Preliminary Report

Evaluation of Facial Volume Changes after Rejuvenation Surgery Using a 3-Dimensional Camera

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Abstract

Background: Surgical rejuvenation alters facial volume distribution to achieve more youthful aesthetic contours. These changes are routinely compared subjectively. The introduction of 3-dimensional (3D) stereophotogrammetry provides a novel method for measuring and comparing surgical results.

Objectives: We sought to quantify how specific facial areas are changed after rejuvenation surgery using the 3D camera.

Methods: Patients undergoing facial rejuvenation were imaged preoperatively and postoperatively with 3D stereophotogrammetry. Images were registered using facial surface landmarks unaltered by surgery. Colorimetric 3D analysis depicting postoperative volume changes was performed utilizing the 3D imaging software and quantitative volume measurements were constructed.

Results: Nine patients who underwent combined facelift procedures and fat grafting were evaluated. Median time for postoperative imaging was 4.8 months. Positive changes in facial volume occurred in the forehead, temples, and cheeks (median changes, 0.9 mL ± 4.3 SD; 0.8 mL ± 0.47 SD; and 1.4 mL ± 1.6 SD, respectively). Negative changes in volume occurred in the nasolabial folds, marionette basins, and neck/submental regions (median changes, −1.0 mL ± 0.37 SD; −0.4 mL ± 0.9 SD; and −2.0 mL ± 4.3 SD, respectively).

Conclusions: The technique of 3D stereophotogrammetry provides a tool for quantifying facial volume distribution after rejuvenation procedures. Areas of consistent volume increase include the forehead, temples, and cheeks; areas of negative volume change occur in the nasolabial folds, marionette basins, and submental/chin regions. This technology may be utilized to better understand the dynamic changes that occur with facial rejuvenation and quantify longevity of various rejuvenation techniques.

Level of Evidence: 4

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Facial aging involves a progressive redistribution of facial volume resulting from atrophy and deflation of the midface with inferior descent of soft tissue. The process distorts the primary arcs of the young face and creates the inverted heart shape characteristic of aging. These morphologic changes have been objectively characterized by volume analysis studies with magnetic resonance imaging (MRI) and computed tomography (CT) imaging, which has enhanced understanding of how to achieve more youthful contours with rejuvenation surgery (ie, lifting facial tissue and restoring volume). However, despite the dependence

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of volume restoration on the success of rejuvenation procedures, the assessment of facial aesthetic outcomes after surgery remains largely a subjective observation.

The introduction of 3-dimensional (3D) stereophotogrammetry creates a practical method for objectively comparing surgical results and determining longevity of procedures after rejuvenation surgery.6,7 The terminology for this technology is derived from the terms photogrammetry, which is the science of making reliable measurements from photographs, and stereo, which refers to the use of two or more cameras configured for simultaneous image capture to create 3D coordinates. Thus, the 3D stereophotogrammetry system uses data from multiple digital cameras that simultaneously capture an image of the same object from different angles. The image is calculated from a collection of points obtained along x, y, and z coordinate system. The data, besides rendering a 3D image, is easily obtained and included software can be utilized to perform anthropometric analysis of facial soft tissue landmarks with a reliability of <1 mm.8-13 For this reason, this stereophotogrammetry has been rapidly employed in evaluating preoperative and postoperative changes in frontal soft tissue in the fields of dentistry, orthognathics, and cranio-maxillo-facial surgery.10,14

For cosmetic purposes, 3D cameras are commonly used for visual communication with patients by simulating projected postoperative changes or demonstrating 3D augmentation. However, realizing additional clinical utility of this technology in facial plastic surgery is an active source of investigation. Since 2009, we have utilized a 3D camera system to take preoperative and postoperative 3D images of facial rejuvenation patients. For the current study, we sought to evaluate the Vectra 3D camera (Canfield, Fairfield, NJ) system’s utility for classifying change in facial volume and describe the redistribution of volumes after facial rejuvenation surgery. Furthermore, we aimed to develop a useful, clinical protocol for reproducibly assessing volume changes in the face over time.

METHODS

Patient Population

After obtaining IRB approval (Sharp Memorial Hospital, San Diego, CA), the first 9 patients imaged in our practice with preoperative and postoperative 3D pictures who underwent facial rejuvenation were included for study. Patients featured in the figures provided consent to allow their photos to be used. Imaging and procedures were performed between December 2011 and June 2012. Facial rejuvenation included face and necklift with facial fat grafting. No patients underwent repeated interventions, including revisions or additional injectables (ie, fillers or fat grafting) between surgery and analysis for this study.

Surgical Technique

Surgical facial rejuvenation (eg, facelift and necklift) was performed under general anesthesia. After induction of anesthesia, patients were infused with a saline; 0.25% Marcaine with 1:200,000 epinephrine tumescent solution. Skin flaps were raised via pre-auricular and post-auricular incisions. The superficial muscular aponeurotic system (SMAS) was addressed on an individual basis utilizing SMAS flaps, SMASectomy, or SMAS plication as necessary. When SMAS flaps are performed, a SMAS pennant was repositioned behind the ear in a posterior-superior vector. Neck rejuvenation consisted of an open approach including a submental incision, direct lipectomy, and corset platysmoplasty; all patients in the study were treated in this fashion. Excess skin was removed and skin incisions were repositioned without tension and surgical closure was performed. A single drain placed intraoperatively in the submental region was used for 1 day to collect any drainage or residual tumescent fluid. Patients underwent additional rejuvenation procedures (eg, blepharoplasty, browlift, etc.) based on individual need. The first 2 patients in the study underwent browlifting; the remainder did not.

Fat Grafting Technique

The facelift incision was utilized, when possible, or stab incisions were made with an 18-gauge needle at sites that provided easy access to areas requiring fat grafting. Fat was harvested using a 3.7 mm cannula attached to a 60 mL Toomey syringe (Bard Medical, Covington, GA) and grafted throughout the face, but primarily in key areas such as the temporal region, lateral eyebrows, malar regions, upper and lower eyelids, the nasolabial folds, marionette basins, labiomental grooves, pre-jowl regions, lips, buccal fat pads, and at the mandibular border. Fat was placed in the earlobes when indicated and used as a thin layer in the subcutaneous tissues around the lips and in areas of acne scars, if present. Fat injections were performed using a blunt cannula in small threads or microdroplets deposited in a retrograde fashion. Detailed location and amount of fat injected was recorded in the operating room for each patient. The range of total amount of fat grafted was between 10 to 70 mL in the face (mean, 36 mL ± 19 SD). The volume varied depending on individual need. We injected approximately 2 to 5 mL of fat in each temporalis region, 1 to 3 mL in each glabellar region, 3 to 7 mL in each buccal region, 1 to 3 mL in each nasolabial fold, 2 to 10 mL in the perioral region, and 1 to 3 in each supramental crease, as needed. We estimate approximately 50 to 80% of fat is retained and the remainder is resorbed due to non-viability.

If cell-enriched fat grafting was planned, the fat was harvested prior to the surgical facelift. A minimum of 200 mL of liposapirite was obtained and inserted into the Celution
(Cytori, San Diego, CA) device (not FDA approved) to obtain stromal vascular fraction cells. The process takes approximately 90 minutes. During processing for stromal vascular fraction, the facelift is performed.

**Image Analysis**

Patients were imaged with the Vectra 3D Face and Body System for image capture and analysis. The system consists of 4 geometric and 2 texture cameras positioned with the subject in a triangulated configuration. Each image is composed of high-resolution 3D surface geometry (x, y, z coordinates), color, and texture. Image analysis to construct postoperative volume changes was performed utilizing the included Mirror 3D (Canfield) imaging software. Two raters trained in direct anthropometric techniques performed the analysis (JB, BM). The included software package provides a grid to orientate patient landmarks.

All images were first prepared by deleting any imaging below the base of the neck using the selection tool. Each preoperative image was registered to the software grid system manually by aligning the vertical vector in the midline of the face, and the horizontal grid placed at the Frankfort horizontal line. Both face forward and lateral views were utilized during this process. The image was saved as the “registered preoperative” picture. The postoperative picture was then registered to the “registered preoperative” image using a 2-step process. First, the postoperative image was aligned manually for a “best fit” relative to the preoperative image. Then, a split-screen view was utilized to place common surface landmarks on each image. The postoperative image was then registered to the preoperative image by creating accommodation vectors at the named surface landmarks. Seven landmarks unaltered by surgery were chosen on each image for this registration process including bilateral lacrimal caruncle, the inferior attachment of bilateral nasal alar bases, the base of the columella, and the bilateral intertragal notch of ears (Figure 1). The landmarks were least likely to move during the rejuvenation process (ie, medial lacrimal caruncle). These landmarks initialize the orientation of the superimposed images. The software then takes the 3D images and automatically registers them to each other, aligning as many areas of similarity as possible (Figure 2). After registration, colorimetric analysis was performed depicting relative distance from postoperative to preoperative image after registration (Figures 3 and 4). Areas of green indicate areas of no change from preoperative to postoperative images.

**Figure 1.** (A) Preoperative and (B) 8 month postoperative 3D images of a 66-year-old woman who underwent facial rejuvenation. The image registration process was based on surface landmarks unaltered by surgery. For each patient, 7 landmarks were used (bilateral lacrimal caruncles, the inferior attachment of each nasal ala, the base of the columella, and bilateral intertragal notches). The postoperative image was then registered to the preoperative image based on these landmarks. The image features the patient’s left face. The same patient is featured in the color map in Figure 3 with her front and right sides shown.
Volume Analysis

Protocol 1: Facial Zone Analysis

In order to evaluate the volume shift after facial rejuvenation surgery, volume change was analyzed according to designated facial zones: neck, lower face, and midface. This required a 2-step process. First, a colorimetric map depicting distance from the registered preoperative and postoperative image was made, as described above, and each blue or red color-changed area was isolated using the selection tool (Figure 3). A separate volume measurement was constructed at each isolated area. Next, the face was divided into the designated facial zones and a net volume change was calculated within each respective zone by adding all the identified volume changes. The face was divided into zones with the midface including the zygoma, upper buccal region, and temporalis; this represented the area most positively affected by the rejuvenation procedures. The lower face included the jowls, perioral region, nasolabial folds, and deflated lower buccal fat pads. All images for analysis were captured in 3D. The transverse plane was drawn on the 3D image as it was rotated on the computer monitor.

Protocol 2: Isolated Analysis of Treated Areas

In order to examine how specific areas of the face may change with treatment, volume change was specifically assessed at bilateral cheeks, bilateral nasolabial folds, and forehead for each patient. For this process, the selection tool was used to isolate each aforementioned anatomic area on the registered preoperative and postoperative image. A volume measurement depicting the distance from postoperative to preoperative image was calculated for each anatomic site. A unique template was drawn out for each zone separately on every preoperative patient image. The same template was superimposed onto the postoperative image and the volume difference calculated. This was done to limit individual measurement variability.

Statistical Analysis

The primary outcome of interest was volume change in each facial zone in postoperative image relative to preoperative image. Statistical comparisons were made between the right and left midfacial zones. A t-test was used for comparison of the means. Cohen’s kappa statistic measured the level of agreement in each patient. To accomplish this comparison, the volume difference was assigned a “0” if the amount of change varied by more than 1 mL, and assigned a “1” if the volume changed varied by less than 1 mL. All reported P-values were 2-sided, with values of P of < .05 considered statistically significant. Statistical analyses were performed using SPSS (version 20; Chicago, IL).

RESULTS

Patient Population

Of the 9 patients, all underwent face and necklift. All patients were female ranging from 47 to 66 years of age (mean, 60 years ± 6.7 SD). The median follow-up for postoperative pictures was 4.8 months (mean, 6.4 months ± 4.7 SD; range, 1.1-12.4 months). Patients with greater degrees of ptosis and deflation achieved greater amounts of positive change compared to patients with less facial aging. Some patients had net negative volume changes.

Changes in Facial Volume: Protocol 1 (Facial Zone Analysis)

Table 1 describes volume changes according to 3 facial zones. The midface demonstrated a positive change in
Figure 3. (A) Frontal and (B) right face three-quarters views of 3D colorimetric analysis of a 66-year-old woman (the same patient as in Figure 1) depicting areas of volume change at 8 months postoperatively. Increasing depth of blue color represents gain of volume while increasing depth of red color indicates loss of volume relative to preoperative photo. Areas of green represent no volume change and this serves as one measure of registration adequacy. This patient lost volume around her nasolabial folds and neck and gained volume around the anterior cheeks and temples. Additional postoperative images for comparison were unavailable.

Figure 4. (A) Left lateral view and (B) right lateral view color maps of the registered preoperative and 6 month postoperative profile images of a 58-year-old woman who underwent facial rejuvenation. The different shades of green represent relative volume loss and gain. There was a net volume loss in the neck region (~8.9 mL).
volume (mean, 2.97 mL for the right; mean, 2.78 mL for the left). No statistical difference existed between changes in volume of the right and left midface ($P = 0.85$). A level of agreement for the right and left sides of each patient’s face was calculated with a Cohen’s kappa statistic. This test found no correlation between the amount of change between one side and the other ($\kappa < 0, P = 0.15$); these results represent the inherent asymmetry of the face and the different degree of augmentation that occurs during the rejuvenation process.

The lower face and neck showed a loss of volume for the postoperative picture vs the preoperative one (−5.73 mL and −4.75 mL, respectively) (Figure 4). Two patients underwent browlift. Measurements of the upper face found a small positive change in overall volume. This finding is likely due to the tissues being repositioned higher into the same facial compartments (ie, lower forehead to upper forehead) and did not fully represent the degree of change that occurred.

### Changes in Facial Volume: Protocol 2 (Isolated Analysis of Treated Areas)

Positive changes in facial volume occurred in the forehead, temples and cheeks (median changes, 0.9 mL; 0.8 mL; and 1.4 mL, respectively). Negative volume changes occurred in the nasolabial folds, marionette basins, and neck/submental regions (median changes, −1.0 mL; −0.4 mL; and −2.0 mL, respectively).

### DISCUSSION

Facial aging is a process of soft-tissue descent and deflation from the upper-to-mid and mid-to-lower-faces. The aim of facial rejuvenation is to lift tissues and restore volume. Defining these changes quantitatively allows for more objective assessment of postoperative outcomes. This study presents a method for objectively classifying these changes in volume distribution after aesthetic contouring.

In this report, we described two protocols for measuring volume change in the rejuvenated face. Our first protocol divided the face into 3 zones in order to more broadly assess volume redistribution across the entire face (ie, neck, lower face, and midface). The other protocol evaluated volume change in specific areas of the face, including the bilateral cheeks, bilateral nasolabial folds, and forehead. Both protocols demonstrated a trend in volume gain in the upper and middle face with a loss of volume in the lower face and neck. This is a reversal of the aging process where the midface hollows and skin and soft tissue sags into the lower face and jowl area.1,3

Interestingly, when considering specific areas of the face with protocol 1, we observed only modest volume changes in any particular area. The greatest volume gain was in the cheeks; however, even this gain was small (1.4 mL). While this volume change may seem mild, similar volumes are observed in quantitative studies of the aging face. For example, based on MRI data, the most dramatic changes in soft tissue volume between age groups (young, middle-aged, and old) occurred in the cheek area, but that difference was only around 2.2 mm.4 Thus, small volume shifts in the face may represent a larger clinical significance. We also observed differences between the right and left sides of the same individual’s face. This results from a number of inherent factors.15 Namely, the face is not a symmetric structure and most patients generally have a long-narrow side and short-wide side,16 which are preserved even after

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Mean ± SD 60 ± 7 22 ± 3 36 ± 19 32 ± 17 2.7 ± 2.3 2.9 ± 1.9 5.7 ± 2.9 −5.7 ± 6.6 −4.7 ± 3.4

BMI, body mass index.
facial rejuvenation. The face also undergoes asymmetric aging as the left face generally receives more sun damage while driving. Additional documented factors that contribute to asymmetric rejuvenation include the handedness of the surgeon and the laterality order in which the procedures are performed. We believe all of these factors contribute to the difference we obtained. Changes in volume occurred collectively from both lifting and filling; the measured volumes in this study could not differentiate between the two.

The median follow-up time for this study was 4.8 months (mean, 6.4 months ± 4.7 SD). This follow-up duration time allows us to quantify facial volumes and define the changes of the face in its rejuvenated state after the majority of edema has resolved. After longer periods of time (eg, 1 year), a certain degree of recurrent ptosis is frequently observed and longer-term results may misrepresent the face in its newly rejuvenated state. A collection of longitudinal serial images assessing incremental changes over time would help define the longevity of the procedures.

When the volume change was measured according to the facial zones as in protocol 2, we found a net-negative change in volume from the neck and lower face (−4 mL and −5 mL, respectively) and a net volume gain in the midface (+5 mL). While the location of volume shift that we observed in our study may be intuitive, classifying these findings numerically can be used to follow surgical changes in an individual patient over time and to objectively catalog the longevity of the facelift procedure and quantify fat graft retention. Previous estimates using Global Aesthetic Improvement Scores defined the longevity of surgical correction of the face at 5.5 years. However, these estimates indicated a differential aging by facial region, with the neck recurring quicker than the jowls, nasolabial, and marionette areas. This difference in recurrence makes observer objectivity less reliable by specific region, as the overall appearance of aging can be underestimated when they are seen in comparison to variable aged adjacent areas. Alternatively, 3D photographic measurements reduce the limitation of subjective measurements and subconscious relative comparisons, and provide more credibility to single observer judgments. It must be emphasized, these numbers are not compared to each other, as each patient will undergo various amounts of facial change depending on their individual need. The values can be used to follow the longevity of rejuvenation. Augmentation can vary depending on various factors, including patient anatomical factors, degree of facial ptosis, amount of soft tissue augmentation, and amount of retention. Patients receive correction based on their individual needs. This data begins to provide the information needed to support the stereophotogrammetry-based optical profilers to provide acceptable surface quality and image overlays suitable for measurement and visual inspection to which others can compare.

The image registration process is important to understand when analyzing changes between preoperative and postoperative images utilizing 3D software. During this progression, the two images are superimposed and then the differences between them are visualized by a color scale, or distance map (Figures 2 and 3). It is imperative that this process be highly accurate, as any differences between the photos can be a result of inherent error in the registration technique or as a result of actual change related to surgical treatment. While several studies have examined various 3D digital photogrammetry systems with respect to linear metric abilities, few studies address the precision and error of the registration process. Maal et al determined surface-based registration is the most accurate method to compare 3D photographs of the same individual at different times and that performing the registration procedure with the preprocessed photographs, the registration error decreases. If these two things are done, the registration error is less than 0.3 to 0.4 mm. However, it is important to understand the limitations of the registration process when analyzing study data. Accuracy determinations are dependent on assurances of the industry and software developers and included measuring tools. Future studies to test precision may include correlation with MRI, CT, cone beam CT, and laser surface scanning. Their accuracy may be more accurate, however this has not been clearly elucidated in the literature. In all, we did not find the measuring tools to be user-friendly and it was difficult to obtain consistent, reproducible results. After extensive multi-rater evaluations we feel confident with our obtained values. However, this tool’s volume measurement use for routine clinical practice in its current generation is very time consuming. Therefore, it is currently used primarily in our practice for research purposes. The 3D camera is a significant investment and may not be cost-effective for many practices. Image capture and retrieval is straightforward, however manipulation, volume measurement, and analysis is time consuming and not user friendly enough for accurate, routine comparisons of small volume changes. With future generations, our hope is that this camera can become an increasingly valuable tool for clinical and research purposes.

For this study, resident physicians learned the computer’s software by reviewing the included instruction manuals and completing telephone-training sessions by company representatives and software developers to create standardized protocols for conventional clinical purposes. Even with this training, the professional grade software is not intuitive to an average computer user. Additionally, the camera comes with multiple redundant functions, which are difficult to understand and time consuming to master for consistent, efficient use. However, over time, we achieved good registration for most patients with a systematic approach. First, all images were processed by removing hair and any data below the
clavicle that would interfere with registration. Next, the preoperative image was registered to the surface grid. The postoperative image was then manually aligned to the registered preoperative image. The postoperative photo was then registered to the preoperative image according to the corresponding landmarks. This process worked for most patients, however there were instances where alternate landmarks were needed depending on specific surgical intervention (ie, blepharoplasty or rhinoplasty). In these cases, a combination of landmark and manual registration was performed. On average, it took approximately 1 hour to achieve good registration and classify each patient according to each volume calculation protocol, which may limit applicability for routine clinical use.

CONCLUSIONS
Positive and negative volume distribution changes occur after facial rejuvenation surgery which can be quantified using 3D imaging technology. The differences in volume distribution include an average net volume loss in the neck and lower face (−4 mL and −5 mL, respectively) and a net volume gain in the midface (+5 mL). These changes appear to be due to a combination of fat redistribution as the underlying SMAS and subcutaneous tissues are shifted much as tectonic plates along with the addition of grafted fat. We present a protocol using the included Vectra Mirror software that offers an approach for classifying changes after facial rejuvenation. These quantitative measurement techniques using the 3D camera require experience with imaging software and dedicated training as the software is not intuitive for the average computer user. Even after developing fluency with the software, the measurement techniques are still time consuming and it can be difficult to obtain reproducible results. Our hope is that future software generations will become more efficient and user friendly. At current, we find the 3D camera’s utility for measuring volume change to be a difficult tool to easily incorporate into a busy clinical practice. However, despite these limitations, this technology still offers a unique tool for visual patient communication and has promising potential for noninvasively collecting and comparing volumetric measurements.

Disclosures
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