Evaluation of a New Measurement Tool for Facial Paralysis Reconstruction

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Evaluation of facial movement, including distance and direction, is essential for anyone interested in facial paralysis reconstruction. The authors' goal was to develop a measurement system that is simple, uses commercially available equipment, takes little time, and provides meaningful and accurate measurements. This technique is called the facial reanimation measurement system. It involves placing dots around the patient's mouth and video recording the patient performing maximal effort smiles. Using a video editing program, one frame showing the patient at rest is overlaid with a second frame showing the patient's smile. This overlaid image is imported into Adobe PhotoShop, where measurements are obtained using tools available in the program. Twenty patients were used to test interrater and intrarater reliability of the facial reanimation measurement system. The accuracy of the measurement process was tested by comparing 10 known distances and angles with those obtained using the facial reanimation measurement system. Both intrarater and interrater reliability of the distance and angle measurements are highly accurate, with intraclass correlations greater than 0.9. The facial reanimation measurement system is accurate to within 0.6 mm and 2.0 degrees when compared with a "known" distance and angle. The facial reanimation measurement system has been used to measure smile movements of more than 200 patients and has been demonstrated to be valuable for detecting changes of facial movements over time. This system is simple and economical and only requires 20 minutes to perform. Although the authors demonstrated evaluation of smile movement, the system may be used to evaluate other movements, such as mouth puckering, eye closure, and forehead elevation. (*Plast. Reconstr. Surg.* 115: 696, 2005.)

A patient with facial paralysis must cope with many functional and aesthetic difficulties. The inability to communicate emotions, for example, by smiling, is one of the most troubling aspects of this condition.

The current technique used to provide a smile for unilateral facial paralysis patients involve a cross-facial nerve graft followed by a neurovascular muscle transfer.[1] The goal of this operation is to move the paralyzed commissure and upper lip the same distance and direction as on the normal side. Many surgeons have attempted to improve this reanimation technique and have reported their results.[2–13] A limitation with the reporting of these results is that each surgeon has used a different method to evaluate the surgical outcomes, making comparisons between surgi-

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cal techniques impossible. To compare the effectiveness of different surgical techniques, agreed-on assessment tools are required. One of these tools should provide an objective measurement. The tool should be valid, reliable, specific to the goal of the surgery, and simple to use.

Several grading, scoring, and measurement techniques have been developed for facial paralysis evaluation. Of the grading scales,[14–17] the House-Brackmann is the current standard.[18] However, these scales are subjective and ambiguous. They involve an assessment of the entire face and are too broad in scope to be useful for evaluation of a specific area of facial reconstruction, such as smile reanimation. Furthermore, they do not provide a vector assessment of facial movement.

Several objective measurement systems have been proposed that are designed to measure facial movement. Most systems involve a computerized analysis of a photograph[19,20] or video recording.[21–29] These systems either track marked points on the face,[19,21,22,24–26,29] count pixels,[20,28] look at variation in light reflections,[27] or draw contour lines of the surface of the face.[30] Because of their complexity, none of these measurement systems have been accepted for clinical use by other investigators for the analysis of facial paralysis reconstruction.

Our goal is to develop a simple and practical technique that is effective for measuring facial movement in any area of facial reanimation. Our clinical and research interest has been in the measurement of smile reconstruction; therefore, we will demonstrate this technique by measuring distance and direction of movement of selected points around the mouth. The accuracy, interrater and intrarater reliability, and our clinical experience with this technique are reported.

Materials and Methods

The Facial Reanimation Measurement System Technique

The facial reanimation measurement system involves video recording and computer analysis of facial movements. To analyze smile movement, a water-soluble makeup pencil was used to place dots around the mouth at the red-white lip margin at eight key landmarks important in smile movement (Fig. 1), as follows: philtral point, left mid upper lip, left commissure, left mid lower lip, lower lip midpoint, right mid lower lip, right commissure, and right mid upper lip.

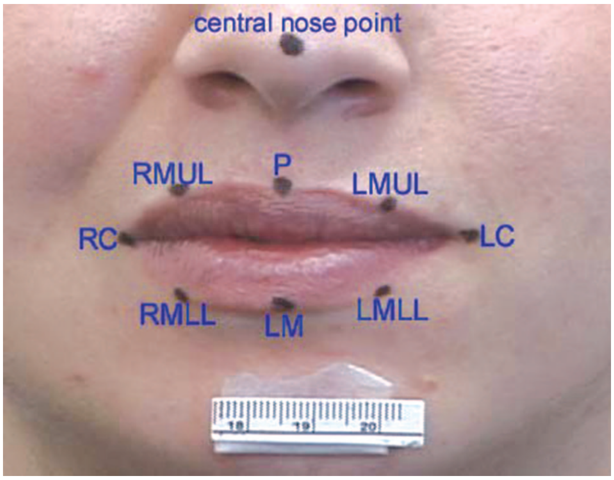

FIG. 1. The facial landmarks: *P*, philtral point; *LMUL*, left mid upper lip; *LC*, left commissure; *LMLL*, left mid lower lip; *LM*, lower lip midpoint; *RMLL*, right mid lower lip; *RC*, right commissure; *RMUL*, right mid upper lip.

A central nose point (Fig. 1) was used as a static reference point. A 1-cm ruler was taped to the patient's chin to act as a reference scale.

A digital video camera was mounted to a tripod, with the lens at the same height as the patient's nose. This study used a Sony Digital Video Camera Recorder (DCR-TRV900) (Sony, Tokyo, Japan).

The patient was instructed to sit comfortably and remain relatively still. Because the central nose point provides a reference from which the photographs are aligned, no device was used to fix the patient's head in place.

The patient's lower face, from the nose to the chin, was videotaped while the patient was performing and repeating a series of smiles. The patient was instructed to relax completely between movements and to exert a maximal smile when performing the facial expression. These images were captured when the patient was facing directly at the camera and when the patient was turned at an angle such that the commissure moved in a plane that was approximately perpendicular to the camera lens (semiprofile view) (Fig. 2). Observing the movement of the patient's commissure during smiling allowed one to choose the plane that was perpendicular to the camera lens. A modest degree of accuracy was required when selecting the angle of the camera relative to the patient's face. The measurement was accurate to within 3 percent if the camera axis was between 75 and 105 degrees from the plane of movement [$error = sin(angle\ \pi/180)$]. Therefore, it was easy to estimate this position and place the patient within this 30-degree range.

The video image was captured from the camera to the computer and edited using standard video editing software. The software used in this study was Radius Edit DV Version 1.0 (Radius, Inc., Sunnyvale, Calif.). The video recorded at 30 frames per second, which allowed exact selection of the two frames representative of the rest and maximum smile positions. Both frames were set to opacity 50 percent and aligned using the central nose point. Each dot around the mouth was visible from both the rest and smile frames (Fig. 3).

This final image, representing the two overlaid frames, was imported into Adobe PhotoShop (Adobe Systems, Inc., San Jose, Calif.) (any standard photographic imaging software can be used). Angle and distance measurements were made by enabling the "ruler" tool on the utilities bar and using the mouse to select the rest followed by the smile landmark. When using the mouse to select the landmark, the same location on each dot was chosen. This allowed for precise measurements despite the size of the dot used. This was repeated for each landmark around the mouth. In total, eight distances and angles were measured. The first two measurements were the midline measurements, the philtral point and the lower lip midpoint, and were obtained on the image of the patient facing forward into the camera (Fig. 3). The next six measurements, which included all landmarks except the philtral point and the lower lip midpoint, were obtained on the image of the patient facing at an angle away from the camera (semiprofile), such that the commissure moved in a plane perpendicular to the camera lens (Fig. 4). The ruler on the chin calibrated the measurements to millimeter units. Because the distance between the patients and the camera did not change from the front to the profile view, the ruler was only required for the front view.

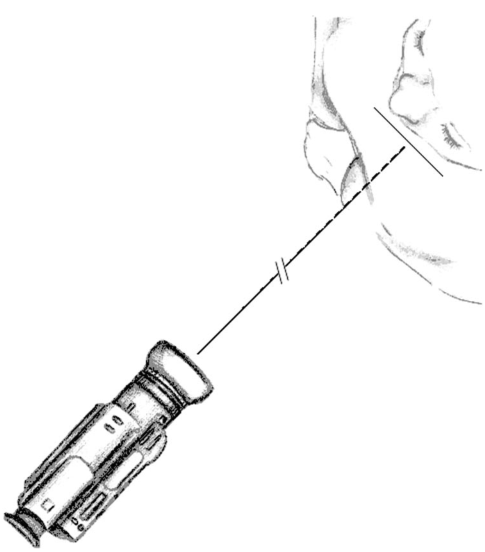

FIG. 2. A representation of how the patient is seated in front of the camera for the semiprofile view. The patient is turned at an angle such that the commissure moves in a plane that is perpendicular to the camera lens. The smile movement is captured by video and transferred to the computer for analysis.

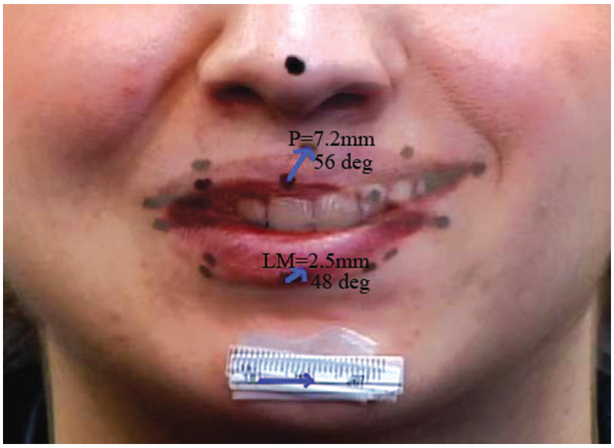

FIG. 3. When two images are aligned and the opacity set at 50 percent, each dot around the mouth is visible from both the rest and smile frames. When the patient is facing forward into the camera, the first two distances and angles, the philtral point (*P*) and the lower mid lip (*LM*), are measured.

Interrater and Intrarater Reliability of the Facial Reanimation Measurement System

The study group includes 20 randomly selected patients with varying degrees of unilateral facial paralysis. Preoperative and postoperative patients were included. The average age at the time of analysis was 39 years, with a range between 19 and 69 years. Excluded were those patients with long facial hair that visually impeded the analysis and patients with neurological tremors, from whom an accurate measure could not be obtained.

The facial reanimation measurement system, as described above, was completed for all 20 patients. Two observers (L.R.T. and S.F.) measured 60 images [each of the 20 patients had three sets of measurements: one facing the camera and two at an angle to the camera (semiprofile view)]. The measurements were

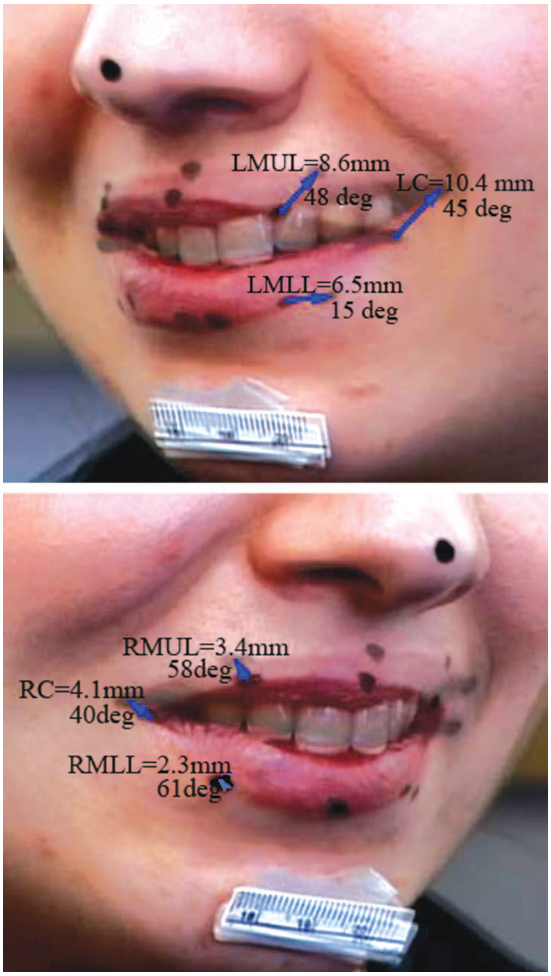

FIG. 4. The patient viewed at an angle (semiprofile) is used to measure six distances and angles. (*Above*) Distance and angle measurements at the left mid upper lip (*LMUL*), left commissure (*LC*), and left mid lower lip (*LMLL*). (*Below*) Distance and angle measurements at the right mid lower lip (*RMLL*), right commissure (*RC*), and right mid upper lip (*RMUL*).

repeated with a 2-week time lapse between repeat measures.

Intraclass correlation was used to measure the agreement between raters. The question we are answering is whether the observers performing these measurements are interchangeable. The intraclass correlation is the correlation between one measurement (either a single rating or a mean of several ratings) on a facial landmark and another measurement obtained on that same landmark. For this, we performed the analysis of variance and considered random as random effects.

Accuracy of Measurement Process Used in the Facial Reanimation Measurement System

Ten randomly chosen distances and angles were drawn on a blank sheet of paper. The distances and angles were within the normal clinical range for facial movement during smiling. The first observer manually measured the distances and angles, three times, using a microcaliper accurate to 0.1 mm (Digimatic caliper 7000103B, Mitutoyo/MTI Corp., Paramus, N.J.) and a drafting protractor accurate to 0.5 degree.

The drawing was videotaped and captured into the computer using the same video editing software as described above. The resulting image was imported into Adobe PhotoShop. The second observer measured the distances and angles three times by enabling the ruler tool on the utilities bar in PhotoShop and using the mouse to select the start point and the endpoint of the line.

The standard error for each measurement, based on the 10 drawn angles, using both manual techniques and the facial reanimation measurement system, was calculated. Because each angle and distance was measured three times, there were 30 measurements.

The objective of this exercise was to determine whether the video capture, computer software, and computerized analysis used in the facial reanimation measurement system process are accurate in measuring distance and angles. Therefore, we consider manual measurements to be exact or standard for accuracy. The manual measurements were compared with those obtained with the facial reanimation measurement system.

RESULTS

Interrater Reliability of the Facial Reanimation Measurement System

The interrater reliability (agreement between raters) of the distance measurements for the facial reanimation measurement system technique was highly accurate, with an intraclass correlation of greater than 0.9 for all facial landmarks (Table I). The average intraclass correlation for all facial landmarks was 0.988 and 0.990 for the front and profile views, respectively.

The interrater reliability of the angle measurement for the facial reanimation measurement system technique was also highly accurate, with the exception of facial point left commissure. Excluding facial point left commissure, the intraclass correlation for the facial landmarks in both the front and profile views was greater than 0.99 (Table I).

TABLE I
Intraclass Correlation Coefficients for Testing Interrater Reliability*

Landmark	Front Distance	Front Angle	Semiprofile Distance	Semiprofile Angle
P	0.978	0.999		
LMUL			0.998	0.999
LC			0.995	0.999†
LMLL			0.993	0.999
LM	0.998	0.999		
RMLL			0.995	0.999
RC			0.982	0.999
RMUL			0.980	0.999

ICC, intraclass correlation coefficient; P, philtral point; LMUL, left mid upper lip; LC, left commissure; LMLL, left mid lower lip; LM, lower lip midpoint; RMLL, right mid lower lip; RC, right commissure; RMUL, right mid upper lip.
* Distance and angle measurements taken from the front and semiprofile views of the patient are given.
† Semiprofile angle for the left commissure landmark was transformed, allocating the zero-degree mark to a point away from the direction of movement.

The facial point left commissure had an intraclass correlation of 0.887. The angle for facial point left commissure was transformed, allocating "zero degrees" to a point away from the direction of movement. This provided an intraclass correlation of 0.999 for both the front and profile views and thus corrected the discrepancy.

Intrarater Reliability of the Facial Reanimation Measurement System

The intrarater reliability (retest reliability) of the distance measurements for the facial reanimation measurement system technique was highly accurate, with an intraclass correlation of greater than 0.9 for all facial landmarks, for both raters (Table II).

The average intrarater reliability for distances measured from the front view was 0.968 and 0.996 for raters 1 and 2, respectively. The average intrarater reliability for distances measured from the semiprofile view was 0.969 and 0.994 for raters 1 and 2, respectively.

The intrarater reliability of the angle measurement for the facial reanimation measurement system technique was highly accurate, with an intraclass correlation greater than 0.99 for both raters (Table II). The exception is measurement of the left commissure, semiprofile view, rater 2, which had an intraclass correlation of 0.58. This angle was subsequently transformed, allocating the zero degrees to a point away from the direction of movement. This gave an intrarater reliability of 0.999 for this point, correcting the discrepancy.

Accuracy of Measurement Process Used in the Facial Reanimation Measurement System

Assuming the calipers represent the "exact" measurements, the deviation (standard error) of the facial reanimation measurement system measurement from the caliper measurement was 0.6 mm. In relation to the distances measured, the facial reanimation measurement system results varied from the caliper results an average of 3.82 percent. Half of the time, the facial reanimation measurement system measurements were larger and half the time they were smaller than the manual measurement.

TABLE II
Intraclass Correlation Coefficients for Testing Intrarater Reliability*

	Front Distance		Front Angle		Semiprofile Distance		Semiprofile Angle	
Landmark	Rater 1	Rater 2	Rater 1	Rater 2	Rater 1	Rater 2	Rater 1	Rater 2
P	0.939	0.996	0.999	0.999				
LMUL					0.998	0.995	0.999	0.999
LC					0.978	0.992	0.999	0.999†
LMLL					0.976	0.995	0.999	0.999
LM	0.997	0.997	0.999	0.999				
RMLL					0.993	0.991	0.998	0.999
RC					0.930	0.993	0.998	0.999
RMUL					0.929	0.998	0.998	0.998

ICC, intraclass correlation coefficient; P, philtral point; LMUL, left mid upper lip; LC, left commissure; LMLL, left mid lower lip; LM, lower lip midpoint; RMLL, right mid lower lip; RC, right commissure; RMUL, right mid upper lip.
* Distance and angle measurements taken from the front and profile views of the patient are given.
† Semiprofile angle, rater 2, left commissure landmark, was transformed, allocating the zero-degree mark to a point away from the direction of movement.

Similarly, assuming the manual measurements represent the "true" angle, the facial reanimation measurement system angle deviated from the mean true angle by 2.0 degrees. Four of 10 times the facial reanimation measurement system angles were smaller and six of 10 times they were larger than the manual angles.

In calculations of the standard error, the variation attributable to the raters had not been taken into account. However, for the facial reanimation measurement system measurements, this was tested through interrater reliability analysis.

Clinical Applicability

The facial reanimation measurement system technique has been used at our center to measure the smile movements of over 200 patients. It has been demonstrated to be valuable for detecting changes in facial movement over time (Fig. 5).

FIG. 5. The facial reanimation measurement system technique has been demonstrated to be valuable for detecting changes in facial movement over time. (*Above*) Unilateral facial paralysis patient before smile reanimation surgery. (*Below*) Same patient postoperatively.

DISCUSSION

One way to evaluate the effectiveness of facial paralysis reconstruction is to use a measurement system that will evaluate facial position and movement. The advantage of a measurement system is that it is objective and provides quantitative evidence. Using a measurement technique, the surgeon can evaluate a patient's progress after surgery and compare the effectiveness of different operative procedures. Our primary goal is to develop a practical technique of measurement that is effective for evaluating facial reanimation, and because our interest has been in smile reconstruction, we applied the technique to smile movements.

There are a number of measurement techniques published; however, none of these techniques have been adopted for widespread clinical use. Each technique has limitations including availability, reliability, accuracy, ease of use, and clinical relevancy. The reported techniques can be divided into two groups: those that measure movement of regional surfaces of the face and those that measure movement of designated facial points.

There are several computer-assisted measurement systems designed to measure movement of facial surfaces. Neely et al.[28] manipulated digitized video images and compared pixel values of areas of the face at rest and in animation. Meier-Gallati et al.[27] recorded videos and used a computer program to evaluate the variations of luminance during facial movement. The variations in reflected light between the resting face and the animated face indicate the movement of facial surfaces. These variations were given a numerical value for each area of the face. Yuen et al.[30] used moiré topography to produce contour lines representing the three-dimensional facial shape. From this, they developed indexes based on the number and bending pattern of the lines. The concept of measuring the movement of a region or surface of the face is appealing, as this represents the goal of certain facial reconstructions. However, these techniques have not provided the type of measurements that allow evaluation of the effectiveness of a facial paralysis reanimation procedure.

Many point measurement systems have been developed. The idea is that the movements of selected points are representative of the movements of the particular expression being assessed. The simplest technique is to hold a hand-held ruler against the patient's face to measure animation.[31] Burres,[32] followed by Frey et al.,[23] used hand-held calipers to measure the distances between fixed landmarks. An advantage of the ruler or caliper is that a measurement is immediately available and is thus practical in the clinical setting. We tested the caliper and found it awkward to use because the examiner must simultaneously place and hold the two tips of the caliper on two separate points on the face while the patient maintains a facial expression, such as a maximum smile. Furthermore, the measurement is indirect because it requires subtracting the smile point, which is in relation to a reference point, from the rest point, which is also in relation to a reference point. In addition, the caliper does not provide the direction of movement of the facial point. The angle of movement is important when analyzing a smile because a respectable amount of commissure movement can be unappealing if the movement is in the wrong direction, such as on a very horizontal axis. Reporting the amount of movement without indicating the direction can be misleading. For example, 5 mm of movement toward the tragus of the paralyzed side is a respectable smile, whereas 5 mm of movement toward the nonparalyzed side is indicative of the paralyzed side of the face being pulled toward the nonparalyzed side.

In 1994, we published a technique that used a cine camera.[33] This involved a life-size projection of images, representing rest and smile positions, that allowed direct measurement of positional changes of points around the mouth. The process provided useful output concerning the distance and direction of movement; however, the technique was tedious and impractical in the clinical setting.

Recently, most of the measurement systems have focused on the computerized measurement of movement of selected points on the face. Sargent et al.[20] used a still camera to take a sequence of images of facial movement and transferred them to a computer. These images were overlaid, the movements of selected points were tracked, and the x and y coordinates were obtained. In 1999, Frey et al. reported on the development of a three-dimensional measuring system to track the movements of selected points on the face.[34] This system uses a video camera, a system of optically precise mirrors, and a custom computer program. A centralized data processing facility is located in Vienna and a multicenter study is in progress. The output includes a graphic display of the movement of points on any two axes, the movement of points over time, and a three-dimensional image of point movement that can be rotated. Linstrom et al.[26] used the peak performance system, a commercially available motion analysis system, to measure the movement of points on the x and y axes and the movement of points over time. Johnson et al.[19] used digitized still photographs to measure the x and y coordinates from the movement of selected points and developed an assay to quantify facial expression. Wachtman et al.[29] used an automated tracking algorithm, which appears to simplify the analysis proposed by Johnston et al.[19] The automated tracking algorithm system provides x and y coordinates for selected facial points during animation and provides a representation of the actual path of movement. The systems that are proposed by Frey et al.,[34] Wachtman et al.,[29] Yuen et al.,[30] and Linstrom et al.[26] are measurement techniques that require specialized equipment, expensive or custom software, and time-consuming analyses. There have been no publications by other investigators supporting these techniques. They do not appear to be practical for the routine assessment of facial paralysis reconstruction.

The facial reanimation measurement system provides critical information for the analysis of smile reconstruction. The output represents the distance and angle at which key points move. This system is simple and requires a standard video camera, economical and commercially available software, a standard computer, and 20 minutes of analysis time. We feel that this system provides the essential information that the clinician or researcher needs to evaluate the dynamic effect of smile reconstruction surgery. Although we have been most interested in evaluating smile reconstruction, the system may also be used to evaluate other facial movements such as mouth puckering, eye closure, and forehead elevation.

Using only frontal images to record movement provides measurements on only the x and y axes. For some parts of the face, this view will provide a shortened impression of the extent of movement. It does not take into account the fact that movement is around the spherical surface of the face. During smiling, there is a significant amount of movement of the lateral part of the lip on the z axis (from front to back).[23] Although Frey has accomplished recording in three dimensions, it is at the expense of significant measurement system complexity. Our facial reanimation measurement system technique accounts for the contour of the face, which includes the *z* axis, by having the patient turn their head to a semiprofile view. This view places the movement of the commissure points (left commissure and right commissure) and the points at the mid lateral upper and lower lip (left mid upper lip, left mid lower lip, right mid lower lip, and right mid upper lip) in a plane that is approximately perpendicular to the axis of the camera's lens. A modest degree of accuracy is required when selecting the angle of the camera to the patient's face because the measurement is accurate to within 3 percent if the camera axis is between 75 and 105 degrees from the plane of movement [$error = sin(angle\ \pi/180)$]. This maneuver removes the need for complex three-dimensional analyses, it measures movement on the *z* axis, and it provides a measurement that is the true linear distance moved.

Images for the facial reanimation measurement system technique are recorded with the patient comfortably seated without restraints. The patient is instructed to minimize head movement so that the overlay of images is simplified. These instructions are sufficient because the central nose point is then used to adjust the position of the overlaid images, including identifying any head rotation that may have occurred. The selection of a facial point that does not move during smiling is controversial.[21,22] Various locations on the nose, from the nasion to the tip, have been studied as potential "static" points. Although it is likely that the least mobile point varies from person to person, we have found the nasal tip to be suitable.

The interrater reliability of the facial reanimation measurement system technique is highly accurate. As reported, our results identified a variation in the repeat measurements within two of the 60 angles tested. These two angles were transformed, allocating the zero-degree mark to a point away from the direction of movement, and this successfully corrected the problem. Because angles are measured on a 360-degree rotation, a zero point must be designated. It is possible for the angle of a smile to be very close to the designated zero-degree point. Therefore, on repeat measurements, the angle may be measured as 1 degree or 359 degrees. Clinically, this represents only a 2-degree difference. Statistically, it represents a 358-degree difference. Whichever point is designated as zero degrees will be subject to this possible variation with repeat measure, such as when calculating the reliability of the angle. The issue is resolved by allocating the zero-degree mark to a point away from the direction of movement. This issue is relevant when performing this test but has no clinical relevance. There is high intrarater reliability for the facial reanimation measurement system technique.

The accuracy of the measurement technique is excellent and highly precise for the clinical setting. When measuring soft tissue, a 0.6-mm deviation of the facial reanimation measurement system measurement from the caliper measurement is quite acceptable for movements that are usually in the range of 5 to 20 mm.

The facial reanimation measurement system measurement technique has been used to measure smile movements of more than 200 patients at our center. It is valuable for detecting changes of facial movements over time because a reproducible landmark can be reevaluated over and over without a large time investment. Which landmarks are compared depends entirely on the area of the face that is of interest when evaluating a surgical procedure. For example, when analyzing a smile, the points of most interest are at the commissures and mid upper and lower lips. With the facial reanimation measurement system, surgeons from different centers can compare techniques by reporting objective and applicable values instead of subjectively evaluating photographs. In general, there are endless possibilities of how the facial reanimation measurement system technique can be used by those interested in facial reanimation.

Conclusions

The facial reanimation measurement system is a valid, reliable, and easy-to-use measurement system that can be used to assess the outcome of facial paralysis reanimation surgery. The patient video can be captured anywhere, anytime, and can be stored for analysis at a later date. This allows for ease of use and transportability to clinic settings. The facial reanimation measurement system provides a true measure of the amount and direction of movement of selected points while capturing movement on the *x*, *y*, and *z* planes by simply recording at an angle that is perpendicular to the camera lens. With this technique, patients do not need to have their head fixed in place and do not have physical markers placed on their face that may impede movement. With the use of this measurement tool, facial paralysis patients can be compared between surgical centers such that effectiveness of facial reanimation operations can be evaluated.

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