Objective Outcome Evaluation of Breast Surgery

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Abstract. A new method is proposed to unambiguously define a geometric partitioning of 3D models of female thorax. A breast partitioning scheme is derived from simple geometric primitives and well-defined anatomical points. Relevant measurements can be extrapolated from breast partition. Our method has been tested on a number of breast 3D models acquired by means of a commercial scanner on real clinical cases.

1 Introduction and Motivation

Analysis and definition of breast shape based on clinical semantics can help plastic surgeons to objectively evaluate the outcome of plastic surgery. Until today, visual assessment is the common clinical practice. Although several reproducible measurement methodologies have been proposed in the literature, none of them reached clinical practice. Some authors propose to measure the breast volume by means of water displacement, MRI, X-rays, or thermoplastic moulding [1,2,3,4,5,6]. Others use anatomical landmarks and manual measurements. However, their measurement techniques are inaccurate (e.g., area of breast surface, length of the path over the breast surface, and so on). Moreover, manual measurements heavily depend on experimental settings, such as the posture of the patient. 3D scanning technologies can be exploited to acquire useful data for accurate and reproducible analysis of breast surface.

We define a non-ambiguous geometric segmentation of 3D models of the thoraco-mammary surface, starting from the informal specifications of the surgeons. We also indicate a set of measurements and visualisation methods to objectively evaluate the outcome of breast surgery, and to provide a sound and objective meaning to vague terms, such as *sweet slope* and *well defined inferior pole*. The proposed partitioning scheme has been implemented in a custom tool named Breast Shape Analyzer 0.1 (BSA 0.1).

2 Breast Surface Analysis

The models used in our work were collected according to common cosmetic and reconstructive criteria (e.g., age, menopausal status, ptosis classification). A commercial laser scanner has been used to acquire the data.

Fig. 1. Patient positioning

The recruited volunteers were seated on a chair with their back at 45 degrees (Figure 1). Three scans of the same volunteer were acquired: facing the camera and rotating the chair at 45 degrees to the left and to the right. We choose not to merge the different scans because of uncontrollable physiological movements (e.g., breathing and imperceptible body torsions) during the scanning process. The time lag required by laser scanning is not compatible with the patient breathing. This difficulty may be overcome by adopting faster but less accurate shape-from-video techniques [7].

Therefore, the analysis has been performed on partial views. Unsampld areas have been filled using volumetric diffusion [3]. This method is compatible with precision requirements of surgeons when it deals with small gaps (below 0.8 cm of diameter). Gaps of larger size have been filled only for visualisation purposes and the reconstructed areas have not been used in landmark positioning.

2.1 Anatomical Landmarks

In order to unambiguously define breast sub-units, we exploited the following anatomical landmarks, suggested by surgeons because of their easy reproducibility (Figure 2):

1. *Sternal Notch or Jugulum* (p_j)
2. *Xiphoid* (p_x)
3. *Nipple* (p_c)
4. *Pectoralis insertion in the arm* (p_{aa})
5. *Acromial extremity of clavicle* (p_s)
6. *Mid-axillary point* (p_{pa})
7. *Lowest breast point with respect to the vertical body axis* (p_d)

Fig. 2. Anatomical landmarks

These points are interactively placed by surgeons on the model using the BSA 0.1 tool described in Section 3.

2.2 Anatomical Sub-units

In clinical practice, breast sub-units are manually traced and the outcome strongly depends on the experience and ability of surgeons. We aimed at defining a tracing scheme that is less dependent on the ability of the user. The proposed scheme employs simple geometric primitives such as planes, lines, and geodesics. Geometrically-defined breast partitioning guarantees a more objective and reproducible subdivision procedure and opens the way to objective quantitative measuring methods. The proposed subdivision algorithm defines four elements:

1. *Thoraco-mammary bilateral symmetry plane* (π_s);
2. *Breast meridian plane* ($\pi_{m,l}$ and $\pi_{m,r}$ for left and right breast, respectively);
3. *Breast equatorial plane* ($\pi_{e,l}$ and $\pi_{e,r}$ for left and right breast, respectively);
4. *Breast box hull*.

Fig. 3. Planes used for breast segmentation. (a) Thoraco-mammary bilateral symmetry plane. (b) Breast meridian plane (c) Breast meridian curve obtained by intersecting the 3D model and the meridian plane. (d) Nipple-areola plane. (e) Construction of the equatorial plane. (f) Breast equatorial curve.

First, we define the *bilateral symmetry plane* as the axial plane through p_j (*jugulum*), p_x (*xiphoid*) and the derived point M_{jx} . M_{jx} is the middle point of the geodesic between p_j and p_x . Notice that these three points are not collinear due to the natural curvature of the thorax (Figure 3(a)).

The *breast meridian plane* is defined by three points (see Figure 3(b)): the nipple, the midpoint, M_{js} , of the straight line between p_j (sternal notch) and p_s (acromial extremity of the clavicle), and the midpoint M_{px} of the straight line between p_{pa}

Fig. 4. Construction of the *Breast Box Hull*

(pectoralis insertion in the arm) and p_x (xiphoid). This plane intersects the model subdividing the surface in lateral and medial aspects. The curve produced on the model is usually referred to as *breast meridian* (Figure 3(b) and Figure 3(c)).

In order to define the *equatorial plane*, we imitate a very common device used by plastic surgeons to mark the nipple-areola complex. The *nipple-areola plane* is defined as the tangent plane at the nipple, p_c (Figure 3(d)). The equatorial plane is orthogonal to the nipple-areola plane and to the line defined by the intersection of this plane and the meridian plane (Figure 3(e)). The intersection between the equatorial plane and the breast surface is called *breast equator*. It separates the upper and lower halves of the breast (Figure 3(f)).

A region of interest (*breast box hull*) has been selected in compliance with surgeons' specifications to analyse breast surface properties. It is made up of six surfaces:

- *Breast surface*
- *Back plane*, π_b , orthogonal to π_s and containing p_s and p_{aa} (Figure 4(a))
- *Thoraco-mammary bilateral symmetry plane* π_s (Figure 3(a))
- *Lateral plane*, $\pi_{l,i}$, orthogonal to π_b and containing p_{aa} and p_{pa} (Figure 4(b))
- *Lower plane*, π_L , orthogonal to π_s and passing through p_d (Figure 4(b))
- *Upper plane*, π_U , orthogonal to π_s and to π_b and including p_j and p_s (Figure 4(b))

2.3 Measurements

Given the partition defined in Section 2.2 a number of relevant measurements can be computed:

Line Measurements. Distances between all the landmark pairs and distances between p_c and the bilateral symmetry plane, and between the nipple, p_c , and the back plane, π_b (Figure 5).

Area measurements. We computed the area of some relevant surfaces: the front box hull, the upper pole, the lower pole, and the sub-units defined by the intersection of the meridian plane, $\pi_{m,i}$, and the equator plane, $\pi_{e,i}$.

Angles. Let us define $O_i x_i y_i z_i$ the (generally non-orthogonal) coordinate system induced by the intersection of the planes π_s , $\pi_{m,i}$, $\pi_{e,i}$ (refer to Section 2.2 and Figure 6), where i stands for l (left) or r (right). We compute

the angles $\widehat{x_i y_i}$ and $\widehat{x_i z_i}$, where x_i is the axis including the nipple, p_c . The former gives a measure of the *divergence* of the nipples with respect to the bilateral symmetry plane. The latter quantifies the *breast ptosis*.

Curvature and convexity. Visualising the mean curvature and convexity of the breast surface is useful to capture the concept of widely used clinical terms, such as “sweet slope” and “well defined inferior pole”. Since no unambiguous definition of breast shape features is available, surgeons found false-colour visualisation more useful than any attempt to make accurate measurements of data.

Fig. 5. Line measurements

Fig. 6. The Angle Reference System

3 The *Breast Shape Analyzer* Tool

The Breast Shape Analyzer tool (BSA 0.1) allows the positioning of landmarks directly on the 3D model. When a point in screen space is acquired, a ray is cast from the near plane to the far plane, in the OpenGL context, and the closest vertex to this ray is automatically selected as a landmark point. Every landmark shift on the mesh is interactively shown and the coordinates values are visualised in a separate text area of the interface for feedback. The tool automatically computes and shows all the relevant planes as soon as all the needed landmarks are positioned. A critical issue is the computation of the tangent plane at the nipple, p_c . This is done using an approximation of the normal to the surface. The segmented subunits may be visualised in different contrasted colours (Figure 7(a)). All the measures that have been listed in the previous section can be calculated, visualised, and stored.

Finally, the model is painted in false colours according to the mean curvature and to the convexity of the breast surface. Two colouring modes are allowed: curvature and convexity (Figures 7(b) and 7(c)). Curvature is displayed using a colour ramp ranging from blue to red, in increasing order of curvature. Convexity is encoded using two colours, representing concave and convex regions. Surface colouring significantly captures breast shape features, thus guiding surgeons in post-operative outcome evaluation. Colouring does not fulfill our expectations due to the sampling noise of the surface. This effect can be partially reduced by smoothing the surface, while preserving significant details (i.e., high curvature regions). Edge-preserving

Fig. 7. Visualisation of the 3D model of a volunteer's breast using the BSA tool

smoothing can be implemented using many different filters, such as Bilateral filter [8]. Alternatively, curvature can be computed on a simplified mesh and then mapped back to the original model e.g., using a point-surface distance.

4 Clinical Test

Most of the published medical studies on breast shape evaluation focus on reconstruction using volume estimation or simple linear measurements [1,2,3,4,5,6]. None of them has reached clinical practice since either the landmarks are ambiguously and arbitrarily placed, or their definition is hard to reproduce in complex cases. We place landmarks on bony extremities, since they are more reproducible. Building on these points, the resulting unambiguous geometric partitioning of the breast shape is useful to develop a reliable breast topography and a proper outcome evaluation protocol. Our method cannot be compared to any other existing technique due to lack of objective methods for breast shape measurement in the literature as well as in clinical practice. We rather demonstrate the capabilities of our method to capture commonly-used clinical evaluation parameters by analysing a case study.

In Table 1 and Figure 8, we report a clinical case of a woman (Patient CH) who underwent mastectomy and reconstruction with permanent silicone implants and developed a Baker Grade IV capsular contracture. Our measurements correctly predict a severe alteration of biometric parameters, such as shoulder *adduction*

Fig. 8. Local mean curvature

Table 1. Relevant measurements for patient Ch

		Reconstructed breast	Natural breast
Surfaces Area (cm^2)	Total	461.00	522.30
	Upper outer quadrant (Red)	147.30	218.00
	Upper inner quadrant (Blue)	60.38	74.50
	Lower outer quadrant (Green)	187.00	171.20
	Lower inner quadrant (Yellow)	66.00	57.00
Upper/lower surface ratio		0.82	1.28
Distances (cm)	$\overline{p_c \pi_s}$	10.00	11.10
	$\overline{p_c p_j}$	18.40	20.20
	$\overline{p_c p_s}$	18.90	19.40
	$\overline{p_c p_{aa}}$	14.50	15.80
	$\overline{p_j p_s}$	13.40	14.30
	$\overline{p_j p_{aa}}$	14.50	15.82
	$\overline{p_s p_{aa}}$	15.20	16.70
	$\overline{p_x p_{aa}}$	21.90	23.20
Angles (degrees)	Ptoxis	95	84
	Divergence	39	31

($\overline{p_j p_s} = 13.4cm$ on the reconstructed side and $14.3cm$ on the natural side) and *flexion* of vertebral spine ($\overline{p_x p_{aa}} = 21.9cm$ on the reconstructed side and $23.2cm$ on the natural side). The reconstructed nipple lies $18.4cm$ apart from the jugulum, while this distance is $20.2cm$ on the natural side. Surface area measurements show an overall reduction of the breast box hull surface after the operation ($461\,cm^2$ reconstructed, $522\,cm^2$ natural). Moreover, the area ratio between the upper and the lower halves of the breasts show a predominance of the inferior half of the reconstructed side, while on the natural side the upper areas are wider. We also introduce the *divergence angle* (see Section 2.3) as a new parameter for breast shape evaluation. This measurement is considered by surgeons capable of capturing important features of the breast shape. Basically, it expresses the patient’s observation point on her breast (from the top), a feature that cannot be guessed by doctors staying in front of her. The analysis of cases who underwent bilateral augmentation, and whose breasts are modelled by two identical implants underneath, show similar estimates on both sides. Finally, the false-colour visualisation (Figure 8) of the local mean curvature of the breast surface is considered particularly useful by surgeons. The figure shows the alteration of a reconstructed breast in the clinical case CH. Highly curved surfaces are predominant on the reconstructed side, while the natural breast is smother and almost flat close to the upper-inner quadrants. Although this information can be collected from visual in *vivo* observation or from observation of 2D photographs, these procedures do not allow objective evaluation and data exchange between surgeons.

The reproducibility of the reported numerical measures is assured by the partitioning algorithm defined in Section 2.2. We are currently evaluating the effect of landmark misplacement of the final result.

5 Conclusions

Evaluating the post-operative outcome of breast plastic surgery is currently a little more than craftsmanship and intuition, strongly relying on the professional skills of surgeons. Clinical capabilities and personal experience of plastic surgeons

cannot be embedded into a standard clinical procedure, unless a new theoretical background in anatomical shape analysis is established.

A series of feature points uniquely characterising woman breast surface was fixed in compliance with surgeon's suggestions and requirements. Building on these landmarks, we devised a simple and reproducible breast partitioning scheme employing only geometric primitives as simple as planes, lines, and geodesics. We came out with a simple and intuitive description of breast surface that has been appreciated by the plastic surgery community and is being clinically validated. Our unambiguous geometric breast partitioning is a first step towards the definition of a portable and reproducible analysis scheme, and opens the path to the definition of objective breast biometrics that, in turn, can lead to the definition of a standard clinical evaluation protocol.

A prototype software, *Breast Shape Analyzer* (BSA 0.1), based on our novel methodology, has been produced to empower surgeons with useful measuring and visualisation tools. BSA will be soon available in our website . Many challenging issues are left open by this work:

- a) use of faster (and/or cheaper) scanning techniques;
- b) modelling of the elastic and structural deformation of the breast shape;
- c) parametric fitting of a standard breast model from few 3D anatomical landmarks and/or a low resolution scan of the body.

Future works will be focussed on these issues.

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