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CASE REPORT

Experimental methodology for digital breast shape analysis and objective surgical outcome evaluation☆

G. Catanuto [a,*], A. Spano [a], A. Pennati [a], E. Riggio [a], G.M. Farinella [b], G. Impoco [c], S. Spoto [b], G. Gallo [b], M.B. Nava [a]

[a] *Istituto Nazionale per lo Studio e la Cura dei Tumori — Via Venezian 1, 20133 Milano, Italy*
[b] *Image Processing Laboratory, Dipartimento di Matematica e Informatica — University of Catania, Viale A.Doria 6, 95125 Catania, Italy*
[c] *Image Processing Laboratory, Dipartimento di Elettrotecnica, Elettronica e Informatica — University of Trieste, Via Valerio 10, 34100 Trieste, Italy*

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Summary Outcome evaluation in cosmetic and reconstructive surgery of the breast is commonly performed visually or employing bi-dimensional photography.

The reconstructive process in the era of anatomical implants requires excellent survey capabilities that mainly rely on surgeon experience. In this paper we present a set of parameters to unambiguously estimate the shape of natural and reconstructed breast. A digital laser scanner was employed on seven female volunteers. A graphic depiction of curvature of the thoracic surface has been the most interesting result. Further work is required to provide clinical and instrumental validation to our technique.

Outcome evaluation in breast reconstructive and cosmetic surgery is commonly performed in a visual and barely reproducible way.[1,2]

The female breast is a complex three-dimensional object lying on a curved surface (the chest wall). Its boundaries are rather fuzzily defined and few anatomical landmarks are easily identifiable. Following careful observation of the breast area we suggest a set of measurements that can describe the geometrical properties of this region (Table 1).

Case reports

Methodology

Some of the selected parameters were easily identified on female volunteers belonging to relevant reconstructive and

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* Corresponding author. Tel.: +39 2 23 902 797; fax: +39 2 23 902 602.
E-mail address: giuseppecatanuto@yahoo.it (G. Catanuto).

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Table 1 Cluster of parameters characterising the breast shape

Distances	Linear measurements between relevant anatomical landmarks
Surface measurements	Total surface area, anatomical subunits area
Angles	Divergence angle: it should express divergence between the two nipples in the patient's point of view Ptosis angle: to describe the inclination of the breast mound on the chest wall
Curvature	Curved surface properties calculation and visualisation
Symmetry	Analysis of symmetry between the two sides of the chest wall
Inframammary fold (IMF) shape	Geometrically IMF is a 'saddle'. Its properties characterise natural and reconstructed breast shape

cosmetic subgroups. We report in this paper on three women on whom shape analysis yielded the most interesting results.

A three-dimensional laser scanner device was employed (Konika-Minolta Vi-900) for model acquisition. Three views were acquired rotating volunteers by 45° on each side (Figs. 1 and 2). We analysed data with a customised software tool named BSA (Breast Shape Analyzer).

Breast surface was segmented in four quadrants using reproducible landmarks (Fig. 3a, b). Total surface area and single subunit areas were computed. The proposed methodology relies on geometrical planes (bilateral symmetry plane, meridian plane and equatorial plane) that allowed calculation of significant clinical angles. The angle between the breast meridian plane and the bilateral symmetry plane was called 'divergence angle' (Fig. 4); the 'ptosis angle' is given by the equator plane and the meridian plane on the vertical axis (Fig. 3b). A colour scale ranging from blue to red has been used to visually represent curvature (values ranging from $c > 0.2$ to $c < -0.2$). In this coding the green

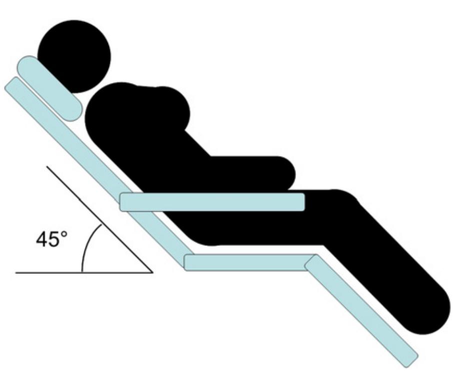

Figure 1 Patient positioning.

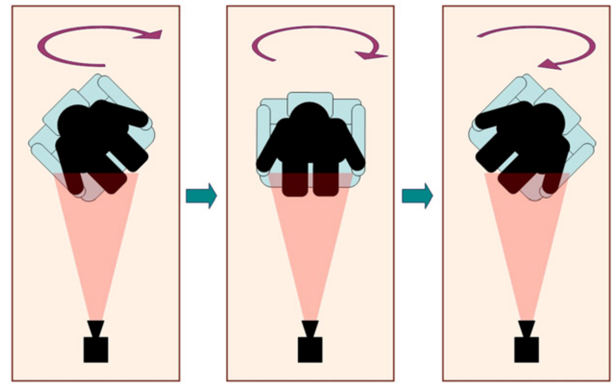

Figure 2 Chair rotation.

colour is associated to almost flat regions, positively curved areas (like spheroids, Fig. 5) are blue, negatively curved areas (such as hyperboloids, Fig. 6) are red.

Case 1

Patient CH underwent left modified radical mastectomy and implant-based reconstruction followed by Baker grade IV capsular contracture. Shape analysis revealed a severe reduction of the overall surface on the implant side (reconstructed side 461 cm^2, natural side 522 cm^2) (Table 2; Fig. 7).

Distances (on flying) between anatomical landmarks (such as nipple, and sternal notch or midaxillary point, etc.) are shortened. Visual depiction of 'curvature' on the chest wall surface indicated that the reconstructed breast is entirely positively curved (values ranging from 0.1 to >0.2) while on the natural side surfaces are smoother and almost flat in the inner quadrants (values ranging from 0.1 and −0.1).

Case 2

Similar results were generated for patient MP (nipple-sparing mastectomy and implant reconstruction Baker grade III) with a reduction of the reconstructed surface area and of most of the other linear measurements on this side when compared to the contralateral. The 'ptosis angle' in this case is higher on the natural side (105° vs 86° reconstructed side) (Table 3). Curvature mapping yielded

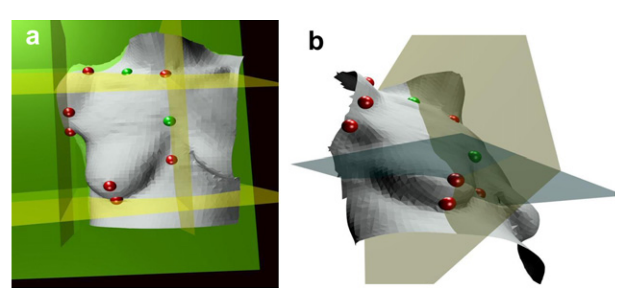

Figure 3 (a) Box-hull definition with simple geometrical planes. (b) Breast meridian and equator identify four quadrants in a clinical-like fashion.

Table 2 Breast shape analysis on a three-dimensional digital model of a clinical case of Baker grade IV capsular contracture

Case CH: mastectomy (left) and implant-based reconstruction. Baker IV capsular contracture rate	Reconstructed breast	Natural breast
Surface area (cm^2)		
Total	461	522
Upper outer quadrant	147.3	218
Upper inner quadrant	60.38	74.5
Lower inner quadrant	187	171.2
Lower outer quadrant	66	57
Distances (cm)		
Nipple—sternal notch	18.4	20.2
Nipple—acromial extremity of clavicle	18.9	19.4
Nipple—midaxillary point	14.5	15.8
Sternal notch—acromial extremity of clavicle	13.4	14.3
Sternal notch—midaxillary point	14.5	15.82
Sterna notch—pectoralis insertion in the arm	15.2	16.7
Xiphoid—midaxillary point	21.9	23.2
Angles (degrees)		
Divergence	39	31
Ptosis	95	84

Table 3 Breast shape analysis on three-dimensional digital model of a clinical case of nipple-sparing mastectomy (Baker grade III)

Case MP: nipple-sparing mastectomy (right) and implant-based reconstruction. Baker grade III	Reconstructed breast	Natural breast
Surface area (cm^2)		
Total	417.5	594.1
Upper outer	147	221.6
Upper inner	59.77	85.8
Lower inner	160.4	222.7
Lower outer	59.7	63.9
Distances (cm)		
Nipple—sternal notch	18.9	23.1
Nipple—acromial extremity of clavicle	19.1	21.8
Nipple—midaxillary point	13.9	16.2
Sternal notch—acromial extremity of clavicle	11.5	15.6
Sternal notch—midaxillary point	13.9	16.2
Sternal notch—pectoralis insertion in the arm	13.8	18.7
Xiphoid—midaxillary point	18.2	23.6
Angles (degrees)		
Divergence	63	64
Ptosis	86	105

similar findings of patient CH with less evident negative areas at medial and lateral borders.

Case 3

Patient PB, who received a bilateral breast augmentation, demonstrated similar surface area and linear measurements on each side. The divergence angles were nearly identical (right: 20.8°, left: 21°). The right 'ptosis angle' is slightly closer (right: 82.5°, left: 89.2°). Curvature assessment indicated a reduction of flat territories on the upper quadrants of the breast, while the lower pole has a constant highly positive curvature (Table 4; Fig. 8).

Discussion

Three-dimensional scanning of the breast surface according to our experimental methodology generates good estimates of some of the proposed parameters (Table 1).

The digital technique allowed computation of new distances such as 'nipple—acromial extremity of the clavicle' or 'xiphoid—midaxillary point'. These are taken on flying and not on the body surface, avoiding any distortion due to chest and breast shape. In our opinion, surface area

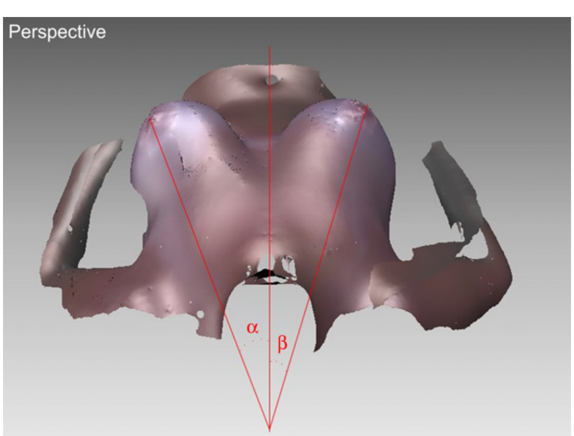

Figure 4 Divergence angle on a three-dimensional model.

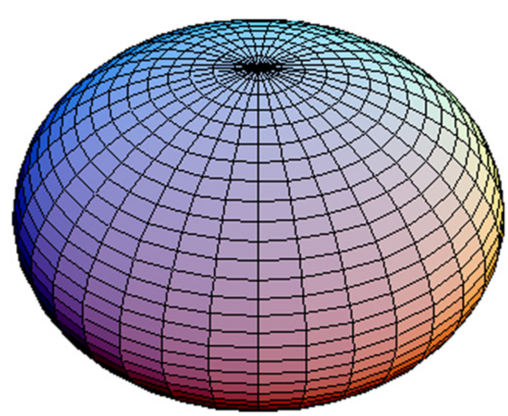

Figure 5 Spheroid (positive curvature).

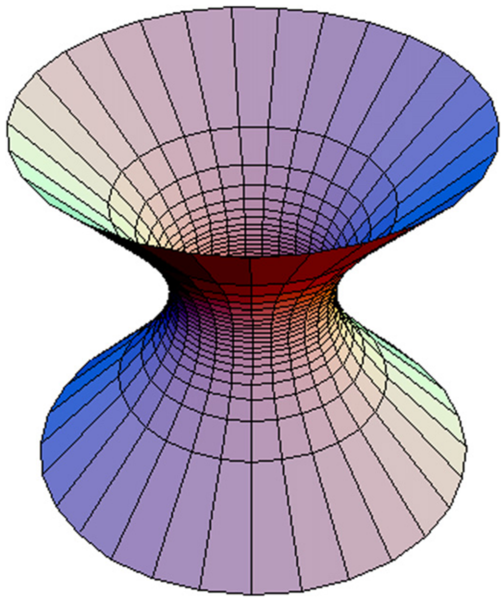

Figure 6 Hyperboloid (negative curvature).

Table 4 Breast shape analysis on three-dimensional digital model of a clinical case of bilateral augmentation

Case PB: bilateral augmentation	Right	Left
Surface area (cm^2)		
Total	409	421.7
Upper outer quadrant	130.6	187.3
Upper inner quadrant	169.7	136.9
Lower inner quadrant	64.35	48.6
Lower outer quadrant	44.31	49.61
Distances (cm)		
Nipple—sternal notch	19.7	19.07
Nipple—acromial extremity of clavicle	18.4	18.06
Nipple—midaxillary point	14.9	14.8
Sternal notch—acromial extremity of clavicle	9.7	10.1
Sternal notch—midaxillary point	14.9	14.8
Sterna notch—pectoralis insertion in the arm	12.6	14.6
Xiphoid—midaxillary point	18.9	19.09
Angles (degrees)		
Divergence	20.8	21
Ptosis	89	82.5

measurements can be an indicator of capsular contracture, as shown in the cases of CH and MP.

We found angle calculations very interesting. The 'divergence angle' for instance could express the patient's point of view on her breast (Fig. 4).

Graphic depiction of the breast 'curvature' is the most innovative result of this study (Figs. 7 and 8). The colour map produced gives a representation of the breast as a complex curved surface.

The superior half of the healthy breast was shown to be almost flat (green or yellow colours) especially in the inner quadrants (Fig. 7, natural side) while moving towards the upper outer quadrants curvature becomes negative. Capsular contracture largely modified colour distribution on the map of patient CH with a predominance of areas at high curvature (blue on the breast mound and red at its edges with severely reduced flat territories).

Curvature representation can, in our opinion, replace current terminology usually related to volumes. For instance the term 'full' can be translated to positively curved and the degree of curvature may be expressed by numerical coefficients.

Volume measurement, in our view, is nowadays partially obsolete because of the advent of anatomical prosthesis whose selection is made according to three linear parameters (height, width and projection). Furthermore, breast boundaries are rather undetermined and the posterior wall (i.e. the thoracic wall) cannot be estimated using surface scanning.[3]

On the other hand it is rather obvious that two completely different shapes can result from identical volumes.

We found partial and total contraindications in determining the two last morphological items of our panel with the tested methodology (Table 1).

Symmetry analysis requires implementation of an ad hoc system capable of acquiring the whole surface in a single scan. Our device is currently based on three scans and may be helpful only for visual representation. Losken and

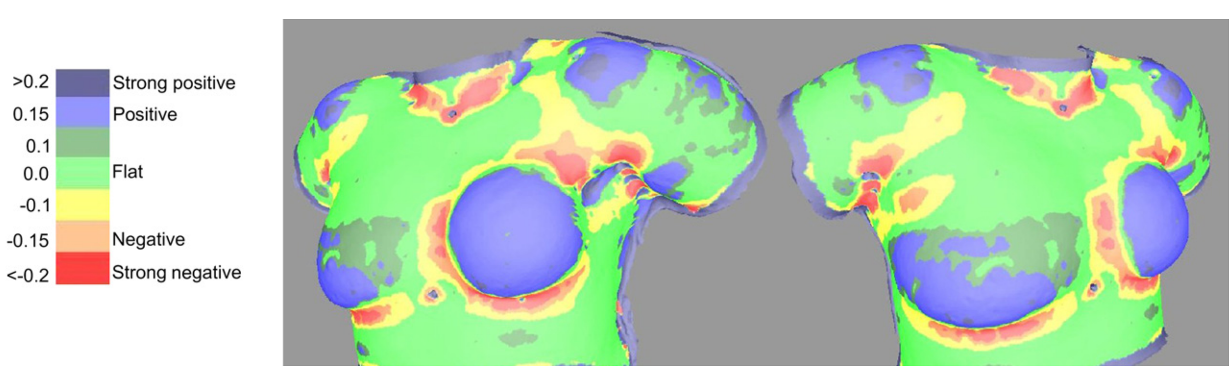

Figure 7 Baker grade IV capsular contracture on the left side and natural breast contralaterally. Colour scale associates values to a curvature colour scale.

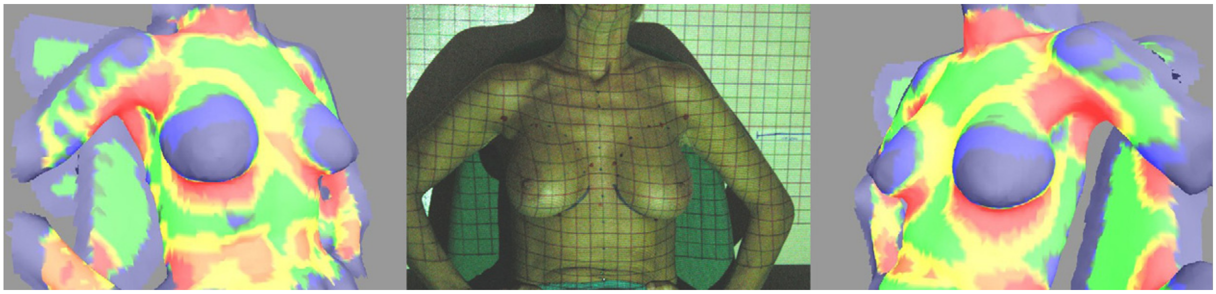

Figure 8 Curvature on a three-dimensional model of bilateral breast augmentation.

Carlson[4] produced an objective analysis of this parameter superimposing three-dimensional models of the two breasts. Breathing and chest wall movement artefacts are solved by the employed methodology. However, light physical deformities of the chest wall or spine may, in our opinion, easily impair the final results.

Areas completely hidden by glandular folding on the chest wall are often undetectable. No light-based scanners can overcome this physical obstacle. For these reasons IMF shape analysis is absolutely contraindicated with the tested system.

We believe that many of the difficulties in this field can be overcome in the near future by building standard graphic parametric models of the breast simulating the inframammary fold shape and fitting them to data obtained with optical measurements.[5]

The validation of three-dimensional imaging of the breast is, in our opinion, very challenging. Losken et al. estimated the in vivo breast volume with an optical scanner and compared it to that of the postmastectomy specimen. Unfortunately, this methodology does not take into consideration the residual skin flaps that are not irrelevant, especially in the case of skin-sparing operations.[6]

Kovacs described the most reliable acquisition protocol for breast shape assessment.[7] In this case the use of two laser scanners seems too expensive for everyday clinical practice. Cheaper and faster scanning techniques based on commercial digital cameras should be available in the next few years.[8]

Our institutions are currently developing a customised scanning system allowing detection of hidden areas and avoiding breathing artefacts. This will be based on preliminary works on the item published by Baroni et al.[9–11] and will be tested on larger cohorts of women undergoing breast cosmetic and reconstructive surgery.

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