A method for calculating dynamic breast centre of mass during running

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A METHOD FOR CALCULATING DYNAMIC BREAST CENTRE OF MASS DURING RUNNING

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This study aimed to develop a novel method for calculating breast centre of mass (COM) during running for use in musculoskeletal modelling. Magnetic resonance imaging (MRI) scans and kinematic data were collected from a female participant running at 2.6 $m \cdot s^{-1}$. A breast surface marker array was used to calculate the COM of 16 segments, based upon tissue composition from the MRI scan. The motion of the surface markers were used to calculate breast COM position during running. Breast COM was more superior, medial and posterior than the nipple marker. Breast COM range of motion was lower (~50%) in all directions during running when compared to the nipple marker. Results suggest that the localised breast deformation is the key factor in calculating breast COM during running.

KEYWORDS: breast biomechanics, breast motion, soft tissue deformation

INTRODUCTION: The majority of literature regarding breast motion uses the nipple to represent the motion of the whole breast. In addition to being simple to identify and repeatable between conditions (Mason, Page, & Fallon, 1999; Scurr, White, & Hedger, 2010), the nipple is usually chosen as it is assumed to be close to the point of maximum bust projection where the largest amount of movement occurs and therefore represents the worst case scenario breast motion (Milligan & Scurr, 2015). For the purpose of whole-body computer modelling, the motion of the nipple does not represent COM motion therefore may lead to inaccuracies when estimating muscular demand.

The breast is composed of a combination of glandular and fatty tissue (Jesinger, 2014). The distribution and relative ratios of these tissues vary, not only from person to person, but between breasts (Ekpo, Hogg, Highnam, & McEntee, 2015). Using a single mass density value to estimate breast COM not only assumes a uniform distribution of mass but also neglects the variation in the ratios of the breast tissues seen in women. Magnetic resonance imaging (MRI) is used to identify different types of tissue in the body and therefore can be used to distinguish between the fatty and glandular tissues in the breasts. A more accurate representation of COM may be possible when breast composition is considered. Due to their composition, the breasts locally deform when loaded during running (Milligan & Scurr, 2015) resulting in different motion occurring at different locations within the breast. As a result the COM will move within the breast as it deforms; this could lead to an overestimation of muscle activity when considering forces experience during sporting activities. The aim of this study was to develop and evaluate a method for calculating the centre of mass location of the breast during running, for use in a subject specific simulation model.

METHODS: Following institutional ethical approval, one female participant (age 27 years, height 1.64 m, mass 65 kg, UK bra size 34D, breast volume 638 cc) provided written informed consent. All data was collected bare breasted. The left breast boundary was identified using the lift and fold technique (Risius, 2012) and used with the position of the nipple to mark a 21-marker breast array using a surgical marker (Figure 1a). MRI visible markers were then applied over the marked array in addition to four torso markers (sternal notch, xiphoid process, C7 and T10 vertebrae). A Philips Ingenia 1.5 T (Philips Healthcare, Best, NL) magnetic resonance imaging (MRI) scanner with a breast coil was used to acquire scans of the torso and breasts. An acquisition matrix of 300 x 300 was used with in-plane resolution of 1.5 x 1.5 mm^2 and a slice thickness of 3 mm.

Following the MRI scan, retroreflective markers were applied over the marked array in addition to the four torso markers. A prone static trial was captured with the breast hanging freely, using a six-camera motion capture system, to replicate the position of the MRI scan. Marker trajectories were then tracked using a 16-camera motion capture system (Qualisys, Sweden, 300 Hz) whilst the participant ran, bare breasted, at a self-selected speed (2.6 $m \cdot s^{-1}$).

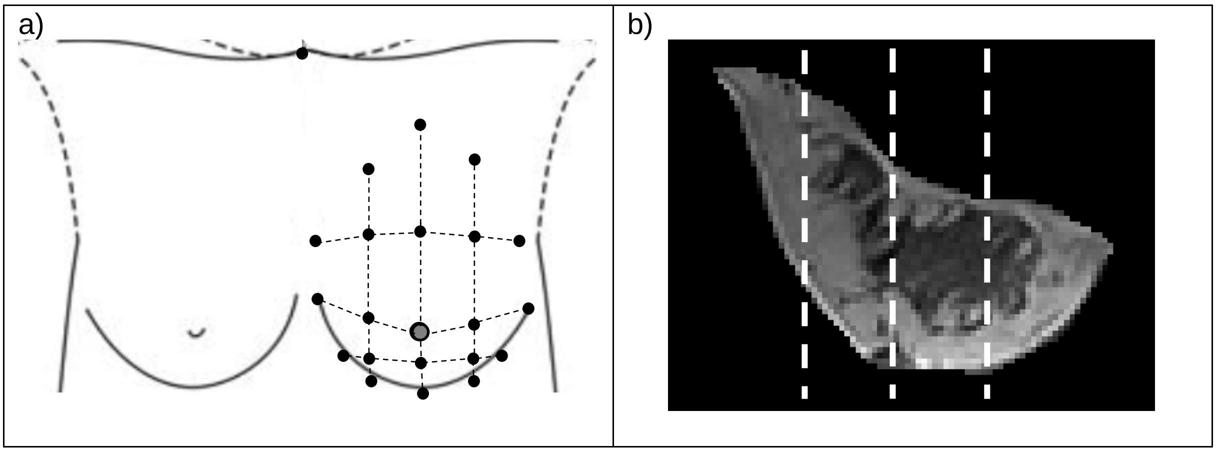

Figure 1. Segmentation of the breast (a) Surface marker array (b) segmented MRI slice of the breast.

Kinematic data were transformed to the local coordinate system of the torso as defined by the four torso markers (Scurr, White, & Hedger, 2009). For both MRI and static kinematic data, the position of the surface markers was used to create 21 virtual markers on the chest wall. Medio-lateral (m/l) and inferior-superior (i/s) position were defined by the position of surface array markers; anterior-posterior (a/p) position was defined by the sternal notch, assuming a flat chest wall. Breast COM was then calculated using three different methods:
Method 1 calculated breast COM assuming a rigid breast of non-uniform density. From the greyscale MRI scan, each pixel, of known area, was identified as either fatty (900 $kg \cdot m^{-3}$) or glandular (1057 $kg \cdot m^{-3}$) tissue (Matlab, Mathworks, USA). Voxel mass (area x slice thickness x density) and coordinates were used to calculate the COM of the whole breast relative to the position of the nipple surface marker and the corresponding chest wall marker.
Method 2 calculated breast COM assuming a deforming breast of uniform density. Each breast segment was defined by four surface markers and four virtual markers located on the chest wall. Virtual marker positions were fixed on the torso, assuming that the tissue at the breast root is fixed to the chest wall; segments were assumed to move about this fixed pivot point. The mass of each breast segment was calculated from the volume, whilst prone, and tissue density of 945 $kg \cdot m^{-3}$ (Mills, Sanchez, & Scurr, 2016). From the kinematic data, segment COM positions were calculated; the posterior aspect of each volume, defined by the virtual marker position whilst prone, was assumed be fixed on the torso. From the 16 segment COM trajectories, COM of the whole breast was calculated during running.
Method 3 calculated breast COM assuming a deforming breast of non-uniform density. The surface and virtual markers were used to segment the MRI scan into 16 breast volumes (Figure 1b). For each of the 16 segments the position of the COM was calculated in relation to the segment dimensions using the same method for COM calculation in Method 1. The centre of mass of each segment was used to calculate whole breast centre of mass as in Method 2. Root mean squared difference (RMSD) was calculated between the nipple and each of the derived centre of mass positions.

RESULTS: During running, i/s nipple range of motion (ROM) was 0.07 m (Figure 2). Deriving COM location from Method 1 resulted in a reduction in range of motion (0.03 m), which occurred superiorly to the nipple position (RMSD 0.02 m). The COM calculated in Method 2 resulted in a further reduced i/s ROM (0.01 m) compared to both the nipple and Method 1. The position of the Method 2 COM was also superior to both the nipple (RMSD 0.05 m) and Method 1 position. The i/s range of motion of the Method 3 COM was 0.02 m; and was positioned superiorly to both the nipple (RMSD 0.05 m) and the Method 1 COM.

A similar pattern was observed when considering both the a/p and m/l movement (Figure 2). The nipple trajectory displayed the largest range of motion (a/p 0.03 m, m/l 0.05 m) positioned in the most lateral, anterior position. Derived COM trajectories from Method 2 resulted in reduced range of motion (m/l 0.2 m, a/p 0.06 m), positioned more medially (RMSD 0.03 m) and posteriorly (RMSD 0.06 m) to the nipple.

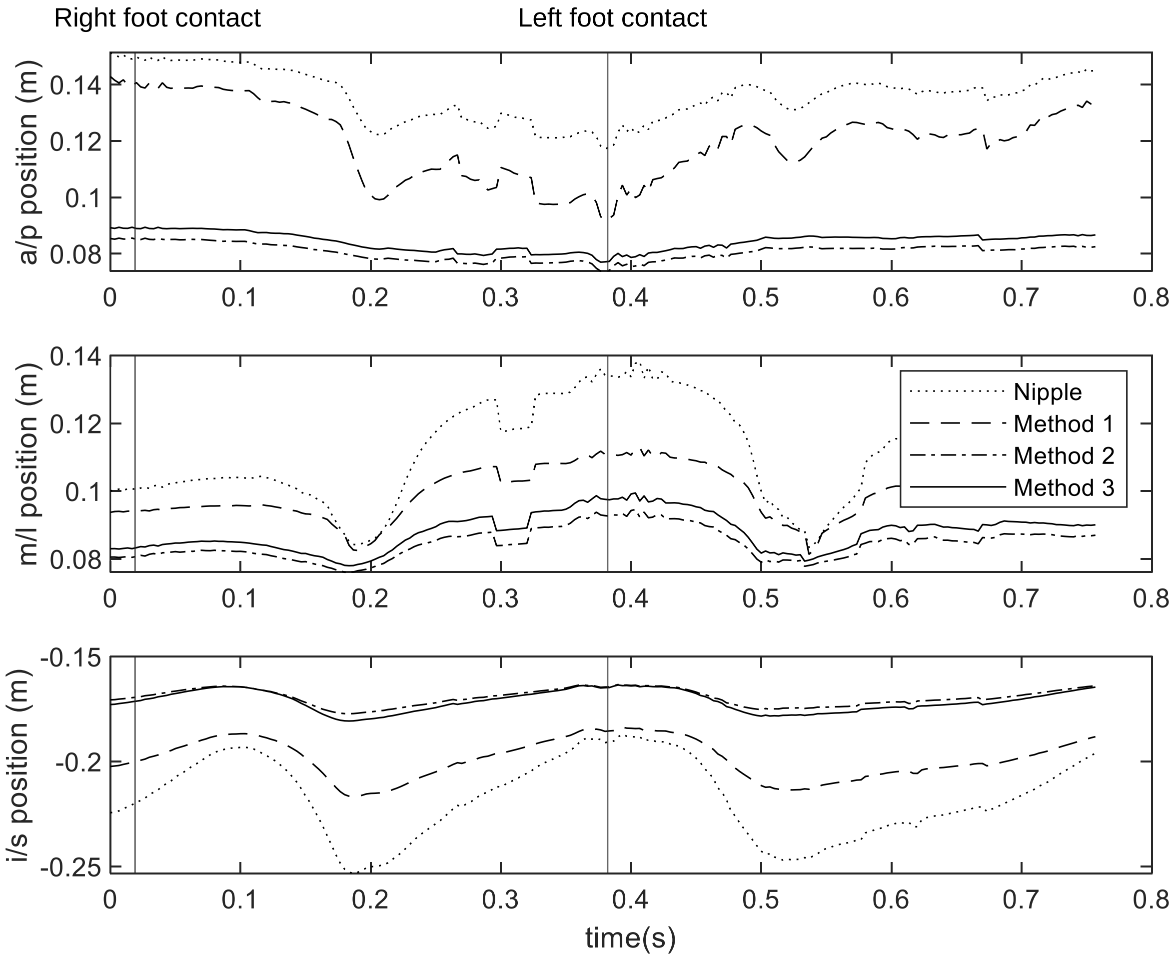

Figure 2. (a) anterior/posterior (b) medial/lateral (c) inferior/superior position of the nipple and calculated centre of mass (COM) positions during a gait cycle.

DISCUSSION: The aim of this study was to develop and evaluate a method for calculating centre of mass location of the breast during running, for use in a subject specific simulation model. Results showed that representing breast motion by breast COM, rather than nipple position resulted in a reduced range of motion in all three planes and positioned the breast in a more medial, superior, posterior position. All methods of calculating COM assumed the posterior aspect of each segment fixed to the chest wall. The centre of mass of each segment is located posteriorly to the surface, closer to the static tissue, resulting in the reduced range of motion values observed. This rooting of the posterior breast tissue also results in a translation of the represented breast position.

Little difference was observed between methods 2 and 3; calculating the COM of a deforming breast. Method 2 assumed uniform density, in contrast to Method 3 which considered non-uniform density and tissue distribution from MRI data. These results suggest that the breast deformation is the key factor which influences centre of mass position. It is likely that the addition of tissue density distribution made little difference to the COM trajectory due to the fact that the more dense, glandular tissue was located centrally in the breast. Additional analysis of a large sample size is necessary to determine if this pattern of tissue distribution is seen consistently throughout the female population. The importance of breast deformation in breast COM calculation is supported when comparing methods 1 and 3; calculating the COM

of a non-uniform breast. The addition of breast deformation (Method 3) resulted in further translation of the COM and reduction in ROM compared to Methods 1.
Nipple motion is typically used to represent breast motion in breast biomechanics literature; located close to the point of maximum bust projection, it represents the largest range of motion occurring in the breast (Milligan & Scurr, 2015). When modelling the breasts and the torso, using the nipple position to represent whole breast mass motion will increase the moment arm to the point of force application, and therefore may misrepresent the musculoskeletal loading in the body. Representing the breast mass at the location of the COM reduces the moment arm and the distance travelled, reducing the impact of forces applied to the torso during running, altering the induced muscular demand. When modelling the female body it is important to consider the position and motion of the breasts as this is likely to impact muscular activity, particularly in the back (Schinkel-Ivy & Drake, 2016). Therefore, it is important to accurately model the breast COM, to allow accurate recommendations regarding technique and injury risk.

CONCLUSION: When considering the whole mass of the breast, nipple motion exaggerates the magnitude of whole breast motion during running. Calculating COM from MRI scans and a breast surface array provides a better method of representing the breast as a single mass. The distribution of tissues in the breast had little impact on the trajectory of the centre of mass, suggesting that it may be appropriate to assume uniform density, providing breast deformation is considered. Further investigation, with a large sample size is needed to determine if this assumption can be made for a wider population.

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