Author's Accepted Manuscript

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PII: S0021-9290(16)31097-1
DOI: http://dx.doi.org/10.1016/j.jbiomech.2016.10.012
Reference: BM7920

To appear in: *Journal of Biomechanics*
Accepted date: 11 October 2016

Cite this article as: Chris Mills, Amy Sanchez and Joanna Scurr, Estimating th gravity induced three dimensional deformation of the breast, *Journal o Biomechanics,* http://dx.doi.org/10.1016/j.jbiomech.2016.10.012

Short Communication

ESTIMATING THE GRAVITY INDUCED THREE DIMENSIONAL DEFORMATION OF THE BREAST

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Abstract

As human breast tissue is continuously deformed by gravity, it is difficult to identify the non-loaded neutral breast position from which to take measurements. To estimate the neutral nipple position, this study proposed a simple novel method to counteract the three dimensional effect of gravity on the breast using the buoyant forces from water and soybean oil (ρ_{WATER} = 994 kg.m^{-3}; ρ_{OIL} = 909 kg.m^{-3}). Fourteen female participants with breast sizes ranging from 30 to 34 inch under band and B to E cup size took part in this study. Each participant had their static gravity-loaded nipple position measured and their neutral nipple position estimated (as the midpoint between the nipple position during water and soybean oil immersion). Participants were asked to sit in each fluid and fully submerge their torso and breasts. The mean gravity-induced nipple displacements from the neutral nipple position were 15.3 mm in the posterior direction, 7.4 mm in the lateral direction, and 25.7 mm in the inferior direction. Gravity had a significant ($p < 0.05$, $r > 0.82$) measurable effect on the static nipple position, particularly in the inferior and posterior directions. Furthermore the density difference between water and soybean oil produced a significant difference ($p < 0.05$, $r = 0.72$) in superior-inferior nipple position (5.6 mm). These findings suggest that neglect of gravity-induced breast deformations may lead to errors when assessing breast position and its relationship to possible breast pain, and that water alone may not be sufficient to estimate the neutral nipple position.

Keywords: breast density; neutral position; gravitational deformation

Introduction

The human breast is a highly malleable structure that is easily deformed by external forces such as gravity (Rajagopal et al., 2008). Assessment of gravity-induced breast deformations requires the prior identification of the non-loaded neutral breast position. Although the neutral breast position is a relatively novel concept within breast research, there have been several attempts to identify the neutral position of the nipple in both biomechanical and clinical research. Existing methods for identifying the neutral nipple position are: the breast drop technique (Haake and Scurr, 2011; Haake et al., 2012); treadmill running (Knight et al., 2014); vertical jumping (Knight et al., 2014); and water immersion (Rajagopal et al., 2008; Zain-Ul-Abdein et al., 2013). The breast drop, running, and jumping methods for identifying the neutral nipple position were all underpinned by the assumption that gravity acts inferiorly on the breast, and only the superior-inferior component of the neutral nipple position could be estimated (Haake and Scurr, 2011; Haake et al., 2012; Knight et al., 2014).

The water immersion method, based on Archimedes' principle, has been used in both bra design (Zain-Ul-Abdein et al., 2013) and clinical (Rajagopal et al., 2008) research. Previous studies implementing this method have presented only one component of the neutral nipple position, although this method could potentially be used to identify the three-dimensional neutral nipple position. Archimedes' principle asserts that an object immersed in a fluid of equal density would remain suspended in its equilibrium position (Heath, 1897). Hypothetically, if the breast were immersed fully in a fluid of equal density then the effect of gravity over the surface of the breast could be counteracted, enabling the static three-dimensional neutral nipple position to be measured.

Radiological breast data demonstrates that the ratio of fat to glandular tissue within the breast varies widely between women (Alonzo-Proulx et al., 2012; Heine et al., 2012; Olson et al., 2012). Sanchez et al. (2016) estimated breast mass density using a retrospective analysis of radiological data from 111, 123 women and found that the calculated mass-density of the breast ranged from 911 kg.m^{-3} to 999 kg.m^{-3} with an overall mean mass-density value of 945 kg.m^{-3}. The varying proportions of fat and glandular tissue and hence mass-density within the female breast leads to the suggestion that a single-density fluid is unlikely to match the density of each woman's breast, and that water (ρ_{WATER} = 994 kg.m^{-3}) (Kell, 1975) is likely to over-estimate the mass-density of the breast for some women in previous neutral position research. It was proposed that a more accurate method for assessing the neutral position could be developed by implementing the immersion method using two separate fluids which over (water) and under (soybean oil) estimate the mass-density of the breast. Immersion in higher density water (ρ_{WATER} = 994 kg.m^{-3}) (Kell, 1975) and lower density soybean oil (fat) (ρ_{OIL} = 909 kg.m^{-3}) (Pryde, 1980) could be used to identify the boundaries of the neutral nipple position. The mid-point between the nipple positions in the two fluids may represent a more accurate estimate of the neutral nipple position than could be achieved using either fluid in isolation.

Estimation of the three-dimensional neutral nipple position may have important implications for future assessment of breast kinematics. Measurements of nipple motion relative to the neutral nipple position may provide a better representation of the static and dynamic loads placed on the breast's structure than the conventional nipple range of motion (ROM) measurements. As the neutral nipple position represents the non-gravity loaded position of the breast, a distinction can be made between breast motion that increases (away from the neutral position) or decreases (towards the neutral position) the loading on the breast structure, a concept which may in the future improve the understanding of motion-induced breast pain. Therefore, the aim of this study was to estimate the gravity induced three dimensional deformation of the breast. The first hypothesis stated that there will be a significant difference between the estimated neutral and gravity-loaded nipple positions, which would highlight the importance of considering gravitational breast deformation when measuring breast motion. The second hypothesis stated that there will be a significant difference between the nipple positions measured in water and soybean oil, which would offer an improved, and preferred method to estimate the neutral position of the breast compared to one fluid in isolation.

Methods

Following institutional ethical approval, 14 females gave written informed consent to take part in this study. All participants were aged between 20 and 27 years (mean ± SD: age 23 ± 2 years, height 1.67 ± 0.07 m, mass 64 ± 8 kg), were nulliparous, and had not undergone surgical procedures on their breasts. Participants had their bra size assessed by a trained bra fitter using best-fit criteria (McGhee and Steele, 2010), and were assigned a participant number in ascending cup size to allow comparison of individual data across conditions without compromising participant anonymity.

Retro-reflective markers (12 mm diameter) were applied to the participants' suprasternal notch, xiphoid process, right and left anterior-inferior aspect of the 10^{th} ribs, and left nipple using hypoallergenic tape, based on the marker set described by Scurr et al. (2011). Three synchronised underwater cameras (25 Hz, VB5C6 Submersible Colour Camera, Videcon PLC) were calibrated using a custom-made 36-point calibration frame. A 16 order Direct Linear Transformation (DLT) was used to correct for image distortion caused by the fluids. Participants sat on an adjustable stool in a (820 x 820 x 1070 mm) 600 litre tank, so that their entire torso was submerged in the fluid, whilst three 1s trials were recorded, firstly in water, (water removed and replaced with soybean oil) and then in soybean oil. Participants also had their static gravity-loaded breast positions recorded in six 1 s trials (three before each fluid immersion) using an optoelectronic camera system (200 Hz, Oqus, Qualisys, Sweden).

The 3D positions of the torso and nipple markers collected in the immersion conditions were identified and reconstructed using SIMI (version 8.5.5, Tracksys Ltd) software, and the gravity-loaded marker positions were identified using Qualisys Track Manager (QTM) (Qualisys, Sweden). All data were then exported to Visual 3D (v4.96.4, C-motion) for further analysis. Within Visual 3D, a torso segment was created for each participant using the suprasternal notch and two rib markers to define the proximal and distal ends respectively (Mills et al., 2014). The torso segment origin was defined at the proximal end of the segment and the xiphoid process marker was added to aid segment tracking. The 3D co-ordinate data for all markers were filtered using a generalised cross-validatory quintic spline and the mean position of the left nipple marker relative to the torso segment was calculated for each participant in the water, soybean oil and gravity-loaded conditions. The mid-point between the nipple positions in soybean oil and water was used to estimate the neutral nipple position for each participant. Comparisons between the neutral and gravity-loaded nipple positions were used to evaluate the gravitational effect on nipple position. Paired samples t-tests were also conducted using SPSS (IBM SPSS statistics version 22) to investigate whether there were significant differences between the nipple positions in the water, soybean oil, and neutral conditions. The correlation coefficient (r) was used to calculate effect size where effect sizes were defined as: small = 0.1; moderate = 0.3; and large = 0.5 (Field, 2009).

Results

For all participants the static gravity-loaded nipple position was posterior and inferior to their neutral nipple position (Figure 1 a and c). All but one participant (Participant 5) had a gravity-loaded nipple position lateral to their neutral nipple position (Figure 1 b). The largest absolute differences in nipple position between conditions occurred in the superior-inferior direction, with mean (and peak) differences of: 25.7 mm (45.7 mm) between the neutral and gravity-loaded condition; 5.1 mm (11.2 mm) between the water and soybean oil condition; and 2.5 mm (5.6 mm) between each fluid and the neutral condition (Figure 2). Significant differences, with large effect sizes, were observed in the superior-inferior component of nipple position between all conditions and in all directions between the gravity-loaded and the estimated neutral position condition (Table 1).

Discussion

This study developed a simple novel method to estimate the three-dimensional neutral nipple position and subsequently to quantify the effect of gravity induced three dimensional deformation of the breast. Key findings demonstrated that the nipple moves significantly posteriorly, laterally and inferiorly when loaded statically by gravity and that the fluid density difference between soybean oil and water was sufficient to induce a significant change in nipple position.

Based on previous literature describing the inferior and lateral change in nipple position over prolonged periods of time (Brown et al., 1999), combined with the predominantly inferior action of gravity on the breast in the upright position, it was anticipated that the nipple would displace inferiorly and laterally from the neutral to the gravity-loaded position (Brown et al., 1999). Results confirmed this assumption, with the nipple displacing 25.7 mm inferiorly and 7.4 mm laterally under gravity (Figure 2), accepting hypothesis one. The magnitude of the inferior nipple displacement caused by gravity highlights the importance of considering gravitational breast deformation when measuring breast motion.

Perhaps the most interesting finding within this study was the extent of posterior nipple displacement (up to 15.3 mm) that occurred due to gravity (Figure 1 (a) and Figure 2). This result may be explained by two contributory factors. Firstly, the marker set used to construct the torso segment caused the superior-inferior axis of the torso to tilt backwards with respect to the global vertical axis. This backwards torso tilt meant that gravity had both inferior and posterior components when resolved into the torso co-ordinate system. Secondly, it was proposed that during immersion in the water and soybean oil participants' breasts were hemispherical or conical in shape, whereas in the gravity-loaded condition a large proportion of the breast mass falls to the base of the breast forming a tear-drop shape. This change in breast shape may have caused the change in posterior nipple position observed in this study.

A significant difference between nipple positions was observed in the superior-inferior direction between the water and soybean oil, and the neutral position, accepting hypothesis two. This reinforces the suggestion that water may not accurately replicate the density ranges of the breast for the participants in this study, and that immersion in two separate fluids provides an improved neutral position estimate. However, it was also acknowledged that the largest absolute difference in nipple position between the water immersion and the estimated neutral position using both fluids was 5.6 mm (participant 9), which is only just above the maximum reported accuracy for breast measurements (5 mm) (Hansson et al., 2014). So from a practical perspective, where whole body immersion in soybean oil is not possible, water could be used to estimate the neutral position with a maximum absolute error of 5.6 mm.

In conclusion, this simple novel method used to estimate gravity induced breast deformations found that gravity caused significant three-dimensional static nipple displacements (15.3 mm posteriorly, 7.4 mm laterally, and 25.7 mm inferiorly). Immersion of the breast in a single fluid (water or oil) may not accurately estimate the superior-inferior neutral nipple position. Incorporation of the neutral nipple position into measurements of breast motion may enable an improved understanding of motion induced breast pain as a distinction could be made between breast deformation that is away from, or towards the neutral position.

Conflict of interest statement

The authors have declared no conflicts of interest associated with this research.

Acknowledgements

The authors would like to thank Hanes Brands Inc. for funding this research; however the sponsors did not have any direct involvement with the preparation of this paper.

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Figure Captions:

Figure 1: Anterior-posterior (a), medial-lateral (b) and superior-inferior (c) displacement of the left nipple from the neutral nipple position in the water, soybean oil, and gravity-loaded conditions. Error bars represent the standard deviation in nipple position between trials.

Figure 2: Mean (SD) gravity-induced change in nipple position (n=14).

Table 1: Statistical comparison of nipple position in the water, soybean oil, neutral and gravity-loaded conditions.

	Anterior-posterior		Medial-lateral		Superior-inferior	
	t-value (t)	Effect size (r)	t-value (t)	Effect size (r)	t-value (t)	Effect size (r)
Water and soybean oil	0.119	0.03	0.316	0.09	3.753*	0.72†
Neutral and water	0.119	0.03	0.311	0.09	3.772*	0.72†
Neutral and soybean oil	0.119	0.03	0.321	0.09	3.732*	0.72†
Neutral and gravity-loaded	9.773*	0.94†	5.100*	0.82†	10.819*	0.95†

* denotes a significant difference ($p < 0.05$); † denotes a large effect size ($r > 0.5$)

Fig.1

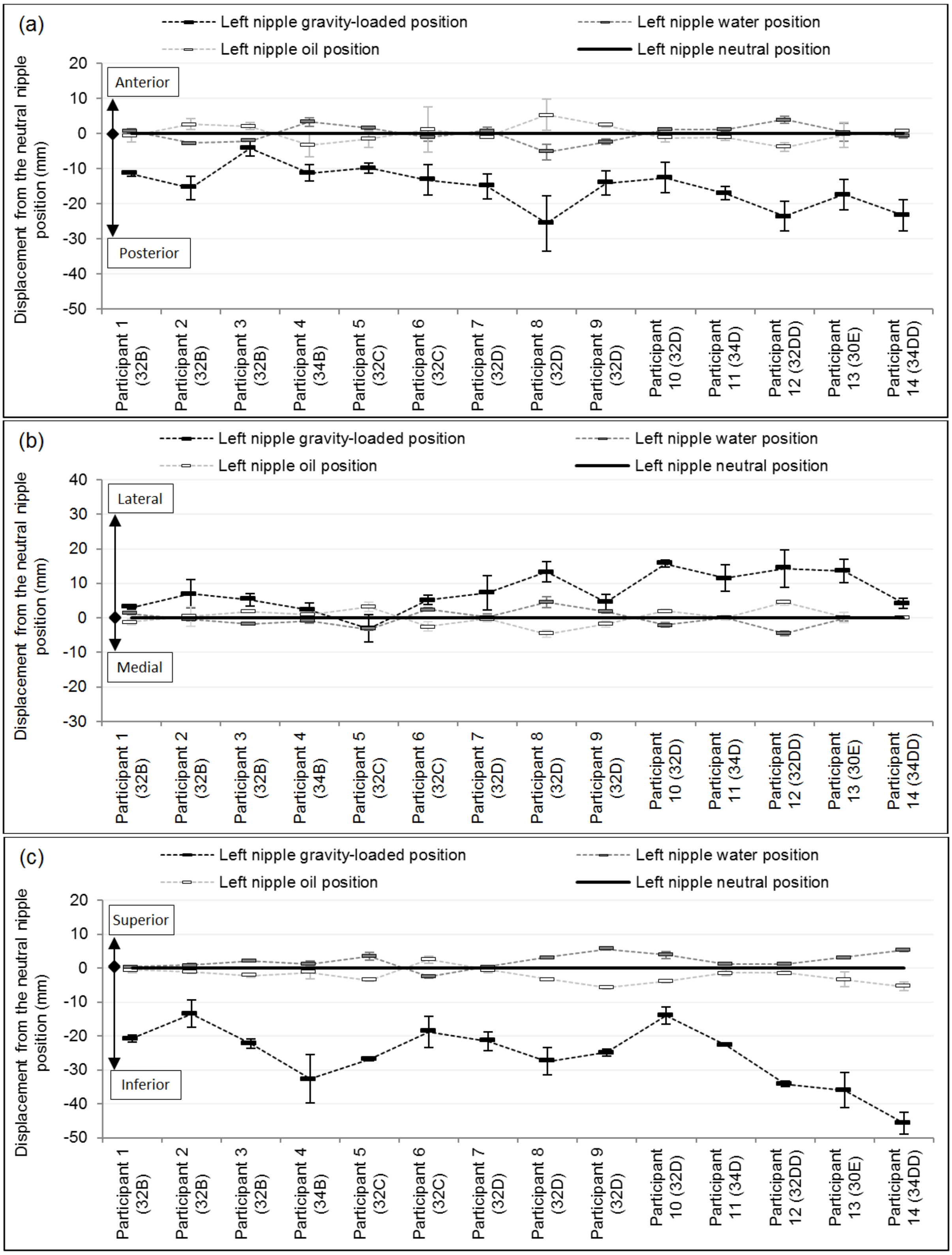
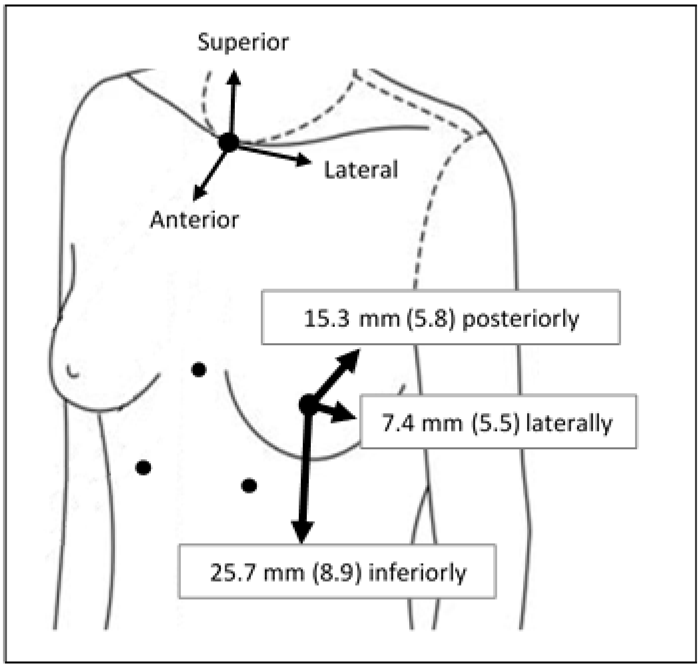

(a)
Left nipple gravity-loaded position
Left nipple water position
Left nipple oil position
Left nipple neutral position
Displacement from the neutral nipple position (mm)
Anterior
Posterior
20
10
0
-10
-20
-30
-40
-50
Participant 1 (32B)
Participant 2 (32B)
Participant 3 (32B)
Participant 4 (34B)
Participant 5 (32C)
Participant 6 (32C)
Participant 7 (32D)
Participant 8 (32D)
Participant 9 (32D)
Participant 10 (32D)
Participant 11 (34D)
Participant 12 (32DD)
Participant 13 (30E)
Participant 14 (34DD)
(b)
Left nipple gravity-loaded position
Left nipple water position
Left nipple oil position
Left nipple neutral position
Displacement from the neutral nipple position (mm)
Lateral
Medial
40
30
20
10
0
-10
-20
-30
Participant 1 (32B)
Participant 2 (32B)
Participant 3 (32B)
Participant 4 (34B)
Participant 5 (32C)
Participant 6 (32C)
Participant 7 (32D)
Participant 8 (32D)
Participant 9 (32D)
Participant 10 (32D)
Participant 11 (34D)
Participant 12 (32DD)
Participant 13 (30E)
Participant 14 (34DD)
(c)
Left nipple gravity-loaded position
Left nipple water position
Left nipple oil position
Left nipple neutral position
Displacement from the neutral nipple position (mm)
Superior
Inferior
20
10
0
-10
-20
-30
-40
-50
Participant 1 (32B)
Participant 2 (32B)
Participant 3 (32B)
Participant 4 (34B)
Participant 5 (32C)
Participant 6 (32C)
Participant 7 (32D)
Participant 8 (32D)
Participant 9 (32D)
Participant 10 (32D)
Participant 11 (34D)
Participant 12 (32DD)
Participant 13 (30E)
Participant 14 (34DD)

Fig.2


Superior
Lateral
Anterior
15.3 mm (5.8) posteriorly
7.4 mm (5.5) laterally
25.7 mm (8.9) inferiorly