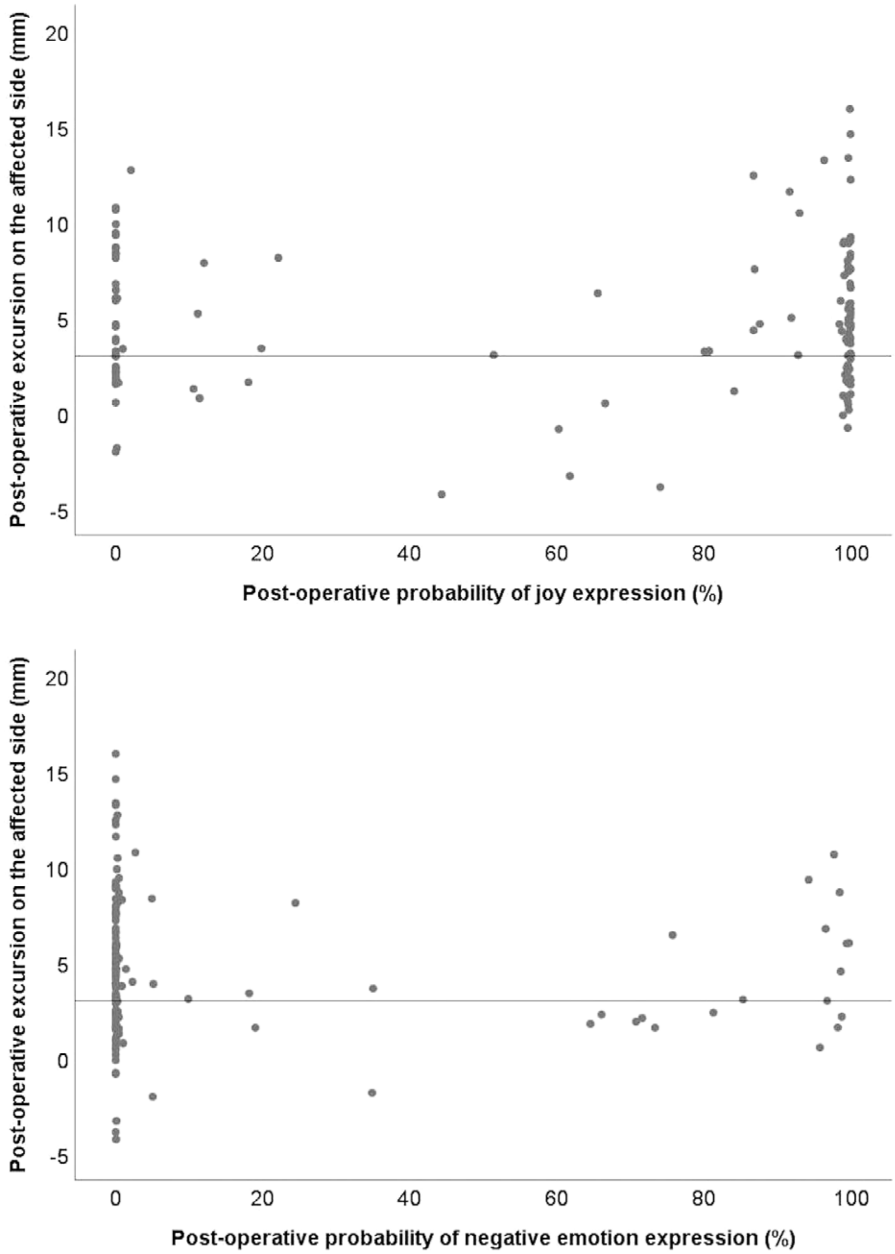

Fig. 5. Scatter plots of postoperative excursion and probability of perceived joy (*above*) and perceived negative emotion (*below*). Horizontal line placed at 3-mm excursion to represent commonly used threshold for defining failure in smile reanimation. Negative values represent a movement of the affected side oral commissure toward the facial midline during a voluntary smile effort, as is commonly seen in flaccid facial palsy preoperatively. No correlation was found between excursion and the probability of perceiving joy (correlation coefficient, 0.068; $p = 0.433$) or negative emotion (correlation coefficient, −0.055; $p = 0.527$).

software (e.g., MEEI Facegram and Emotrics) or manually.[18,22,27] Such measurement systems generate an absolute measure of commissure excursion (usually between 3 and 15 mm) but do not take into consideration the overall aesthetic outcome of the face, or whether the voluntary smile is able to communicate joy. Layperson assessment may be the ideal method of assessing these additional considerations.[20,28–30] However, it is not practical to include layperson assessments in routine clinical care and thus a proxy for layperson assessments would be extremely useful.

In this study, artificial intelligence software was used to detect expressions of emotion in the

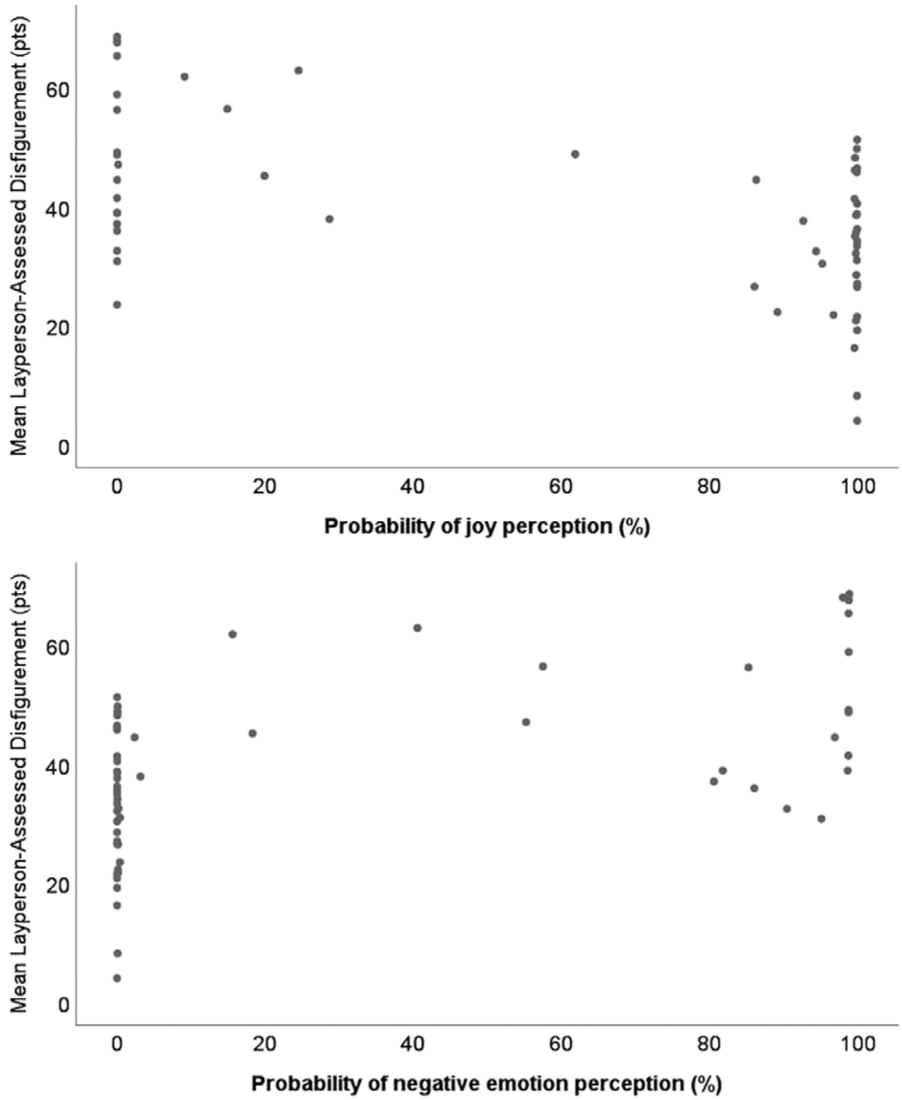

Fig. 6. Scatter plots of mean layperson-assessed disfigurement and probability of perceived joy (*above*) and perceived negative emotion (*below*). Mean layperson-assessed disfigurement score showed a significant positive correlation with perceived negative emotion (correlation coefficient, 0.516; $p < 0.001$) and a significant negative correlation with perceived joy (correlation coefficient, −0.452; $p < 0.001$).

voluntary smiles of facial palsy patients, to quantify the deleterious effect of facial palsy on the ability to communicate nonverbally, and to quantify the sensitivity to change of the emotionality quotient by comparing preoperative and postoperative smiles. To determine the role of the emotionality quotient within the current paradigm of facial palsy outcome assessment, we compared emotionality quotient scores to commissure excursion in postoperative patients. We also compared emotionality quotient scores to layperson data, generated from the same videos previously viewed by 593 laypersons.

We found that the software perceived 100 percent joy in smiles of normal controls and 0 percent joy in flaccid facial palsy. The emotionality quotient was sensitive to change and highly reliable. In flaccid facial palsy, the perception of joy was increased by a median 84 percent after smile reanimation. Both flaccid and nonflaccid facial palsy also demonstrated a high level of perceived negative emotion preoperatively that was reversed to minimal levels after surgery. These findings were highly statistically significant ($p < 0.001$). In comparing the emotionality quotient to oral commissure excursion, we did not find a correlation with either joy or negative emotion perception, regardless of whether patients were flaccid or nonflaccid preoperatively. These unexpected findings warrant further investigation to identify the key factors that influence communication of nonverbal information in facial palsy. Finally, we found a correlation between layperson-assessed disfigurement and both perceived negative emotion, which was correlated with high facial disfigurement (correlation coefficient, 0.516; $p < 0.001$), and perceived joy, which was negatively correlated (correlation coefficient, −0.452; $p < 0.001$). A major strength of this analysis was that the same video clips were viewed by a large number of laypersons and our computer vision software, and that the patients had been selected, a priori, to represent the full spectrum of facial palsy, raising the possibility of emotionality quotient functioning as a proxy for layperson assessment.[20]

A facial recognition and emotion detection tool trained using machine learning from millions of encounters with normal subjects could represent a standard to which facial reanimation results are compared. It is known that laypersons perceive the facial expressions of facial palsy patients negatively when compared to normal subjects, and significant improvements in layperson assessment of facial disfigurement have been shown following smile reanimation.[29,31,32] The fact that an artificial intelligence algorithm detects a high probability of a negative emotion does not mean the patient in fact appears contemptuous or disgustful, but rather that there are features of these expressions picked up by the algorithm. That these features correspond to cases where laypersons consider there is a high degree of disfigurement tells us that a high negative emotion score from the emotionality quotient may be a proxy for disfigurement. The emotionality quotient is an objective and automatic outcome measure that could be used as an automated layperson equivalent, assessing facial palsy patients without having to show clinical images of patients to the public.

Our results have quantified the significant nonverbal communication deficits suffered by facial palsy patients and the dramatic improvements afforded by smile reanimation. Attempting to smile with flaccid facial palsy produces a unilateral cheek raise, formation of a nasolabial fold, and upper lip raise (Fig. 2, *left*). These action units are hallmark features of contempt (**see Appendix, Supplemental Digital Content 1**, ***http://links.lww.com/PRS/D582***). In contrast to flaccid facial palsy patients, those with nonflaccid facial palsy may also form a nasolabial fold on the affected side (Fig. 1, *right*), allowing for perception of higher levels of joy preoperatively, in addition to increased levels of negative emotion. In addition, the synkinetic oral commissure is often immobile, leading to what appears like a version of disgust when bilateral lip raise, cheek raise, and nose wrinkle are present without lateral lip corner pull (Fig. 1, *right*).

Interestingly, we did not find a correlation between oral commissure excursion and either joy or negative emotion perception, suggesting that success of smile reanimation to convey meaning may be based on several factors other than oral commissure excursion (Fig. 5). Although formal analysis is required to identify these other factors, we hypothesize that contralateral side movements, preexisting facial function or synkinesis, vector of pull of the gracilis muscle, static procedures, and patient age may all play a role in the discordance between oral commissure excursion and perceived emotionality (**see Figure, Supplemental Digital Content 8**, ***http://links.lww.com/PRS/D595***). In contrast to excursion, layperson-assessed disfigurement was moderately yet significantly correlated with perceived emotion (Fig. 6). It is likely that this moderate level of correlation is attributable to the vastly different methodologies used to obtain the results in each group (i.e., mean layperson-assessed disfigurement versus computerized calculation of perceived emotion probability). We expect that a more highly correlated proxy would be generated from comparing emotionality quotient to layperson assessments of perceived emotion in facial palsy. Dedicated studies comparing these outcome measures are required to validate the emotionality quotient as a layperson proxy. It is intriguing that the output of an artificial intelligence–generated facial analysis tool is correlated with layperson assessments of facial disfigurement, yet both perceived joy and negative emotion were correlated and highly statistically significant. It is possible that the emotionality quotient may have the capacity to serve as an automated layperson equivalent, and emotionality quotient delta (the change in the emotionality quotient after an intervention) could supplant or complement commissure excursion as a quantifiable outcome measure of success or failure in smile reanimation. Further studies comparing the emotionality quotient to clinician grading and layperson assessments of outcomes are required to determine what level of emotionality quotient delta is clinically significant.

The present study only applied artificial intelligence emotion detection software to the analysis of voluntary smile efforts. We anticipate many more potential uses for this software as our understanding of emotionality in facial palsy increases.

For example, the real-time assessment capability of the emotionality quotient could be used to give additional feedback during physical therapy rehabilitation. It is also foreseeable that emotionality assessments will be useful preoperatively. For instance, in synkinetic patients, knowledge of preoperatively perceived joy and negative emotion would help to set treatment goals and manage expectations regarding potential improvements.

Limitations and Confounders

As computer vision analyzes the whole face, it may be confounded by multiple factors, including healthy side facial movements, synkinesis, and the effects of other static and dynamic surgical procedures. Affdex is dependent on the quality of photography and may fail to detect a face if the lateral border of the cheek has been cropped, for example, which was a problem in several of our cases. Other factors such as age, facial hair, gross facial abnormality, soft-tissue thickness, scarring, radiotherapy change, or bony abnormality may impair the ability of the software to detect the face or subtle facial movements. Spontaneous facial nerve recovery may also confound results, as we have shown that preoperative emotionality quotient of flaccid facial palsy is much worse than that of nonflaccid facial palsy patients. Thus, any improvement in emotionality quotient delta is likely to be more significant if a preoperative photograph is taken in the flaccid state compared with the nonflaccid state. We chose to focus on flaccid facial palsy for our analysis because of the homogeneity of the patient population and the isolated role of the gracilis muscle in producing smile on the affected side. Heterogeneity of the nonflaccid facial palsy population makes any gross statistical comparisons with flaccid facial palsy invalid. Further studies should be used to understand the emotionality penalty paid by incomplete facial palsy patients and varying degrees of synkinesis.

The artificial intelligence software used was not trained with images of facial palsy patients and thus may be inaccurate for determining the probability of stereotypical expressions of emotion in facial palsy patients in the preoperative state. However, an ideal of facial reanimation specialists is for our patients to appear normal in the eyes of naive observers, and so software validated from millions of recordings of normal facial expressions may well be an appropriate outcome measurement tool to use, particularly in the postoperative state. Interestingly, we did find a moderate correlation between perceived emotionality and layperson assessment of facial palsy in the preoperative state. A major advantage of using layperson assessments to quantify outcomes is that they are the recipients of nonverbal communication cues expressed by facial palsy patients. However, many laypersons may also be unfamiliar with the appearance of facial palsy. Machine learning models generate predictions of the emotional state being communicated by facial palsy patients based on an enormous database of facial expressions of normal subjects. As such, the emotionality quotient may perhaps be used as an automated layperson equivalent. Future work should investigate whether computer vision-assessed probability of perceived emotion among patients with unilateral facial palsy corresponds to other previously studied domains of layperson assessments, such as attractiveness, approachability, and negative facial perception, and novel domains, such as layperson-assessed emotionality.[31,33]

Although it would have been very interesting to include, the present study did not analyze spontaneous smiles. To clearly understand the efficacy of the emotionality quotient at detecting the communication of joy, we analyzed voluntary smile frames only, as quantifying spontaneous smiling remains subjective. Likewise, this study did not seek to make inferences about the felt emotional state, because of the difficulties of inferring true emotional state from facial expressions alone.[34,35]

CONCLUSIONS

Artificial intelligence computer vision software perceived a lower probability of joy and an increased probability of negative emotion expression in smiles of facial palsy patients compared with normal subjects. After smile reanimation, significantly more joy and less negative emotion were detected. The emotionality quotient was reliable, highly sensitive to change after smile reanimation, and correlated with layperson assessments of facial disfigurement for both joy and negative emotion perception. Previously, commissure excursion has been used as an outcome measure of the technical success of gracilis functional free muscle transfer. However, we found that excursion was poorly correlated with perceived joy and negative emotion expression, indicating that there is more to facial expression of joy than simply oral commissure excursion. This facial recognition and emotion detection software has quantified the ability of smile reanimation surgery to alleviate the deficits in nonverbal communication suffered by facial palsy patients. The efficiency, sensitivity, and objectivity of the emotionality quotient render it an extremely attractive tool that may serve as a proxy for layperson assessment, an ideal outcome measure in facial palsy.

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PATIENT CONSENT

Patients provided written consent for the use of their images.

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