Accurate Assessment of Breast Volume

A Study Comparing the Volumetric Gold Standard (Direct Water Displacement Measurement of Mastectomy Specimen) With a 3D Laser Scanning Technique

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Abstract: Preoperative assessment of breast volume could contribute significantly to the planning of breast-related procedures. The availability of 3D scanning technology provides us with an innovative method for doing this. We performed this study to compare measurements by this technology with breast volume measurement by water displacement. A total of 30 patients undergoing 39 mastectomies were recruited from our center. The volume of each patient's breast(s) was determined with a preoperative 3D laser scan. The volume of the mastectomy specimen was then measured in the operating theater by water displacement. There was a strong linear association between breast volumes measured using the 2 different methods when using a Pearson correlation ($r = 0.95$, $P < 0.001$). The mastectomy mean volume was defined by the equation: mastectomy mean volume = (scan mean volume × 1.03) −70.6. This close correlation validates the Cyberware WBX Scanner as a tool for assessment of breast volume.

Key Words: mastectomy specimen volume, water displacement, laser scanner, 3D scanning, breast reconstruction

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Accurate preoperative volume assessment of women undergoing breast reconstruction is an important requirement for improving quality of results in these patients. An accurate assessment tool would also have a role in surgery for breast reduction, developmental asymmetry, and augmentation. Currently, there is no noninvasive technique routinely used for the quantitative volumetric measurement of breasts. Traditionally, the amount of breast tissue removed or reconstructed is estimated by the plastic surgeon visually, usually with the aid of a tape measure, and accuracy is largely dependent on the surgeon's experience.

The perceived need to determine breast volume more accurately has produced several diverse methods for measurement. Plaster casting, initially used by Ingleby[1] involved creating a plaster cast of the patient's breasts and then filling it with sand of known density. The sand that filled each cast was weighed, and the breast volume determined by dividing the weight by the density. This method was later validated by Campaigne et al[2] and further used by other researchers.[3–6] A modification of this method was suggested by Edsander-Nord et al,[7] that used thermoplastic casts filled with water. The technique of casting is considered reliable, but has the disadvantage of being messy, time consuming, and uncomfortable for the patient. It may also be technically difficult in the large-breasted patient. Water displacement of the intact breast is another method for measuring breast volume, immersing the patients' breasts, and using the Archimedes principle to calculate the volume.[8–11] However, water displacement measurement of the intact breasts can be inaccurate due to the interface between the breasts and chest wall and is an awkward method for patients to tolerate.

Direct measurement of breast tissue as a mastectomy specimen by water displacement methods can be described as the "gold standard" for accuracy in breast volume measurement but is not available in those patients not undergoing mastectomy and cannot be used for preoperative planning. Other methods described in the literature include anthropometric measurement,[3,12–15] magnetic resonance imaging (MRI),[11,15,16] biostereometric analysis,[12,13,17,18] computed tomography,[19] mammography,[11] ultrasonography,[20] and novel measurement devices.[21–24]

Three-dimensional (3D) laser scanning is one of the newer methods available for calculating breast volume.[15,25–31] It does not use ionizing radiation, and therefore allows a noninvasive, quick, and safe method for acquiring breast volume.

The purpose of our study was to examine the validity of using 3D laser scanning techniques in assessment of patients undergoing breast reconstruction and other breast surgery.

To do this, we used the aforementioned classic method of water displacement as a means to compare with our 3D laser scanning method. To our knowledge, there is only one other report in the literature of this sort of comparison.[25] The authors of Losken et al's study suggested that refinements in 3D scanning technique may be needed, especially for women with ptotic breasts. The aim of our study was to test a modified method of 3D scanning and examine its accuracy across a wide spectrum of breast volumes.

METHODS

Participant Recruitment and Data Collection

Approval was obtained for this study from the Flinders Clinical Research Ethics Committee (application no. 269/08). The population from which the study sample was derived was the group of patients treated by the Flinders Surgical Oncology Unit at Flinders Medical Centre. Women with clinically detectable hematoma of the breast (eg, subsequent to biopsy procedures) were excluded to avoid the confounding factor of significant change in breast volume between the time of scanning and time of mastectomy.

Patients planned for mastectomy were approached by the attending breast care nurse about participation in the study, and written informed consent was obtained by one of the research team.

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Each participant was then given a unique study number and diagnosis, and plan for surgery was recorded.

Whole-body imaging was performed preoperatively using the method outlined later in the text, usually within a week of surgery. Three scans were performed for each patient. Scans were stored by the study number in a secure manner. Scans were analyzed after mastectomy specimen measurement and where possible, by different researchers, to avoid bias.

Method for 3D Laser Scanning of Breast and Volume Extraction

Image Acquisition

We chose a Cyberware WBX scanner (Cyberware, Monterey, CA) for our study. This scanner has 4 laser heads and 4 cameras which move vertically on pillars and scans patients in a standing position. Total time for each individual scan is 15 seconds, and total procedure time, including marking takes 15 minutes.

Patients wore custom-made, close-fitting, gray cotton lycra shorts, and were asked to remove any jewelry before scanning. Patients were scanned in a standing position with feet slightly apart and arms abducted. Positioning was standardized by having feet markers on the floor of the scanner. Further, arm positions were standardized at 300 mm distance between the wrists and the hips of the patients.

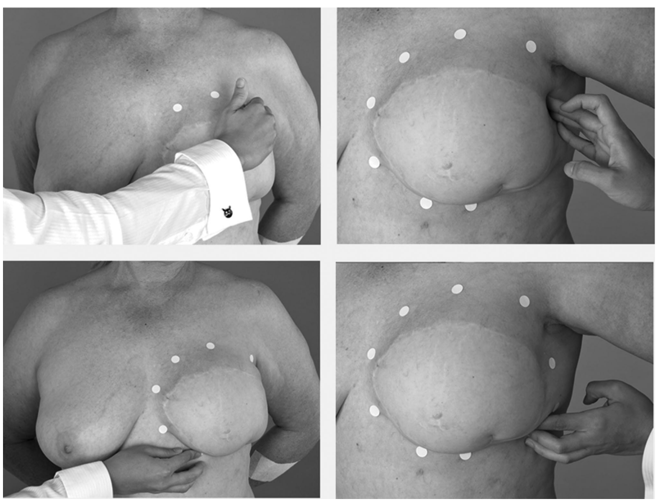

FIGURE 1. Determination of the breast borders by palpation, and placement of landmarking stickers.

The scanner was purchased, the software commissioned, and the method developed for a study on breast reduction patients by the Anthropometry for Elective Surgery Assessment (AFESA group) (mentioned in acknowledgment section). Details on the anthropometric aspects of this protocol are yet to be published (D. Veitch et al, unpublished data, 2010). The key part to this protocol is that the margins of the breast base must be marked by a series of landmarking stickers. This is done by palpation of the chest wall to find the breast margins. In breasts where parenchymal tissue extends below the inframammary fold, the line where the breast skin meets the chest or abdominal wall is used as the line for separation of the breast from the rest of the body. For the remainder of the breast margin, flat white paper stickers, 10 mm diameter, were used for landmarking. These stickers enable the precise location of the breast edge on the scanned data, reducing error due to measuring in the wrong place (Fig. 1).

Data Extraction

Data from the 4 scan heads are merged using "Cyscan" (Cyberware) to generate a 3D mesh which is then rendered. An operator then highlights the skin landmarks sequentially so that the software program can then generate a line to section the breast portion of the data from the torso and calculate the volume of the 3D breast image (Fig. 2). Software used for data extraction was CySlice (headus Pty Ltd) modified for AFESA requirements (P. Dench, Headus, Osbourne Park, Western Australia, Australia). An important innovation of this software is the accommodation of a contoured cut plane which means that the volumetric cut plane between breast and torso is curved to match real body shape, hence allowing us to take into account the concavity of the posterior breast surface (Fig. 3). Image analysis takes approximately 30 minutes.

Mastectomy Specimen Measurement

Intraoperatively, the volume of the mastectomy specimen was measured using a water displacement method as follows: the mastectomy specimen was handed off the sterile field into a lightweight polythene bag (<1 g), which was then molded to the specimen and twisted at the top in such a way as to minimize any trapping of air within the bag. The bag containing the specimen was then placed in a partially filled straight-sided laboratory measuring beaker (3000 mL volume, KAR811, Kartell, Australia) on a set of calibrated digital weighing scales. (The volume of 1 mL of tap water was taken to be 1 g and this was verified with preliminary measurements.) The water was then topped up to the next whole liter graduation on the beaker, with the reading being taken at the bottom of the meniscus of the water and ensuring that the whole of the breast specimen was

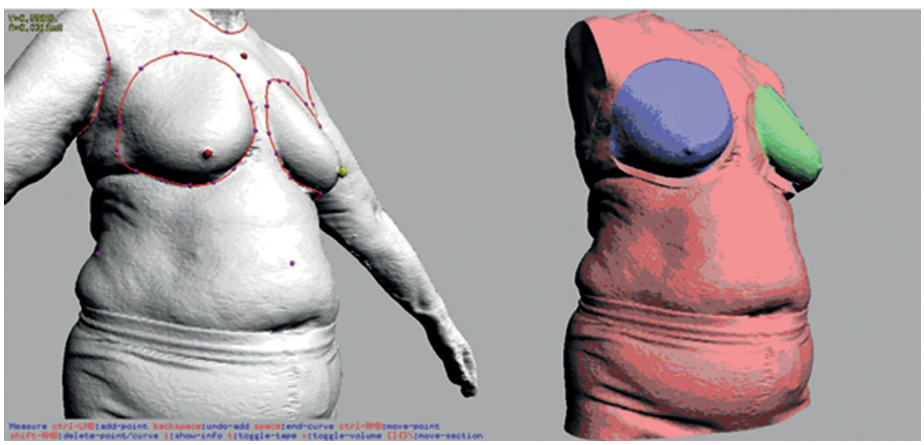

FIGURE 2. Utilizing CySlice (Cyberware) to section the breast portion of the scan from the torso for volume analysis.

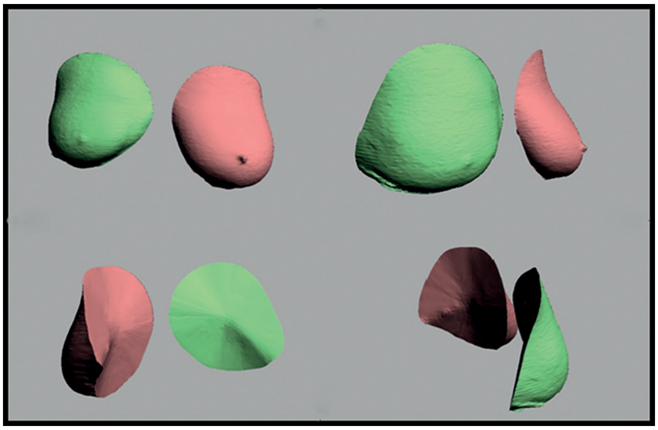

FIGURE 3. The concavity of the posterior surface of the breast is taken into account by the scanner when sectioning the breast away from the torso.

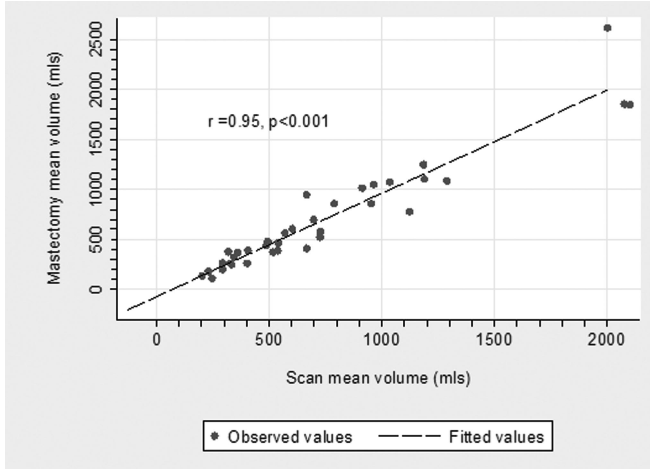

FIGURE 4. Pearson correlation—mastectomy mean volume and scan mean volume.

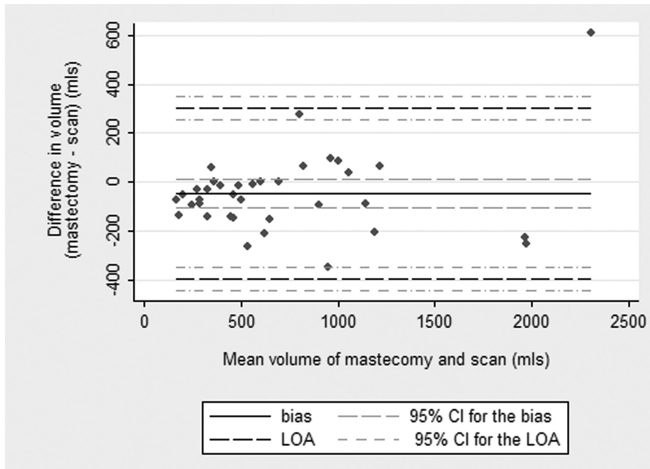

FIGURE 5. Bland-Altman analysis of volumes.

submerged. The bag containing the specimen was then removed. The scales were then tared to zero and the beaker was carefully topped up to the same graduation on the beaker. The weight of the water added to reach this level was taken as the volume of the specimen. The measurement process was repeated 3 times and the measures recorded on a data sheet. Bilateral mastectomy specimens were handled sequentially. The weight of the specimen and the impression of any swelling in the breast were also recorded. The breasts were not infiltrated with local anesthesia prior to mastectomy.

Statistical Analysis

All statistical analysis was performed using Stata version 11.0 (StataCorp, Texas, US). A Pearson correlation was performed to assess the degree of linear association in breast volume measurement using the 2 methods, and simple least squares linear regression was used to define the linear relationship between the 2 methods. Bland Altman analysis was performed to assess agreement between methods. The 95% limits of agreement were formed using the mean difference in volumes ± 1.96 standard deviation (SD) of the differences in volumes. Fixed and proportional bias was assessed using the 95% confidence interval (CI) for the mean difference and simple linear regression of the differences on the means, respectively. A fixed bias indicates that the difference is similar in absolute value for high and low measurements, whereas proportional bias means that the difference is relative to the size of the measurement. The coefficient of variation (CV) for each method was assessed using the formula CV = within-subject SD/mean volume; within-subject SD was assessed using the residual error term from separate random-intercept models for each method. Each model incorporated the 3 measured volumes for each subject (for each method). Despite its limitations, we still feel that the CV gives a useful measure of variability for repeat measurements.[32]

RESULTS

A total of 31 patients were invited to participate in the study over a 1-year period and 30 consented. All patients completed both methods of measurement with 1 set of missing data for mastectomy specimen volume. Median age of patients was 47 years (range, 19–65) and all were white and Australasian.

In all, 16 left breasts and 23 right breasts were measured. The first mastectomy specimen measurement was excluded because of an outlying value and a different technique was used for the measurement of the specimen. Two of the breasts were thought to have some degree of swelling at the time of operation.

The mean mastectomy volume was 712 mL with a range of 158 to 2612 mL, whereas the mean breast volume, as measured by the 3D laser scanner, was 727 mL with a range of 202 to 2101 mL.

There was a strong linear association between breast volumes measured using the 2 different methods when a Pearson correlation was used ($r = 0.95$, $P < 0.001$) (Fig. 4). The mastectomy mean volume was defined by the following equation: mastectomy mean volume = (scan mean volume $\times$ 1.03) -70.6. The point of intersect of the line on the graph reflects an offset between the 3D scanned volumes and volume by mastectomy specimen measurement, with the 3D scan method slightly overestimating the breast volume. This gives the figure 70.6 in the formula. The multiplication fact 1.03 shows that the slope of the graph is virtually 45 degrees.

Figure 5 displays the results of the Bland-Altman analysis of volumes. There was no evidence of proportional bias ($\beta = 0.08$, 95% CI = -0.03 to 0.19, $P = 0.13$), ie, the relationship between the 2 measurement methods was not shown to vary depending on volume, and although there was a tendency for the 3D scan volumes to be higher than the mastectomy volumes, there was no fixed bias proven (mastectomy mean volume − scan mean volume = 46.7 mL, 95% CI = −104.8 to 11.5).

The mastectomy specimen weights ranged from 153 to 1196 g with a median of 450 g. There was a high degree of correlation between specimen weight and both methods of breast volume measurement on Pearson correlation (Fig. 6).

In terms of repeatability of the 2 measurement techniques, the within-subject CV was 8.2% for the scanning method and 5.6% for the water displacement method, ie, on average when a patient was scanned 3 times, the difference between the measurements was only 8.2% for scans, and 5.6% for specimens with a single examiner. Interrater reliability was not assessed in this study but is being included in another study using this methodology.

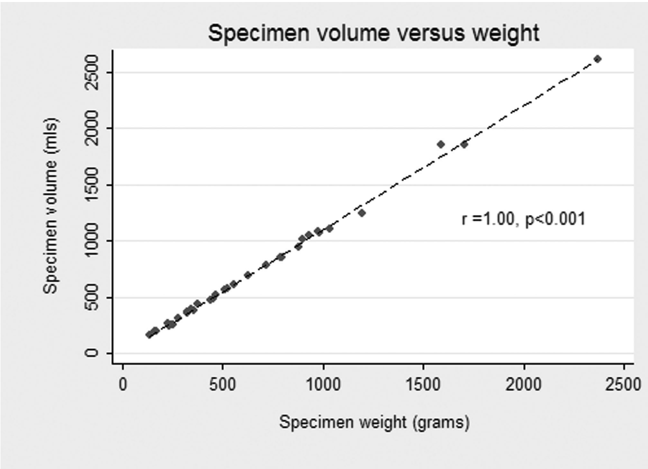

FIGURE 6. Pearson correlation—mastectomy specimen weight and mastectomy mean volume.

CLINICAL APPLICATION

Using the equation derived from the Pearson correlation (Fig. 4), the authors developed the following formula for predicting breast volume:

Breast tissue volume = (Scan volume × 1.03) − 70.6.

This formula was then used to aid clinical management of several cases. Two cases are described below.

Patient 1 was a 27-year-old woman who had developmental asymmetry of her breasts (Fig. 7). Preoperative 3D scans measured the right breast to be 244.4 mL before correction with the formula and 181.1 mL after correction, and the left breast to be 581.3 mL before correction and 528.1 mL after correction. She underwent insertion of a 290 mL implant to the right breast and a mastopexy of the left breast. The predicted final breast volume was, therefore, 181.1 + 290 = 471.1 mL for the right breast and a minimal reduction in volume for the left breast (representing a portion of excised skin and subcutaneous fat). Postoperative scans measured the right breast volume to be 516.4 mL before correction and 461.3 mL after correction, and the left breast to be 554.4 mL before correction and 500.4 mL after correction. The difference between our predicted breast volume on the right and the measured breast volume was only 9.8 mL, hence showing that the scan gave an accurate method for predicting breast tissue volume. It also demon-

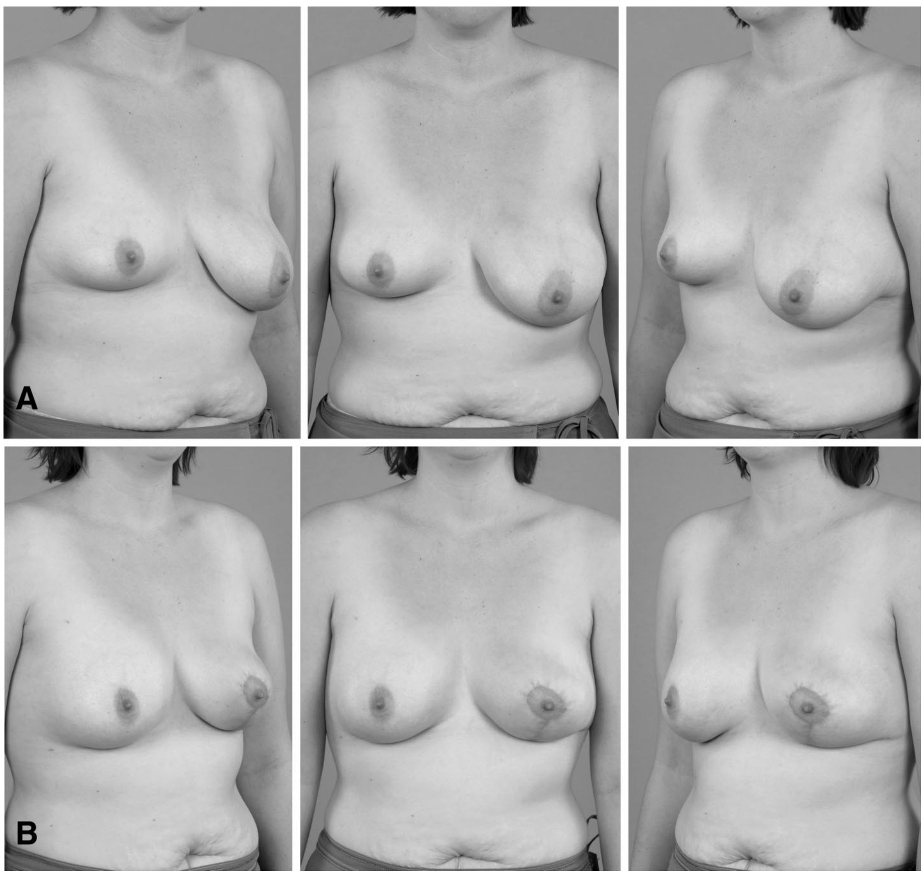

FIGURE 7. Patient 1. A, Preoperative photographs, developmental asymmetry. B, Following insertion of implant in left breast and right mastopexy.

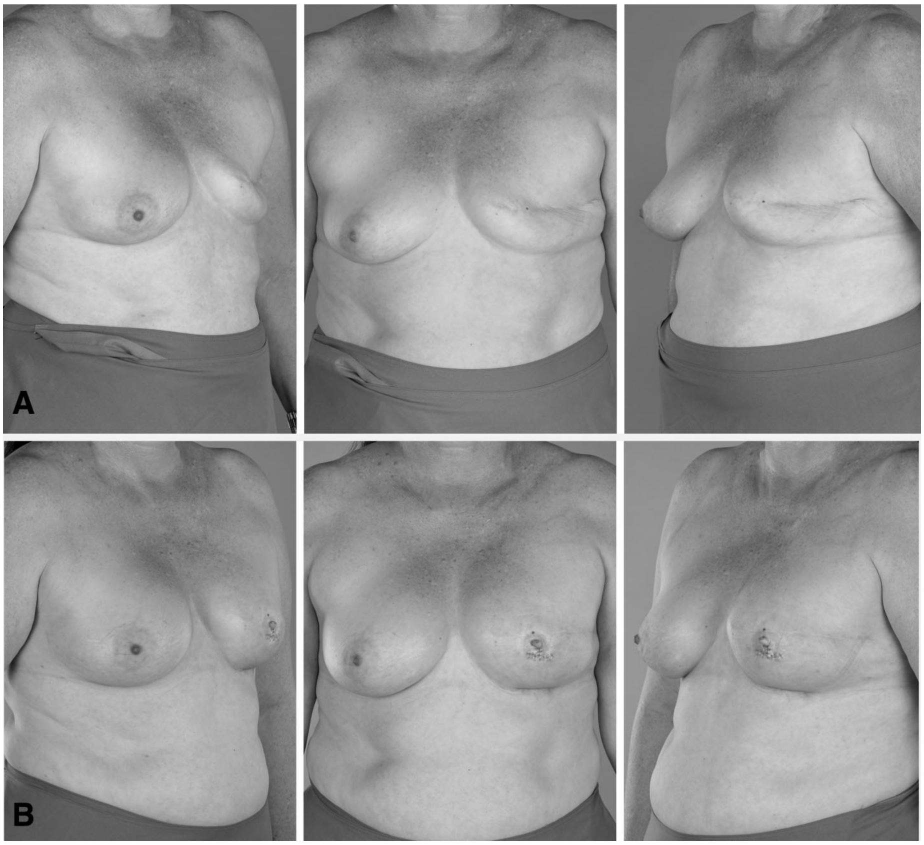

FIGURE 8. Patient 2. A, Preoperative photographs, left mastectomy defect. B, Following implant reconstruction of left breast (and left nipple-areolar reconstruction) and right breast augmentation.

strated the wider clinical goal of achieving good symmetry for the patient (volume difference of only 39.1 mL between breasts).

Patient 2 was a 47-year-old woman who presented for a delayed reconstruction of her left breast following mastectomy (Fig. 8). Her remaining right breast was scanned preoperatively and was 436.8 mL (379.3 mL after correction) in volume. She elected to have an implant reconstruction of her left breast and augmentation of her right breast. A 560 mL implant was chosen for reconstruction of her left breast and a 220 mL implant was inserted into her right breast. Therefore, the predicted volumes were 560 mL for the left breast and 379.3 + 220 = 599.3 mL for the right breast. Postoperative scans revealed the left breast volume to be 691.3 mL (641.4 mL after correction) and the right breast volume to be 639.6 mL (588.2 after correction). The difference between predicted and actual breast volume for the left side was 81.4 mL and for the right side was 11.1 mL. The difference in volume of the 2 breasts was 53.2 mL.

DISCUSSION

This study was performed to determine the accuracy of the Cyberware WBX Scanner, and a particular method for using it, as a tool for measuring breast volume, with the aim of using it as an adjunct to preoperative planning in the future. Our results, from measuring 39 breasts in 30 women, showed a close correlation between preoperative scan volume and volume of the mastectomy specimen as measured by water displacement. There was a tendency for the scan volume to be greater than mastectomy volume, which is shown as a constant on the Pearson correlation (Fig. 4). We postulate this difference to be because of the volume of the overlying skin and subcutaneous tissues that are present in the whole breast and not the mastectomy specimen. To predict breast tissue volume from raw 3D scan volume, the following formula can be used:

$$\text{Predicted breast tissue volume} = (\text{3D scan volume} \times 1.03) - 70.6.$$

Although it seems intuitive that the correction factor would increase as breast volume increases (as one would expect greater volume of skin in larger breasts), our data have not found that to be the case. Application of this formula, which virtually only removes a constant from the scan volume, seems to give a good prediction of breast tissue volume. The explanation for this may be that the volume of skin is only one of the factors that is being corrected by application of the formula and there is another factor, intrinsic to the scanning process (for example, the scanner may tend to overestimate the volumes in smaller breasts, and underestimate volumes in larger breasts), which is changing in the opposite direction as the breast volume increases, the net effect being constant.

We used a Bland-Altman equivalence of means analysis to try to further verify the equivalence of the 2 methods of measuring breast volume and their relationship. Although the analysis again showed a tendency for scan volume to be greater than mastectomy volume, numbers were insufficient to prove this relationship with this method.

We found a high degree of correlation between the weight and volume of mastectomy specimens. This supports the common practice of using the weight of the mastectomy specimen as a guide for the volume of tissue or implant in immediate breast reconstructions.[33]

In Losken et al's study, 19 breasts of 14 women were measured by preoperative 3D scanning and intraoperative water displacement.[25] They found no significant overall difference in the volume between intraoperative specimen measurement and preoperative scans. However, they did find that there was variability in volume measurements from 13% to 16% of the actual breast volume, with larger breasts demonstrating less measurement bias. This is different from our results, where we found no measurable bias with change in breast volume. A key difference in methods between our study and that of Losken et al is that in their study landmarks were made on the scan rather than on the patient and were made at fixed bony points rather than at the clinical limits of the breast. We would argue that, as there is significant variation between individuals in regards to the position of the breast tissue in relation to the skeleton, it is more relevant to define the limits of the breast by palpation prior to scanning. We found our technique to be suitable for all patients, regardless of degree of breast ptosis.

The availability of 3D laser scanning technology for breast volume measurement has prompted researchers to investigate its validity and its potential uses. Isogai et al[26] used a 3D scan technique to compare reconstructed and normal breasts but did not compare 3D scanning with other modalities. Kovacs et al[15] compared 3D scanning to 3 other methods (nuclear MRI, thermoplastic castings, and anthropomorphic measures) in 6 patients to assess the advantages and disadvantages, as well as the reproducibility of each method. They found that MRI and 3D laser scanning provided a high degree of accuracy in measurement and compared very well with each other, as opposed to thermoplastic casting and manual anthropometric measurement techniques, which were significantly less accurate. Tepper et al[29] performed a prospective study where they followed 12 breast reconstruction patients with 3D scans throughout the entire process of reconstruction following mastectomy, including procedures for symmetry. They concluded that 3D scanning can be a useful aid in surgical planning, and has the potential to optimize results of breast reconstruction, in addition to being acceptable to patients. In a separate study, they performed 3D assessments of patients undergoing reduction mammaplasty, specifically examining changes in surface anatomy, tissue distribution, and projection as well as volume, and concluded that this technology could lead to improved objectivity and consistency in mammaplasty procedures.[31] Although it can be argued that the cost of a 3D laser scanner may be prohibitive to some units, this must be weighed up against the cost of revisionary procedures for patients with suboptimal results in complex breast surgery.

One of the limitations to our study is the potential for variability in determining the boundaries of the breast. Preoperative scans were performed by 3 investigators, with the margins of the breasts determined by palpation and marked with scanning stickers. The accuracy of these margins directly affects the accuracy of the volume calculated using the computer software. It would be useful to perform a follow-up study that assesses interrater variability in marking out the boundaries of the breasts to determine if this significantly affects the final calculated volume. However, the strength of this method over using fixed bony points is that it allows for variation in the position of the breast base and is not hindered by significant breast ptosis (which is common in the reconstructive age group).

A further limitation is that the study had a small sample size, which made it difficult for us to address the problems in accurately measuring very large breasts which showed higher variability. In the absence of a large sample size, it may have been useful, like Kovacs et al,[15] to be able to include another modality for measuring breast volume in this study, eg, MRI, to see how those volume measurements compared with the volumes from 3D scanning. However, we designed this study to cause as little disruption to the patients' routine care as possible, hence limiting their commitments to a single 3D scanning session. Our unit is currently utilizing the scanner and the formula derived from this study to assist with breast reconstruction and symmetrizing procedures. We hope that further clinical cases will provide more information on the validity of this method (and the formula) over time.

In addition to the above limitations, we also performed the examination in a standing position only. It can be argued that scanning patients in a supine position would eliminate breast ptosis in large-breasted patients, hence increasing accuracy. However, the scanner used in this study was designed to perform examinations in a standing position only. It would have been useful to scan the same patients in a supine position as well to see if those results correlated better.

Despite these limitations, we feel that our findings are sufficient to validate the use of the Cyberware WBX Whole Body Scanner in the manner described to measure breast volume, with a good correlation between the volume measured by 3D scanning and by water displacement. The formula to predict breast tissue volume from scan volume is breast volume = (scan volume $\times$ 1.03) $-$ 70.6. This formula has been shown to be useful and valid in initial clinical cases.

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A Cyberware WBX Scanner (Cyberware, Monterey, CA) was used in this study; Image capture was performed using Cyscan (Cyberware); Image analysis was performed using CySlice, Headus (metamorphosis) Pty Ltd; Statistical analysis was performed using Stata version 11.0 (StataCorp, College Station, TX).

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