Correspondence of Breast Measurements for Bra Design After Reconstruction Surgery

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Abstract

Bra fit is a common quality of life problem for women with breast reconstruction. However, there is a lack of knowledge of how the changes in breast size and shape due to breast reconstruction surgery affect a woman's bra comfortability. There exists a unique opportunity to capture surgeons' knowledge of how breasts change after reconstruction and relay that information to clothing designers to aid designing bras for this patient population. Our goal is to investigate how to translate surgical knowledge about breast size, shape, and symmetry changes to quantitative data usable for bra design. We compared common measurements of the breast used by clothing designers to determine bra fit to standard clinical measurements used by surgeons for reconstruction planning. In consultation with a clothing designer and reconstructive surgeon, we determined 7 bra measurements and 8 associated fiducial points that can be localized on the type of clinical images that is widely used for documenting surgical outcomes. The measurements summarize the width, height, and projection of the breasts, as well as, the location of the breasts in reference to each other and to the torso. From our previously gathered database of 3D surface images of the torsos of 505 women who underwent breast reconstruction at The University of Texas MD Anderson Cancer Center, we selected a sample of 32 women who had implant-based reconstruction and had 3D images before breast surgery and images from at least three months after final implant placement. Using software developed by our team members at the University of Houston, a team member marked fiducial points, which were reviewed by an expert, on the pre-operative and post-operative images to calculate the bra measurements. Using these fiducial points, we measure the size, shape, and symmetry changes in a manner that is directly translatable to clothing design from the pre-operative image to the post-operative image for each patient to identify common changes for implant-based reconstruction. Future work will lend insight into how different types of reconstruction affect bra fit and how bra design can be adapted to improve quality of life after breast reconstruction.

Keywords: Apparel design, Breast reconstruction, 3D body images

1. Introduction

Breast reconstruction can have a positive impact on breast cancer patients' psychosocial well-being, but some quality of life issues can also arise from reconstruction procedures. The goal of breast reconstruction is to recreate an aesthetically acceptable breast mound, but reconstructed breasts do not have the same characteristics as natural breasts. Bra fit can be a daily concern for women with reconstructed breasts because bras are designed for breast shapes typical of natural breasts and the elasticity qualities of reconstructed breasts vary. In a preliminary focus group study, we found that 53% of women with breast reconstruction were less satisfied with their bra fit after surgery and 46% were less satisfied with their bra comfort.

Bra comfort and fit is an important topic for all women, with more researchers using engineering principles to determine how to improve bra functionality and fit [1]–[5]. Numerous studies have shown that many women with natural breasts wear the incorrect bra size [5], [6]. Thus, the task of finding a well-fitting bra for reconstruction patients, who have to accommodate for changes in breast shape, symmetry, size, and softness, can be significantly frustrating. Fig. 1. provides an example of how breast shape can change after an implant-based reconstruction.

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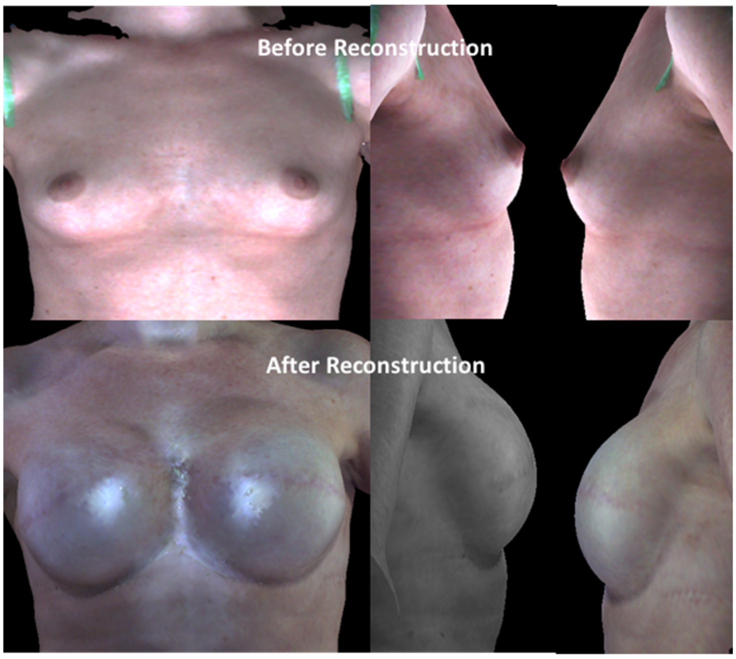

Fig. 1. Significant morphological changes occur after breast reconstruction that can affect bra fit

Little quantitative research has been conducted to understand the specific bra needs of women with reconstructed breasts, but qualitative studies have shown that breast cancer patients have common complaints and challenges pertaining to bra comfort and fit [7], [8]. From focus groups and an online survey our team conducted in 2014, we learned that women with breast reconstruction had difficulty finding post-surgical garments that addressed their specific needs [8]. Most women were wearing bras purchased from a retail store versus a bra provided by a healthcare provider, highlighting the need for clothing designers to learn how to design bras for these women to increase access and bra options. Frequent complaints included uncomfortable fabrics and design elements such as difficult closures, spillage or gaps in the cups, seams over scars, and poor aesthetics. As other studies have demonstrated that the physical characteristics of the breast and torso affect bra fit [9], [10], we aim to inform clothing designers about the unique characteristics of women with reconstructed breasts by utilizing clinical expertise in the assessment of breast shape and symmetry. Reconstructive surgeons already possess the tools and standardized metrics to describe breast size, shape, and symmetry changes. But, the clothing design and plastic surgery communities have different lexicons, and it is necessary to find common ground between them in order for designers to be able to use the valuable clinical knowledge. This study outlines the first step necessary to construct a system to transform surgeons' knowledge of how breasts change after reconstruction, as quantified from standard clinical images used to document surgical outcomes, into the measurements that clothing designers need to create bras.

2. Materials and Methods

2.1. Terminology

The key component of this study is validating a system to relate terminology and measurements used for surgical purposes to terminology used in the clothing industry for designing bras. The sections below outline the terminology we selected to develop our breast measurement system for 3D surface images.

2.1.1. Clothing Terminology for Determining Bra Fit

The anatomical landmarks used for bra fitting are in relation to the *breast base*, which is the area of the breast on the chest wall. Fig. 2. demonstrates the landmarks on the breast base for a right breast. The critical points are the *top point*, which is the most superior point of the breast base, the *front point*, which is the point towards the center front of the breast base, the *side point*, which is on the outer side of the breast base, the *under-bust point*, which is the lowest point of the breast base, and the *bust point (BP)*, which is the most projecting point of the breast (may or may not be the nipple) and the most important point for clothing designers.

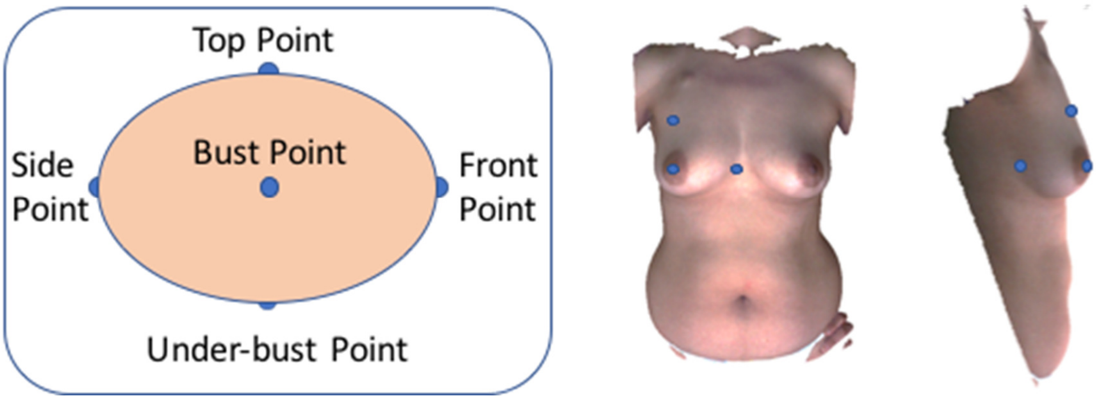

Fig. 2. Landmarks used for measuring the breast for bra design. The figure represents a right breast base.

The main components of the bra are the cups, bridge between the cups, cradle underneath the cups, wing, shoulder strap, and closure. In order to create these elements, five contour measurements are taken: (1) under band length, which is the circumference of the torso at the level of the under-bust point, (2) cup length, measured from the top point to the under-bust point, (3) under cup length, taken from the bust point to the under-bust point, (4) front cup width, which is the length from the front point to the bust point, and (5) side cup width, measured from the bust point to the side point. Additional body measurements include straight line measurements such as the distance between the left and right bust points and the distance from the front neck point to bust point, the half-way point of the shoulder line to the bust point to determine the starting point of the shoulder strap, and the bust point to the point that lies between the breasts along the center line of the torso.

2.1.2. Surgical Terminology for Determining Breast Shape

There are numerous measurements of the breast that help inform the size, shape, and volume of a breast [11], [12]. Not all of these measurements are available from 3D torso images, so our team has developed a set of standardized fiducial points and measurements to measure breast symmetry, shape, and volume. These fiducial points are the sternal notch (SN), nipple (N), midclavicle (MC), transition point (TP), medial point (MP), midline (M), inframammary fold at the meridian (IMF), anterior axillary point, and lowest visible point. Surface measurements include SN to N, MC to N, MC to TP, IMF to N, MP to N, M to MP, LP to N. Straight line measurements include difference in height of the lowest visible points between the left and right breast, contour distance (curvilinear distance measure along the surface) between left and right nipple, and nipple to chest wall distance (projection).

2.1.3 Proposed Correspondence System

Based on the experiences of the clothing designer (Liu) and reconstructive surgeon (Reece) on our team, we selected seven clothing measurements that correspond with clinical metrics that we can measure on 3D surface images of the torso that are routinely collected to document reconstruction outcomes. We used eight fiducial points: sternal notch, midclavicle, transition point, medial point, midline, inframammary fold, lateral point, and most projecting point (MPP). We used most projecting point instead of the nipple because it more closely aligns with the bust point; in addition, many women do not have a nipple after reconstruction so it is necessary to select another point in order to make the measurements. While the under band length is an important bra measurement, it is not possible to measure with the 3D torso images as the images do not include the back of the patient. Fig. 3. displays the locations of the fiducial points on a 3D torso surface image.

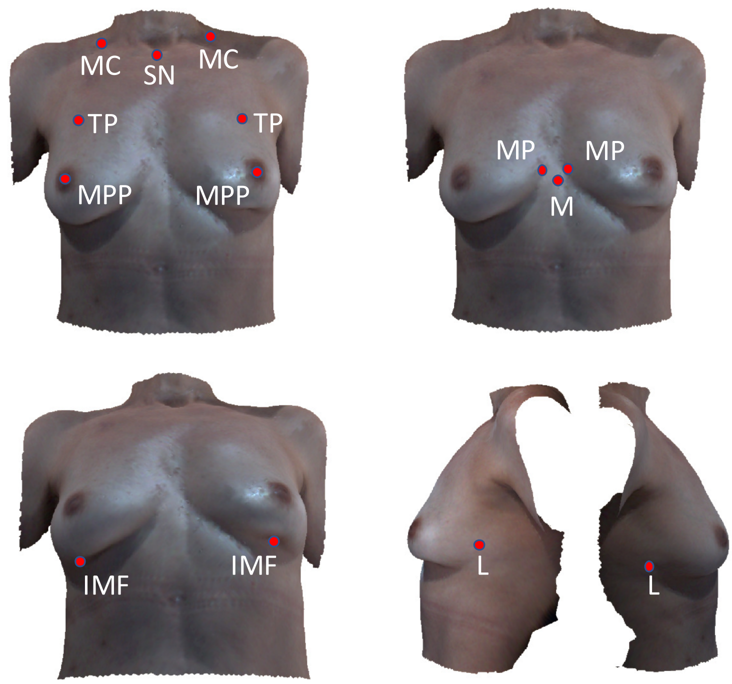

Fig. 3. Location of selected fiducial points: Sternal notch (SN), Midclavicle (MC), Transition Point (TP), Nipple (N), Medial Point (MP), Midline (M), Inframammary Fold (IMF), and Lateral Point (L)

Table 1 outlines the seven measurements we included in our system and the definition we used to make the measurement using surgical terms. Five measurements are contour measurements; bust point distance and front neck point to bust point are straight line distances.

Table 1. Defining clothing terminology in surgical terms

Clothing Terminology	Definition
Bust Point Distance	Straight line distance between most projecting points of each breast (MPP to MPP)
Under-Bust Point of Breast Base to Bust Point	Distance from inframammary fold to most projecting point for each breast (IMF to MPP)
Front Neck Point to Bust Point	Straight line distance from sternal notch to most projecting point for each breast (SN to MPP)
Front Point of Breast Base to Bust Point	Distance from medial point to most projecting point for each breast (MP to MPP)
Side Point of Breast Base to Bust Point	Distance from lateral point to most projecting point for each breast (LP to MPP)
Center Front Point on the Bust Line to Bust Point	Distance from midline to most projecting point for each breast (M to MPP)
Mid-Shoulder Point to Bust Point	Distance from mid-clavicle to transition point plus the distance from the transition point to the most projecting point (MC to TP, TP to MPP)

2.2. Participants

From a database of 505 women who underwent breast reconstruction at The University of Texas MD Anderson Cancer Center from 2008 to 2016, we selected participants who had implant-based reconstruction as well as 3D torso images taken at baseline before any surgical breast cancer treatment and at a time point at least 3 months after breast reconstruction, yielding 72 participants. 3D torso images were taken with a 3dMDTorso system (3dMD, Atlanta, GA, USA). Excluded from the study were women who originally had implant based reconstruction but later received an autologous reconstruction. This selection process yielded 32 patients who we were able to verify met all of the criteria. For preliminary evaluation of our system, we chose 12 patients for whom we were able to identify at least seven out of the eight fiducial points. Four had unilateral reconstruction and eight had bilateral reconstruction. The post-operative image was taken at 9 months after initial reconstruction for four of the patients and at least 18 months after the initial procedure for eight of the participants.

2.3. Breast Measurements

Measurements were taken with software developed by our team members at University of Houston (Merchant) [13]. The software requires the user to manually select the fiducial points on each individual image and then automatically calculates the associated measurements. A team member (Chu) was trained to identify the anatomical fiducial points and take measurements on the images described in the previous section. The team member's point locations were evaluated and approved by an expert reconstructive surgeon (Reece).

3. Results

3.1. Validation of Correspondence System

We analyzed 64 images from 32 patients to determine the feasibility of identifying our selected fiducial points and gathering the necessary measurements. The non-surgeon team member was able to confidently identify the fiducial points on 28 images after training, needed additional guidance for specific points on 29 images, and was unable to analyze 7 images. We were able to evaluate both the baseline and post-reconstruction images of 12 patients. Of these, the complete set of measurements was available for eight patients. Four patients had images with either holes or data missing so that a fiducial point was either not visible or present. Fig. 4. visualizes the seven measurements as traced by the software.

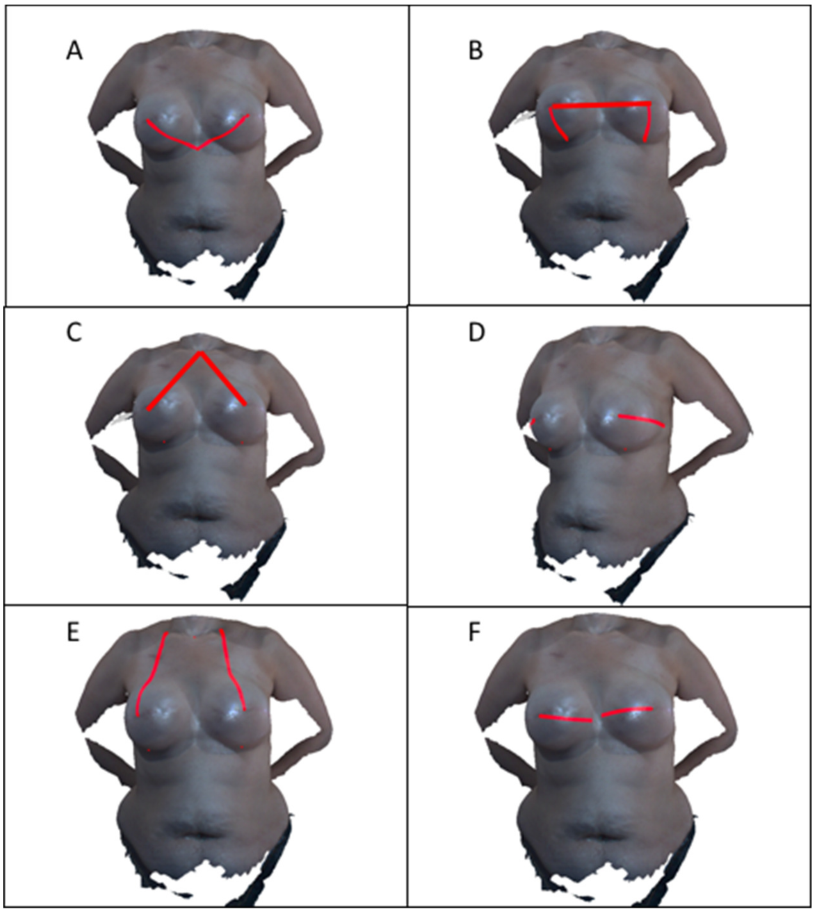

Fig. 4. Selected measurements for correspondence system. A) Most projecting point (MPP) to midline, B) MPP to MPP (calculated as straight line distance) and inframammary fold to MPP, C) Sternal notch to MPP (calculated as straight line distance), D) Lateral point to MPP, E) Midclavicle to transition point and transition point to MPP, F) Medial point to MPP

3.2. Preliminary Measurements

From the measurements taken from 12 patients, we were able to preview how the images and measurements may inform bra fitting for this patient population. Except for the distance between the most projecting points, each metric is calculated separately for each breast. The difference between the breasts can indicate signs of asymmetry (here calculated as the right breast value minus the left breast value). Table 2 charts the difference between the baseline and post-reconstruction asymmetry values. A sample observation is that all of the selected patients experienced a decrease in the distance between the most projecting points for implant based reconstructions.

Table 2. Difference between baseline and post-operative measures (mm)

Patient	MPP to MPP	IMF to MPP	SN to MPP	MP to MPP	LP to MPP	M to MPP	MC to TP
1	44.67	-13.92	0	0	38.4	-22.68	10.39
2	4.13	25.78	-6.26	17.66	-17.05	18.85	-65.2
3	4.51	20.63	-7.36	5.84	-35.97	13.51	-14.88
4	54.88	2.51	8.78	0.17	11.64	9.8	0.03
5	34.74	-	0.74	-6.71	30.8	-6.79	36.36
6	16.96	-4.63	5.5	1.37	-0.74	3.42	-
7	2.62	-	-23.52	5.63	-27.45	24.06	-20.35
8	12.71	0.21	-29.23	-5.87	-13.13	-16.97	-24.58
9	11.64	10.74	-14.32	-4.2	17.2	-1.34	-1.63
10	44.76	6.14	-9	-23.89	24.94	-22.2	22.74
11	27.96	5.84	13.02	37.41	2.23	37.83	11.71
12	34.01	-	-5.01	-8.87	-	-17.42	-48.62

4. Discussion

4.1. Bra measurements to clinical measurements

Our system for relating clinical metrics and terminology to bra design was successful for most torso measurements. We could not measure girth of the torso or under band length, which is a key measurement for bra design, on the 3D surface scans used in this study. The 3D surface scans used in this study are of the type routinely used to document surgical outcomes. Measuring girth is not relevant for assessing surgical outcomes since reconstruction surgery does not affect the rib cage as much as the breast mound. Some of our selected fiducial points do not exactly correspond with the clothing design landmarks, such as the midclavicle and half-shoulder length point. In order to further test the viability of our approach, measures from our system could be compared with measurements taken on the body with a standard bra measurement protocol.

4.2. Challenges

There are both advantages and challenges to using 3D surface images of the torso to take measurements of the body. While the availability of images is convenient and provides one with the opportunity to make more measurements than originally accounted for, there is the possibility that some measurements may not be feasible due to image errors or the imaging instrumentation set up. In our study, multiple factors affected our ability to perform the selected measurements of our approach on our dataset. First, significant training is needed in order for a non-surgeon to accurately identify the necessary fiducial points as well as time investment from an expert surgeon to conduct training and verify the points before measurements can be made. Second, physical characteristics of the participants can prevent access to certain fiducial points. For example, the inframammary fold is not visible in a surface image if a patient has ptosis. The lateral point can be obscured by a patient's arm or excess fat in the axillary area. If one were taking measurements of these patients in person, the body could simply be repositioned, which is not possible when using images. Third, surface scans can often contain missing data on various parts of the image, which cannot be recovered. In these cases, we still made measurements with the fiducial points that were accessible on the image. Some of these challenges could be avoided for future studies that involve taking 3D surface scans of the torso by considering what information is being gathered from the scans and planning a protocol that will maximize the ability to visualize those fiducial points.

4.3. Future Work

The next step after defining the relationship between clinical and clothing terminology is to use our system to observe if any patterns of breast shape or size irregularities emerge that can be useful to designers. While this study focuses on implant-based reconstruction, the system can be expanded to analyze different types of reconstruction.

References

[1] J. R. Steele, "The biomechanics of better bras: improving support and comfort during exercise," in *ISBS-Conference Proceedings Archive*, 2013, vol. 1.
[2] S. Gill, "A review of research and innovation in garment sizing, prototyping and fitting," *Text. Prog.*, vol. 47, no. 1, pp. 1–85, Jan. 2015.
[3] Y. Liu, J. Wang, and C. L. Istook, "Study of optimum parameters for Chinese female underwire bra size system by 3D virtual anthropometric measurement," *J. Text. Inst.*, vol. 0, no. 0, pp. 1–6, Jun. 2016.
[4] S. Edmundson, "Invest In Fit: A Comparison of Poorly-Fitting and Properly-Fitting Bras," 2015.
[5] J. White and J. Scurr, "Evaluation of professional bra fitting criteria for bra selection and fitting in the UK," *Ergonomics*, vol. 55, no. 6, pp. 704–711, 2012.
[6] A. R. Greenbaum, T. Heslop, J. Morris, and K. W. Dunn, "An investigation of the suitability of bra fit in women referred for reduction mammaplasty," *Br. J. Plast. Surg.*, vol. 56, no. 3, pp. 230–236, Apr. 2003.
[7] S. A. Gho, B. J. Munro, S. C. Jones, and J. R. Steele, "Evidence-based recommendations for building better bras for women treated for breast cancer," *Ergonomics*, vol. 57, no. 5, pp. 774–786, May 2014.
[8] K. Bravo, S.-C. Huang, and M. K. Markey, "Breast cancer survivors who undergo mastectomy and breast reconstruction choose to wear cotton undergarments," presented at the Cotton Utilization Conference, 2015.
[9] C.-M. Chen, K. LaBat, and E. Bye, "Physical characteristics related to bra fit," *Ergonomics*, vol. 53, no. 4, pp. 514–524, 2010.
[10] C.-M. Chen, K. LaBat, and E. Bye, "Bust prominence related to bra fit problems," *Int. J. Consum. Stud.*, vol. 35, no. 6, pp. 695–701, Nov. 2011.
[11] M. Westreich, "Anthropomorphic measurement of the breast," in *Breast Augmentation*, Springer, 2009, pp. 27–44.
[12] C. N. Creasman, D. Mordaunt, T. Liolios, C. Chiu, A. Gabriel, and G. P. Maxwell, "Four-Dimensional Breast Imaging, Part I: Introduction of a Technology-Driven, Evidence-Based Approach to Breast Augmentation Planning," *Aesthet. Surg. J.*, vol. 31, no. 8, pp. 914–924, Nov. 2011.
[13] G. P. Reece *et al.*, "3D surface imaging of the human female torso in upright to supine positions," *Med. Eng. Phys.*, vol. 37, no. 4, pp. 375–383, Apr. 2015.