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Preoperative implant selection for unilateral breast reconstruction using 3D imaging with the Microsoft Kinect sensor☆

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Summary *Aims:* This study aimed to investigate whether breast volume measured preoperatively using a Kinect 3D sensor could be used to determine the most appropriate implant size for reconstruction.
Methods: Ten patients underwent 3D imaging before and after unilateral implant-based reconstruction. Imaging used seven configurations, varying patient pose and Kinect location, which were compared regarding suitability for volume measurement. Four methods of defining the breast boundary for automated volume calculation were compared, and repeatability assessed over five repetitions.
Results: The most repeatable breast boundary annotation used an ellipse to track the inframammary fold and a plane describing the chest wall (coefficient of repeatability: 70 ml). The most reproducible imaging position comparing pre- and postoperative volume measurement of the healthy breast was achieved for the sitting patient with elevated arms and Kinect centrally positioned (coefficient of repeatability: 141 ml). Optimal implant volume was calculated by correcting used implant volume by the observed postoperative asymmetry. It was possible to predict implant size using a linear model derived from preoperative volume measurement of the healthy breast (coefficient of determination $R^2 = 0.78$, standard error of prediction 120 ml). Mastectomy specimen weight and experienced surgeons' choice showed similar predictive ability (both: $R^2 = 0.74$, standard error: 141/142 ml). A leave one-out validation showed that in 61% of cases, 3D imaging could predict implant volume to within 10%; however for 17% of cases it was >30%.

☆ Parts of this work have been presented as a student presentation at the student and annual symposium of the Manchester Breast Centre, 17 July 2015.

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Conclusion: This technology has the potential to facilitate reconstruction surgery planning and implant procurement to maximise symmetry after unilateral reconstruction.

Introduction

The most common form of immediate breast reconstruction in the UK uses a tissue expander/implant.[1] Surgeons choose implants on the basis of patient anatomy as assessed by subjective linear measurements,[2,3] personal experience and availability of implants. However, linear measurements including height, width and projection are insufficient to describe the breast shape and size accurately, and small measurement discrepancies may lead to variation in volumetric implant size estimation[4] and potentially unacceptable asymmetry. Registry data show that asymmetry after reconstruction necessitating further surgery affects around one-fifth of patients.[5,6] An accurate and reproducible preoperative measurement of breast size and shape would provide an objective assessment and help avoid asymmetry. Although various methods have been developed, there is no universally accepted objective method for determining breast volume[7–9] and choosing implant size for breast reconstruction.

Recently, 3D imaging has found application in planning breast surgery including augmentation procedures,[10–14] reduction[15] and reconstruction surgery.[16–20] Most studies used commercial 3D scanning equipment such as the Konica Minolta Vivid,[21] Axis Three[11] or Di3D[22] surface scanners. Accuracy is very high (errors <1 mm), scanning speed is fast (<3 s), but commercial equipment is very expensive (20,000–130,000 US Dollars) and usually requires calibration at setup or before each use.[23]

The use of 3D scanning with the Microsoft Kinect, a small sensor based on infra-red (non-ionising) light emission and originally designed for computer gaming has been investigated as a convenient, inexpensive alternative.[24–26] The technique is based on transportable and cheap equipment ($\sim$100 US Dollars), which is ready to use without time and labour intense installation and calibration. Recently, the feasibility of using the Kinect for breast imaging has been demonstrated assessing cosmetic outcomes after breast surgery,[24,25] although it has not been used for planning breast reconstruction. Moreover, there is no consensus which imaging position is the most appropriate for this task either in terms of arm position[26] or body inclination.[27,28] In addition, Xi et al. identified the definitions of the breast boundary and the posterior wall as critical factors that could potentially limit the accuracy of the breast volume measurement.[7]

Aims of this study

This study aimed to analyse the preoperative breast volume in patients with breast cancer and hence predicts the implant size for reconstruction. Different definitions of the breast boundary were studied to maximise measurement repeatability. Additionally, the most useful imaging position was determined optimising reproducibility and predictive power to estimate implant sizes correctly.

Methods

Patient selection and 3D image acquisition

For this explorative study, ten female patients who underwent unilateral mastectomy with breast reconstruction between March 2015 and May 2016 were enrolled. Eligible patients were those without history of breast surgery and whose reconstruction was performed as immediate implant-based reconstruction or two-stage procedure using a tissue expander. The Kinect II (Kinect for Xbox One, Microsoft) was used to acquire 3D images of the patients' breasts before surgery (preoperative) and at least 2 weeks after surgery (postoperative). A simple acquisition protocol was applied, omitting stationary equipment, as in,[22,27] in addition to avoiding complicated patient positioning[16,27] and time-consuming fusion of multiple images.[25] The imaging protocol for both time points featured seven different imaging positions, which combined different patient poses including sitting and lying with arms hanging and above the head with different Kinect positions (see Table 1). For imaging position 4, the Kinect was moved around the patient and a 3D model reconstructed continuously using open source software (KinectFusion).[29] The treating surgeons were blinded to the image-based breast volume measurements and chose implants according to their current practice.

Breast volume measurement

All acquired 3D images were pre-processed by downsampling using Meshlab (3D image points closer than 0.5 mm were merged) to guarantee fast and robust volume calculations. To separate the breast volume from the residual torso, breast boundaries were defined by manually selecting landmarks on the computer-generated 3D model surface, by using Meshlab again. Four different boundary definitions were assessed for this feasibility study (see Figure 1):

A. Three landmarks were annotated outlining the extreme points of the breast, indicated by the measurement points used by Qiao.[30] Inferiorly, the lowest point of the inframammary fold was chosen; medially, a point on the mid-sternal line at the level of the maximum breast