Assessing the Accuracy of a 3-Dimensional Surface Imaging System in Breast Volume Estimation

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Background: Preoperative prediction of breast volume can guide patient expectations and aid surgical planning in breast reconstruction. Here, we evaluate the accuracy of a portable surface imager (Crisalix S.A., Lausanne, Switzerland) in predicting breast volume compared with anthropomorphic estimates and intraoperative specimen weights.

Methods: Twenty-five patients (41 breasts) undergoing mastectomy were scanned preoperatively with the Crisalix surface imager, and 1 of 3 attending plastic surgeons provided an anthropomorphic volume estimate. Intraoperative mastectomy weights were used as the gold standard. Volume conversions were performed assuming a density of 0.958 g/cm^3.

Results: The Pearson correlation coefficient between imager estimates and intraoperative volumes was 0.812. The corresponding value for anthropomorphic estimates and intraoperative volumes was 0.848. The mean difference between imager and intraoperative volumes was −233.5 cm^3, whereas the mean difference between anthropomorphic estimates and intraoperative volumes was −102.7 cm^3. Stratifying by breast volume, both surface imager and anthropomorphic estimates closely matched intraoperative volumes for breast volumes 600 cm^3 and less, but the 2 techniques tended to underestimate true volumes for breasts larger than 600 cm^3. Stratification by plastic surgeon providing the estimate and breast surgeon performing the mastectomy did not eliminate this underestimation at larger breast volumes.

Conclusions: For breast volumes 600 cm^3 and less, the accuracy of the Crisalix surface imager closely matches anthropomorphic estimates given by experienced plastic surgeons and true volumes as measured from intraoperative specimen weights. Surface imaging may potentially be useful as an adjunct in surgical planning and guiding patient expectations for patients with smaller breast sizes.

Key Words: breast reconstruction, breast, mastectomy, mammaplasty, breast implant, Crisalix, breast volume, volume estimation, surface imaging, surface imager

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Breast reconstruction is an important and routine aspect of the surgical management of patients with breast cancer. In 2017, more than 100,000 reconstructive procedures were performed in the United States.[1] It is well established that breast reconstruction improves patients' psychological health, body image, and sexual well-being.[2–4] Breast volume estimation is critical in surgical planning for breast reconstruction and enables surgeons to choose appropriately sized implants, an important factor in determining the cosmetic result of the reconstruction. Moreover, accurate estimations can help patients undergoing breast reconstruction envision their postoperative outcomes and guide their expectations for surgery. Current methods available to assess breast volume include water immersion, magnetic resonance imaging, computed tomography, mammography, anthropomorphic estimation, and other specialized equipment.[5–10] However, these methods are often limited by balancing accuracy against convenience and cost to patients and providers.

Recently, 3-dimensional (3D) surface imaging has emerged as a powerful and noninvasive tool for estimating breast volume. Several 3D surface imaging systems have been described in recent literature, including 3dMD (3dMD LLC, Atlanta, GA), Axis Three 3D Imaging (AX3 Technologies LLC, Miami, FL), Crisalix 3D Surface Imager (Crisalix, S.A., Lausanne, Switzerland), Dimensional Imaging DI3D (Direct Dimensions Inc., Owings Mills, MD), and Vectra XT 3D (Canfield Scientific, Parsippany, NJ) software.[11–13] The Crisalix system is unique in its ability to generate web-based analyses via cloud computing, enabling it to maintain full portability on a tablet computer with a small camera attachment.[12–14] In addition to breast volume estimation, this technology enables patients to visualize and interact with a realistic 3D simulation of postsurgical outcomes, a popular feature that contributes to overall patient satisfaction and communication during the operative planning process.[13–15] Overall, 3D imaging technology is promising for improving the convenience of breast volume estimation and the prediction of postoperative aesthetic results in the outpatient setting. Previous studies in the breast augmentation population have demonstrated Crisalix's ability to simulate postoperative outcomes as well as generate favorable patient experiences during preoperative planning.[14,16] However, further characterization is needed to determine the accuracy with which these systems are able to estimate breast volume, especially in the breast reconstruction population. We report the results of a single-institution, prospective study using the Crisalix 3D Surface Imager to predict the volume of breast tissue removed intraoperatively in patients undergoing mastectomy with immediate reconstruction.

METHODS

Ethical approval was granted by the Stanford University Institutional Review Board. Written informed consent was obtained from all study subjects. Patients at our single institution undergoing unilateral or bilateral mastectomy with immediate reconstruction between July 2017 and March 2018 were prospectively enrolled. All subjects were at least 18 years old. Subjects with preexisting implants were excluded. A total of 25 subjects (41 breasts) were included in the current study, with a mean age of 47 years (range, 27–70 years). The number of subjects was determined before enrollment using a power analysis to detect an estimated 10% difference with a power of 80% and alpha of 0.05.

Preoperatively, subjects were scanned using the Crisalix 3D Surface Imager Camera (Crisalix S.A., Lausanne, Switzerland) mounted on a 9.7-in. iPad (Apple Inc., Cupertino, CA). The Crisalix iPad App (Crisalix S.A., Lausanne, Switzerland) was used to estimate preoperative breast volumes from the scanned images. Per manufacturer's recommendations, skin thickness was set to 0.5 cm, and muscle thickness was set to the default with no additional added thickness (that is, the "muscle increase" parameter was set to 0.0 cm). Boundaries for each breast were determined using the application's automated image analysis software. Additionally, 1 of 3 board-certified plastic and reconstructive surgeons specializing in breast reconstruction (D.H.N., G.K.L., R.S.N.)

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provided an anthropomorphic preoperative breast volume estimate based on his or her individual experience and physical examination, which included inspection, palpation, and measurement of chest and breast dimensions. Mastectomies were performed by 5 breast surgeons at our single institution, and all specimens were weighed before fixation. The intraoperative mass of removed mastectomy tissue was used as the gold standard for breast volume. Volume conversions were performed assuming a constant density of 0.958 g/cm^3.[6,17]

Statistical analyses were performed using Microsoft Excel (Microsoft, Redmond, WA) and SPSS (IBM, Armonk, NY). A *P* value less than 0.05 was considered statistically significant.

RESULTS

The mean weight ± SD of the subjects was 72.4 ± 14.0 kg (range, 49.0-94.3), and the mean height ± SD was 1.617 ± 0.061 m (range, 1.524–1.740 m). The mean body mass index ± SD was 27.8 ± 5.6 kg/m^2 (range, 18.7–37.2 kg/m^2).

Scatterplots of surface imager estimates compared with intraoperative specimen volumes indicated a positive linear relationship, with a Pearson correlation coefficient of 0.812 (Fig. 1A). A plot between surgeon's anthropomorphic estimates and intraoperative volumes revealed a similar linear relationship with a Pearson correlation coefficient of 0.848 (Fig. 1B). The 2-way mixed intraclass correlation coefficients for absolute agreement were 0.660 for the imager compared with intraoperative volume and 0.861 for anthropomorphic techniques compared with intraoperative volume.

The mean breast volume was 690.1 cm^3 (range, 155.1–1876.8 cm^3) by intraoperative specimen weight, 456.6 cm^3 (range, 110.0–1018.0 cm^3) by the imager, and 587.4 cm^3 (range, 140.0–1252.6 cm^3) by anthropomorphic estimates. The mean difference between the imager and intraoperative volumes was −233.5 cm^3 (95% confidence interval, −160.2 to −306.9 cm^3). The corresponding value for anthropomorphic techniques compared with intraoperative volumes was −102.7 cm^3 (95% confidence interval, −41.3 to 164.0 cm^3). Student *t* tests revealed that both the imager and the anthropomorphic techniques differed significantly from the true intraoperative specimen volumes, with *P* values of 2.17×10^{-7} and 2.17×10^{-3}, respectively. The estimates of the imager and anthropomorphic techniques were also significantly different, with a *P* value of 2.48×10^{-5}. Stratifying the estimates according to the range of intraoperative volumes reveals that both estimation methods closely match specimen volumes for smaller breast sizes (Fig. 2). However, for larger breast sizes, the 2 estimation techniques both underestimate the true volume, with the imager tending to do so more strongly than anthropomorphic estimates.

Bland-Altman analyses were performed for the relationship between imager estimates compared with intraoperative volumes, as well as anthropomorphic techniques compared with intraoperative volumes (Fig. 3). Confirming the results of the weight-stratified means analysis, the Bland-Altman plots indicated both estimation methods underestimate breast volumes with increasing intraoperative weight. Stratification by plastic surgeon providing the anthropomorphic measure continued to show the systematic underestimation for larger specimens (Fig. 4). Similarly, stratification by breast surgeon performing the mastectomy did not eliminate the bias toward underestimation in larger specimens for either imager or anthropomorphic estimates (Fig. 5).

DISCUSSION

Three-dimensional surface imagers have become increasingly popular in cosmetic plastic surgery to estimate breast volume and to simulate results after breast augmentation.[18] However, their use and validity in cancer reconstruction surgery after mastectomy have been limited. Surface imaging offers the advantages of speed, convenience, and lack of radiation exposure compared with conventional breast volume estimation techniques, such as magnetic resonance imaging,[6,7] water displacement,[19–21] and computed tomography,[9] thus allowing seamless incorporation into the clinical workflow. In contrast to intraoperative specimen weights, which have served as the gold standard for breast volume estimation,[16] surface imaging can be performed in the preoperative

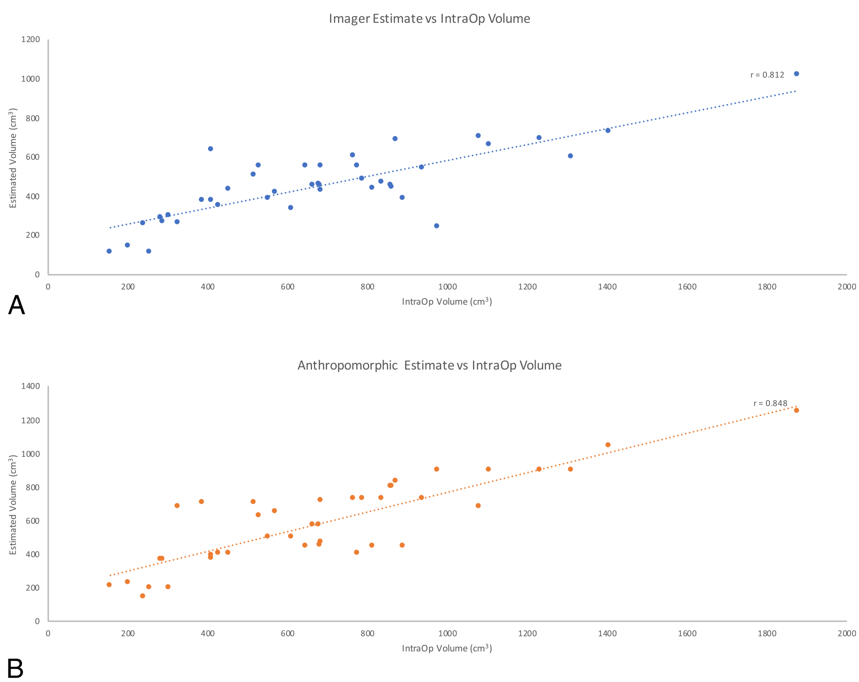


FIGURE 1. Scatter plot of breast volume estimates versus intraoperative specimen volume. Pearson correlation coefficients reveal good linear relationship between estimated volumes by (A) the surface imager and (B) surgeons' anthropomorphic techniques compared to the intraoperative volume gold standard. full color online

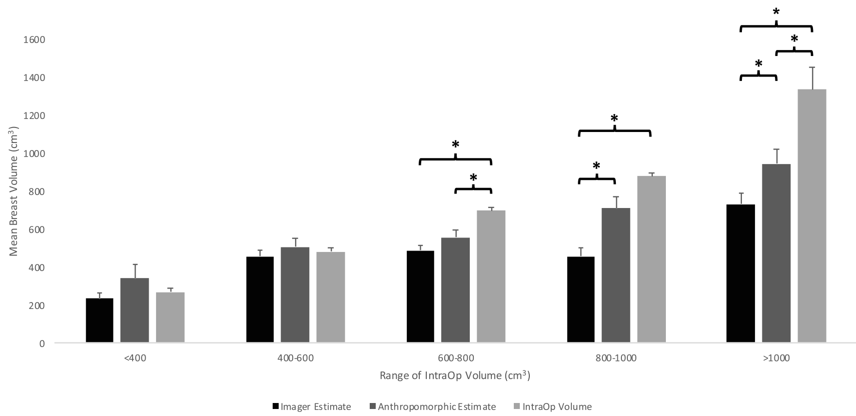


FIGURE 2. Mean breast volume stratified by intraoperative volume. Separating estimates by intraoperative breast volume reveals that both the surface imager estimates and surgeons' anthropomorphic estimates closely track with intraoperative volume for breast sizes 600 cm^3 or less. For larger breast sizes, both estimation methods tend to provide underestimates (*$P < 0.05$, ANOVA repeated measures with Bonferroni post hoc test).

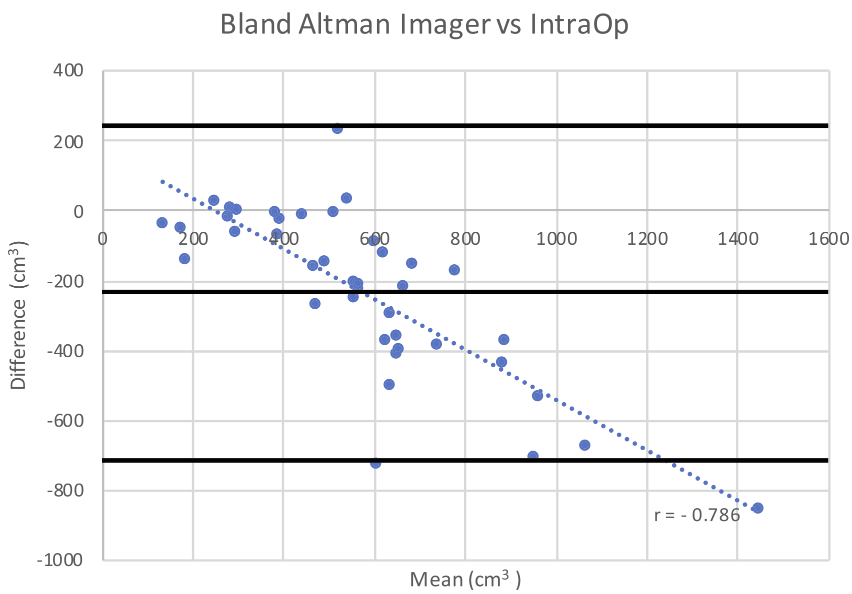
setting, allowing its use for surgical planning and guiding patient expectations. Of the several commercially available surface imagers, we chose to evaluate the Crisalix system because of its portability, relatively low cost, and ease of use. In this study, we attempted to compare the accuracy of the commercially available surface imager Crisalix to both anthropomorphic estimations, which are commonly used clinically, and intraoperative specimen weights.

The scatterplots and Pearson correlation coefficients indicate a reasonable linear relationship between both estimation techniques and intraoperative volume, and the intraclass correlation coefficients indicate moderate and good reliability for surface imager and anthropomorphic estimates, respectively.[22] However, the Bland-Altman plots and volume-stratified bar graph reveal the imager and anthropomorphic techniques are most accurate for breast volumes less than 600 cm^3. At larger breast volumes, the imager and anthropomorphic techniques underestimate the true breast volume. Stratification by plastic surgeon providing the estimate or breast surgeon performing the mastectomy did not reduce underestimation at larger volumes. Thus, the observed bias is likely a direct effect of breast size, rather than an effect of variations in anthropomorphic estimation methods or mastectomy techniques.

Previous reports of the accuracy of surface imagers in breast volume estimation have been conflicting. Losken et al[23] did not find an underestimation bias in the 3dMD Torso surface imager compared with water displacement measurements. Although this may be attributed to a different imager system compared with the one we use here, their study notably included only 4 breasts with volumes greater than 600 cm^3, whereas in the current study, breasts with volumes greater than 600 cm^3 make up more than half of the specimens included. O'Connell et al[24] used the Vectra XT imaging system and found good accuracy between the imager estimates and true volume, but the study utilizes breast casts as opposed to human subjects. In Lee et al's study,[11] the authors used the Axis Three surface imager and included 5 breasts with volumes greater than 600 cm^3; they found a notable trend toward underestimation at larger breast volumes, supporting the results reported here. In light of the design of most surface imagers, several factors may contribute to underestimation at larger breast volumes. First, the Crisalix, Axis Three, and Vectra XT systems are advertised for use in breast augmentation surgery.[25–27] Consequently, these technologies are intended to be applied in patients with smaller breast sizes, possibly explaining their greater accuracy in this patient population. Additionally, larger breasts have a lower surface area to volume ratio. Because surface imaging attempts to determine volume from body surface contours, the relative decrease in surface area in larger breast sizes may account for the imagers' decreased accuracy in these specimens.

Moreover, in our study, we assume that all patients have a constant breast tissue density, skin thickness, and muscle thickness, an assumption that does not accurately reflect the variation in these parameters in the general population. Our parameter estimates may be more reflective of patients with smaller breast sizes and may, thus, partially account for the relative inaccuracy of the imager estimates in patients with larger breast volumes. Interestingly, though, although previous reports have found significant variability in breast tissue density among patients, there has been no demonstrated correlation between density and age, body mass index, breast size, or menopausal status.[28,29] Consequently, the appropriate predictors for breast tissue density remain to be established, and the variability in breast density may contribute to the difficulty of calculating specimen weights from a given volume estimate. Finally, volume estimation in patients with large ptotic breasts, prominent pectoral muscles, or irregular anatomic processes of the axillary region has been shown to be generally more challenging and less accurate.[30,31] Specifically with breast ptosis, the inferior breast pole is directly adjacent to the chest wall. In this situation, there is poor definition of breast landmarks, especially the boundary between fatty tissue and breast tissue, and there is concealing of the inferior breast surface area; these may be further reasons accounting for surface imagers' underestimation of larger breast volumes.

For intraoperative volumes less than 600 cm^3, however, surface imaging appears to provide an estimate of breast volume that is comparable to a surgeon's anthropomorphic estimate. Notably, surgeons who provided estimates in this study were experienced clinicians with a combined total of more than 25 years of experience in breast reconstruction. Consequently, surface imaging may be used as a potential pedagogical tool in teaching plastic surgery trainees with less experience to be more accurate in breast volume estimation, both for reconstructive and cosmetic purposes. As well, in direct implant breast reconstruction, such preoperative estimates can be used to prepare appropriately sized implants for surgery. Although intraoperative specimen weights remain the most accurate and least expensive method of determining breast volume, surface imaging offers the advantage of providing a preoperative estimate of size that may be helpful in counseling patients regarding goals surrounding reconstruction size. The ability to interact with simulated postsurgical outcomes, a common feature of multiple surface imagers, may also be helpful in guiding patient expectations in the outpatient consultation setting, especially for patients



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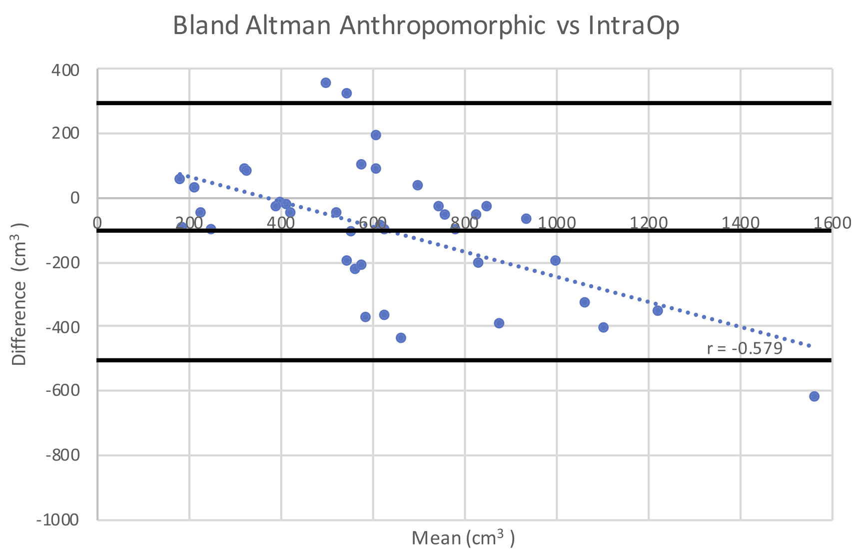

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FIGURE 3. Bland-Altman analyses of surface imager or surgeon estimates compared with intraoperative specimen volume. Bland-Altman analyses suggest that both (A) the surface imager and (B) surgeons' anthropomorphic estimates of breast volume are reasonably accurate compared with intraoperative specimen volumes. However, the accuracy of both estimation techniques declines at larger specimen volumes. full color online

wishing to have reconstructions larger or smaller than their existing breast size. Such simulations have been shown to improve patient satisfaction in the augmentation setting,[15] but future studies will be needed to investigate the impact of this feature in the reconstructive realm.

This study has several limitations. First, we assumed the volume estimate of each breast was independent of all the other estimates. Although this is true for the imager algorithm, it might be less valid for anthropomorphic measures, as surgeons often take into account the relative size of the contralateral breast. However, this approach reflects the use of anthropomorphic estimation techniques in practice. Additionally, this study assesses the accuracy of anthropomorphic estimates from 3 attending plastic surgeons at a single institution. Volume estimates will vary among surgeons with different levels of training, or those at other institutions with dissimilar techniques for anthropomorphic estimates. Lastly, because this study was conducted in a single academic center, this group of plastic surgeons may have been familiar with the mastectomy techniques of their colleagues in breast surgery, so the accuracy of anthropomorphic techniques reported here may be overestimated.

CONCLUSIONS

Surface imaging is a novel technology that may be useful in surgical planning, guiding patient expectations in breast reconstruction

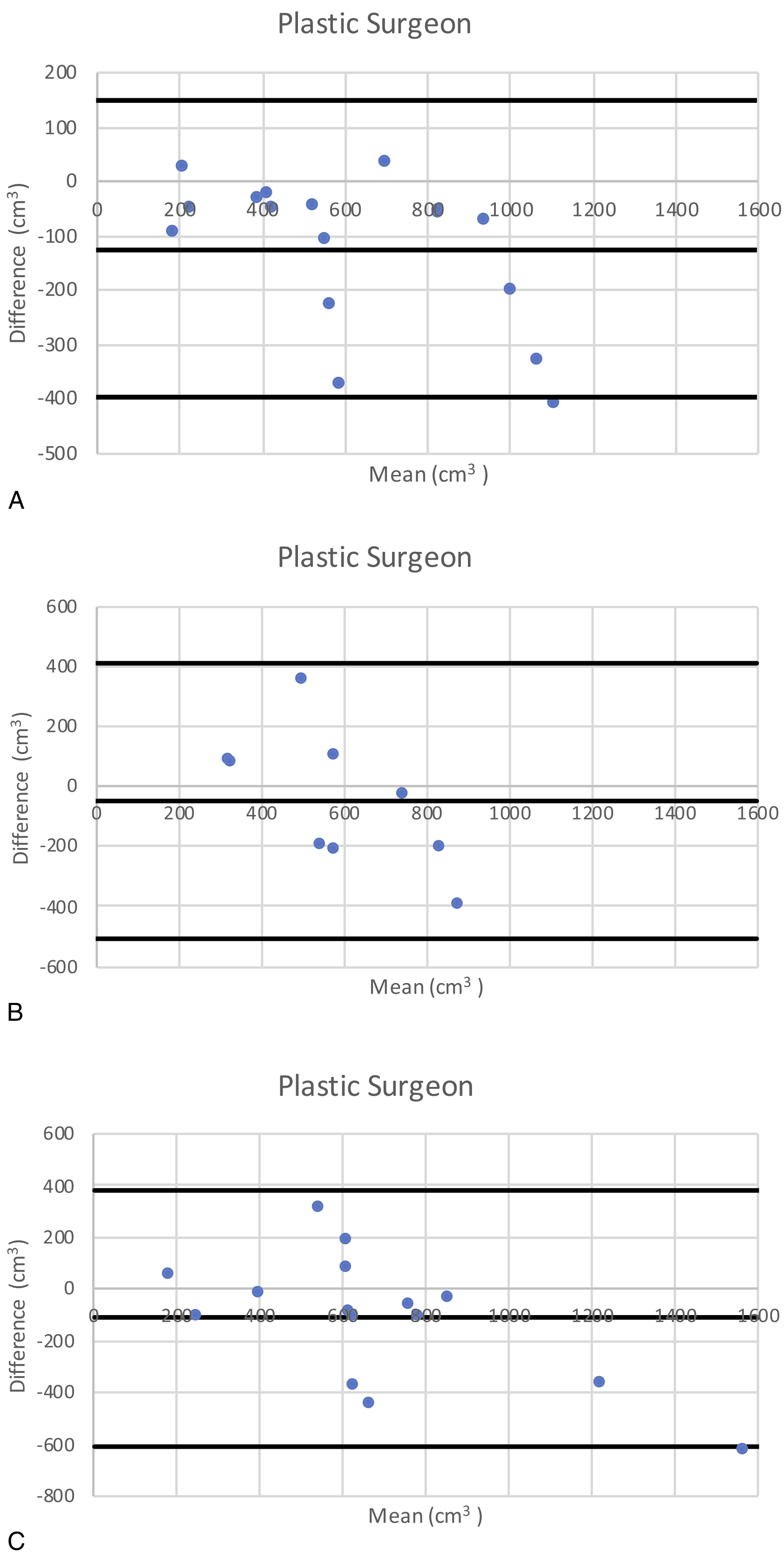

FIGURE 4. Stratification of anthropomorphic estimates by plastic surgeon providing the estimate. A stratified analysis by plastic surgeon does not remove the trend toward underestimation by anthropomorphic techniques at higher breast volumes. full color online

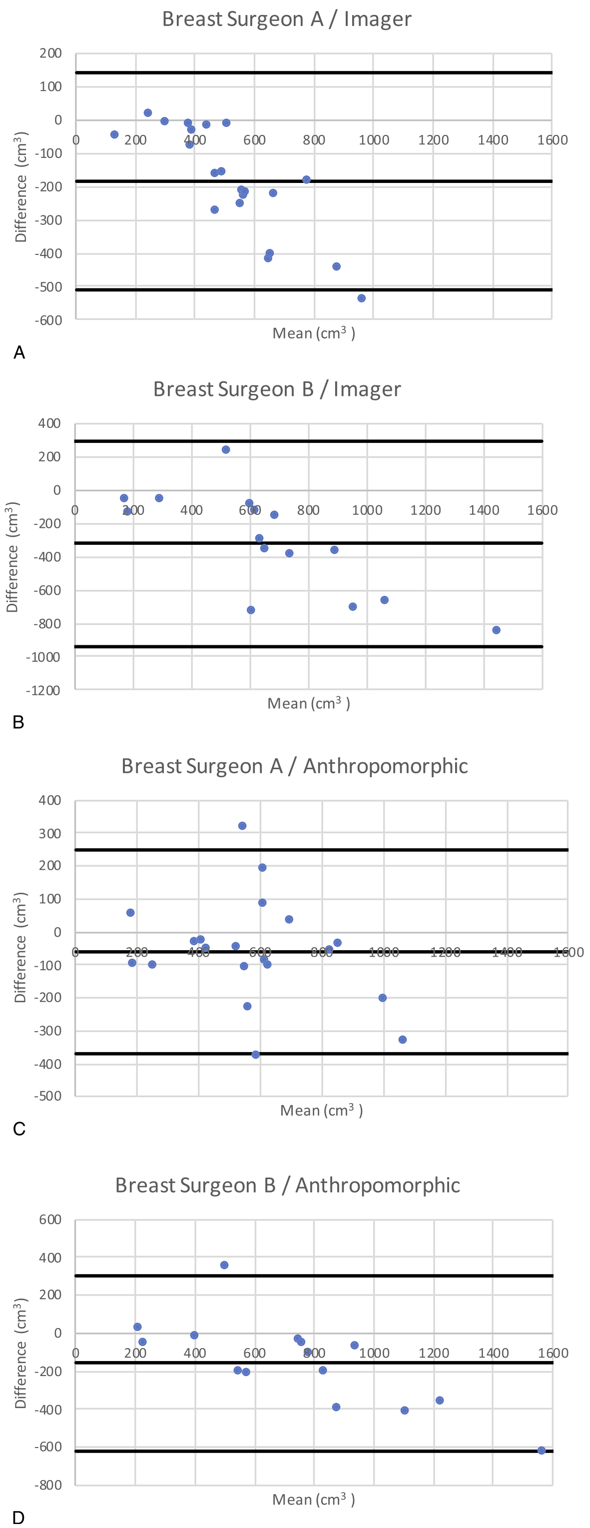

FIGURE 5. Stratification of imager and anthropomorphic estimates by breast surgeon performing mastectomy. A stratified analysis by breast surgeon does not remove the trends toward underestimation by both imager and anthropomorphic techniques at higher breast volumes. Results are shown for 2 breast surgeons only; each of the remaining 3 breast surgeons performed 2 mastectomies or fewer included in this study. full color online

surgery, and teaching trainees to perform breast volume estimation. For breast volumes 600 cm^3 and less, the accuracy of the Crisalix surface imager closely matches the anthropomorphic estimates given by experienced plastic surgeons and the true volume as measured from specimen weights. Future refinements in surface imaging are likely to reduce the tendency of this technology to underestimate larger breast volumes. Further research is needed to identify the impact of years of experience on the accuracy of anthropomorphic estimates, as well as to more clearly delineate how differences in anthropomorphic techniques impact the accuracy of surgeons' estimates.

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