Journal of Plastic Surgery and Hand Surgery

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/iphs20

Clinical assessment of breast symmetry and aesthetic outcome: can 3D imaging be the gold standard?

Lucy Bai, Ola Lundström, Hemming Johansson, Farid Meybodi, Brita Arver, Kerstin Sandelin, Marie Wickman & Yvonne Brandberg

To cite this article: Lucy Bai, Ola Lundström, Hemming Johansson, Farid Meybodi, Brita Arver, Kerstin Sandelin, Marie Wickman & Yvonne Brandberg (2022): Clinical assessment of breast symmetry and aesthetic outcome: can 3D imaging be the gold standard?, Journal of Plastic Surgery and Hand Surgery, DOI: 10.1080/2000656X.2021.2024553

To link to this article: https://doi.org/10.1080/2000656X.2021.2024553

Published online: 17 Jan 2022.

JOURNAL OF PLASTIC SURGERY AND HAND SURGERY
https://doi.org/10.1080/2000656X.2021.2024553

ARTICLE

OPEN ACCESS Check for updates

Clinical assessment of breast symmetry and aesthetic outcome: can 3D imaging be the gold standard?

Lucy Bai[a], Ola Lundström[b], Hemming Johansson[a], Farid Meybodi[c,d], Brita Arver[a], Kerstin Sandelin[e], Marie Wickman[e,f] and Yvonne Brandberg[a]

[a]Department of Oncology-Pathology, Karolinska Institutet, Stockholm, Sweden; [b]Department of Medical Imaging, Karolinska University Hospital, Stockholm, Sweden; [c]Westmead Breast Cancer Institute, Westmead, Australia; [d]Sydney University, Sydney, Australia; [e]Department of Molecular Medicine and Surgery, Karolinska Institutet, Stockholm, Sweden; [f]Sophiahemmet University, Stockholm, Sweden

ABSTRACT

There is a lack of an accurate standardised objective method to assess aesthetic outcome after breast surgery. In this methodological study, we investigated the intra- and inter-observer reproducibility of breast symmetry and volume assessed using three-dimensional surface imaging (3D-SI), evaluated the reproducibility depending on imaging posture, and proposed a new combined volume-shape-symmetry (*VSS*) parameter. Images were acquired using the VECTRA XT 3D imaging system, and analysed by two observers using VECTRA Analysis Module. Breast symmetry was measured through the root mean square distance. All women had undergone bilateral risk-reducing mastectomy and immediate breast reconstruction. The reproducibility and correlations of breast symmetry and volume measurements were compared using Bland–Altman's plots and tested with Spearman's rank correlation coefficient. 3D surface images of 58 women were analysed (348 symmetry measurements, 696 volume measurements). The intra-observer reproducibility of breast symmetry measurements was substantial–excellent, the inter-observer reproducibility was substantial, and the inter-posture reproducibility was substantial. For measurements of breast volumes, the intra-observer reproducibility was excellent, the inter-observer reproducibility was moderate–substantial, and the inter-posture reproducibility was substantial–excellent. The intra-observer reproducibility of *VSS* was excellent while the inter-observer reproducibility was substantial for both observers, independent of posture. There were no statistically strong correlations between breast symmetry and volume differences. The intra-observer reproducibility was found to be substantial–excellent for several 3D-SI measurements independent of imaging posture. However, the inter-observer reproducibility was lower than the intra-observer reproducibility, indicating that 3D-SI in its present form is not a great assessment for symmetry.

Abbreviations: 2D: Two-dimensional; 3D-SI: Three-dimensional surface imaging; d_b: 'characteristic' length or diameter of breasts; d_{RMS}: Root mean square distance; IBR: Immediate breast reconstruction; RC: Repeatability coefficient; RRM: Risk-reducing mastectomy; ΔV: Volume difference; VC: Variance component; V_L: Volume of the left breast; V_R: Volume of the right breast; V_{rat}: Volume ratio; VSS: Volume-shape-symmetry

ARTICLE HISTORY
Received 14 May 2021
Revised 1 November 2021
Accepted 27 December 2021

KEYWORDS
Three-dimensional surface imaging; stereophotogrammetry; aesthetic outcome; breast symmetry; breast volume; imaging posture; reproducibility

Introduction

Volume, shape, and symmetry are important factors that influence the aesthetic appearance of the breasts. Clinical assessment of these factors often requires different techniques, where results are heterogeneous with varying reproducibility [1–6]. As breasts are three-dimensional (3D) structures, conventional techniques such as panel assessment or photogrammetry using biostereometric evaluation, might miss important information as they are based on two-dimensional (2D) images.

Three-dimensional surface imaging (3D-SI) uses the concept of triangulation to obtain coordinates of the imaged surface based on stereophotogrammetry. With more than one camera angle, a software system can plot the coordinates of a surface image based on the intercepting points from different camera angles, and create a perception of depth which is lost in traditional 2D photography [7]. Breast volumetric measurements acquired through the Vectra XT 3D imaging system was recently described to have excellent reliability, with higher reproducibility than measurements obtained through magnetic resonance imaging (MRI) [8]. However, there is still a lack of a standardised objective clinical method to assess breast symmetry and aesthetic outcome after surgery. Previous studies investigating breast symmetry have used ratios of measurements between anatomical landmarks, or differences between sagittal 2D sections of the breasts obtained from 3D images [9–11]. With evolved and enhanced 3D imaging techniques, we are now able to make use of more information from the 3D surface images during analysis [12,13].

The aim of the study was to investigate if the VECTRA XT 3D imaging system could provide reproducible assessments of breast symmetry and aesthetic outcome. The 3D measurements obtained from 3D surface images of women standing in two different bodily postures were evaluated with respect to intra- and inter-

CONTACT Lucy Bai lucy.bai@ki.se Department of Oncology-Pathology, Karolinska Institutet, BioClinicum J5:17, SE-171 64 Solna, Sweden

Figure 1. Pre-marking one of the anatomical landmarks (the xiphoid process) prior imaging.

observer reproducibility. A secondary aim was to investigate whether symmetry correlates with volume difference or not, and to propose and evaluate a combined volume-shape-symmetry (*VSS*) parameter as a potential future measure in the clinical assessment of aesthetic evaluation.

Materials and methods

Study sample

During October 2016 and January 2017, a pilot study was performed on healthy volunteers to test and optimise a running schedule for the current study. Subsequently, 88 women with high hereditary risk for breast cancer who were part of a long-term psychosocial follow-up study after bilateral risk-reducing mastectomy (RRM) and immediate breast reconstruction (IBR) with submuscular permanent silicone implants published in 2019 were invited for 3D-SI [14]. All women were operated at Karolinska University Hospital in Stockholm between 1997 and 2010. For asymptomatic healthy women, bilateral RRM and IBR was performed. For women who had previously undergone breast conserving surgery or mastectomy due to breast cancer, a contralateral RRM and IBR was performed in addition to a complementary ipsilateral procedure when needed. Written informed consent was signed by all participants included in this study regarding publication of their data and 3D surface images.

Photography procedure

Women were imaged using the VECTRA XT 3D imaging system (Canfield Scientific, Parsippany, NJ) with a camera shutter speed of approximately 3.5 ms. The device was calibrated daily. Measures to preserve anonymity were taken. Prior to imaging, the photographer marked out four anatomical landmarks with a pen: the suprasternal notch, the left and right clavicle 7 cm from the suprasternal notch, and the xiphoid process (Figure 1). 3D surface images were captured in two different postures: (i) arms abducted at 45° with palms towards the floor and (ii) hands placed on their hips, shoulders in resting position, palms resting on the iliac crest. The position of the women was adjusted according to the camera screen gridlines, and the camera height was adjusted if needed. Three images per posture were captured at the end of a normal exhalation, with a short break for resting and repositioning of the women between each image to resemble a new 3D-SI appointment, yielding six unique images per participant.

Measurement of 3D-images

Procedure of measurements

The measurements were performed according to a protocol developed by one of the co-authors (FM). Two observers measured the 3D images independently. Observer 1 (LB) analysed the image from the 'first appointment' of all women before moving on to the image from the 'second appointment', simulating a scenario where image analysis was performed continuously after each appointment. Observer 2 (OL) analysed all six images of one woman before moving on to the next set of images of another woman, simulating a scenario where images of the same woman captured at different time periods were analysed consecutively in order to study postoperative changes. All assessments were combined and stored for statistical analysis.

Measurement of breast symmetry

Root mean square distance (d_{RMS}) is defined as the mean distance between corresponding coordinates of two image layers or two 3D image surfaces expressed as a length. This is so far the only way that 3D-SI can measure the breast symmetry. It uses the information from thousands of coordinates that describes the imaged breast surface generated from the intercepting points from several camera angels plotted in a *xyz*-coordinate system to create an electronic 3D surface image, which can be examined and rendered when imported to different software programmes. By utilising the mathematical properties of d_{RMS} on a 3D surface image of a torso together with a copied and reflected 3D surface image of the same torso, the mean distance between the corresponding coordinates of the left and the right side of the torso could be calculated. d_{RMS} would then act as a measure of how symmetrical the left side of the torso is in comparison with the right side, where a d_{RMS} of 0 mm would implicate that the corresponding coordinates of the two 3D surfaces are overlapping, i.e., the torso has perfect symmetry.

Breast symmetry was assessed by importing the 3D surface images into the VECTRA Analysis Module software, where image adjustments were performed to position the breast surface images in line with a coordinate gridline prior to further analysis, i.e., the pre-marked vertical anatomical landmarks (the suprasternal notch and xiphoid process) were aligned where $x = 0$, while the horizontal landmarks (on the clavicles) were aligned where $y = 0$. The images were cropped to maintain a fully anonymous 3D-SI torso, without chin or arms visible. By using the tool *'paint area selection'*, the breast area of interest was set to encompass an area 2 cm below the suprasternal notch to the left and right breasts where the pectoral muscle meets the breast, along the anterior axillary line, to 2 cm below the inframammary fold (Figure 2(a)). The breast area of interest was then copied and reflected in the plane where $x = 0$, overlapping identically at the coordinates where $x = 0$ on the original breast surface, before d_{RMS} was calculated.

Measurement of volume

Returning to the original non-reflected breast surface layer in VECTRA Analysis Module, the right breast area of interest was erased with the vertical midline as the border, using the '*lasso tool*'.[1] The volume was measured to an interpolated virtual chest wall surface (Figure 2(b)), expressed in cubic centimetres. The same was done for the left breast volume measurement but

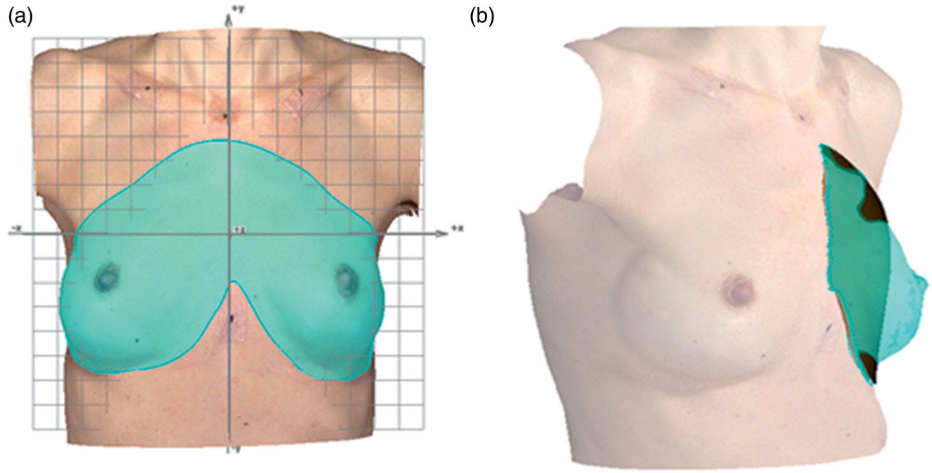

Figure 2. (a) Analysis in VECTRA Analysis Module, measurement of the breast area of interest (turquoise) for calculations of the mean distance between the two breast surfaces (d_{RMS}) as an expression for breast symmetry and (b) volume measurement of the left breast against the interpolated virtual chest wall (brown). Skin marks adjusted in relation to the *xyz*-plane.

erasing the right breast area of interest. The volume measurements of each woman were performed by two independent observers once per breast for all six images per woman.

Proposal of a new combined volume-shape-symmetry measure

d_{RMS} has a physical meaning of the mean difference between the surfaces of the two breasts. The dimension of this quantity is a length. However, the absolute value of this length is not always easy to judge, i.e., whether this value is large or small. Thus, in order to judge the d_{RMS} value, it is important to compare this quantity with another value of length of the breasts. Since the volume of the breasts is measured, it is possible to estimate a 'characteristic' length of breasts (d_b). As the shape of the breasts is complex, the length of the breasts can only be determined by simplifying the shape of the breasts to certain ideal shapes, for example, a half oval or a hemisphere. A half oval or any other shapes than a hemisphere involves two or more lengths to define; thus, we have suggested to use a hemisphere as the model shape of the breasts:

$$d_b = \left(\frac{12\overline{V}}{\pi}\right)^{\frac{1}{3}} \approx \left(\frac{6}{\pi}(VL + VR)\right)^{\frac{1}{3}}$$

where $\overline{V}$ is the mean volume of the left and right breast. Both d_{RMS} and the characteristic diameter are lengths, and they have the same unit of a length (mm, cm or m, Figure 3). If not, the unit must be converted to the same one. The ratio between d_{RMS} and the mean diameter (d_b) of the two hemispherical breasts is thus a non-dimensional quantity that represents the relative difference between the two quantities. A value of zero of this quantity means that the two breasts are identical.

The proposed parameter to assist in the interpretation of d_{RMS}, *VSS*, is 1 minus the ratio between the d_{RMS} and the mean diameters of the two hemispherical breasts. $VSS = 1$ means that the two breasts are identical; $VSS = 0$ means that the difference between the two breasts is 100% (the difference between the two breasts is nearly the size of the breasts).

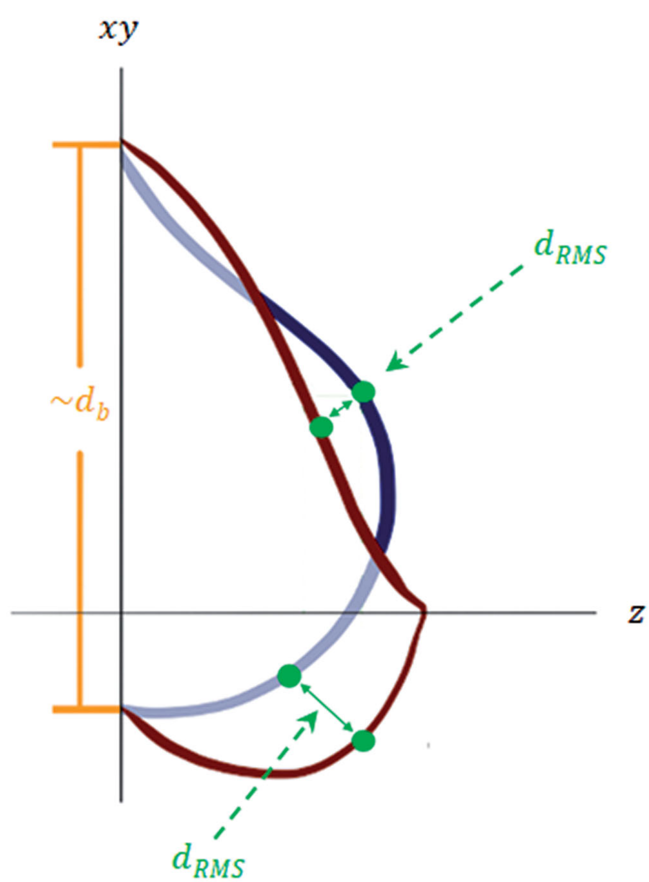

Figure 3. Illustration of the coordinates and data used to obtain the mean distance between two breast surfaces (d_{RMS}) and the characteristic diameter (d_b) of the left (blue) and the right (maroon) breast, calculated from the measured volumes of the breasts in VECTRA Analysis Module. d_{RMS} is calculated based on measuring the shortest distance between more than 1000 points on one surface to the corresponding points on the other surface.

Statistical analysis

The term *reproducibility* is used as an umbrella term for both the concepts of *agreement* (related to the measurement unit) and *reliability* (a dimensionless parameter ranging from 0 to 1) according to de Vet et al. [15] Descriptive statistics for each image and observer are presented as means, standard deviations, range (min–max) and variance components (VCs). Graphical results are presented as Bland–Altman's plots, where each observation is based on the mean of the measurements on each of the three measured 3D-SI per woman. The 95% limits of agreement were

Table 1. Clinical data of the study sample.

Variable	No cancer n (%)	Cancer n (%)
Number of women	36	22
Age at risk-reducing surgery (years)		
Range	26.1–62.4	30.2–63.7
Mean	44.2	43.4
Median	43.8	44.2
Age at 3D-imaging (years)		
Range	40.7–71.1	42.1–73.1
Mean	56.8	60.9
Median	55.2	55.1
BRCA mutation status		
BRCA1/BRCA2/BRCAX[a]	24 (67)	15 (68)
No mutation or unknown	12 (33)	7 (32)
BMI		
<18.5	2 (6)	1 (5)
18.5 to <25	23 (64)	15 (68)
25–30	3 (8)	4 (18)
≥30	2 (6)	1 (5)
Missing	6 (17)	1 (5)
Bilateral prophylactic salpingo-oophorectomy		
Yes	22 (61)	13 (59)
No	14 (39)	9 (41)
Type of breast cancer		
In situ		4 (18)
Invasive		17 (77)
Missing		1 (5)
Type of breast cancer surgery prior risk-reducing surgery		
Breast conserving cancer surgery		10 (45)
Mastectomy (cancer surgery)		12 (55)
Radiotherapy		
Yes		15 (68)
No		6 (27)
Missing		1 (5)
Chemotherapy		
Yes		15 (68)
No		5 (23)
Missing		2 (9)
Endocrine therapy		
Yes		11 (50)
No		7 (32)
Missing		4 (18)
Unanticipated reoperations after risk-reducing breast surgery		
Yes	17 (47)	14 (64)
No	16 (44)	8 (36)
Missing	3 (8)	

[a]*BRCAX*: women with family history of breast cancer screened negative for *BRCA1/BRCA2*.

calculated taking the repeated measurements into account as described below.

Agreement was estimated using the repeatability coefficient (RC) for measurements by the same observer. The RC was estimated as $1.96 \times \sqrt{2} \times \sqrt{\sigma^2_{error}}$, with the σ^2_{error} estimated, using a one-way ANOVA model with a random patient effect [16]. Agreement between observers was estimated using 95% Bland–Altman's limits. To take the data structure into account, these limits were calculated as mean differences (bias) between observers $\pm 1.96 \times \sqrt{2} \times \sqrt{(\sigma^2_{observer} + \sigma^2_{error})}$, where the VCs were estimated using a mixed-effects two-way ANOVA model with random patient effect and fixed observer effect [17].

Intra-observer reproducibility (for each observer separately) was estimated as $\frac{\sigma^2_{patient}}{\sigma^2_{patient} + \sigma^2_{error}}$ in the one-way models, and as $\frac{\sigma^2_{patient} + \sigma^2_{observer}}{\sigma^2_{patient} + \sigma^2_{observer} + \sigma^2_{error}}$ in the mixed-effects two-way models. In the mixed effects two-way models, inter-observer reproducibility was estimated as $\frac{\sigma^2_{patient}}{\sigma^2_{patient} + \sigma^2_{observer} + \sigma^2_{error}}$ [16].

The interpretation of levels of reproducibility for different intra-class coefficient (ICC) values was as follows: 0.00–0.20 poor, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 substantial and 0.81–1.00 excellent to perfect reproducibility [8,18]. The estimates of agreement and reproducibility are presented together with 95% confidence intervals.

The correlation between breast symmetry and volume difference ($\Delta V = |VL - VR|$), and *VSS* and volume ratio ($V_{rat} = \frac{|VL-VR|}{VL+VR}$) were estimated using the non-parametric test Spearman rank-order correlation coefficient (ρ), with a statistical significance level of .05.

All statistical analyses were performed using Stata/IC 14.2 for MAC. In this software, the procedure mixed is used for the random effect models.

The study was approved by the Regional Ethics Committee in Stockholm (dnr 2015/735-31/4).

Results

Sixty-four (73%) women took part in the study. The images of six women were excluded due to corrupt files, thus 3D surface images of 58 women were analysed. Clinical data are presented in Table 1. The reproducibility of the raw data (d_{RMS} and breast volumes) was analysed by prior analysis of the proposed combined parameter *VSS*. Both observers' results including RC, reproducibility, and VC for the raw data and *VSS* obtained from 3D surface images captured in two different postures are presented in Tables 2 and 3, respectively.

Intra-observer reproducibility

For measurements of breast symmetry, the intra-observer reproducibility for observer 1 and 2 was substantial (ICC = 0.73–0.76) and perfect to excellent (ICC = 0.85–0.86), respectively (Table 2). The intra-observer reproducibility of breast volume measurements was perfect to excellent for both observers 1 and 2 (ICC = 0.83–0.92 and 0.89–0.95, respectively).

Inter-observer reproducibility

There was a small, but consistent systematic difference, when comparing the two observers' measurements (Table 2, Figure 4). Observer 1 measured overall smaller values compared to observer 2. The inter-observer reproducibility was substantial (ICC = 0.60–0.63) for measurements of breast symmetry, and moderate–-substantial (ICC = 0.54–0.66) for breast volumes.

Inter-posture reproducibility

The inter-posture reproducibility was substantial (ICC = 0.71) for breast symmetry, and excellent to perfect (ICC = 0.78–0.88) for breast volume measured by observer 1, data not shown. The inter-posture reproducibility was substantial (ICC = 0.72) for breast symmetry, and substantial–excellent to perfect (ICC = 0.78–0.88) for breast volume measured by observer 2, data not shown. There were no systematic errors between the measurements obtained from the 3D surface images captured in the two different postures for either observer. No significant difference was observed between breast symmetry and breast volume measurements performed by the observers.

Table 2. Estimates of agreement and reproducibility of breast symmetry (d_{RMS}), left breast volume (V_L), and right breast volume (V_R), in two different postures, 45° arm abduction and hands placed on hips.

	$d_{RMS,45}$ (mm)	$d_{RMS,Hip}$ (mm)	$V_{L,45}$ (cm^3)	$V_{L,Hip}$ (cm^3)	$V_{R,45}$ (cm^3)	$V_{R,Hip}$ (cm^3)
One-way random effects ANOVA						
Observer 1						
Mean [SD]	7.1 [2.9]	7.1 [2.8]	282 [102]	281 [90]	281 [110]	289 [107]
Range	2.2–15.7	2.4–16.4	102–580	81–526	62–644	56–565
$\sigma^2_{patient}$	5.99	5.79	9352	6700	11284	10214
σ^2_{error}	2.17	1.83	1217	1408	922	1283
Repeatability coefficient (95% CI)	4.1 (3.6–4.6)	3.8 (3.3–4.3)	97 (85–110)	104 (91–118)	84 (74–96)	99 (87–113)
Intra-observer reproducibility (95% CI)	0.73 (0.63–0.82)	0.76 (0.66–0.84)	0.88 (0.83–0.92)	0.83 (0.75–0.88)	0.92 (0.89–0.95)	0.89 (0.83–0.93)
Observer 2						
Mean [SD]	8.0 [3.4]	8.2 [3.3]	337 [129]	346 [139]	323 [116]	331 [120]
Range	2.3–19.6	2.5–19.2	47–685	22–830	79–766	46–849
$\sigma^2_{patient}$	9.76	9.44	15271	18485	12534	12954
σ^2_{error}	1.61	1.73	1674	1068	1015	1521
Repeatability coefficient (95% CI)	3.5 (3.1–4.0)	3.6 (3.2–4.1)	113 (100–129)	91 (80–103)	88 (78–100)	108 (95–123)
Intra-observer reproducibility (95% CI)	0.86 (0.79–0.91)	0.85 (0.77–0.90)	0.90 (0.85–0.94)	0.95 (0.92–0.96)	0.93 (0.89–0.95)	0.89 (0.84–0.93)
Two-way mixed effects ANOVA						
$\sigma^2_{patient}$	6.18	5.66	9132	8478	6910	7757
$\sigma^2_{observer}$	1.70	1.96	3180	4115	4999	3827
σ^2_{error}	1.89	1.78	1445	1238	968	1402
Bias (95% CI)	−0.9 (−1.5 to −0.3)	−1.1 (−1.7 to −0.5)	−55 (−77 to −32)	−65 (−89 to −40)	−42 (−69 to −15)	−42 (−66 to −18)
95% limits of agreement	−6.2 to 4.3	−6.5 to 4.3	−243 to 134	−268 to 138	−256 to 172	−242 to 158
Intra-observer reproducibility (95% CI)	0.81 (0.74–0.86)	0.81 (0.74–0.86)	0.89 (0.85–0.93)	0.91 (0.88–0.94)	0.92 (0.90–0.95)	0.89 (0.85–0.92)
Inter-observer reproducibility (95% CI)	0.63 (0.50–0.75)	0.60 (0.46–0.73)	0.66 (0.53–0.78)	0.61 (0.46–0.75)	0.54 (0.37–0.70)	0.60 (0.44–0.73)

Table 3. Estimates of volume-shape-symmetry (*VSS*) agreement and reproducibility, based on raw data measurements from the three-dimensional surface images including the variance components, presented for two postures (arms at 45° and hands placed on hips).

	VSS_{45}		VSS_{Hip}	
	Observer 1	Observer 2	Observer 1	Observer 2
Mean [SD]	0.929 [0.029]	0.923 [0.034]	0.930 [0.028]	0.923 [0.032]
Range	0.828–0.975	0.806–0.977	0.820–0.977	0.788–0.980
One-way random effects ANOVA				
$\sigma^2_{patient}$	0.0006	0.0010	0.0006	0.0009
σ^2_{error}	0.0002	0.0001	0.0002	0.0002
Repeatability coefficient (95% CI)	0.041 (0.036–0.046)	0.033 (0.029–0.038)	0.038 (0.034–0.043)	0.035 (0.030–0.039)
Intra-observer reproducibility (95% CI)	0.74 (0.63–0.83)	0.87 (0.81–0.92)	0.76 (0.66–0.84)	0.85 (0.78–0.90)
Two-way mixed effects ANOVA				
$\sigma^2_{patient}$	0.0006		0.0006	
$\sigma^2_{observer}$	0.0002		0.0002	
σ^2_{error}	0.0002		0.0002	
Bias (95% CI)	0.006 (−0.0004 to 0.012)		0.007 (0.001–0.013)	
95% limits of agreement	−0.046 to 0.060		−0.037 to 0.050	
Intra-observer reproducibility (95% CI)	0.82 (0.75–0.87)		0.81 (0.75–0.86)	
Inter-observer reproducibility (95% CI)	0.62 (0.48–0.74)		0.61 (0.47–0.73)	

Correlation between breast symmetry and volume difference

There were no strong statistically significant correlations between breast symmetry and breast volume differences (Table 4).

Volume-shape-symmetry parameter

The intra-observer reproducibility of *VSS* was excellent to perfect for both observers (ICC = 0.81–0.82), while the inter-observer reproducibility was substantial (ICC = 0.61–0.62), independent of posture (Table 3). Based on measurements performed by observer 1, *VSS* values were slightly higher than *VSS* values by observer 2. The variability between the observers' measurements was smaller for higher *VSS* values than for smaller *VSS* values, i.e., the observers' measurements were less coherent for women with less symmetrical breasts. No statistically significant correlations were found between *VSS* and volume ratio (data not shown).

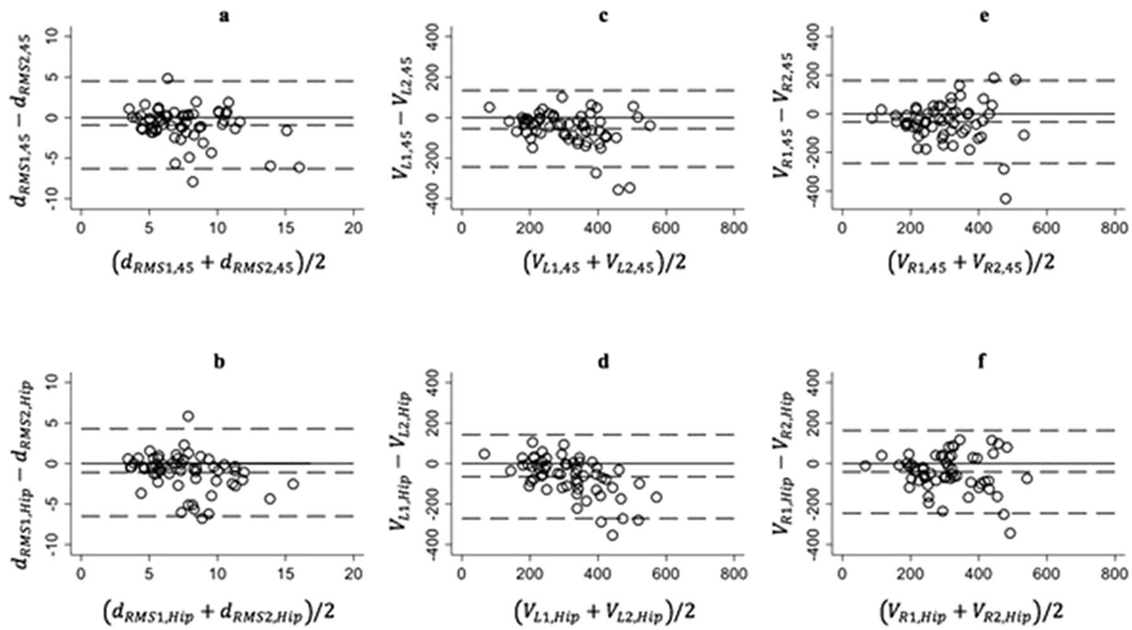

Figure 4. (a) Bland–Altman's plots of the inter-observer reproducibility comparing observer 1 in relation to observer 2 with corresponding limits of agreement (upper and lower dashed lines) for breast symmetry measurements with arms at 45° ($d_{RMSi,45}$), (b) breast symmetry with hands on the hips ($d_{RMSi,Hip}$), (c) left breast volume at 45° ($V_{Li,45}$), (d) left breast volume with hands on the hips ($V_{Li,Hip}$), (e) right breast volume at 45° ($V_{Ri,45}$), and (f) right breast volume with hands on the hips ($V_{Ri,\ Hip}$). $i = 1$ for measurements by observer 1, $i = 2$ for measurements by observer 2.

Table 4. Spearman's rank correlation (ρ) between breast symmetry (d_{RMS}) and breast volume differences ($\Delta V =$ left–right breast volume) of measurements from six 3D surface images of 58 women captured in two different postures (45° and hands placed on hips) obtained by two observers.

	Observer 1		Observer 2	
	Spearman's ρ	p	Spearman's ρ	p
Arms at 45°				
Image 1	0.138	0.303	−0.090	0.502
Image 2	0.315	0.016	−0.110	0.412
Image 3	0.043	0.752	0.138	0.302
Hands on hips				
Image 4	0.330	0.011	−0.041	0.760
Image 5	0.128	0.338	−0.004	0.979
Image 6	−0.015	0.912	−0.140	0.294

Discussion

Measurements acquired from the VECTRA XT 3D imaging system which describes breast aesthetic outcomes in terms of breast symmetry were found to have substantial–excellent to perfect intra-observer reproducibility, while the intra-observer reproducibility of breast volume measurements was excellent to perfect. The inter-observer reproducibility was, however, moderate–substantial. The reproducibility of 3D-SI measurements did not seem to be affected by which posture the women were standing in during imaging. No strong statistically significant correlations were found between breast symmetry and breast volume differences, nor between *VSS* and volume ratio. *VSS* was found to have excellent intra-observer reproducibility and substantial inter-observer reproducibility after being combined from the raw 3D-SI measurements.

3D-SI of breasts was first described in the early 2000s and claimed to be a useful tool in postoperative asymmetry corrections, helping surgeons understand factors affecting breast shape and aesthetic outcome after mammaplasty [19,20]. This was questioned in later studies, and the technique has not gained broad acceptance amongst breast surgeons [6,10]. Most studies of reproducibility using 3D-SI techniques have investigated volume measurements, with varying results [21–25]. More recent studies have shown better usefulness of the 3D-SI system in breast surgery [12]. In agreement with our results, both studies showed better intra-observer reproducibility when measuring breast volume than breast symmetry.

One of the disadvantages with measuring breast symmetry using d_{RMS} is the difficulties with positioning the women un-tilted and completely parallel with the cameras. To overcome or decrease the impact of this, four anatomical landmarks were pre-marked and used when adjusting the 3D surface image in the VECTRA Analysis Module prior to copying and reflecting the 3D surface images over each other. Nevertheless, there might still have been a component of human error since the adjustments of a 3D surface image in relation to what the software gridlines uses as the *xyz*-coordinates is carried out by an observer. Small differences in defined coordinates of point of reflection (the plane where $x = 0$) yield differences in superimposed breast surface images between different observers. This could explain the moderate inter-observer reproducibility. Standardisation of 3D acquisition in pre- and postoperative breast imaging has been suggested to improve imaging reproducibility [22]. The limits of agreement of the inter-observer reproducibility for breast symmetry were similar in size as previously described [12]. The standard error of measurement was larger for observer 1's measurements compared to observer 2's. One reason could be differences in the order of image analysis. Observer 2 might have had an advantage in repeating the adjustments of the torso in the *xyz*-plane, in the selection of breast area of interest, and furthermore remembered the previous assessments of the same woman. However, both methods resulted in substantial–excellent to perfect intra-observer reproducibility for breast symmetry and breast volume measurements.

Previously, it has been described that images of women with arms at 90° were more reproducible compared to images with hands placed on their hips [22]. In our study, the inter-posture reproducibility was substantial–excellent to perfect, indicating that as long as patients are 3D imaged in the same posture, the choice of posture of having arms at 45° or with hands on their hips seems to be less important.

No statistically strong correlations were found between breast symmetry and breast volume difference. Previous studies have typically evaluated these two factors separately. The goal with the proposal of a new parameter *VSS* was to incorporate both measurements into an overall parameter evaluating aesthetic outcome of 3D structures, and to facilitate work and application of such a measurement in clinical practice. We did not find any statistically significant correlations between *VSS* and volume ratio, indicating that breast volume is independent of d_{RMS} and *VSS*. This means that the volume measurements on its own do not give information about the breasts' shape symmetry, thus d_{RMS} is of interest/importance to take into consideration in the evaluation of breast aesthetic outcome using 3D-SI measurements. However, as described earlier, the value of d_{RMS} is difficult to judge on its own, thus the introduction of a relative value (*VSS*) is motivated. This parameter had excellent to perfect intra-observer reproducibility, indicating that it might be a potential parameter in future research to illustrate an overall measure of the aesthetic outcome. However, further studies testing its clinical utility are needed. The reasons to why the inter-observer reproducibility was lower than the intra-observer reproducibility originates from the issues with using d_{RMS} as a way of describing breast symmetry as discussed earlier.

A strength with this study was that we showed that aesthetic outcome in terms of breast symmetry and breast volume could be assessed with an objective method with moderate–excellent to perfect intra- and inter-observer reproducibility. Moreover, the reproducibility for both breast symmetry and breast volume measurements, i.e., the raw data, were investigated before introducing and analysing the reproducibility of a summated score (*VSS*). d_{RMS} itself may not accurately reflect breast asymmetry. This combined parameter has the advantage of offsetting the effect of breast volume on d_{RMS} and makes it usable across a wide range of breasts. Other strengths with this study were the relatively large cohort of study participants and the amount of 3D surface images acquired with a standardised imaging procedure (three images captured in two different postures for each woman, in total six images per woman). In addition, each breast was assessed individually with respect to 3D-SI breast volume measurements.

The study also has some limitations. Clinical assessment of the aesthetic evaluation in terms of breast symmetry and breast volume using 3D-SI is not a time-efficient method. Although it can be considered to be an objective method, there are certain subjective components involved [3,21,25–27]. First, the skin marks on the women are manually placed, thus individual changes may influence the assessment results. Second, the breast area of interest is selected by the observer based on specified landmarks, but occasionally it may be difficult to define the inframammary fold or the boarder of where the pectoral muscle meets the breast depending on the woman's body constitution. Both these aspects influence the reproducibility of the method. A limitation with stereophotogrammetry itself is the inability to capture obscured objects, which for instance is a problem during image analysis of ptotic breasts. Detailed clinical data such as anatomical distances or implant volumes and shapes were not available during the data analysis in the current study. Nevertheless, implant shape has not been shown to be easily determined by surgeons *in vivo* [28]. The clinical importance of our results needs further evaluation. The size of clinically acceptable limits of agreement has not yet been investigated for 3D-SI measurements. Studies evaluating the magnitude of variabilities in breast symmetry and breast volumes estimated using 3D-SI that are clinically acceptable, compared to subjective ratings of aesthetic outcomes by the women themselves are also of interest to investigate. Generalisation of our results to other 3D-SI methods other than VECTRA XT 3D imaging system should be made with caution, as it is possible that the results are dependent on the specific imaging system.

Conclusions

The VECTRA XT 3D imaging system has potential to be applied in clinical practice as the intra-observer reproducibility of 3D-SI measurements related with aesthetic outcome was found to be substantial–excellent to perfect, independent on imaging posture in this methodological study. Breast symmetry did not show any statistically strong correlations with breast volume differences, strengthening the need for a parameter incorporating both measurements. The proposed new parameter (*VSS*) was not statistically significantly correlated with volume ratio of the breasts, which further stresses the need for a relative parameter to aid in the interpretation of d_{RMS} and evaluation of the aesthetic outcome using 3D-SI measurements. *VSS* showed excellent to perfect intra-observer reproducibility, albeit further confirmation is needed prior any use of it as a measure of aesthetic outcome in clinical practice. The inter-observer reproducibility was lower than the intra-observer reproducibility throughout the study, indicating that unless we come up with an automated system, d_{RMS} is not an ideal tool for the assessment of breast symmetry.

Acknowledgements

The authors would like to thank the participating women, and Vivianne Lindbergh and Maria Norberg Barkman, Department of Medical Imaging, Karolinska University Hospital. Associate Professor Elisabeth Elder, Westmead Breast Cancer Institute, University of Sydney.

Note

1. The lasso tool is useful for drawing freehand boarders to select or de-select an area of an image. It works similarly as in Adobe Photoshop or Illustrator.

Disclosure statement

The authors declare that they have no competing interests.

Funding

This study was funded by the Swedish Cancer Society, Swedish Research Council, Radiumhemmets forskningsfonder, and the Breast Cancer Foundation Research Fund.

References

[1] Visser NJ, Damen THC, Timman R, et al. Surgical results, aesthetic outcome, and patient satisfaction after microsurgical autologous breast reconstruction following failed implant reconstruction. Plast Reconstr Surg. 2010;126(1):26–36.

[2] Kuroda F, Urban C, Zucca-Matthes G, et al. Evaluation of aesthetic and quality-of-life results after immediate breast reconstruction with definitive form-stable anatomical implants. Plast Reconstr Surg. 2016;137(2):278e–286e.

[3] Henseler H, Smith J, Bowman A, et al. Subjective versus objective assessment of breast reconstruction. J Plast Reconstr Aesthetic Surg. 2013;66(5):634–639.

[4] Fitzal F, Krois W, Trischler H, et al. The use of a breast symmetry index for objective evaluation of breast cosmesis. Breast. 2007;16(4):429–435.

[5] Cardoso MJ, Cardoso J, Amaral N, et al. Turning subjective into objective: the BCCT.core software for evaluation of cosmetic results in breast cancer conservative treatment. Breast. 2007;16(5):456–461.

[6] Cardoso MJ, Cardoso JS, Oliveira HP, et al. The breast cancer conservative treatment. Cosmetic results – BCCT.core – software for objective assessment of esthetic outcome in breast cancer conservative treatment: a narrative review. Comput Methods Programs Biomed. 2016;126:154–159.

[7] Chang JB, Small KH, Choi M, et al. Three-dimensional surface imaging in plastic surgery: foundation, practical applications, and beyond. Plast Reconstr Surg. 2015;135(5): 1295–1304.

[8] Killaars RC, Preuβ MLG, de Vos NJPD, et al. Clinical assessment of breast volume: can 3D imaging be the gold standard? Plast Reconstr Surg Glob Open. 2020;8(11):1–8.

[9] Chapman BV, Lei X, Patil P, et al. Quantitative 3-dimensional photographic assessment of breast cosmesis after whole breast irradiation for early stage breast cancer: a secondary analysis of a randomized clinical trial. Adv Radiat Oncol. 2020;5(5):824–833.

[10] Eriksen C, Lindgren EN, Frisell J, et al. A prospective randomized study comparing two different expander approaches in implant-based breast reconstruction. Plast Reconstr Surg. 2012;130(2):254–264.

[11] Eriksen C, Lindgren EN, Olivecrona H, et al. Evaluation of volume and shape of breasts: comparison between traditional and three-dimensional techniques. J Plast Surg Hand Surg. 2011;45(1):14–22.

[12] O'Connell RL, Khabra K, Bamber JC, et al. Validation of the Vectra XT three-dimensional imaging system for measuring breast volume and symmetry following oncological reconstruction. Breast Cancer Res Treat. 2018;171(2):391–398.

[13] O'Connell RL, Di Micco R, Khabra K, et al. The potential role of three-dimensional surface imaging as a tool to evaluate aesthetic outcome after breast conserving therapy (BCT). Breast Cancer Res Treat. 2017;164(2):385–393.

[14] Bai L, Arver B, Johansson H, et al. Body image problems in women with and without breast cancer 6–20 years after bilateral risk-reducing surgery – a prospective follow-up study. Breast. 2019;44:120–127.

[15] de Vet HCW, Terwee CB, Knol DL, et al. When to use agreement versus reliability measures. J Clin Epidemiol. 2006; 59(10):1033–1039.

[16] Bartlett JW, Frost C. Reliability, repeatability and reproducibility: analysis of measurement errors in continuous variables. Ultrasound Obstet Gynecol. 2008;31:466–475.

[17] Gerke O, Vilstrup MH, Segtnan EA, et al. How to assess intra- and inter-observer agreement with quantitative PET using variance component analysis: a proposal for standardisation. BMC Med Imaging. 2016;16(1):1–9.

[18] Landis J, Koch G. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159–174.

[19] Galdino GM, Nahabedian M, Chiaramonte M, et al. Clinical applications of three-dimensional photography in breast surgery. Plast Reconstr Surg. 2002;110(1):58–70.

[20] Nahabedian MY, Galdino G. Symmetrical breast reconstruction: is there a role for three-dimensional digital photography? Plast Reconstr Surg. 2003;112(6):1582–1590.

[21] Pöhlmann STL, Harkness E, Taylor CJ, et al. Preoperative implant selection for unilateral breast reconstruction using 3D imaging with the Microsoft Kinect sensor. J Plast Reconstr Aesthet Surg. 2017;70(8):1059–1067.

[22] Hameeteman M, Verhulst AC, Maal TJJ, et al. An analysis of pose in 3D stereophotogrammetry of the breast. Br J Plast Surg. 2016;69(12):1609–1613.

[23] Kovacs L, Eder M, Hollweck R, et al. Comparison between breast volume measurement using 3D surface imaging and classical techniques. Breast. 2007;16(2):137–145.

[24] Wesselius TS, Verhulst AC, Vreeken RD, et al. Accuracy of three software applications for breast volume calculations from three-dimensional surface images. Breast. 2018;142(4):858–865.

[25] Yang J, Zhang R, Shen J, et al. The three-dimensional techniques in the objective measurement of breast aesthetics. Aesthetic Plast Surg. 2015;39(6):910–915.

[26] Yip JM, Watson DI, Tiggemann M, et al. Determinants of breast reconstruction outcome: how important is volume symmetry? J Plast Reconstr Aesthet Surg. 2015;68(5): 679–685.

[27] Chae MP, Hunter-Smith DJ, Spychal RT, et al. 3D volumetric analysis for planning breast reconstructive surgery. Breast Cancer Res Treat. 2014;146(2):457–460.

[28] Gahm J, Edsander-Nord Å, Jurell G, et al. No differences in aesthetic outcome or patient satisfaction between anatomically shaped and round expandable implants in bilateral breast reconstructions: a randomized study. Plast Reconstr Surg. 2010;126(5):1419–1427.