Breast augmentation techniques have continued to evolve since the first report of adipose delivery to the breast in 1895 by Czerny. Early techniques for breast augmentation, such as paraffin and liquid silicone injections showed variable success but were limited by the inability to reliably predict changes in volume and shape. In 1962, breast implants were introduced and soon thereafter became the predominant approach to breast augmentation. According to the American Society of Plastic Surgery, 347,500 breast augmentations were performed in the United States in 2008, a 64% increase from 2000. Currently, a variety of different surgical techniques as well as implant subtypes are available. Traditionally, saline implants were used primarily for breast augmentation but this paradigm has changed in the United States since the recent FDA approval of silicone implants in 2006.

To aid in implant selection, various algorithms have been proposed based on implant characteristics, such as size, type (saline versus silicone, textured versus smooth, and round versus anatomic), projection profile, and width. While these factors aid in preoperative planning, surgeons lack a complete 3-dimensional (3D) preoperative blueprint of the breast and thus still rely on linear measurements and some subjective approaches for operative planning. Correct implant selection is critical to a successful breast augmentation to avoid the pitfalls of ptosis, shell visibility, palpability, and lateral displacement.

Not only are current techniques for preoperative evaluation limited, but the assessment of postoperative results also lacks a systematic and objective system. Currently, augmentation mammoplasty results are generally assessed by visual inspection. 2D imaging can be used to perform some surface measurements and assess symmetry, but they are limited in scope and depth. Patient surveys may also be used to determine success, but the outcome measured under these circumstances may include inherent subjectivity that poses obvious limitations. Other studies may record the success of the procedure as defined by the willingness of a patient to recommend the surgery to a friend or family member. Unfortunately, these study protocols fail to objectively define postoperative results or document the changes to breast morphology after implant insertion.

Given the 3D nature of the breast, an optimal tool for assessing breast augmentation surgery would provide objective breast data in multiple dimensions, including shape, volume, and contour. We, and others, have recently demonstrated that 3D imaging may be a valuable resource for the assessment of breast symmetry and other clinical measurements that 2D photography does not provide. The following study applies 3D imaging technology to breast augmentation and represents the first report, to our knowledge, that documents true anatomic changes that occur with augmentation mammoplasty.

METHODS

Patient Enrollment and 3D Scans

Patients undergoing augmentation mammoplasty were offered enrollment into the study. All procedures were performed using a periareolar approach by one of 2 senior authors (M.C., N.S.K.). Informed consent was obtained in accordance with the guidelines set forth by the New York University Medical Center Institutional Review Board. 3D scans were obtained as previously reported. The customized chest-wall template was constructed for each patient. Breasts were isolated as closed polygon models and 3D data analysis was performed as outlined.
Breast Volume Analysis and Volumetric Distribution

Total breast volume was calculated for each pre- and postoperative 3D model. A horizontal-split plane (XZ plane) was placed through the lateral border of the inframammary fold (IMF) to divide the breast into upper and lower poles. To ensure accuracy and reproducibility, this individualized horizontal-split plane was applied to all postoperative images as well. Tissue distribution in the upper and lower poles was determined by calculating the percent of volume above and below this plane.

Breast Projection and Internal Angle

Sagittal sections were taken through the nipple on each breast to identify the point of maximal breast projection. The computer software identified the maximum distance from the chest wall to the breast surface. The maximum anterior-posterior (AP) distance of the breast relative to the chest wall was determined for each pre- and postoperative image. The angle of the upper pole of the breast at the chest wall was also measured and was termed the internal angle of the projection of the breast.

Surface and Vector Distances

The following surface distance measurements were performed: sternal notch to the nipple, and nipple to the IMF. Concurrently, vector measurements were taken from the nipple to the level of the sternal notch on the y-axis.

Statistical Analysis

All data are presented as the mean ± SD. Pre- and postoperative values were compared using a paired t-test and a P < 0.05 was determined to represent statistical significance.

RESULTS

Patient and Implant Characteristics

The average age of the patients was 32 years old (range: 20–51) with a preoperative breast volume that was 184.8 ± 75.0 mL. Round smooth saline and silicone implants were used equally (14 each) with an average implant size of 304.3 ± 39.1 mL. The average AP projection of the implant documented by the manufacturer was 37.3 ± 2.3 mm (Fig. 1).

Volumetric Analysis After Augmentation Mammaplasty

The volume of the breast significantly increased in size from an average of 184.8 mL to 486.3 mL. This change of 301.5 ± 57.7 mL was consistent with the implant size 304.3 ± 39.1 mL (P < 0.01) (Fig. 2). Preoperatively, the average percentage of tissue in the superior and inferior poles was 51.6% ± 9.9% and 48.4% ± 9.7%, respectively. Volumetric distribution of the breast did not change with augmentation (superior pole 52.5% ± 14.7%, inferior pole 47.5% ± 14.7%, P = 0.81) (Fig. 3).

Anterior-Posterior Projection and Internal Angle

The average preoperative anterior-posterior projection was 35.4 ± 10.5 mm. The average implant AP projection documented by the manufacturer was 37.3 ± 2.3 mm. After breast implant insertion, AP projection significantly increased to 58.7 ± 7.9 mm (P < 0.01) (Fig. 4). Interestingly, the average expected postoperative projection was larger than the actual projection. (Average preoperative AP projection + average implant dimension = 72.7 ± 9.73 mm). This change between actual (58.7 ± 7.9 mm) and expected (72.7 ± 9.73 mm) represents a 20.9% decrease from the expected anterior-posterior projection (P < 0.01) (Fig. 5). This observation occurred in both saline and silicone groups to a similar extent (saline: 20.1% ± 5.0%; silicone: 21.7% ± 7.4%; P = 0.535) (Fig. 6). Increased
projection of the breast was associated with a 13.6-degree increase in the internal angle of the breast (8.8 ± 2.2 degrees preoperatively to 22.4 ± 6.4 degrees postoperatively; P < 0.01) (Figs. 7, 8).

**Surface and Vector Measurements**

Sternal notch to nipple surface distance significantly increased by 11.0 ± 9.7 mm (185.3 ± 18.6 mm to 196.3 ± 14.8 mm;
The vector measurement of nipple height was 145.5 ± 17.1 mm versus 146.3 ± 16.3 mm \( (P = 0.86) \), thus demonstrating a stable nipple height. Nipple to IMF surface distance significantly increased from 58.3 ± 10.77 mm to 85.88 ± 11.30 mm \( (P < 0.01) \) (Fig. 8).

**DISCUSSION**

The following study demonstrates the clinical utility of 3D photography for assessing changes in breast morphology that occur with augmentation mammoplasty. New breast parameters are introduced (AP projection, volumetric distribution, and internal angle) that provide significant improvement from previous studies, which are limited to 2D images, surface measurements, and patient evaluations. We believe these techniques are of clinical value and represent an important step toward a more standardized approach to aesthetic breast surgery.

Our initial comparison between preoperative and postoperative volumetric measurements confirmed our techniques and served as an internal control. 3D volume measurements showed no significant difference between the implant size and 3D volumetric change (postoperative volume – preoperative volume). No recognizable changes occurred in the percentage of tissue above and below the horizontal-split plane. This later finding was expected as breast...
Internal Angle = \tan^{-1}(\text{AP projection/nipple height})

**FIGURE 9.** The predicted postoperative internal angle can be predicted using 3D imaging and basic trigonometric analysis. We can determine the postoperative nipple height (unchanged by surgery) and postoperative AP projection (80% of the sum of preoperative projection and the manufacturer-stated implant projection) with preoperative 3D imaging. Therefore, since we know both the postoperative AP projection and the nipple height, we can calculate the postoperative internal angle using an inverse tangent function.

augmentation with round implants should increase the fullness of the upper and lower poles proportionately if placed centrally within the breast.

To further assess morphologic changes, we measured the changes in AP projection after implant insertion. Interestingly, the actual AP projection of the breast was found to be 20% less than predicted based on manufacturer implant dimensions. A likely explanation for this observation may be tissue attenuation of the overlying pocket. Posterior displacement of the chest wall after insertion of the implant in a submuscular pocket may also play a role. This finding has been described in other alloplastic implants, such as in the chin, but has yet to be reported for breast augmentation.\(^\text{10}\) The effects of capsule formation in relationship to the projection of the implant remains unknown, but is unlikely to play a significant role in this study due to the relatively short postoperative follow up. Furthermore, whether these findings are less prevalent with subglandular implants remains unknown.

Also, our data revealed an increased fullness in the superior pole of the breast associated with a 13.6-degree increase in the internal angle. This measurement is unique to 3D imaging and suggests the possibility of predicting the operative changes as well as providing a guide for the implant selection. One useful tool of 3D imaging is the ability to calculate, using basic trigonometric analysis, the predicted postoperative internal angle. From a preoperative 3D scan, we can determine the postoperative nipple height (unchanged by surgery) and postoperative AP projection (80% of the sum of preoperative projection and the manufacturer-stated implant projection). Therefore, since we know both the postoperative AP projection and the nipple height, we can calculate the postoperative internal angle using an inverse tangent function (Fig. 9). Data-based predicted changes such as these (projecting angle of the superior pole and the expected projection of the breast) would allow simulation software to indicate the expected postoperative shape of the breast, thus creating a scientifically based model.

3D data measurements could offer a useful compliment to some of the existing systems for implant selection including the TEPID system, the High Five System, and the Body Logic system. The TEPID system, based on patient’s tissue characteristics, addresses tissue (T), tissue envelope (E), parenchyma (P), implant (I), and tissue dynamics (D).\(^\text{11}\) The High Five system assesses implant coverage/pocket planning, implant size, volume, implant type, infra-mammary fold position, and incision.\(^\text{12}\) The Body Logic System, developed by Mentor (Santa Barbara, CA), includes base diameter, projection, and volume measurements for determining the correct implant. Although these systems are simple and practical methods to evaluate the preoperative breast, they lack in their ability to create a complete objective evaluation of the preoperative breast. 3D measurements provide not only new relevant parameters such as internal angle and volumetric distribution but also provide a computer-based approach for existing measurements (ie, base width) that are currently operator dependent.

The present study also establishes a foundation for utilizing 3-dimensional analysis to compare various surgical approaches. While our study is limited to submuscular, periareolar implant augmentation, these imaging tools can easily be applied to studying results of other surgical techniques. Based on our findings, a surgeon may want to select implants with 20.9% greater projection than desired because of postoperative morphologic changes. However, long-term studies (5 years) should be conducted to highlight definitive postoperative changes following augmentation mammoplasty with varied surgical techniques. Evaluation of long-term results would determine the extent of implant migration, changes in nipple position, or the redistribution of soft tissue. Potential practical applications of long-term analysis include choice of pocket, incision techniques, implant selection to optimize postoperative breast projection, and contour.

To this point, the authors propose 3D photography as a way of creating a new set of objective measurements to document the changes of breast topography over time. The authors believe that by compiling a true series of changes to the breast, surgeons will be able to better assess surgical outcomes.

**CONCLUSION**

3D imaging provides an objective approach to obtaining various breast parameters, some of which have previously not been possible to determine. This technology affords the ability to assess immediate and long-term operative results, and correlate these changes with implant dimensions. While large scale studies are needed to truly incorporate 3D imaging into surgical preoperative planning in breast augmentation, the authors believe this technology will play an important role in the future of breast augmentation.

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