An Innovative Three-Dimensional Approach to Defining the Anatomical Changes Occurring after Short Scar-Medial Pedicle Reduction Mammaplasty

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Background: Three-dimensional photography of the breast offers new opportunities to advance the fields of aesthetic and reconstructive breast surgery. The following study investigates the use of three-dimensional imaging to assess changes in breast surface anatomy, volume, tissue distribution, and projection following medial pedicle reduction mammaplasty.

Methods: Preoperative and postoperative three-dimensional scans were obtained from patients undergoing short-scar medial pedicle breast reduction. Three-dimensional models were analyzed by topographical color maps, changes in the lowest point of the breast, surface measurements, and the point of maximal projection. Total breast volume and percentage volumetric tissue distribution in the upper and lower poles were also determined.

Results: Thirty patients underwent reduction mammaplasty (mean postoperative scan, 80 ± 5 days). Color maps highlighted the majority of spatial changes in the central, upper poles. Reduction mammaplasty resulted in a significant decrease in the anteroposterior projection of the breast (6.3 ± 0.2 postoperatively compared with 8.1 ± 0.2 cm preoperatively; $p < 0.01$). The point of maximal breast projection was elevated in the cranial-caudal direction (4.8 ± 0.4 cm; $p < 0.01$), with a corresponding elevation in the lowest point of the breast (4.8 ± 0.5 cm; $p < 0.01$). Volumetric three-dimensional measurements identified a significant change in percentage tissue distribution after reduction mammaplasty (45 ± 2 percent above the inframammary fold preoperatively versus 76 ± 2 percent postoperatively; $p < 0.01$).

Conclusions: This study is the first to demonstrate the technical feasibility and clinical utility of three-dimensional geometric data in medial pedicle breast reduction surgery. This novel approach suggests new opportunities to define long-term operative changes following various breast procedures. (*Plast. Reconstr. Surg.* 121: 1875, 2008.)

Breast reduction procedures have been in existence since as early as the sixth century AD. The modern era of reduction mammaplasty originated with Schwarzmann's concept of maintaining the nipple on a vascular pedicle,[1] and this has led to the current practice of pedicle-based approaches to reduction mammaplasty.[2–12] Continued progress in this field therefore depends on our ability to critically assess the surgical outcomes of each of the various reduction mammaplasty techniques available today.

Unfortunately, our ability to objectively analyze surgical results in reduction mammaplasty remains limited. At present, the evaluation of reduction mammaplasty procedures is based largely on surgeon and patient perspectives, both of which carry a degree of inherent bias.[13–15] Al-

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though standard digital photography has enhanced our ability to archive and analyze operative results, this approach fails to document true anatomical changes of the breast.[16–18] Given the three-dimensional nature of the breast, an optimal tool for assessing breast reduction surgery would provide objective breast data in multiple dimensions, including shape, volume, and contour.

A more sophisticated technique with which to analyze breast surface anatomy is now possible with the introduction of three-dimensional photography. Three-dimensional scanning has gained popularity in various medical specialties,[19–22] and we and others have recently suggested that this may be a valuable tool for assessing breast symmetry and other clinical measurements that were previously unattainable to plastic surgeons.[23–26] The following study uses three-dimensional imaging technology to define, for the first time, the anatomical changes that occur with medial pedicle breast reduction.

PATIENTS AND METHODS

Patient Enrollment

All patients undergoing reduction mammaplasty with a short-scar, medial pedicle technique were offered enrollment into the study in accordance with the patient population of the senior authors (M.C., N.S.K.). Approximately 70 percent of the breast reduction patients in the surgical practice of the senior author undergo medial pedicle reduction mammaplasty based on the preoperative surgical assessment of the surgeon. In the senior authors' experience, medial pedicle reduction is typically reserved for patients with less than 1000 g of tissue resection in each breast. The surgical procedure was performed as previously described.[2] Informed consent was obtained in accordance with the guidelines set forth by the New York University Medical Center Institutional Review Board.

Three-Dimensional Scans

Three-dimensional scans were obtained on preoperative and postoperative visits using a noncontact laser scanner (V910; Konica Minolta, Tokyo, Japan) as previously reported.[25] The camera was placed 3 feet from the subject at the level of the breasts, and scans were obtained with the subject facing +90, +45, 0, −45, and −90 degrees relative to the lens. Additional inferior views were obtained with the camera at knee level and tilted upward. Individual images were merged into a single three-dimensional model using computer software that identifies pairs of corresponding points in overlapping regions (Studio 9; Geomagic, Research Triangle Park, N.C.). Geomagic Studio was also used to generate a customized chest wall template for each patient. This is achieved by removing the breast (boundaries are defined superiorly at the level at which the breast projects off the chest, and inferiorly, medially, and laterally by the borders of the inframammary fold) and performing a curvature-based fill. Subsequently, a Boolean operation of the chest wall and surface image was performed to establish a closed object. The overlay of the chest wall template on the preoperative image maintains the previously marked boundaries of the breast. For postoperative images, the customized chest wall template was imported and used in a similar fashion. To reduce any variability with postoperative analysis, the overlay of the chest wall template with the postoperative images replicates the preoperative superior boundary and identifies the medial, lateral, and inferior border of the postoperative breast.

Three-Dimensional Comparison Color Map

Postoperative images were superimposed on their preoperative counterpart by performing a computer-generated best-fit alignment of the chest walls. Color maps were generated by performing three-dimensional comparisons between the two images, using the preoperative image as the test object and the postoperative image as the reference object. Maximum and minimum distance deviations were +25 and −40 mm, respectively. Color scales were divided into 40 segments.

Breast Projection

Sagittal sections were taken through the nipple on each breast to identify the point of maximal breast projection. The maximum anteroposterior distance of the breast relative to the chest wall was determined for each preoperative and postoperative image. In addition, the change in vertical height (cranial-caudal direction) between these two points was calculated. The distance between the lowest point of the breast between preoperative and postoperative images was also determined.

Breast Volume Analysis

All breast images were aligned to reference x, y, and z coordinate axes. Total breast volume was determined for each breast. For every preoperative image, a transverse plane (x axis) was then placed through the lateral border of the inframammary fold intersecting the y coordinate axis to divide the breast into superior and inferior poles. This was done individually for each breast. To ensure accuracy and reproducibility, the initial transverse plane was applied to all postoperative images. Distance measurements between critical landmarks were determined, including the sternal notch-to-nipple surface distance, and the internipple surface distance.

Statistical Analysis

All data are presented as mean ± SEM. Preoperative and postoperative values were compared using a paired *t* test, and a value of $p < 0.05$ was determined to represent statistical significance.

RESULTS

Three-Dimensional Comparison following Reduction Mammaplasty

A total of 30 patients underwent reduction mammaplasty with preoperative and postoperative three-dimensional analysis (mean postoperative days, 80 ± 5). Total resection weights, qualitative preoperative ranking of breast hypertrophy (mild, moderate, or severe), follow-up scan day, and additional procedures are listed for each patient in Table 1. To highlight the overall extent of change in breast anatomy, color maps were generated for all patients by comparing the postoperative breast (reference object) to the preoperative image (test object). Figure 1 demonstrates an example of this overlay technique (*above*) and the corresponding three-dimensional comparison (*below*). Three-dimensional comparisons of 18 study patients are shown in Figure 2 (patient number corresponds to those in Table 1).

Table 1. Patient Summary*

Patient	Age (yr)	Right/Left Resection Weight (g)	Breast Hypertrophy	Postoperative Scan (days)
1	44	600/630	Moderate	58
2	28	484/524	Moderate	109
3	27	535/545	Moderate	55
4	31	310/320	Moderate	75
5	25	360/465	Mild	60
6	23	585/495	Moderate	43
7	28	290/330	Moderate	27
8	39	230/225	Moderate	60
9	59	555/475	Moderate	30
10	24	525/260	Moderate	31
11	31	480/600	Moderate	42
12	60	440/420	Moderate	118
13	32	365/315	Moderate	112
14	60	340/320	Moderate	35
15	38	505/505	Severe	44
16	40	295/290	Moderate	84
17	26	415/610	Severe	86
18	42	360/455	Moderate	117
19	57	370/380	Moderate	155
20	46	190/0	Moderate	95
21	56	502/705	Moderate	141
22	46	80/265	Moderate	19
23	50	190/300	Mild	70
24	24	340/300	Moderate	54
25	41	689/673	Moderate	86
26	38	224/178	Moderate	43
27	27	282/354	Moderate	91
28	49	327/360	Moderate	34
29	23	300/410	Mild	91
30	22	680/780	Severe	66

*A summary of all study patients is provided, including age, type of reduction, resection weights, degree of breast hypertrophy, follow-up scan day, and additional procedures.

Breast Shape Analysis following Reduction Mammaplasty

To objectively assess how reduction mammaplasty alters breast shape, sagittal sections were taken through each breast at the nipple location (Fig. 3, *above*) and then paired with the corresponding postoperative image (Fig. 3, *below*). The sagittal view of the right breast is shown for 18 study patients in Figure 4 (numbers correspond to those in Table 1 and Figs. 1 and 2).

We further quantified these changes in shape by studying the point of maximal projection in terms of both vertical height (cranial-caudal) and anteroposterior distance. For each three-dimensional image, the greatest distance between the chest wall and the breast surface was identified by computer software. In our patient group, three-dimensional photography identified a 4.8 ± 0.4-cm elevation in the height of the point of maximal projection (Fig. 5, *above, left*), with a corresponding elevation in the lowest point of the breast (mean distance, 4.8 ± 0.5 cm; $R^2 = 0.69$) (Fig. 5, *above, right*). The anteroposterior distance from the chest wall significantly decreased by an average of 1.8 cm following surgery (from 8.1 ± 0.2 cm preoperatively to 6.3 ± 0.2 cm postoperatively; $p < 0.01$) (Fig. 5, *below*). Additional surface measurements revealed a significant decrease in the internipple distance (28.3 ± 0.6 cm preoperatively versus 25.4 ± 0.3 cm; $p < 0.01$) and sternal notch-to-nipple distance (28.0 ± 0.8 cm preoperatively versus 21.9 ± 0.3 cm; $p < 0.01$) (Fig. 6). Of note, three-dimensional photographic measurements are approximately equivalent to manual surface measurements (error, <5 percent).

Percentage Volumetric Distribution following Reduction Mammaplasty

The average preoperative and postoperative three-dimensional volume in our patient group was 1040 ± 285 cm^3 (range, 577 to 1585 cm^3) and 677 ± 232 cm^3 (range, 301 to 1168 cm^3), respec-

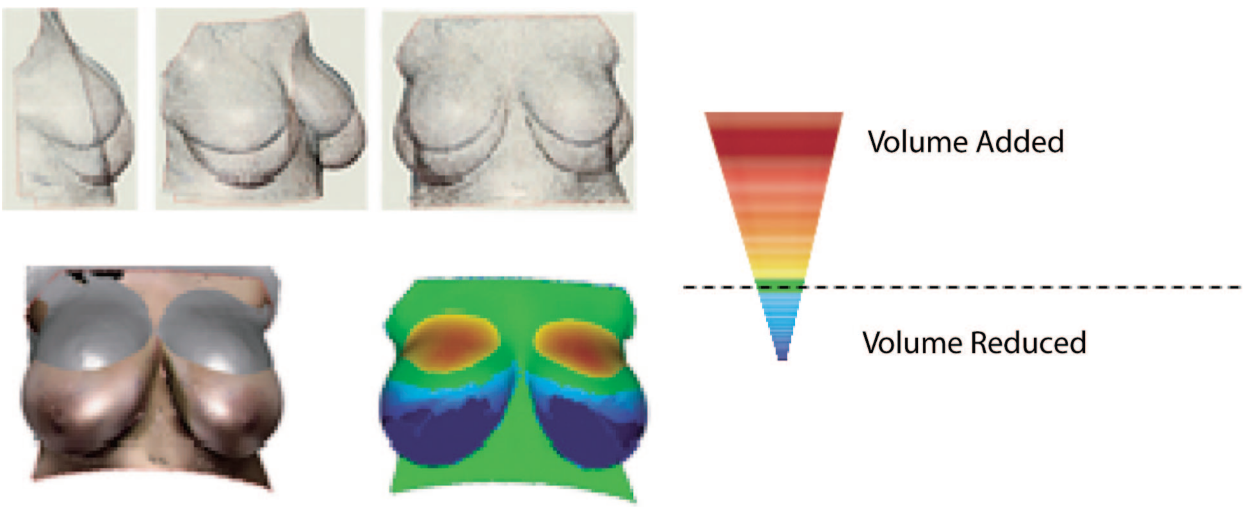

Fig. 1. A relative color map was generated between preoperative and postoperative three-dimensional images. A depiction of color map analysis is shown; preoperative and postoperative images are demonstrated on the top row, whereas the bottom row shows the preoperative image with the postoperative changes represented by a spectrum of color (*red*, volume added; *blue*, volume subtracted).

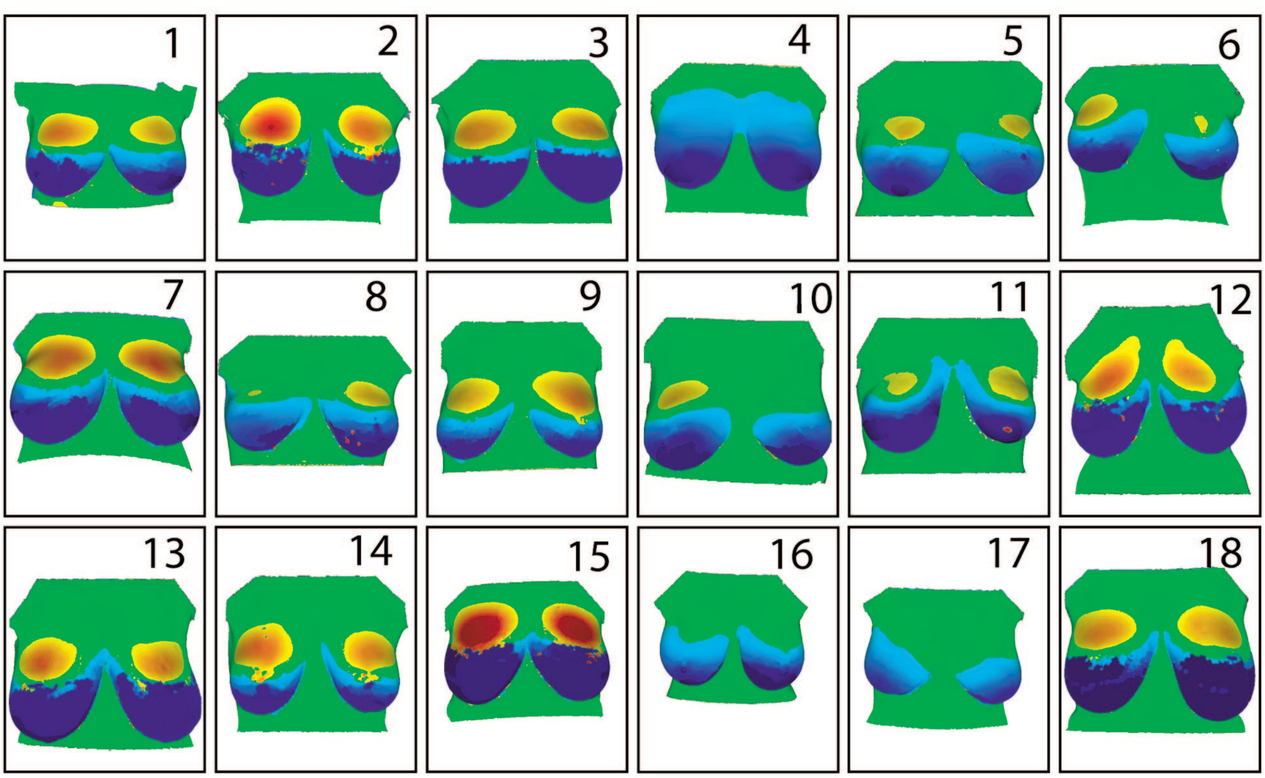

Fig. 2. Color map analysis for 18 study patients. Of note, numbers correspond to the patients listed in Table 1.

tively. Subdivision of the preoperative breast into upper and lower poles demonstrated the following distribution: 45 ± 2 percent of volume above the inframammary fold and 55 ± 2 percent below the inframammary fold. Identical analysis of postoperative images revealed that 76 ± 2 percent of the tissue was in the upper pole and 24 ± 2 percent was in the lower pole. Three-dimensional imaging identified a 31 percent increase in percentage volumetric tissue in the upper pole of the breast ($p < 0.01$) (Figs. 7 and 8).

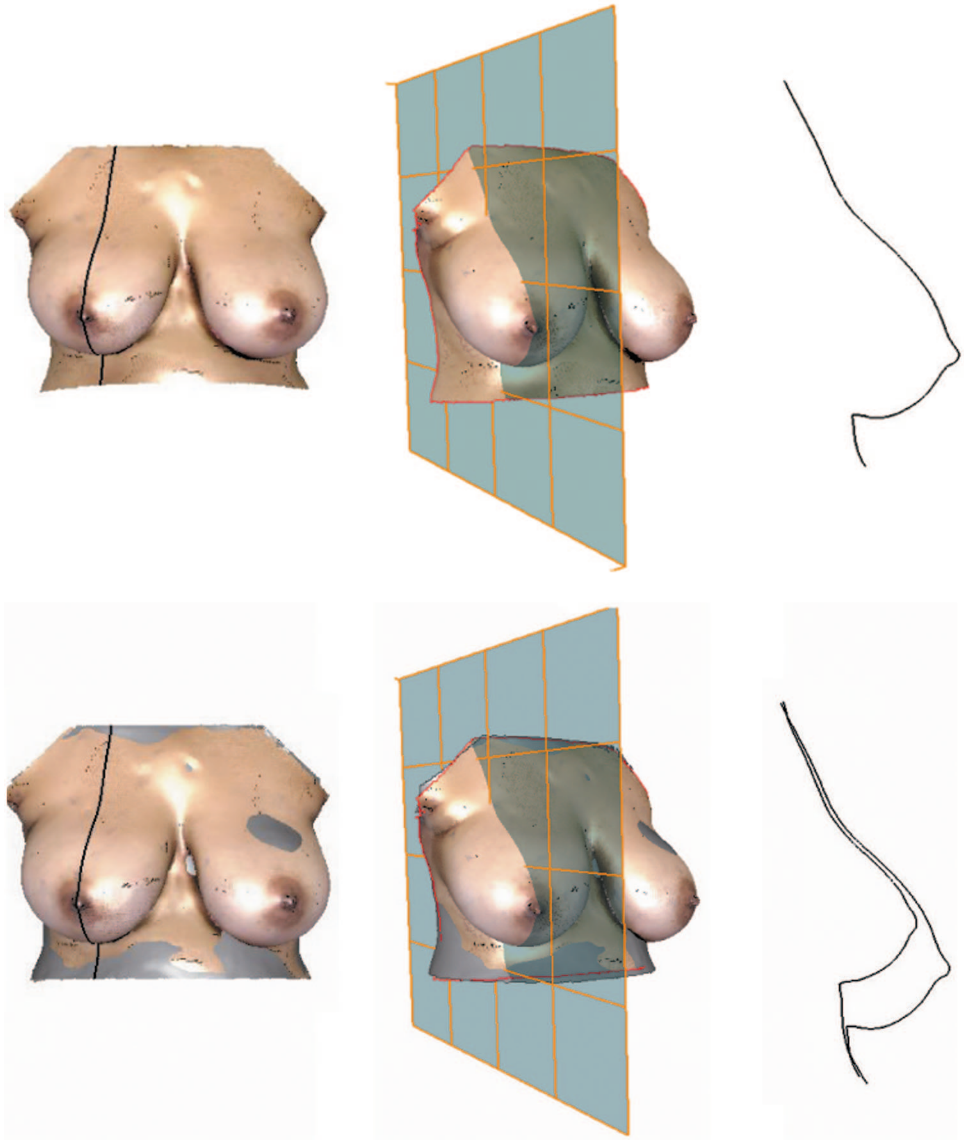

Fig. 3. Breast projection. Sagittal sections were taken through the middle of each breast to highlight the shape of the breast following reduction mammaplasty. An illustration of this plane in a preoperative image is shown (*above*), as is the same plane drawn on a preoperative and postoperative overlay (*below*).

DISCUSSION

Today, imaging modalities are commonly used in a number of plastic surgery procedures to aid in preoperative planning and postoperative analysis. For instance, techniques such as computed tomographic scanning and cephalography provide standardized measurements that are important in planning and assessing craniomaxillofacial surgical procedures. Unfortunately, this level of precision has yet to be integrated into the planning of aesthetic and reconstructive procedures for the breast. This study offers an initial step in that direction by introducing a three-dimensional–based approach to evaluating important anatomical parameters of the breast before and after reduction mammaplasty. Many of the data generated in this article were not available until now, and therefore these techniques have the potential to improve the general understanding, planning, and practice of mammaplasty procedures.

Previous work has demonstrated limited value and benefit with three-dimensional photographic imaging systems in patients with mammary hypertrophy and in patients of African American descent.[23,24] Our group has reported increased accuracy of capturing the entire breast in

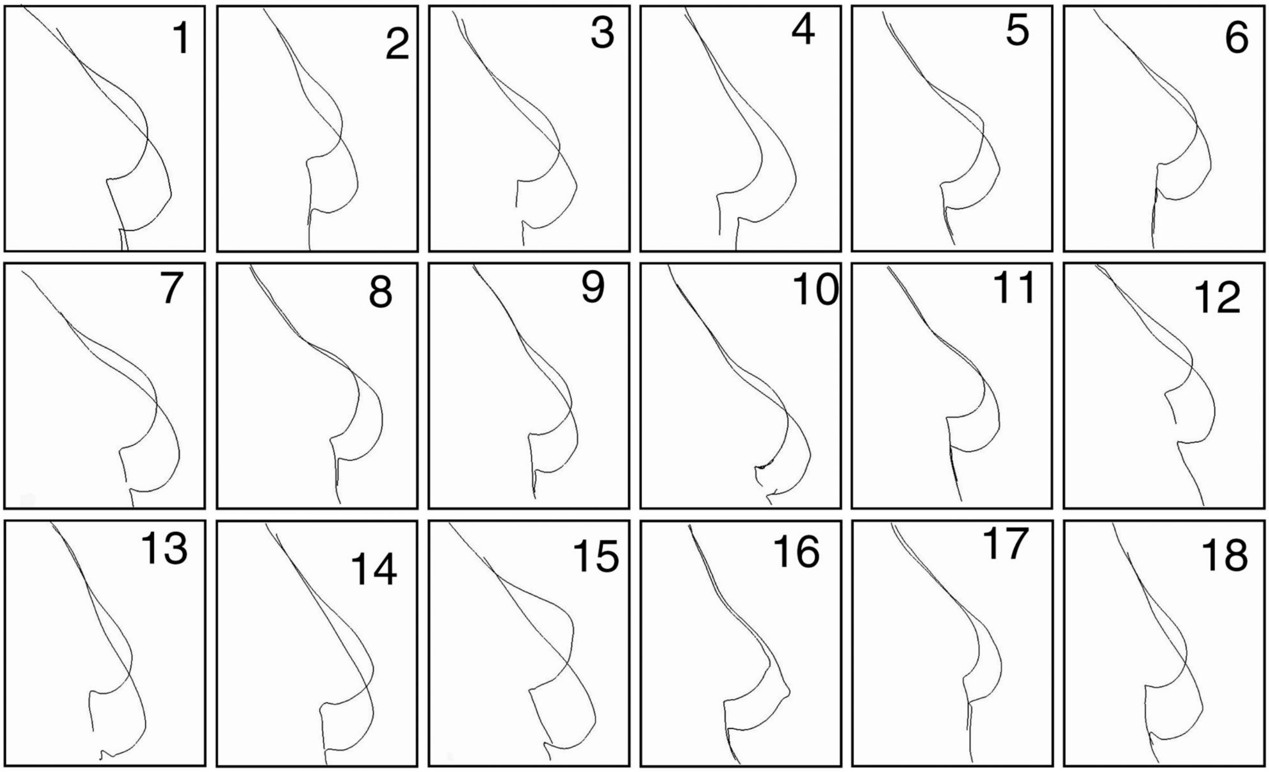

Fig. 4. Breast projection. The surface images are demonstrated for the right breast of 18 study patients. Numbers correspond to the patients listed in Table 1.

these subgroups by adding additional scans to capture the inferior poles of the breast and by using fluorescent lighting to eliminate shadowing.[25] These recent advancements in the scanning protocol allow for broad-spectrum analysis of varying breast size, shape, and contour.

One aspect of three-dimensional imaging demonstrated in this study is topographical color mapping, or three-dimensional comparison, which highlights spatial differences with a color-coded analysis scale (Fig. 1). Although color mapping was limited to qualitative analysis for the purposes of this study, quantitative data are certainly possible using this technique. Isogai et al. recently reported the application of three-dimensional color mapping to objectively assess symmetry following breast reconstruction.[26] In their study, the authors demonstrated the ability to generate a numerical score based on surface deviations of one breast relative to the contralateral side. The present study demonstrates a method for superimposing preoperative and postoperative images so that comparisons can be made over time, rather than be limited to a single three-dimensional photograph (i.e., comparison between sides). Although we did not focus on establishing a numerical score, the notion of a standardized three-dimensional scoring system for breast shape, contour, and symmetry is an intriguing idea that would likely be of clinical use in the future.

This study also illustrates the power of three-dimensional imaging technology to view surface anatomy from different planes, or vantage points. Our experiments used a sagittal plane to identify changes in the maximal projection and lowest point of the breast. Using this approach, we were able to identify a 5-cm elevation in the lowest point of the breast that closely matched the elevation in point of maximal projection. Although it seems quite intuitive that the breast elevates with reduction mammaplasty, the true extent to which this occurs has not been quantified to date. Interestingly, the change in the distance from the sternal notch to the nipple did not correlate as closely (average decrease, 6 cm), because nipple location may not always be consistent with the place of maximal breast projection. This observation underscores the value of identifying a true point of maximal projection through three-dimensional imaging to define changes in breast shape. Of note, we demonstrated that the anteroposterior

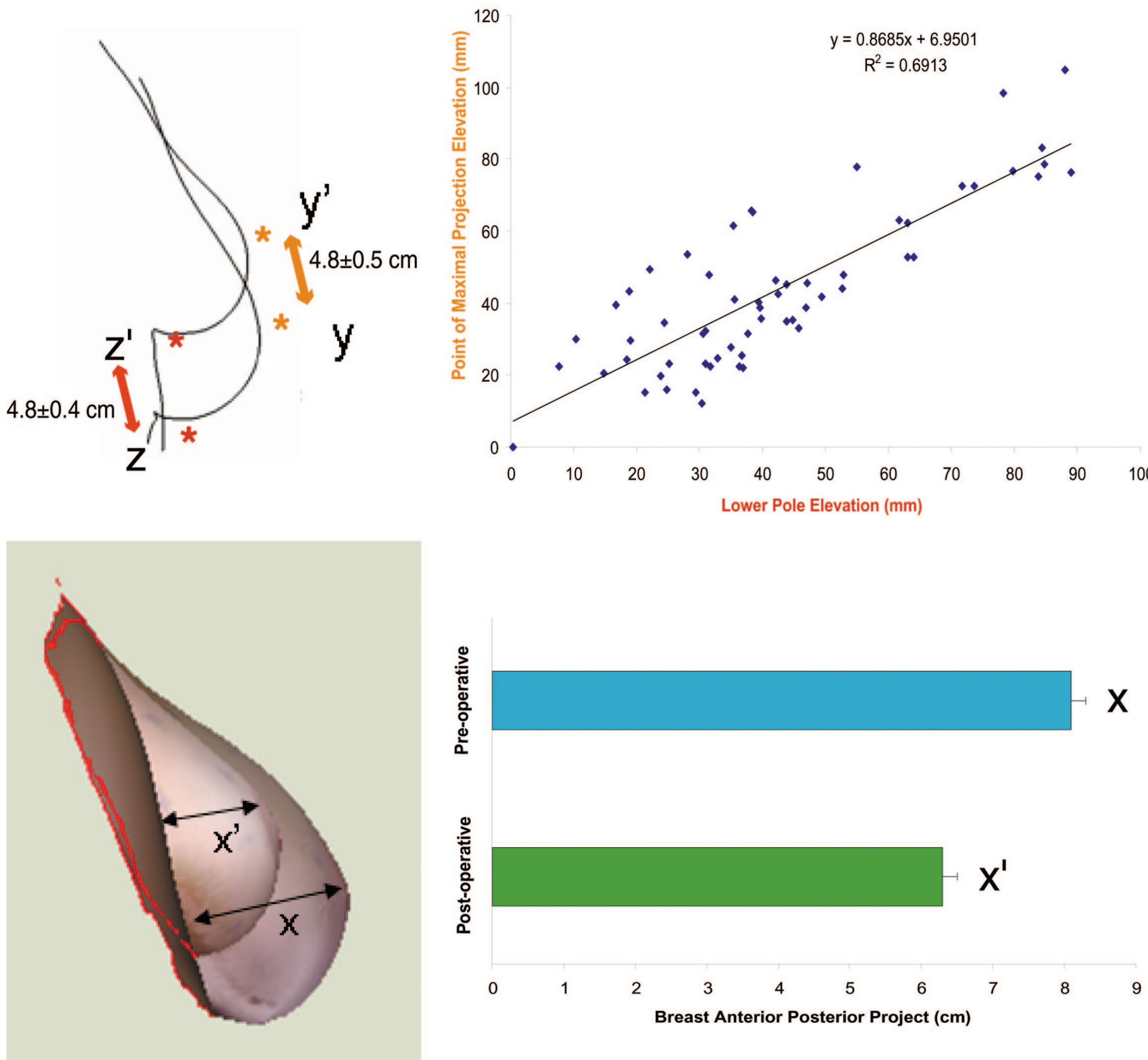

Fig. 5. Change in breast dimensions. The point of maximal projection was determined for each breast (*orange asterisk*), representing the greatest distance between the chest wall and the breast surface. This point was elevated by an average of 4.8 ± 0.4 cm (*y* versus *y*′) in our study group (*above*, *left*). The lowest point of the breast was also identified (*red asterisk*) on preoperative and postoperative images (*z* and *z*′). The degree to which the point of maximal breast projection was elevated (*y* axis) correlated with the extent of elevation at the lowest point of the breast (*x* axis), as shown (*above*, *right*). The anteroposterior projection distance from the chest wall was also calculated for all patients (*x* and *x*′) (*below*, *left*) and demonstrated a significant decrease in anteroposterior distance, with a mean reduction of 1.8 cm (*below*, *right*).

projection of the breast decreased significantly, by an average of 1.8 cm, and the superior pole percentage volume increased 31 percent. We attribute these values to the overall intraoperative tissue resection. Furthermore, the increase in superior pole percentage volume supports the desired fullness following a medial pedicle reduction mammaplasty and parallels the volumetric distribution of tissue with the superior rotation of the pedicle. The establishment of these standard measurements in medial pedicle breast reduction will possibly provide a reference for future studies aiming to quantify the degree of elevation among various approaches to reduction mammaplasty or mastopexy.

Perhaps the most valuable feature of three-dimensional imaging is its ability to calculate breast volume. Although other methods for de-

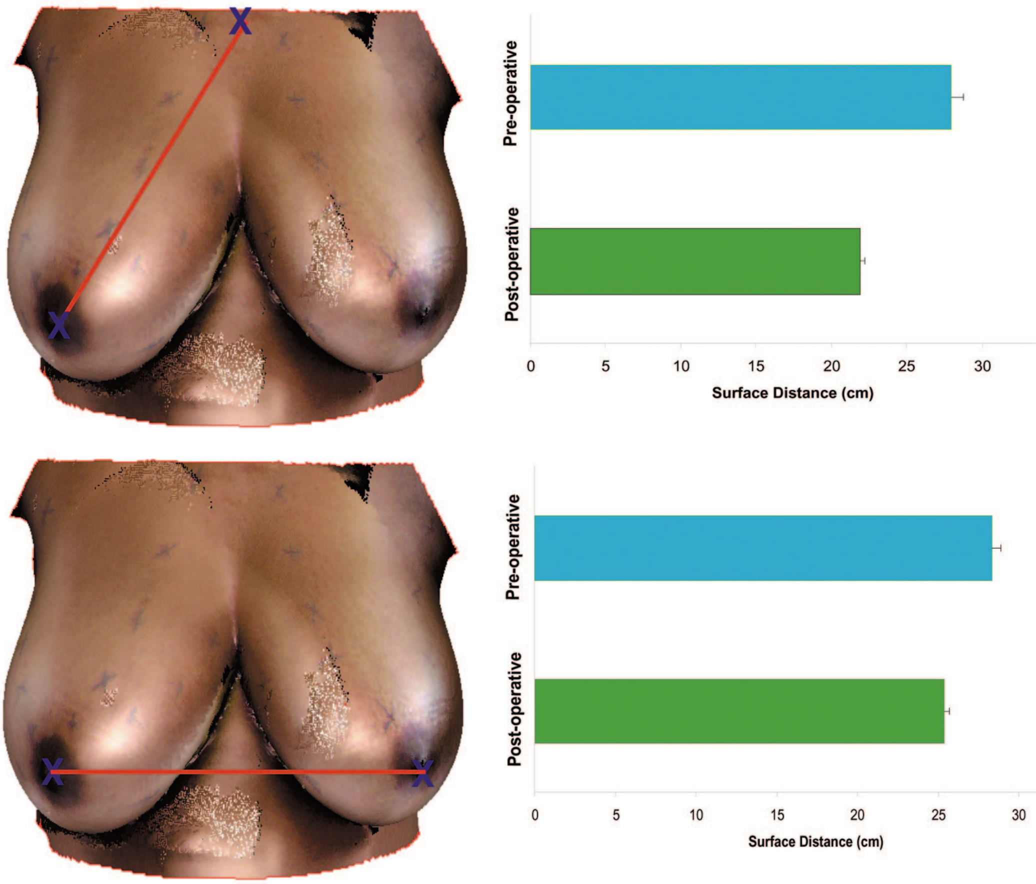

Fig. 6. Surface distance measurements were calculated on three-dimensional models by identifying the sternal notch and nipples. The sternal notch-to-nipple distance was reduced by an average of 6.1 cm in our study group (*above*). Reduction mammaplasty also led to a significant reduction in the internipple distance by 2.9 cm (*below*).

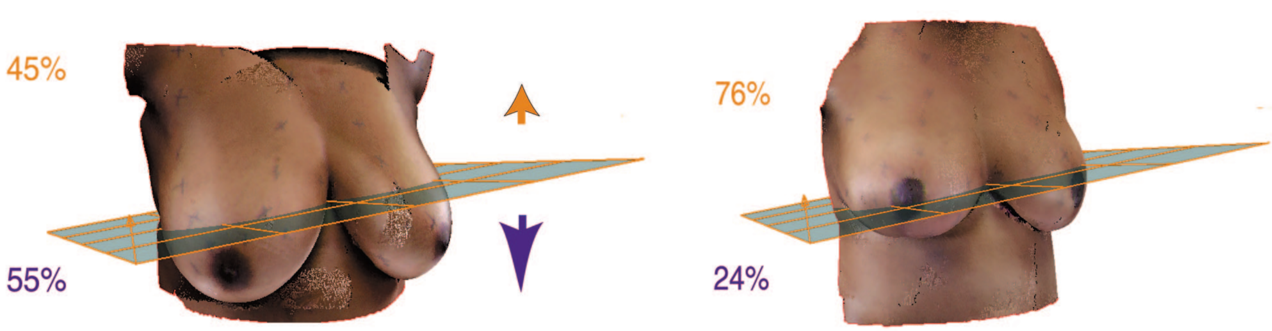

Fig. 7. Percentage volumetric distribution. Each breast was divided into an upper and lower pole in order to determine percentage of volumetric distribution. An identical plane was used on preoperative and postoperative images, and an example of volumetric distribution in right breast is shown for a representative patient (*left*) preoperatively and (*right*) postoperatively.

termining breast volume have been described previously,[27,28] three-dimensional imaging contains a number of distinct features. Previously described techniques, such as Archimedian water displacement or mechanical casts/plasters, have been limited by technical difficulty and an inability to provide quantifiable data. Some have reported breast volume analysis with radiologic tools such as ultrasound, magnetic resonance imaging, and computed tomography; routine use of these modalities is impractical because of high cost, additional radiation exposure, and unsatisfactory

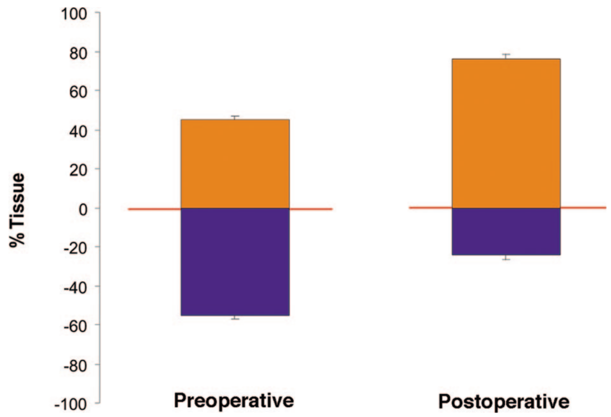

Fig. 8. The percentages of tissue lying above (*orange*) and below (*blue*) the inframammary fold for all patients is shown in graph form, (*left*) preoperatively and (*right*) postoperatively.

patient positioning.[29–31] In comparison, three-dimensional photography is unique in its ability to be performed quickly (on the order of minutes) and in a noninvasive manner, and it is easily analyzed with standard three-dimensional imaging software for measurements such as volume, area, linear distance, and surface distance. Of note, single camera systems range from approximately $20,000 to $100,000. However, more affordable and compact systems are currently being developed and are likely to be on the market soon.[25]

Another distinguishing feature of three-dimensional imaging relative to other measurement tools is the ability to determine relative distribution of volume, rather than total breast volume. Unlike other measurement tools, volumetric analysis with three-dimensional imaging need not be limited to the entire breast. In this article, we chose to focus on upper and lower pole distribution. Three-dimensional breast images, however, can be subdivided into lateral and medial portions, quadrants, or countless other combinations. This type of approach certainly allows for a more thorough analysis of the breast. One area where this type of analysis may provide apparent benefit is fat grafting to the breast, which has recently emerged as a novel approach for augmenting or reconstructing the breast.[32,33] In cases of fat grafting for breast reconstruction, three-dimensional volumetric analysis of the breast would enable the surgeon to determine particular regions that may be deemed deficient or asymmetric, and also help serve as a guide for the injection volume required.

Although previous studies have documented the applicability of three-dimensional volumetric measurements and topographical surface measurements, this study provides novel standard techniques for postoperative analysis including anteroposterior projection and percentage volumetric distribution. These techniques establish a foundation for future analysis whereby three-dimensional imaging may ultimately provide guidelines for preoperative surgical planning. However, long-term studies should be conducted to highlight definitive postoperative changes following medial pedicle reduction mammaplasty. Potential practical applications of long-term analysis (5 to 10 years) include choice of pedicle techniques, incision techniques, and intraoperative tissue resection to optimize postoperative breast projection and contour.

The methods used for postoperative analysis in the current study highlight the prospective use of three-dimensional imaging to track changes in the breast over time. Although we limited our study to identifying changes that occurred during the short-term postoperative period (average postoperative day 80), the potential applications of this technology are much broader. For instance, many surgeons are interested in the occurrence of pseudoptosis (bottoming out),[34,35] but the degree to which this phenomenon may or may not occur with the various breast reduction techniques remains speculative. In this article, we establish techniques in three-dimensional imaging with which we would be able to perform this type of analysis. Key steps for accurate and reliable data that are worth highlighting include (1) the creation of a customized chest wall for each patient that is used for all subsequent images, (2) successful orientation of three-dimensional surface images along a fixed *x-y-z* coordinate axis, and (3) creation of a fixed axis ("datum") that is applied to postoperative images. Our group is currently using these techniques to perform long-term follow-up studies to investigate issues such as bottoming over the course of 5 to 10 years.

Presently, few objective criteria exist to help guide the surgeon in the choice of a reduction mammaplasty technique. For instance, it is generally thought that an inferior pedicle technique is ideal for larger breasts,[4–7] whereas a medial pedicle technique should be reserved for relatively smaller breasts.[2,3] However, these guidelines remain vague, as true volume measurements and volume distribution are not available to surgeons during preoperative planning. Volume measurements obtained by three-dimensional imaging may help shed light on this issue. In the present study, medial pedicle procedures were performed successfully on patients with breast volumes as high as 1657 cm^3, which falls well within the range of three-dimensional volumes we typically encounter in patients undergoing inferior pedicle reduction. Further studies with larger numbers of patients are required to determine whether three-dimensional imaging can truly provide new volumetric guidelines for such procedures. As previously outlined earlier under Patient Selection, the surgical practice of the senior author is predominantly dedicated to short scar medial pedicle reduction mammaplasty; thus, this investigation provides standard analytical tools for other plastic surgery centers with different patient populations with which to assess various surgical techniques.

Although the present study centers on the use of three-dimensional imaging as a postoperative analysis tool, our study also suggests that this technology may soon be used to help to guide operative management. Because differential resection weights are often required for patients with baseline breast asymmetry,[36] preoperative three-dimensional photographs and volume measurements may help quantify this asymmetry and better predict surgical resection volumes. Although our patient population demonstrated an average baseline asymmetry of 10.4 percent (data not shown), these measurements were not used as a guide for surgery. Studies exploring the potential of three-dimensional volumes to aid in resection volumes are ongoing.

CONCLUSIONS

This study is the first to demonstrate the technical feasibility and clinical utility of three-dimensional photography for morphologic breast data (i.e., volume, tissue distribution, and breast projection). Because these measurements were not previously obtainable by plastic surgeons, three-dimensional imaging technology offers a novel approach with which to objectively define operative changes that occur with various aesthetic and reconstructive breast procedures. The present study focused on three-dimensional–based analysis of medial pedicle breast reduction but will possibly serve as a foundation for future studies aimed at better defining short-term and long-term outcomes of other breast procedures. We believe that three-dimensional photography offers a considerable advance in plastic surgery and hope that this technology will lead to improved objectivity and consistency in mammaplasty procedures.

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