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ORIGINAL ARTICLE BREAST SURGERY

The Effect of Respiration on Breast Measurement Using Three-dimensional Breast Imaging

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Abstract

Background Three-dimensional (3D) imaging offers new opportunities to enable objective and quantitative analysis of the breast. Unlike scanning of rigid objects, respiration may be one of the factors that can influence the measurement of breast when using 3D imaging. In this study, we aimed to investigate how the different respiratory phases affect 3D morphologic and volumetric evaluations of the breast.

Methods We performed preoperative 3D breast imaging at the end of expiration (EE) and the end of inspiration (EI). We repeated scans on each respiratory phase, taking four scans in total (EE1, EE2 and EI1, EI2). Using Geomagic Studio 12 software, measurements from the different respiratory phases (EE1 and EI1) were compared for differences in the linear distances of breast. Breast volumetric change error (BVCE) was measured between EE1 and EE2 (R1) and between EI1 and EI2 (R2). A multilevel model was used to analyze the difference of linear-distances parameters between EE1 and EI1 and a paired sample *t*-test was used to analyze the difference between R1 and R2.

Results Our study included 13 Chinese women (26 breasts) with a mean age of 32.6 ± 6.3 years. Compared with EI, EE showed a longer sternal notch to the level of the inframammary fold and shorter nipple to midline ($p < 0.05$). During EI, breast projection increased by 0.23 cm (95% CI − 0.39, − 0.08) and breast base width increased by 0.27 cm (95% CI − 0.46, − 0.09). The position of the nipple moved by 0.18 cm (95% CI − 0.34, − 0.03) laterally, 0.41 cm (95% CI 0.18, 0.64) cranially, and 0.71 cm (95% CI − 0.92, − 0.51) anteriorly. Although there was no significant difference in BVCE between EE and EI, the result seen with EE appeared to be more consistent.

Conclusions The results of this study demonstrate that there was no difference in breast volume results when patients are in the expiratory or inspiratory state during 3D breast imaging. This study, however, holds potential benefits to both surgical practice as well as the 3D imaging industry.

Level of Evidence IV This journal requires that authors assign a level of evidence to each article. For a full description of these Evidence-Based Medicine ratings, please refer to the Table of Contents or the online Instructions to Authors www.springer.com/00266.

Keywords Three-dimensional imaging · Exhalation · Inhalation · Breast morphology · Breast volume · Mammaplasty

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Introduction

Breast augmentation is one of the most popular cosmetic surgical procedures in the world. Accurate assessment of the morphology and volume of the breast is essential for both preoperative surgical planning and postoperative evaluation of outcomes at follow-up [1–3]. In recent years, there has been vast advancement in imaging technologies

and consequent increased availability to physicians, with the three-dimensional (3D) scanning technique gaining increasing popularity among surgeons [4–6]. Compared with computed tomography (CT) or magnetic resonance imaging (MRI), 3D imaging is more affordable, less invasive, and faster [7].

Unlike the scanning of rigid objects in the field of manufacturing, many factors, such as posture and respiratory state, may affect the measurement results of 3D breast imaging. In other fields of medicine, for example radiology, dynamic changes in thoracic excursion, due to respiration, have been shown to significantly affect imaging of the chest/breast and related measurements [8, 9]. Unfortunately, the extent to which respiratory state can influence the breast morphologic parameters obtained from 3D breast imaging is not yet clear. Specifically, the linear distances used for establishing the size of a breast implant are uncertain. The difference in breast volume result, and whether there is any actual difference, when patients shift from an expiratory to an inspiratory state has also not been established. Taking the effect of respiration into consideration should increase the confidence of surgeons in 3D imaging for quantitative surgical planning. Thus, in this study we aimed to investigate how the different respiratory phases affect 3D morphologic and volumetric evaluation of the breast.

Patients and Methods

Patient Enrollment

Patients were enrolled under a protocol approved by our Institutional Ethics Committee and conducted in accordance with the World Medical Association Declaration of Helsinki [10]. A written informed consent was obtained from each patient.

Between January 2017 and September 2017, we enrolled 13 adult patients (26 breasts) who were candidates for bilateral mammoplasty (breast augmentation with implant) at our institution. Patients with prior breast surgery, congenital breast deformities, significant breast ptosis (Regnault type 2 or higher), and other local comorbidities (e.g., wounds and infections) were excluded.

3D Scanning

All patients received preoperative 3D imaging (JRCB-D; Jirui, Beijing, China; accuracy, $\leq$ 0.1 mm) of their breasts using a previously validated protocol (Fig. 1) [11]. Each patient underwent scanning at the end of expiration (EE) and the end of inspiration (EI). Each respiratory phase was repeated twice, that is, two times per each respiratory phase: end of expiration (EE1 and EE2) and end of inspiration (EI1 and EI2). The final stage of respiration was selected because it was seen to be easier to be controlled by the patients and, hence, kept more consistent.

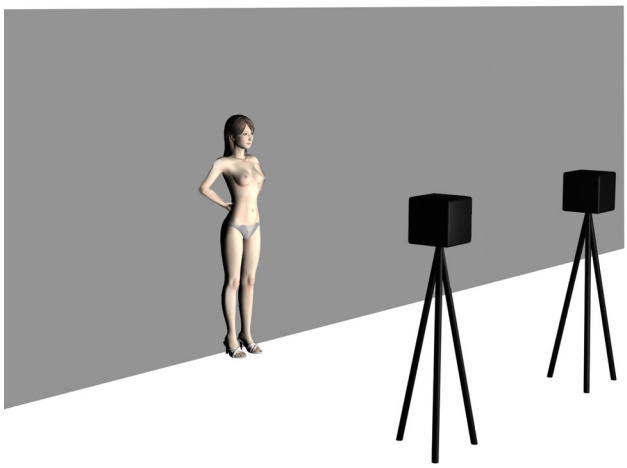

Fig. 1 Schematic illustration of a patient undergoing three-dimensional scanning in the study

Linear-Distance Measurements

The Geomagic Studio 12 software (Geomagic Solutions, Morrisville, NC, USA) was used to measure morphologic changes in the 3D-scanned images between EE1 and EI1. We measured the changes in key breast morphologic parameters including the position of the nipple as well as six linear distances: sternal notch to nipple (SN-N), nipple to inframammary fold (N-IMF), nipple to midline (N-MD), sternal notch to inframammary fold (SN-LIMF), breast projection (BP), and breast base width (BW). The position of the nipple was also measured based on a previous published protocol [12]. For SN-N, N-IMF, N-MD, SN-LIMF, both straight-line linear distance and their projection on the breast surface were measured (Fig. 2).

Breast Volumetric Change Error (BVCE) Measurement

To assess the reproducibility of measurements obtained in EE and EI and their reliability in assessing breast volume, we calculated the BVCE as EE1 and EE2 (R1) or EI1 and EI2 (R2), in accordance with a previously established protocol [13]. Briefly, two breast scans were best-fit aligned in the software. Two identical cylinders were created along the breast border with the breast surface as the dome. The volumetric discrepancy between the two cylinders was regarded as the BVCE.

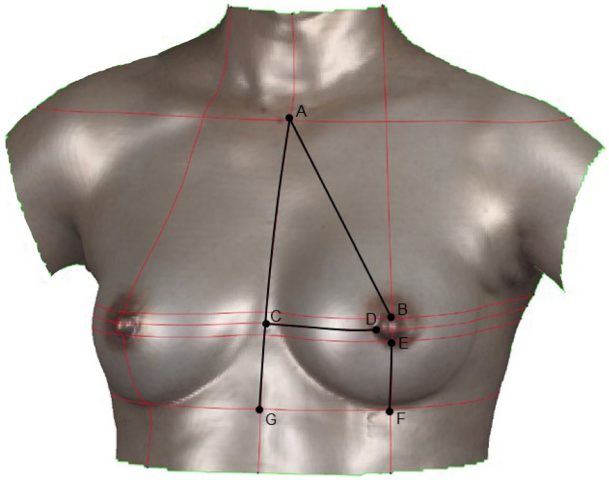

Fig. 2 Representation of measured linear distances on 3D breast scans. AB = SN-N (sternal notch to nipple); CD = N-MD (nipple to midline); EF = N-IMF (nipple to inframammary fold); AG = SN-LIMF (sternal notch to the level of inframammary fold)

Statistical Analysis

For comparison of breast linear-distance parameters, breast parameters (level 1) were measured for both left and right breasts (level 2) for each patient (level 3) since these are correlated and can lose independency if performing ordinary linear regression. A three-level mixed effect model was conducted to estimate the impact of each respiratory phase on breast measurements. Confounders for adjustment in this model included patients' age and body mass index (BMI). We performed statistical analysis on four models with different covariance matrices: variance components, compound symmetry, unstructured components, and autoregression. The final model with the smallest Akaike information criterion (AIC) and Bayesian information criterion (BIC) was chosen. Least square means with adjustment for age and BMI were estimated in the mixed effect model and presented as point estimation with a 95% confidence interval. The Wilcoxon signed-rank test was performed to compare the BVCE changes. The coefficient of variation (CV) was also calculated for R1 and R2 to test the variability of BVCE.

SPSS software (SPSS Inc. Released 2007. SPSS for windows, Version 16.0, Chicago, IL, USA) was used for statistical analysis. Differences were considered statistically significant at p values lower than 0.05.

Results

Patient Characteristics

The mean age of the 13 patients ($n = 26$ breasts) was 32.6 ± 6.3 years (range 20–40 years) and the mean BMI was 19.7 ± 1.9 kg/m^2.

3D Imaging During EE Showed a Longer SN-LIMF but Shorter N-MD Compared to EI

Compared to EI, 3D scans obtained during EE showed a statistically significant increase in SN-LIMF in both straight-line (0.54 cm; 95% CI 0.32, 0.76) and through-skin distance (0.36 cm; 95% CI 0.13, 0.60) (Table 1). Significant differences in N-MD were also noted, with EI showing longer measurements than EE in both straight-line (− 0.15 cm; 95% CI − 0.31, 0.00) and through-skin distance (− 0.25 cm; 95% CI − 0.45, − 0.05) (Table 1). Other linear-distance parameters did not show statistical significance between EE and EI.

EI Displaced the Nipple Laterally, Cranially and Anteriorly, and Increased Both Projection of the Breast and Width of Its Base

EI changed the measured position of the nipple on 3D scans, displacing it laterally (X axis: − 0.18 cm; 95% CI − 0.34, − 0.03), cranially (Y axis: 0.41 cm; 95% CI 0.18, 0.64), and anteriorly (Z axis: 0.71 cm; 95% CI − 0.92, − 0.51) (Table 2).

In addition, EI increased the projection of the breast (− 0.23 cm; 95% CI − 0.39, − 0.08) and the breast base width (− 0.27 cm; 95% CI − 0.46, − 0.09) (Table 2).

Breast Volumetric Change Error (BVCE) was Not Affected by the Respiratory Phase, but Data Obtained from R1 Showed a Higher Stability

The mean BVCE was 7.58 ± 4.05 ml for R1 and 5.52 ± 3.87 ml for R2 (Fig. 3). There was no statistical significance between R1 and R2 and the CV of R1 and R2 was 53.4% and 70.1%, respectively.

Discussion

3D imaging is an ideal tool for morphologic and volumetric breast analysis. In recent years, technological advances have made 3D scans more reliable, easier to use, less cumbersome, and more affordable, increasing their popularity among physicians and surgeons. In breast plastic

Table 1 Measurement of the linear-distance changes between EE and EI

Parameters	EE LS mean (95% CI)	EI LS mean (95% CI)	Difference (95% CI)	*p*
Straight line (cm)				
SN-N	18.00 (17.19, 18.80)	17.96 (17.16, 18.76)	0.04 (− 0.12, 0.20)	0.610
N-IMF	4.87 (4.42, 5.32)	4.76 (4.31, 5.20)	0.11 (− 0.05, 0.28)	0.168
N-MD	8.30 (7.89, 8.72)	8.46 (8.05, 8.87)	− 0.15 (− 0.31, − 0.00)	0.049*
SN-LIMF	20.37 (19.60, 21.15)	19.83 (19.05, 20.61)	0.54 (0.32, 0.76)	< 0.001*
Through skin (cm)				
SN-N	18.18 (17.34, 19.02)	18.20 (17.36, 19.04)	− 0.02 (− 0.20, 0.16)	0.783
N-IMF	6.03 (5.39, 6.67)	6.01 (5.37, 6.65)	0.02 (− 0.32, 0.36)	0.904
N-MD	9.07 (8.47, 9.68)	9.32 (8.72, 9.93)	− 0.25 (− 0.45, − 0.05)	0.018*
SN-LIMF	21.23 (20.45, 22.00)	20.87 (20.09, 21.64)	0.36 (0.13, 0.60)	0.006*

EE end of expiration, *EI* end of inspiration, *SN* sternal notch, *N* nipple, *IMF* inframammary fold, *MD* midline, *LIMF* level of inframammary fold, *LS* mean: Least square mean

*$p < 0.05$

Table 2 Measurement of the nipple position, breast projection and base width changes between EE and EI

Parameters	EE LS mean (95% CI)	EI LS mean (95% CI)	Difference (95% CI)	*p*
Nipple position (cm)				
Lateral displacement (*X* axis)	8.93 (8.51, 9.36)	9.12 (8.70, 9.54)	− 0.18 (− 0.34, − 0.03)	0.025*
Cranial displacement (*Y* axis)	14.87 (13.87, 15.88)	14.46 (13.46, 15.46)	0.41 (0.18, 0.64)	0.002*
Anterior displacement (*Z* axis)	6.66 (5.86, 7.46)	7.37 (6.57, 8.17)	− 0.71 (− 0.92, − 0.51)	< 0.001*
Projection	5.23 (4.57, 5.88)	5.46 (4.81, 6.11)	− 0.23 (− 0.39, − 0.08)	0.006*
Base width	13.86 (13.42, 14.30)	14.13 (13.69, 14.57)	− 0.27 (− 0.46, − 0.09)	0.008*

EE end of expiration, *EI* end of inspiration, *LS mean* least square mean

*$p < 0.05$

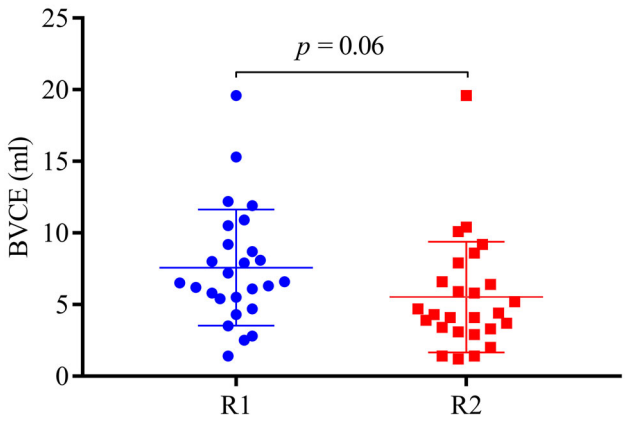

Fig. 3 Breast volumetric change error (BVCE) in R1 and R2 (Mean ± SD). There was no statistical significance between R1 and R2 for BVCE (R1 7.58 ± 4.05 vs. R2 5.52 ± 3.87, $p = 0.06$, Wilcoxon signed-rank test). R1 end of expiration (EE1) versus end of expiration again (EE2); R2 end of inspiration (EI1) versus end of inspiration again (EI2)

surgery, 3D imaging has several advantages over standard two-dimensional imaging, such as CT or MRI, in that 3D imaging is minimally invasive, safe, fast, and relatively inexpensive. It can be repeated multiple times and allows imaging of the breast in a physiological upright position and is normally used by breast surgeons during clinical examinations. Among other indications, 3D scanning has been shown to be a valuable tool for preoperative planning and postoperative follow-up in aesthetic breast augmentation with implants (changes in SN-N, N-IMF, N-MD and SN-LIMF) [12] or for evaluation of graft volume retention in breast fat grafting [5]. In addition, 3D imaging can help assess and quantify physiological breast asymmetry, a common occurrence in most women, as an essential component of preoperative breast assessment [11, 14].

The breast is closely related to the thoracic cage. It is well known that due to the interaction between rib morphology, costovertebral articulations and respiratory muscles, the human ribcage expands and contracts during respiration [15, 16]. Thus, factors like breathing which may

affect the shape of the thoracic cage may create variations in the measurement of breast. However, few studies have investigated the impact of breathing and respiratory phases on the 3D assessment of the volume or morphology of the breast. Patete et al. [17] proposed the use of a handheld laser scanner which actively compensates for breathing motion; yet, that study does not describe, nor measure, the actual impact of the respiratory phases on breast morphology. In addition, data obtained from a handheld device may not be directly applicable to 3D scanning which uses grating photogrammetry technology, as used in this study.

In our study, we first analyzed the influence of respiration on breast linear-distance measurements. Compared with EE, the SN-IMF decreased, and N-MD increased during EI. In other words, compared to EE, during EI the breast was displaced cranially and laterally, with an increased width in its base and projection (Fig. 4). During EI, the position of the nipple also changed, moving more laterally, cranially and anteriorly (Fig. 4). The above differences may be explained by the change in the shape of the thoracic cage during EI, which elevates and moves outward. The SN-N and N-IMF did not significantly change, likely due to the different degrees affected by the respiratory phase for the anatomical landmarks.

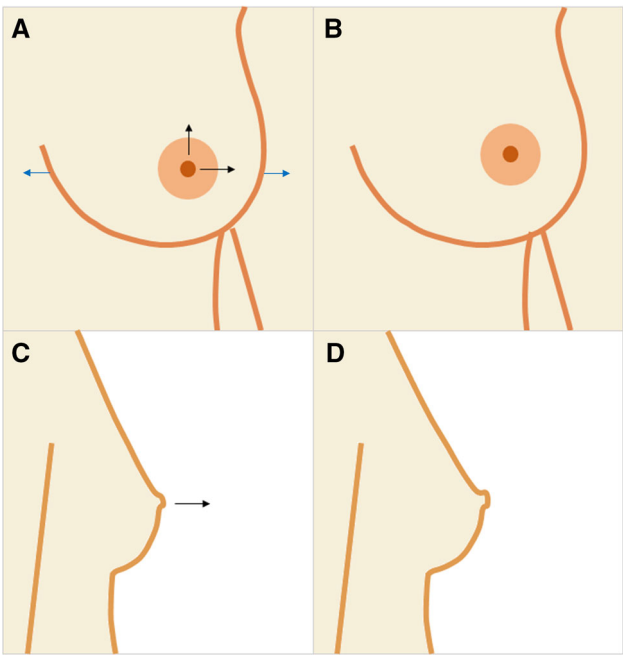

Fig. 4 When compared to EE, during EI the breast was displaced laterally and cranially, with an increase in the width of its base as well as increased projection. The position of the nipple moved laterally, cranially and anteriorly. **a** Frontal view of the breast in EE (Arrow shows the change in nipple position and width of breast base); **b** frontal view of the breast in EI; **c** lateral view of the breast in EE; **d** lateral view of the breast in EI. EFE end of expiration; EI end of inspiration

Although the linear-line distances showed minimal difference between the EE and EI in our study, we support that this difference still holds clinical significance to some extent for the following reasons. First, the changes of linear-line distance correlate with the basic size of the breast. Compared to Chinese women in this study, patients in Western countries have a bigger breast size, a kind of difference which will be proportionally increased. Second, natural breast asymmetry does exist in most females and should not be disregarded preoperatively or postoperatively [11, 14]. Additionally, our previous study showed that the distances of SN-N, N-IMF, N-MD and SN-LIMF significantly increased after breast augmentation [12]. Kovacs et al. [18] showed that for every 100 ml volume implant inserted, the N-IMF distance increases by 0.8 cm and the changes in 3D linear distance correlate with the shape of the implant. Thus, if the effect of respiration on breast morphology is not taken into consideration preoperatively, asymmetry and other parameters may be further augmented postoperatively. Awareness of this effect can minimize the error created by respiration, which is pivotal for improving postoperative patient satisfaction.

Our previous study showed that different respiratory states can result in variations in breast volume measurements using a 3D scanning technique [7]. We, however, did not establish which respiratory state is more stable. Interestingly, our outcomes in this study showed no significant difference between R1 and R2 with regards to the BVCE. This result indicates that if 3D scanning is obtained during the same respiratory phase, then the breast volume can be assessed in a reproducible and reliable manner. In other words, for better evaluation of the breast volume changes after breast augmentation using 3D scanning technique, we need to keep the respiratory state, either EE or EI, constant. From the result of CV of BVCE, R1 showed less variability. This finding might relate to the easier musculoskeletal stability and control of expiratory phase by patients. Based on this outcome, we suggest that EE should be adopted as the standard protocol for 3D breast imaging.

In terms of the clinical significance of this study, our results have the potential to be impactful both in surgical practice as well as in the design of new 3D imaging software, especially given the increasing popularity of the 3D imaging technique. Better understanding of the influence of dynamic variables will assist surgeons to better utilize these tools. In addition, provision of evidence-based guidelines with definition of standards can help improve the accuracy and reliability of 3D imaging in breast surgery. Furthermore, it can assist the industry to build new software which would take into account these variables allowing for compensation of the effects through new settings.

In this study, we analyzed the effect of respiration on the morphologic changes of the breast when patients receive 3D imaging. Our study does, however, have some limitations. Our study population and sample size were limited and consequently might not have sufficiently powered the study to highlight the differences between EE and EI. Furthermore, several other factors, in addition to breathing, can affect the morphology of breasts, such as postural changes, and further studies need to be done.

Conclusions

The results of this study demonstrate that there was no difference in breast volume results, when patients are in the expiratory or inspiratory state during 3D breast imaging. This study, however, holds potential benefits to both surgical practice as well as the 3D imaging industry.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflicts of interest to disclose.

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