3D computer technology addresses body-image issues of breast reconstruction

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A decision support system is being designed to help breast cancer patients choose reconstruction options that meet their quality-of-life concerns.

In the United States, one in eight women can expect to be diagnosed with breast cancer within her lifetime. Treatment of breast cancer often involves mastectomy, the surgical removal of the breast(s). Women at heightened risk may also elect to undergo mastectomy to reduce the chances of developing breast cancer. Many women who undergo a mastectomy have concerns about their body image—i.e., how they view their appearance and the overall functioning of their body. The goal of breast reconstruction is to recreate the appearance of the patient’s breasts in a way that restores her body image.

Breast reconstruction typically requires multiple procedures over time to obtain a final result. Many women are candidates for more than one form of breast reconstruction, such as reconstruction using either an implant or some of the patient’s own tissue (autologous reconstruction). There are a large number of factors a woman must consider when making her treatment decisions, including time, cost, and body-image preferences. For a woman to make optimal decisions about breast reconstruction, she needs some very specific information to understand her surgical options and how her preferences, including her appearance after the surgery, can best be met. This article describes our approach to quantifying a patient’s appearance via imaging and 3D modeling techniques.1–11 We note, however, that developing a greater understanding of patient preferences in terms of quality-of-life measures such as body image12 and modeling the decision-making process for breast reconstruction13 are equally important aspects of our research program.

To extract relevant information about appearance changes, we analyzed both 2D and 3D surface images to quantify the appearance of the female breast and any changes it undergoes, and to develop patient-specific mechanistic models to predict realistic outcomes. Imaging in 2D that consists of clinical photographs with a standardized background and poses is currently the customary practice for documenting surgical outcomes. We achieved the 3D surface imaging via a stereophotography system from 3dMD, a medical imaging company in Atlanta, GA. We find 3D surface imaging of the breast advantageous both because it enables us to measure properties such as curvature and

Figure 1. Surface-curvature analysis produces automated identification of the sternal notch (S), nipples (N), and umbilicus (U). These fiducial points can be used to calculate quantitative measures such as symmetry. Figure prepared by Manas Kawale.

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volume that are more difficult to assess from 2D imaging and because 3D measurements retain their validity despite changes in the subject’s pose.\textsuperscript{15}

We computed measurements of breast morphology such as symmetry\textsuperscript{2,5,8} using distances between fiducial points—natural markers in the image that orient to specific areas—including the nipples, the sternal notch, and the umbilicus. We considered a range of aesthetic properties, not simply measures of symmetry and volume.\textsuperscript{16} For example, we have introduced measures of ptosis\textsuperscript{1,3} (the drape of the breast), scarring,\textsuperscript{6} and curvature.\textsuperscript{9,10} With such measurements, we can investigate surgical options that include different types of mastectomies\textsuperscript{8} and reconstruction procedures.\textsuperscript{9,10} Our goal is to streamline our analyses through techniques such as development of algorithms that automatically align images to a defined orientation\textsuperscript{4} and locate fiducial points.\textsuperscript{5,7,11} For example, we have developed accurate methods for fiducial point localization using 3D surface-curvature analysis coupled with 2D texture analysis (see Figure 1).

A key next step in our research is assessing changes in breast morphology over the course of reconstruction. To conduct longitudinal analyses, it is critical to register 3D images taken at different time points. Toward this goal, we have developed a semi-automated algorithm for registration of multiple images taken over time based on the assumption that the skeleton is relatively stable and thus the transformation can be treated as rigid.\textsuperscript{17}

In a highly innovative component of our current work, we are developing a physics-based, patient-specific biomechanical model that uses the 3D geometry obtained via 3D surface imaging combined with the material properties of the breast to predict breast reconstruction post-operative results (see Figure 2). This represents a new approach because there are few previous studies on the physical properties of the human breast such as skin thickness and deformation\textsuperscript{18} or pectoral muscle thickness and curvature.\textsuperscript{19}

Our progress in developing methods for measuring breast morphology and creating a patient-specific 3D prediction model will enable us to provide highly valuable quantitative feedback. Through the integration of breast aesthetics, body-image measurements, and biomechanical modeling into a decision-analysis framework, we hope to more fully inform both patient and surgeon of possible outcomes. Ultimately, our goal is to design a decision support system to help breast cancer survivors understand their likely appearance changes following breast reconstruction and enable them to choose a reconstruction strategy that will result in maximum psychosocial adjustment.

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\textit{Figure 2.} 3D images of breasts with subject (a) standing upright and (b) lying supine. Finite element analysis can be used to quantify changes in breast shape, such as those occurring with the subject’s position as shown in this example (c). Other methods can be used to quantify changes in skin texture and coloration. Figure prepared by Hamed Khatam.

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References