ORIGINAL ARTICLE

Three-Dimensional Imaging Provides Valuable Clinical Data to Aid in Unilateral Tissue Expander-Implant Breast Reconstruction

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■ **Abstract:** The current approach to breast reconstruction remains largely subjective and is based on physical examination and visual-estimates of breast size. Thus, the overall success of breast reconstruction is limited by the inability of plastic surgeons to objectively assess breast volume and shape, which may result in suboptimal outcomes. A potential solution to this obstacle may be three-dimensional (3D) imaging, which can provide unique clinical data that was previously unattainable to plastic surgeons. The following study represents a prospective analysis of patient volunteers undergoing unilateral tissue expander (TE)-implant reconstruction by one of the two senior authors (MC, NSK). All patients underwent unilateral mastectomy with immediate or delayed insertion of a TE, followed by an exchange for a permanent silicone or saline implant. 3D scans were obtained during routine pre- and postoperative office visits. The 3D breast-volume calculations served as a guide for surgical management. Twelve patients have completed 3D-assisted unilateral breast reconstruction to date. These patients represent a wide range of body habitus and breast size/shape; 3D volume range from 136 to 518 cm^3. The mean baseline breast asymmetry in this group was 12.0 ± 10.8%. Contralateral symmetry procedures were performed in eleven patients, consisting of the following: mastopexy ($n = 6$), augmentation ($n = 1$), mastopexy/augmentation ($n = 2$), and reduction mammoplasty ($n = 2$). Reconstruction was completed in a total number of 2 ($n = 10$) or 3 ($n = 2$) operations. Overall breast symmetry improved at the completion of reconstruction in the majority of patients, with an average postoperative symmetry of 95.1 ± 4.4% (relative to 88% preoperatively). 3D imaging serves a valuable adjunct to TE-implant breast reconstruction. This technology provides volumetric data that can help guide breast reconstruction, such as in choosing the initial TE size, total volume of expansion, and final implant size/shape. 3D imaging technology also provides benefit as a method for assessing tissue expansion, the need for symmetry or revision procedures, and critically analyzing the final reconstructive outcome. ■

Key Words: 3D imaging, implant reconstruction

BACKGROUND

Breast reconstruction plays an important role in the treatment of many breast cancer patients, offering benefits to restore symmetry, correct body image, and improve psychosocial well-being (1–3). There are currently a variety of reconstructive options available to patients, with the ultimate choice of reconstruction based on a number of variables including the patient's specific reconstructive needs and personal preference (4,5). While many debate the relative advantages of autogenous versus implant reconstruction, both approaches remain suitable surgical options that are commonly performed today.

Regardless of the type of reconstruction performed, one obstacle that continues to limit the overall success of breast reconstruction is the inability of plastic surgeons to *objectively* determine the volume, shape, and contour of the breast. At present, most surgeons base their reconstruction on physical examination and visual size-estimates of breast size. For instance, in the case of tissue-expander (TE)-implant reconstruction, surgeons have few standard measurements to assist them in their choice of the optimal TE size, total expansion volume, and permanent implant size/shape. Rather, these critical surgical decisions are largely based on one's clinical intuition and experience. Unfortunately, this somewhat instinctual approach to TE-implant reconstruction may result in suboptimal

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outcomes and the need for additional revision or symmetry procedures (6–8).

The field of reconstructive breast surgery would therefore benefit from the advent of a practical method for objectively assessing breast volume. One such tool that may provide clinical benefit is three dimentional (3D) imaging, which is routinely used by numerous commercial industries to analyze inanimate objects. 3D imaging has proven to be an invaluable tool for performing tasks such as reverse engineering, digital archiving, quality inspection, and animation. Over recent years, 3D imaging has been applied to various medical specialties as well, such as dentistry, craniofacial surgery, and aesthetic facial surgery (9–13).

Reports by our group and others have recently identified breast surgery as an important clinical area that may also be amenable to 3D imaging (14–19). Kovacs et al. have tried to establish optimal 3D scanning techniques for the breast by comparing various methods on dummy models. The authors later compared this data to test persons, and concluded that 3D imaging of the breast is accurate and reproducible (15). Our group has reached similar conclusions regarding the validity of 3D breast imaging in human subjects by developing a method for isolating the breast and re-creating an individualized chest wall for each patient (14). Isogai et al. reported their success using 3D imaging to analyze postoperative symmetry in reconstructive breast patients (16). In this study, the authors exhibit the utility of 3D imaging in comparing the surgical outcomes of various procedures, including TE, rectus abdominis, and latissimus flap reconstruction, and concluded that autologous reconstruction led to the greatest extent of symmetry.

The following study set out to determine the potential of 3D imaging to serve not only as a tool for postoperative analysis, but as a guide for surgical management. 3D breast analysis was performed throughout the reconstructive course with the aim of providing the surgeon with objective data to help with the reconstruction. Our results provide the first clinical evidence that 3D-volumetric data can be a useful surgical aid for TE-implant breast reconstruction.

PATIENTS AND METHODS

Patient Enrollment

Patients scheduled for unilateral mastectomy were referred to the offices of the two senior authors (MC, NSK) for possible breast reconstruction. Patients opting for TE-implant reconstruction, and who had been seen on an office day in which 3D scans were being performed (typically 1–2 days/week), were offered enrollment into the study. Informed consent was obtained from all patients based upon the guidelines set forth by the New York University Medical Center Institutional Review Board (IRB).

3D Scans

Three-dimensional scans were obtained using a previously validated laser scanner (*Konica Minolta—V910*) (20–22). The lens of 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 of the camera. The camera was then lowered to knee-level and tilted upward to obtain additional inferior views at the same positions. Each scan captures the entire area in approximately 2 seconds and then converts the surface shape to a polygon lattice of approximately 300,000 points. The individual images were merged into a single 3D model by identification of pairs of corresponding points in overlapping regions.

Breast-volume measurements were calculated by overlaying the initial surface image with a customized chest wall template for each patient. In order to create a chest wall template, the breast was traced using boundaries defined superiorly at the level at which the breast projects off the chest, and inferiorly, medially, and laterally by the boundaries of the inframammary fold (IMF). On a duplicate image, the polygons within the tracing were removed, and the remaining gap was filled using a curvature based-fill function to complete the chest wall. A software-based Boolean operation of the two-overlapping images was performed and resulted in a closed object with volume measurements. Each customized chest-wall template was used for 3D images taken throughout the course of reconstruction, which included the preoperative visit, the final expansion visit, postexchange procedure, and following revision/symmetry procedures if applicable.

Surgical Technique

Tissue-expander insertion was performed according to the attending surgeons' protocol. Preoperative base width measurements as well as 3D volumetric data were used to determine size TE size. Intraoperatively, the pectoralis muscle was elevated from the pectoralis minor muscle and chest wall. Dissection was carried down to the medial border of the breast as well as to the IMF. The serratus anterior muscle was also dissected free from underlying chest wall. A TE (McGhan or Mentor) was then placed in the subpectoral and subserratus pocket, and the pectoralis and serratus muscles were re-approximated. The amount of saline initially delivered into the TE was determined according to intraoperative assessment of skin viability and accommodation. The skin was closed in two layers.

At the time of the exchange procedure, the mastectomy incision was reopened through the skin and pectoralis muscle, and the TE was identified and removed. A capsulectomy was performed if indicated, and the pocket was irrigated with saline. A sizer was routinely used to determine final implant size. The pectoralis muscle was repaired and the skin was closed in two layers. Contralateral symmetry procedures (i.e., augmentation, mastopexy, or reduction) were performed in a subset of patients according to patient desires, clinical judgment, and 3D measurements.

Data Analysis

Breast asymmetry represents the percent difference between breasts; ([the absolute value of the left breast volume—right breast volume]/volume of larger breast) × 100). All data are presented as mean ± standard deviation.

RESULTS

Preoperative Analysis

Twelve patients have completed 3D-assisted unilateral breast reconstruction with TE-implant. Ten patients underwent immediate reconstruction, with the remaining two having presented for delayed reconstruction. The study population included women with a wide range of physical characteristics, body habitus, and breast size/shape. Patient characteristics included an average age of 51 (range 34–75), weight of 129 lbs (range 112–149), height of 66 inches (range 60–68). Reported bra sizes ranged from 34B to 36C. A summary of these patient characteristics are provided in Table 1.

The average preoperative 3D-volume in patients undergoing immediate reconstruction was 335 ± 129 cm^3 (range 136–518 cm^3). The mean relative size difference between both breasts in this group was 46 ± 30 cm^3. This corresponds to an average baseline asymmetry of 12.0 ± 10.8%, which was distributed as follows: <10% asymmetry (*n* = 4), 10–20% asymmetry (*n* = 4), 20–30% asymmetry (*n* = 2). Examples of 3D images of the patients with the least (0.44%) and greatest (30.46%) asymmetry in the study are provided in Figure 1.

Tissue Expansion

The final pathology of the mastectomy specimens were invasive ductal carcinoma (*n* = 10), ductal carcinoma in situ (*n* = 1), and invasive lobular carcinoma (*n* = 1). Six patients went on to receive chemotherapy and one patient underwent radiation treatment (Table 1). The expanded breast received an average injection volume of 493 ± 101 mL, which corresponded with a mean 3D-volume calculation of 490 ± 140 cm^3. Comparison of the expanded breast to the contralateral breast demonstrated a relative overexpansion of 185% (i.e., 85% additional volume on the expanded side). However, when excluding patients scheduled for a volume-altering procedures (i.e., augmentation or reduction), the average degree of overexpansion was 126 ± 15% (mean additional volume of 141 cm^3). The degree of overexpansion in this patient subset is shown in Figure 2.

Permanent Implant Exchange/Contralateral Procedure

The 3D volumes obtained at the time of final expansion were used as a guide for the final implant

Table 1. Summary of Characteristics of Patients Undergoing 3D-Assisted TE-Implant Breast Reconstruction

Characteristic	Avg or *n*
Preoperative	
Age	51 (34–75)
Bra size	34B (4) 42B (3) 36C (5)
Weight (lbs)	129 ± 15
Height (inches)	66 ± 1.3
3D Preop. volume	335 ± 129 cm^3
Postoperative	
Chemotherapy	8/12
Radiation	1/12
Final pathology	Invasive ductal (10) Invasive lobular (1) DCIS (1)
Implant type	Saline (8) Silicone (4)

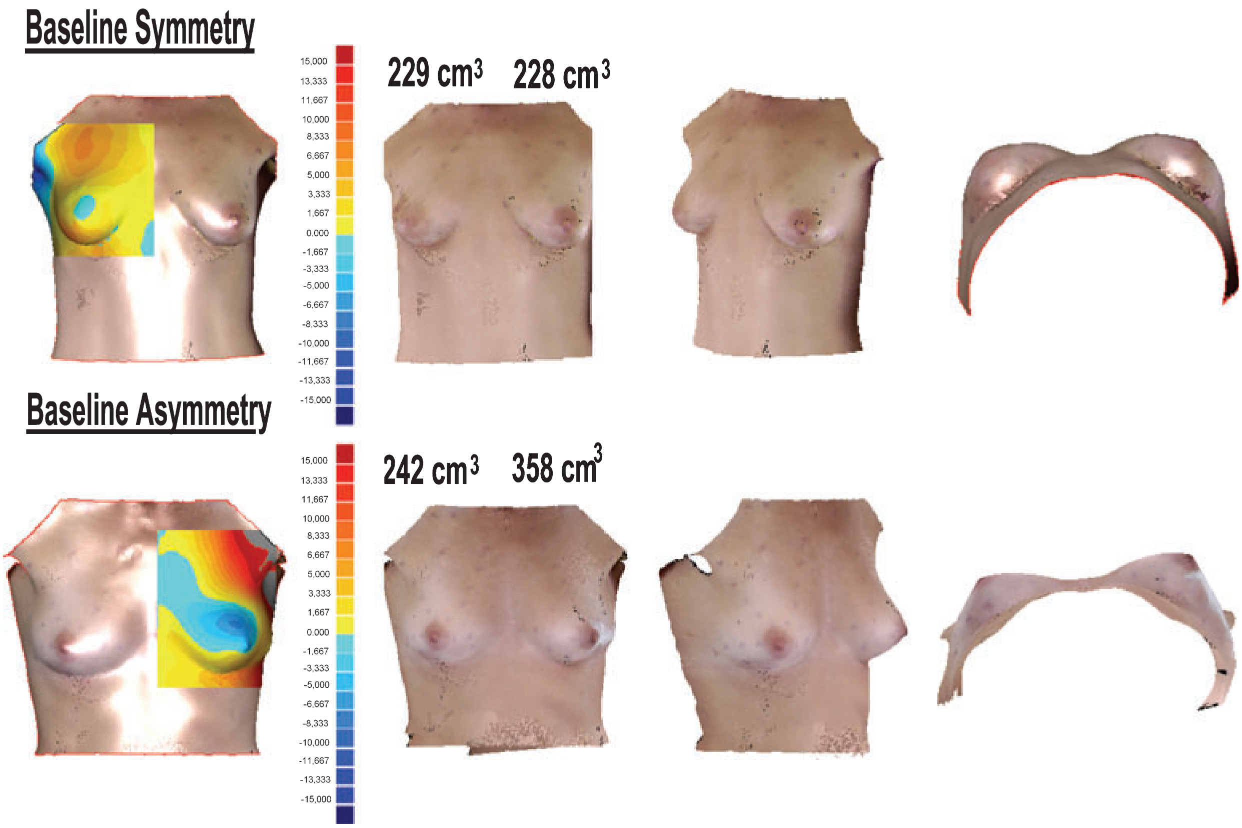

Figure 1. Representative 3D images of the patients with the least (top row) and greatest (bottom row) baseline breast asymmetry are shown from various angles. Images on the left provide a color map analysis of the diseased breast relative to the unaffected breast. (The scale ranges from +15 to −15 mm, and is divided into 20 color segments.) Corresponding 3D volumes are provided above each breast.

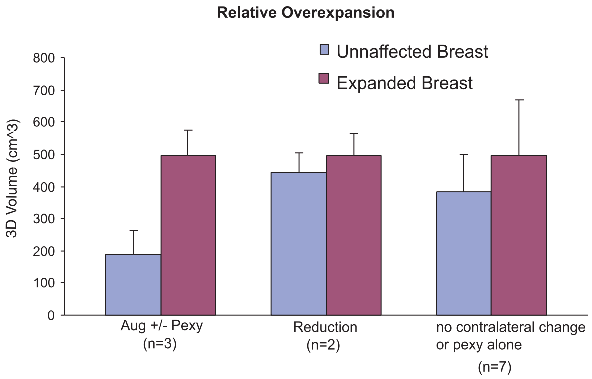

Figure 2. 3D breast volumes at the time of the final expansion demonstrate the degree of overexpansion in various patient groups. Study subjects were divided into contralateral augmentation ± mastopexy (left bars), reduction (middle bars), and mastopexy or no procedure (right bars).

size/shape. Saline or silicone implants were placed in 8 and 4 patients, respectively. A subset of these patients underwent contralateral symmetry procedures at the time of the exchange procedure. While the surgical decision to perform these procedures were based on the patient's desire and clinical judgement, the amount of reduction or augmentation was based on the 3D volume calculations. Contralateral symmetry procedures were performed in eleven patients, consisting of the following: mastopexy ($n = 6$), augmentation ($n = 1$), mastopexy + augmentation ($n = 2$), and reduction mammoplasty ($n = 2$).

In cases of volume-altering procedures (i.e., augmentation or reduction), 3D volumes and relative size differences helped direct surgical management. Examples of how 3D volumes were used clinically for contralateral augmentation or reduction procedures are provided in Figure 3. No ipsilateral revisions procedures were required for symmetry, but one patient did undergo exchange of the TE to an implant with a concurrent latissimus dorsi flap for additional coverage of an implant after irradiation. Figure 3a highlights a patient in which a 375 cc saline implant was chosen for her right breast. With a prospective right breast volume of 375, and a left

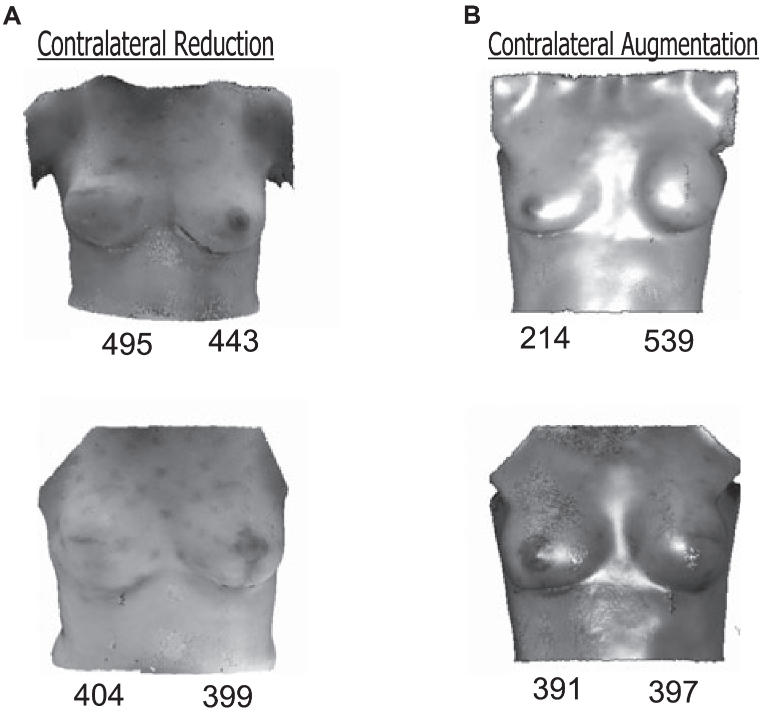

Figure 3. Examples of how 3D volumes were applied clinically for cases in which a contralateral reduction (a) or augmentation (b) were performed. (a) A 61 g reduction was performed on the left breast; this was based on the difference between her left breast 3D volume (443 cm^3)and a 375 cc saline implant chosen for her right breast (difference of 68 cm^3). (b) A 180 cc implant was used to augment the contralateral side that was based on 3D volume calculations of the right breast (214 cm^3) and the implant size to be inserted (375 cc); relative difference of 161 mL^3.

breast 3D volume of 443 ml^3, we deemed that she would be larger on the unaffected size by approximately 68 ml^3. Using this as a guide, a 61 g reduction was performed on the right, resulting in a postoperative symmetry of 98.8%. Figure 3b demonstrates how 3D volumes were helpful for performing a contralateral augmentation. In this patient, a 375 cc implant was chosen for the mastectomy side (left), with the plan for a contralateral augmentation. 3D volume calculations of the right breast were found to be 214 mL^3, thus leaving a relative differences of 161 mL^3. A 180 cc implant was used to augment the contralateral side, resulting in satisfactory postoperative symmetry (98.5%). Similar guidelines were used for the additional patients in which contralateral augmentation was employed.

Postreconstruction Analysis

The average total number of operations required to complete reconstruction in our patient group was 2.08, including the surgery for mastectomy and TE placement. The average postoperative breast volume in the study group was 395 ± 95. Comparison of pre- and postoperative breast symmetry revealed that the majority of patients had improved symmetry following the reconstruction. The average postop symmetry was 95.1 ± 4.4% (compared with 88% preoperatively); Figure 4.

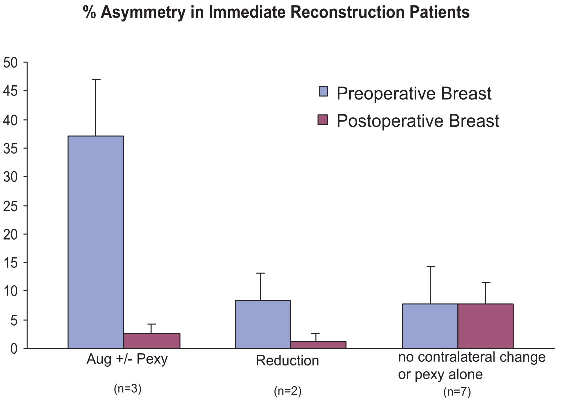

Figure 4. 3D-assisted breast reconstruction yielded suitable postoperative symmetry in patients who underwent contralateral augmentatation ± mastopexy (left bars), reduction (middle bars), or no volume-altering procedure (right bars). The percent pre- and postoperative symmetry are shown.

DISCUSSION

The following study is the first to demonstrate that 3D imaging provides clinically relevant data that can aid in TE-implant breast reconstruction. In these patients, 3D volumetric data was utilized by the surgeon throughout the reconstructive course in order to help guide tissue expansion- and surgical-management. Unlike previous studies which have only shown the utility of 3D imaging as a tool for analyzing postoperative results (16), this study is unique in that it dem-

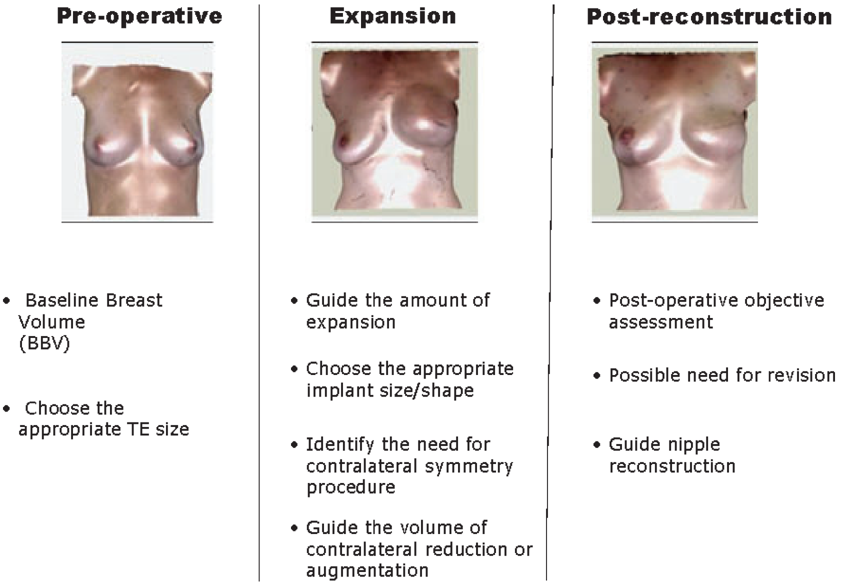

Figure 5. A summary of how 3D-volumetric data can provide clinical data at various stages of TE-implant reconstruction.

onstrates how 3D-volumetric calculations can provide benefit prospectively at various stages of the reconstruction (Fig. 5).

With the advent of 3D imaging technology, one can easily perform breast-volume measurements that were previously unattainable to plastic surgeons. For instance, the term *baseline breast volume* (BBV) represents the preoperative 3D volume, and provides a reference point (or target volume) for proceeding with the reconstruction. BBV is distinct from current indicators of breast size, such as physical examination or cup size, which have been shown to be poor predictors of true breast volume (23). While other techniques such as anthropomorphic measurements have proven to be more accurate for assessing breast volume (24–26), they typically involve formulas that may be too cumbersome or time-intensive for most plastic surgeons. In contrast, 3D imaging offers a practical method for plastic surgeons to accurately obtain breast measurements.

In patients undergoing unilateral TE-implant reconstruction, BBV of the contralateral breast can provide an estimate for the appropriate TE size to insert. Choosing the ideal TE may not always be straight-forward given the variety of patient breast size and shape. Moreover, surgeons must account for some degree of overexpansion (Fig. 2), as well as the possibility of a contralateral symmetry procedure that may add or remove volume. Our experiences with 3D scanning suggest that BBV serves as a reference that can help facilitate this clinical decision.

Three-dimensional imaging also proved to be useful during the expansion process. Although our protocol did not consist of 3D scans at the time of each injection, a final expansion scan was obtained in all patients. This final expansion volume, or *final expansion volume* (FEV), was an important measurement that helped direct the exchange procedure. For instance, in cases where contralateral augmentation or reduction were indicated (Fig. 3), volumetric data was especially valuable. By comparing the unaffected side to the implant size to be inserted, one could predict relative volume differences and the extent of change that is required in the contralateral breast. Of note, while many surgeons favor overexpansion of the TE relative to the unaffected side (27), the degree to which this is done is based on clinical judgment and without the knowledge of true volumetric differences. In the present study, 3D imaging provided a means of determining volumetric differences between the expanded and contralateral breast, and demonstrated overexpansion of approximately 25% in patients whom did not undergo a contralateral procedure.

One intriguing finding in our study was that in some patients, the total amount of saline injected into the TE was greater than the 3D volume at the time of final expansion (FEV). While this observation could be explained by extravasation of saline from the expander, it is also possible that the expander remained intact but was being displaced in a direction that was not measured by the 3D surface image (i.e., not contributing to "functional" breast volume). A potential phenomenon that may be occurring is a degree of posterior displacement of the expander, which we term *posterior expansion volume*. From clinical experience, most plastic surgeons know that some element of posterior expansion does exist. Posterior expansion volume would be an important number to consider when choosing an implant size, especially in patients who were previously irradiated and may have overlying tissue with little laxity. Posterior expansion volume can be calculated using the following equation: (injected volume—3D FEV). In our cohort of patients, the average extent of posterior expansion was 10.8%. Unfortunately, further investigation with MRI into the possibility of posterior expansion is not possible with the metal valves in TEs. However, the authors believe that this finding is noteworthy and warrants future studies with other potential radiographic modalities.

Perhaps the most apparent benefit of 3D imaging to date has been its application as a postoperative analysis tool. Much like the introduction of 2D digital photography, 3D breast data greatly enhances or ability to asses surgical outcomes (28). 3D imaging may serve not only as a valuable research tool, but also as an important device for critically analyzing operative results. Since 3D photography documents the true changes in shape and tissue distribution that occur over time, this technology may help to identify the pitfalls and success of each procedure. Although we limited our analysis to total volume (i.e., size), most commercially available 3D imaging software does have the capability of performing other spatial measurements such as anterior–posterior projection of the breast, surface curvature, distances, and direct vectors. We recently demonstrated the use of these measurements to study the morphologic changes of the breast following reduction mammaplasty (29), and at the time of the manuscript submission have begun analogous prospective studies in breast reconstruction patients. Another potential use of 3D imaging may be to objectively assess breast symmetry, which has previously been described with color mapping (16). Although one potential goal for 3D technology may be surgical simulation, or predicted 3D outcomes, it is important to note that such applications have yet to be well-established.

While the authors believe 3D imaging has a great deal of clinical potential, there are a number of factors that may preclude its widespread use in the near future. Presently, the price of 3D cameras range from approximately $20,000–80,000 and may be too costly for individual practices. Additional costs may also be required for personnel to perform the scans, merge the images (as in the present study in which scans were taken from multiple views), and perform volumetric analysis. Therefore, the current day use of 3D scanners may be limited to specialized or high-volume centers. However, these issues may soon be less relevant with the development of new generation scanners that are being offered at lower costs, as single systems with multiple views obtained simultaneously, and accompanied by user-friendly software for automated breast analysis. Despite initial concerns by our group that patients may not be receptive to 3D scans, it is worth noting that we have achieved nearly 100% success rate in patient enrollment. Thus, patient satisfaction does not appear to be an issue that would prevent the use of 3D imaging clinically.

One question that remains is whether 3D-imaging of the breast yields *better* surgical results relative to traditional reconstructive techniques. To address this issue, a randomized controlled study of patients undergoing conventional- or 3D assisted-reconstruction is required. Our data that over 90% of the patients completed the reconstruction in just two procedures does fair well against historical and nationwide controls (7,8), but does not provide conclusive evidence that 3D imaging can optimize surgical outcomes. On the other hand, this study serves as first ever demonstration of 3D imaging in implant breast reconstruction, and our experiences highlight its utility as a useful adjunct in surgical management, including the decision of implant size, volume of reduction, and volume of augmentation. As 3D imaging becomes less expensive and time-consuming, we hope other physicians will continue to explore clinical benefits of this exciting new modality.

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