Original article

Objective breast symmetry evaluation using 3-D surface imaging☆

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ABSTRACT

This study develops an objective breast symmetry evaluation using 3-D surface imaging (Konica-Minolta V910® scanner) by superimposing the mirrored left breast over the right and objectively determining the mean 3-D contour difference between the 2 breast surfaces. 3 observers analyzed the evaluation protocol precision using 2 dummy models (n = 60), 10 test subjects (n = 300), clinically tested it on 30 patients (n = 900) and compared it to established 2-D measurements on 23 breast reconstructive patients using the BCCT.core software (n = 690). Mean 3-D evaluation precision, expressed as the coefficient of variation (VC), was 3.54 ± 0.18 for all human subjects without significant intra- and inter-observer differences (p > 0.05). The 3-D breast symmetry evaluation is observer independent, significantly more precise (p < 0.001) than the BCCT.core software (VC = 6.92 ± 0.88) and may play a part in an objective surgical outcome analysis after incorporation into clinical practice.

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Introduction

Differences of contour, shape, position or volume of the breast are the most important factors which define breast symmetry and influence cosmesis and patient satisfaction after breast surgery. Subjective methods for breast symmetry evaluation are widely used and based on visual patient assessment or standard digital photographic analysis using split-and-reversed negatives. Objective methods attempt to measure differences between the right and the left breast according to linear distances like anthropomorphic measurements or volume measurements using techniques like water displacement, casting techniques, mammography or CT and MRI measurements. In addition, two software systems called breast analyzing tool (BAT) and the Breast Cancer Conservative Treatment cosmetic result (BCCT.core) were developed to objectively evaluate the aesthetic surgical outcome using patient’s frontal two-dimensional (2-D) photographs. The BAT evaluates breast symmetry by comparing breast area, breast circumference and nipple position between the breasts. The BCCT.core analysis colour differences and scar appearance in addition to asymmetry calculations.

The introduction of three-dimensional (3-D) surface imaging enabled quantitative linear distance measurements, surface and volumetric calculations of the breast region and objective breast symmetry evaluations between the left and the right breast by virtually superimposing the mirrored breasts over each other. However, none of the presented methods have been clinically adopted because of unreliable, time consuming or cost intensive application.

The following study develops and standardizes an improved 3-D evaluation protocol to analyze breast symmetry according to 3-D breast contour differences between the left and the right breast using 3-D surface imaging and evaluates its potential clinical application by comparing it to the established 2-D BCCT.core software.

Materials and methods

3-D data acquisition

Three-dimensional breast imaging were performed using a 3-D surface scanner (Vivid 910® Konica-Minolta Co., Ltd., Osaka, Japan) as previously reported. 3-D acquisition of the test persons...
and patients were obtained in a standing position on predefined ground markers under standardized lighting conditions (light intensity: 350–400 lux), patients back supported by a wall, patients holding their breath during acquisition and arms down the side crossed behind at the height of the pelvis, to minimize potential human artefacts (moving, breathing, change of position). Captured images were converted into a single virtual 3-D model using appropriate software (Raindrop Geomagic Studio 11/C210, Raindrop Geomagic, Inc., NC, USA) for further analysis. The Declaration of Helsinki protocols were followed and all test persons and patients gave their written informed consent in accordance with the guidelines of the Technische Universität München.

**Standardisation process**

Standardisation and precision analysis of the breast symmetry evaluation across different observers was performed on 2 dummy models with different breast sizes (breast volume (BV) of dummy A (dummy B): 305 cm$^3$ (645 cm$^3$), sternal notch to nipple (SN-N) distance: 16 cm (20.2 cm)) to exclude potential human artefacts.

An easily reproducible 3-D breast symmetry evaluation protocol was developed using 8 anatomical landmarks (LM) on the virtual 3-D breast model. 3 landmarks (LM 1 = sternal notch, LM 3 = middle between LM 1 and LM 8 and LM 8 = xiphoid process) in the midline and 5 landmarks (LM 2 = clavicle 5 cm lateral from the sternal notch, LM 4 = medial breast fold, LM 5 = nipple, LM 6 = lateral breast fold and LM 7 = submammary fold) applicable on both breasts (Fig. 1A). The breast region of interest was marked according to our previously described measurement protocol$^{19,23,24,37}$: 1 cm beside the sternal notch (LM 1) along the sternum to the medial breast fold (LM 4), following the submammary fold (LM 7) to the lateral breast fold (LM 6), along the frontal axillary fold and the lateral offshoot of the pectoral muscle up to 1 cm below the clavicle and back to the sternal notch (Fig. 1A,B). This selected breast region is further divided in 4 clinical breast quadrants (I = upper inner quadrant (UIQ), II = lower inner quadrant (LIQ), III = lower outer quadrant (LOQ) and IV = upper outer quadrant (UOQ)) by connecting LM 2 and LM 5; LM 4, LM 5 and LM 6; LM 5 and LM 7 (Fig.1A,B). By placing a mirror plane down the midline through LM 1, LM 3 and LM 8 the left breast is superimposed over the right marked breast. A colour-coded histogram is displayed, quantifying the mean directional distance in mm between each surface point of the 2 superimposed breast model surfaces over the entire breast (Fig. 1C). The single marked quadrants I–IV can be easily quantified separately.

3 observers varying in medical training and experience in the field of breast surgery, independently carried out the 3-D breast symmetry evaluation 10 times on both dummies ($n = 60$) using appropriate software (Raindrop Geomagic Qualify 10/C210, Raindrop Geomagic, Inc., NC, USA). Intra- and inter-observer variability, expressed as the coefficient of variation (VC) of the mean directional breast model surface difference between the left and the right breast, were analysed.

**Evaluation on test persons**

The same 3 observers applied the standardised breast symmetry evaluation protocol (Fig. 1D) 10 times ($n = 300$) on 10 test persons (mean age: 23 ± 1.27 years, mean BMI: 21.6 ± 1.00 kg/m$^2$) with varying breast size (mean BV: 452.7 ± 146.35 cc on the right and...
437.68 ± 116.27 cc on the left, mean SN-N: 20.09 ± 2.44 cm on the right and 20.43 ± 2.71 cm on the left). The mean directional breast model surface difference between the left and the right breast in mm was calculated to analyse the intra- and inter-observer variability, expressed as VC.

Clinical testing

Clinical testing of the 3-D method were performed on 15 breast augmentation (mean age: 31.6 ± 2.31 years, mean BMI: 20.2 ± 2.21 kg/m2, mean pre (post) BV: 215.7 ± 74.2 (425.2 ± 68.1) cc on the right and 205.8 ± 71.4 (412.2 ± 60.2) cc on the left) and 15 breast reduction (mean age: 57.3 ± 2.31 years, mean BMI: 26.7 ± 3.55 kg/m2, mean pre (post) BV: 1315.2 ± 350.7 (682.4 ± 178.8) cc on the right and 1295.3 ± 380.1 (671.9 ± 169.8) cc on the left) patients pre- and postoperatively (n = 60). The 3 observers performed 5 breast symmetry evaluations per patient (n = 900). The intra- and inter-observer variability, expressed as VC, was calculated.

Comparison with 2-D measurements

Postoperative breast asymmetry of 23 patients who underwent secondary free TRAM (transverse rectus abdominis myocutaneous) breast reconstruction were analysed using our 3-D methodology and the BCCT.core software.17,18 The only way to compare the 2-D with the 3-D methods regarding measurement precision is to analyze the breast area (surface) difference (BAD) between the left and the right breast in cm², measured 5 times by 3 observers (n = 345) on the 3-D surface models (Figs. 1 and 2) and on the scaled frontal views of the patients 2-D photographs (n = 345) using the BCCT.core software (Fig. 3). The intra- and inter-observer variability, expressed as VC, was calculated to analyse the measurements precision for both methods. 2-D photographs were obtained according to the standardized requirements.18 In addition, the time needed for landmark placing and for total data evaluation (including data import, landmark placing and calculation) was collected for both techniques.

Statistical analysis

3-D breast symmetry evaluations were aggregated as a mean directional breast surface difference between the left and the right breast in mm, expressed as VC to evaluate precision (VC = 100 X standard deviation/mean). The Kruskal–Wallis test and post-hoc Mann–Whitney U tests applying Bonferroni’s method for multiple testing were performed for independent groups and the Friedman test and post-hoc Wilcoxon test for paired samples. The Pearson coefficient of correlation (r) was computed to compare 3-D and 2-D measurements. All tests were performed two-tailed using a global significance level of p < 0.05 using SPSS® version 13 for windows (SPSS Inc., Chicago IL, USA).

Results

Standardisation process

The mean VC for all observers on dummy A was 1.66 ± 0.14 and 1.91 ± 0.11 on dummy B. The mean calculated total dummy VC of 1.79 ± 0.12 did not significantly differ across both dummies.
(p > 0.995) indicating excellent precision (Fig. 4). No significant intra- and inter-observer VC differences for both dummy models (p > 0.05 for all pairwise comparisons) were found (Fig. 4). High measurement precision and observer independency are also visualised by the colour-coded histogram of dummy A (Fig. 1C).

Evaluation on test persons

The mean test person VC for all 3 observers was 3.33 ± 0.13 with no significant intra- and inter-observer VC differences (p > 0.05 for all pairwise comparisons), representing excellent precision (Fig. 4). The significantly decreased precision (p < 0.025) for the test persons VC (3.33 ± 0.13) compared to the dummy models VC (1.79 ± 0.12) can also be visualised by the 3-D breast symmetry evaluation (Fig. 1E). Patient specific differences for every breast quadrant are objectively quantifiable (Fig. 1F).

Clinical testing

The mean breast asymmetry in breast augmentation was 7.48 ± 0.17 mm preoperatively and 7.33 ± 0.11 mm postoperatively (Table 1), without relevant improvement after surgery (p > 0.05). In reduction mammoplasty the mean breast asymmetry significantly improved from 9.46 ± 0.1 mm before to 7.54 ± 0.14 mm after surgery (p < 0.001). The mean breast augmentation VC for all 3 observers was 3.76 ± 0.15 and 3.48 ± 0.08 for breast reduction (Table 1) without significant intra- or inter-observer differences for both groups (p > 0.05) and no relevant differences to the mean test person VC of 3.33 ± 0.13 (p > 0.05).

Comparison with 2-D measurements

The 2-D BCCT.core software measured significantly smaller mean breast areas and mean BAD’s (both p < 0.001) than the 3-D evaluation methodology (Table 2, Figs. 3 and 4) and poorly correlated to the 3-D method (r = 0.344). The mean 2-D BAD was 13.0 ± 3.5 cm² compared to the mean 3-D BAD of 32.8 ± 0.9 cm². 2-D measurements (VC = 6.92 ± 0.88) were significantly less precise (p < 0.001) than 3-D measurements (VC = 3.58 ± 0.07). Both methods showed no intra-observer differences (p > 0.05). The 3-D methodology demonstrated no inter-observer differences (p > 0.05), but 2-D measurements showed significant inter-observer differences (p < 0.05). The mean 2-D data evaluation lasted 4.2 ± 0.78 min and 9.6 ± 1.8 min for the whole 3-D evaluation including 3-D distance, volume, surface and symmetry calculations.

Discussion

One of the most visible factors which defines breast symmetry is breast contour difference. Conventional breast symmetry assessment techniques are simply based upon difference calculations between the breasts using linear distance, circumference, surface area or volume measurements. 3-D surface imaging provides the surgeon with additional symmetry analysing options. Previous 3-D studies compared the whole breast region and did not differentiate between breast quadrants.
Catanuto et al. applied rigid geometrical planes to divide the breast into different quadrants with resulting limitations in analysing ptotic and larger lateralized breasts. The presented 3-D breast symmetry evaluation protocol provides surgeons, besides conventional parameter comparisons (distance, surface and volume), with an objective 3-D breast surface contour difference analysis based on an individual adaptable breast quadrant definition. The presented technique could assist surgeons in the preoperative planning and optimization of breast corrections after reconstruction and breast conservative approaches. Secondary breast refinements could be objectively planned according to the regional 3-D contour differences. The benefit of this 3-D evaluation protocol for breast surgeons can be easily expanded to other clinical applications: short and long lasting results after fat grafting to determine the resorption rate for reconstruction purposes over time, the temporal effect on skin envelope enlargement and volume increase after expander inflation for breast implant reconstruction, comparison between competitive surgical techniques in breast reduction (short scar vs. inverted T, central pedicled vs. superior-/medial or inferior pedicled) or breast augmentation (round vs. anatomical implants, choice of pocket, incision techniques) could be quantified. Actual clinical studies demonstrated the innovative character and clinical benefit of the technique, especially in plastic and reconstructive breast surgery.

To analyse the clinical value of our 3-D methodology we compared it to an established 2-D measurement method. We chose the 2-D BCCT.core software for our comparison study because it obtained better agreement to subjective evaluation than the BAT® software. The study showed that smaller breast area values are measured in 2-D than in 3-D. These findings are comprehensible and obvious comparing the 2-D and 3-D evaluation of the same person to each other (Figs. 2 and 3). 2-D measurements on the photography only evaluate the visible frontal breast area and reduce it to a flat surface (Fig. 3), disregarding the lateral, non-visible aspects of the curved breast and the complex 3-D breast geometry. In contrast, the observer can rotate the virtual model and exactly select the whole 3-D geometric breast contour of interest using 3-D analysing software, measuring significant larger surfaces.

Table 1
Pre- and postoperative 3-D breast symmetry evaluations for clinical testing: mean directional breast surface difference ± standard deviation (SD) in mm and resulting mean coefficient of variation (VC = 100 X standard deviation/mean) with SD for inter-observer variability analysis. 3 observers performed 5 breast symmetry evaluation processes pre- and postoperatively for 15 breast augmentation (n = 450) and 15 breast reduction (n = 450) patients each.

<table>
<thead>
<tr>
<th>Surgical Technique</th>
<th>Observer 1</th>
<th>Observer 2</th>
<th>Observer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>VC</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td><strong>AUG (n = 15)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pre</td>
<td>7.55 ± 0.28</td>
<td>3.71</td>
<td>7.61 ± 0.29</td>
</tr>
<tr>
<td>post</td>
<td>7.32 ± 0.26</td>
<td>3.55</td>
<td>7.44 ± 0.27</td>
</tr>
<tr>
<td>Mean VC</td>
<td>3.63 ± 0.11</td>
<td>3.72 ± 0.13</td>
<td>3.93 ± 0.12</td>
</tr>
<tr>
<td>Total VC</td>
<td>3.76 ± 0.15</td>
<td>3.61</td>
<td>9.57 ± 0.33</td>
</tr>
<tr>
<td><strong>RED (n = 15)</strong></td>
<td></td>
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</tr>
<tr>
<td>pre</td>
<td>9.43 ± 0.34</td>
<td>3.52</td>
<td>7.53 ± 0.26</td>
</tr>
<tr>
<td>post</td>
<td>7.68 ± 0.27</td>
<td>3.45</td>
<td>7.53 ± 0.26</td>
</tr>
<tr>
<td>Mean VC</td>
<td>3.57 ± 0.06</td>
<td>3.45 ± 0</td>
<td>3.45 ± 0</td>
</tr>
<tr>
<td>Total VC</td>
<td>3.48 ± 0.08</td>
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Fig. 4. Inter-observer variability of the 3-D breast symmetry evaluation protocol: the mean coefficient of variation (VC = 100 X standard deviation/mean) and standard deviation. 3 observers performed 10 symmetry evaluations for both dummy models (n = 60) and 10 test persons (n = 300) each.
in consequence than in 2-D (Table 2 and Fig. 2). In addition, the BCCT.core software only defines the lateral and medial aspect of the breast contour and measures the visible area in between. If the measured area depends on the landmark setting. If the lateral aspect is defined higher for example by observer 1 (Fig. 3 Aa), almost the whole upper breast pole is included for breast area calculation (Fig. 3 Da). But if this lateral aspect is placed further below by observer 2 and 3 (Fig. 3 Bb,Cc), the upper pole is excluded and smaller values are measured (Figs. 3Eb and 4Fc). Landmark positioning on 2-D photography is often not obvious and difficult which influences the measurement precision and inter-observer variability (Table 2), a finding that correlates with our previous studies. In contrast, landmark positioning on 3-D models according to our presented results and our previous findings is precise and accurate, resulting in observer independent, reproducible measurements (Tables 1 and 2 and Figs. 2 and 4).

The main focus of the study was to evaluate the measurement precision and observer influences of the presented 3-D breast asymmetry evaluation protocol and the established 2-D measurements to guarantee a reliable and serious clinical application in the future. The major advantage of the established 2-D BCCT.core and BAT© software solutions compared to our presented study is the possibility to rate the aesthetic outcome in a scoring system from poor to excellent. Moyer et al. presented an objective outcomes measure by defining the existing degree of breast asymmetry based on 3-D surface imaging in comparison to a healthy control group. Our future work will concentrate to develop a breast symmetry index based on the presented 3-D breast contour evaluation protocol to judge the aesthetic surgical outcome in a comparable rating system as the established 2-D software tools. Only after this extrapolation of the 3-D data into a scale which correlates the degree of existing breast asymmetry and the aesthetic result, a comparison between 2-D and 3-D measurements regarding the clinical use and importance are feasible and reasonable.

The used software solutions in this study (Raindrop Geomagic Studio 11© and Qualify 10©, Raindrop Geomagic, Inc., NC, USA) only allow manual landmark setting. The mean 3-D landmark placing took 3.7 ± 0.35 min compared to 2.5 ± 1.2 min for 2-D landmark placing. Currently, the majority of the available software solutions are for industrial use only and have to be adapted to clinical applications. For example, implementation of semi-automatic landmark positioning would overcome time consuming manual landmark placing in the future. If these software automation and optimization will improve current accuracy and precision will have to be analyzed.

However, 3-D data acquisition with the 3-D scanner used in this study takes 2.5 s per shot with a total acquisition time of around 4 min per patient including procedure explanation and patient positioning, comparable to standard 2-D photography acquisition. The total 2-D data evaluation (including data import, landmark placing and calculation) takes 4.2 ± 0.78 min and is obviously faster than the 3-D data evaluation (9.6 ± 1.8 min). But in addition, 3-D scanning delivers 3-D distance, volume, surface and symmetry calculations. In our opinion this process is sufficiently fast for the daily clinical routine and can be performed in the absence of the patient.

Beside obvious advantages of the 3-D scanning technique, technical obstacles and limitations still exist. Only a few years ago the total costs for an overall 3-D solution (soft- and hardware) of nearly 80,000—100,000 € did not permit a wide dissemination of this technique. The devices were heavy, bulky and cumbersome which limited their clinical application to specific pre- and post-operative acquisitions. The clinical necessity accelerated the development of smaller, faster (acquisition time under 0.5 s), lightweight, handler and affordable devices which vary between 20,000 and 50,000 €. Some devices are portable and even enable intra-operative 3-D application in the OR and during consultation. In addition, the 3-D scanning system used in this study requires specific lighting conditions < 500 lux, a potential drawback compared to the BAT© software solution which is not influenced by external lighting conditions. After further improvements of the 3-D technology, the authors believe that 3-D surface imaging will play an important clinical role in breast symmetry evaluation in the near future.

### Conclusion

The 3-D application for objective breast symmetry evaluation is easily applicable, sufficiently fast, observer independent and more precise than 2-D measurements (Fig. 3). Although we are aware of the existing limitations as currently high costs of 3-D imaging systems and the non-essentially need for experience clinicians to determine breast asymmetries using 3-D scanners, we believe in the clinical value and cost-effectiveness of this technology in the future years. The 3-D documentation could help to prevent or correct postoperative breast asymmetries and to improve the surgical outcome following plastic, reconstructive and aesthetic breast surgery after adequate clinical incorporation in the near future.
Conflict of interest statement
All authors disclose any financial and personal relationships with other people or organisations that could inappropriately influence (bias) their work.

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