MEASUREMENT OF BREAST MOTION ACROSS THE BREAST SURFACE LEADS TO BETTER RECOMMENDATIONS FOR BREAST SUPPORT

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Quantifying multiplanar range of motion (ROM) of multiple markers positioned on the breast surface may improve methodologies in breast biomechanics and inform bra design. Nineteen markers were positioned on the breast of 24 females. During running, the nipple marker underwent the greatest ROM of all markers on the breast. Significant differences were reported in multiplanar ROM between the nipple marker and 17 markers within the breast marker array. Furthermore, the distribution of multiplanar ROM differed across the 19 markers positioned on the breast, with the most dominant direction reported as superioinferior. It was proposed that the nipple marker is a good representative of breast motion; however the marker array may provide a more holistic approach to informing sports bra design.

KEYWORDS: Running, females, breast support, bras, marker array.

INTRODUCTION: To quantify relative breast motion, at least three non-collinear markers placed on the thorax and a marker placed on the nipple, have been tracked in three-dimensional (3D) space (Scurr, White, & Hedger, 2010). Despite the ease of identification, and proposed high repeatability between conditions, individuals, and days (Mason, Page, & Fallon, 1999; Scurr et al., 2010), the nipple may not provide sufficient information to represent whole breast motion. Due to the anatomical composition, breast tissue deforms locally during running, which may result in different ROMs and different distributions of multiplanar ROM at different locations on the breast surface, particularly in females with larger breast sizes (>D cup, UK sizing) due to the increased breast mass (McGhee, Steele, Zealey, & Takacs, 2012). Currently, the kinematics of additional locations on the breast, to the nipple, have been examined during running (Chen, Wang, & Jiang, 2012; Mason et al., 1999; Zhou, Yu, Ng, & Hale, 2009). These studies provide the first insight into the magnitude of breast motion at locations other than the nipple, and reported differences in the magnitude of superioinferior ROM (Chen et al., 2012; Zhou et al., 2009) across the different locations on the breast. However, it should be noted that only six additional locations have been examined, commonly situated equidistance from the nipple marker. Therefore, certain aspects of the breast have been ignored, such as the top, base, and the medial and lateral aspects of the breast. Moreover, only superioinferior motion of these additional breast markers has been considered previously (Chen et al., 2012; Mason et al., 1999; Zhou et al., 2009), yet it is well established that breast motion occurs in three directions during activities such as running (Scurr et al., 2010). A greater understanding of multiplanar breast motion across the whole breast may better inform breast support design for effective reduction in breast motion.

This research seeks to inform future marker placement methodologies within dynamic breast biomechanics research, and to inform sport bra design. This research has two aims; firstly to quantify the multiplanar ROM of a breast marker array during treadmill running for larger breasted women, and secondly to identify if the nipple marker can provide sufficient information to represent the whole breast. Firstly, it is hypothesised that the ROM of the 18 additional markers on the breast surface will significantly differ to the ROM of the nipple. Secondly it is hypothesised that the greatest ROM will be reported in different directions of motion across the 19 markers within the breast marker array.

METHODS: Following institutional ethical approval, 24 females (32F, 34E, 32FF, 34F, or 36E bra size) with a mean (SD) age of 23 years (4), body mass of 65.3 kg (6.9), and height of 1.60 m (0.52) participated. Following a warm up, passive markers (Qualisys, Sweden) were positioned on the suprasternal notch (STN), Xyphoid Process (XP), left and right anterioinferior aspect of the 10th rib, C7 and T8 to define the thorax segment. Employing previously published anatomical landmarks (Ying, Wang, Liu, & Zhang, 2011; Lee, Hong, & Kim, 2004), a breast marker array was developed with nineteen markers placed on the breast surface (Figure 1). Finally, a heel marker tracked gait cycles (Zeni, Richards, & Higginson, 2008).

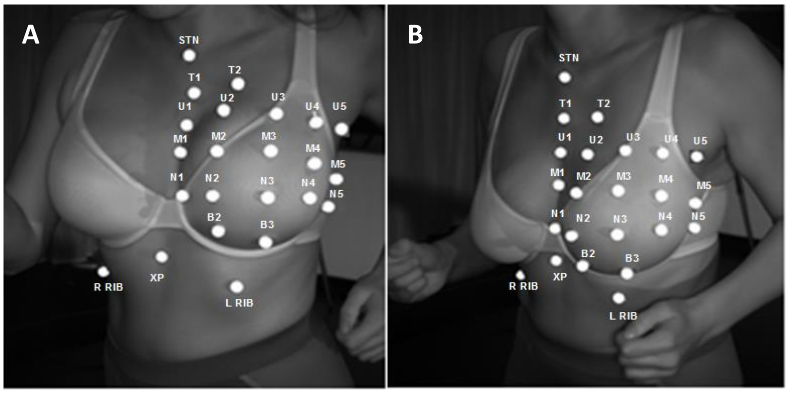

Figure 1. Thorax and breast markers during both flight (A) and stance (B) phases of the gait cycle, to illustrate the upper and lower limits of the breast tissue. The 19 markers on the breast surface were labelled to represent the latitudinal (T (top), U (upper), M (middle), N (nipple line) and B (base)) and longitudinal lines of the breast (1 and 2 = medial, 3 = central, 4 and 5 = lateral).

Eleven Qualisys (Oqus, 310) cameras (200 Hz) were positioned around a treadmill. Participants ran for 120 s without a bra at 10 km.hr^{-1}. Marker coordinates were recorded for 10 s at the end of the run and filtered using a second order Butterworth filter (13 Hz cut-off). Multiplanar coordinates of the 19 breast markers were calculated relative to the thorax within Visual3D (C-motion). Relative multiplanar breast ROM was calculated for each marker over five gait cycles. Percentage distributions (%) of multiplanar ROM were calculated for each breast marker. Data were checked for normality, with assumptions met when $p > .05$. To establish if multiplanar ROM differed between each marker on the breast and the nipple marker, one-way repeated measure ANOVAs were performed with post-hoc independent samples t-tests ($\alpha = 0.05$).

RESULTS: During bare breasted running, the greatest anteroposterior ROM of the marker locations on the breast surface, was reported at N4 (65 mm), whereas, the smallest anteroposterior ROM was reported at T1 (8 mm) (Table 1). The greatest mediolateral and superioinferior ROM of the markers on the breast were both reported at N3, 77 mm and 85 mm, respectively. The smallest ROM in the mediolateral and superioinferior directions were reported at T1 (16 mm) and U1 (17 mm), respectively. The anteroposterior, mediolateral, and superioinferior ROM at N3 (nipple) was significantly greater ($p < .05$) than nine of the 18 additional markers on the breast surface. Moreover, eight of the 18 additional marker's ROMs were significantly ($p < .05$) different to N3 (nipple) in one or two directions of movement.

Of the 19 markers on the breast, the greatest ROM was reported in the superioinferior direction for eight markers, these markers were predominantly located within both the nipple and base latitudinal lines (markers labelled with a B or N). Whereas, the six markers that underwent the greatest ROMs in the anteroposterior direction were located along the lateral longitudinal line of the breast (markers labelled 4 and 5). The five markers that underwent the greatest ROMs in the mediolateral direction were located in the medial longitudinal line of the breast (markers labelled 1 and 2) (Table 1).

Table 1. Mean (SD) relative multiplanar ROM (mm) and percentage distribution (%) of each marker on the breast during treadmill running at 10 $km.hr^{-1}$ with no breast support (n = 24).

MARKER LOCATION	Anteroposterior		Mediolateral		Superioinferior	
	ROM (SD) (mm)	Percentage distribution (%)	ROM (SD) (mm)	Percentage distribution (%)	ROM (SD) (mm)	Percentage distribution (%)
T1	8 (4)*	19%	16 (6)**	38%	**18 (5)*****	43%
T2	17 (8)*	32%	17 (7)**	33%	**18 (6)*****	35%
U1	9 (4)*	17%	**24 (9)****	48%	17 (5)***	35%
U2	18 (7)*	25%	**28 (12)****	38%	27 (11)***	37%
U3	**31 (11)***	36%	28 (11)**	32%	28 (11)***	32%
U4	**44 (14)**	49%	23 (9)**	26%	22 (8)***	25%
U5	**50 (16)**	57%	17 (5)**	19%	21 (6)***	24%
M1	13 (9)*	18%	**37 (17)****	52%	22 (9)***	30%
M2	30 (9)*	22%	**54 (21)****	40%	52 (19)***	38%
M3	45 (14)	29%	53 (19)**	34%	**60 (18)*****	38%
M4	**56 (16)**	38%	42 (15)**	29%	50 (17)***	34%
M5	**58 (18)**	51%	25 (11)**	22%	31 (14)***	27%
N1	22 (16)*	21%	**50 (23)****	49%	31 (18)***	30%
N2	16 (12)*	15%	33 (28)**	32%	**55 (19)*****	53%
N3 (NIPPLE)	60 (21)	27%	77 (28)	35%	**85 (23)**	38%
N4	65 (21)	33%	62 (23)	31%	**70 (23)*****	36%
N5	**60 (20)**	47%	32 (17)**	25%	37 (15)***	29%
B2	49 (19)	25%	70 (21)	36%	**74 (20)**	38%
B3	59 (19)	30%	60 (19)**	31%	**78 (21)**	39%
MEAN	37 (20)	32%	39 (19)	33%	42 (23)	35%

N.B**.** Direction of greatest ROM has been highlighted in bold for each marker on the breast.
*Significant difference in anteroposterior ROM between the highlighted marker and N3 (nipple) ($p < .05$).
**Significant difference in mediolateral ROM between the highlighted markers and N3 (nipple) ($p < .05$).
***Significant difference in superioinferior ROM between the highlighted marker and N3 (nipple) ($p < .05$).

DISCUSSION

This is the first research to quantify multiplanar ROM of a breast marker array during treadmill running for larger breasted women. Key findings identified that the nipple underwent the greatest mediolateral and superioinferior ROM, during treadmill running, when compared to 18 additional locations on the breast surface. Further to this, significantly greater multiplanar ROMs were reported at the nipple than 17 of the 18 additional locations on the breast surface. Finally, the distribution of multiplanar ROM differed between the 19 markers positioned on the breast surface, with the most dominant direction reported as superioinferior.

Of the 19 markers positioned on the breast, the greatest multiplanar ROM reported during treadmill running was at the nipple, in the superioinferior direction. This marker is positioned along the central longitudinal line of the breast. Interestingly, the greatest multiplanar ROM was reported within the central longitudinal and nipple latitudinal lines of the breast, at markers N3 (nipple) and N4. Based upon these findings it is suggested that sports bras designed for the current bra sizes examined, should aim to restrict ROM along the central longitudinal line and the latitudinal nipple line of the breast. Previous research has reported significant positive correlations between peak breast ROM and breast pain (Scurr, et al., 2010), suggesting the greater the movement, the greater the breast pain, with links to skin strain and tissue damage proposed alongside these findings. Not only did the nipple undergo the greatest ROM of all markers on the breast, significantly greater multiplanar ROMs were reported between the nipple marker and 17 of the 18 additional markers. The only marker that did not display differences in multiplanar ROM to the nipple was B2, located in close proximity below the nipple, along the medial longitudinal line and base latitudinal lines of the breast. Based upon the differences reported in multiplanar ROM of the additional markers on the breast to the nipple, hypothesis one can be accepted.

Of the 19 markers on the breast surface, the greatest ROMs were reported most frequently in the superioinferior direction. These markers were predominantly concentrated to the nipple and base latitudinal lines of the breast, which subsequently underwent the greatest ROMs of all markers on the breast. This finding suggests the restriction of superioinferior breast ROM is crucial for limiting the peak relative movement of the breast during running, and should be a key focus for design and product development. Further exploration of the distribution of multiplanar ROM of the remaining markers on the breast surface identified a pattern for both medial and lateral longitudinal lines of the breast. Those markers that underwent the greatest movement in the anteroposterior ROM, were located along the lateral longitudinal lines of the breast, suggesting that the lateral longitudinal line would benefit from intelligent fabrics and design features that would limit the anteroposterior motion. However, the medial longitudinal lines of the breast underwent the greatest ROMs in the mediolateral direction. It is assumed that the greatest mediolateral ROMs of these markers were a result of the stance and flight phase of the gait cycle as the breast tissue is redistributed medially at the height of flight and thorax rotation, as seen in Figure 1a. With differences reported in the distribution of multiplanar ROM across the different markers within the breast array, hypothesis two is accepted.

CONCLUSION

This is the first study to explore multiplanar ROM of multiple markers positioned on the breast surface. During bare breasted running, the greatest ROM was reported at the nipple, therefore, it is proposed that the nipple is a good representative of breast motion, and provides sufficient information for the monitoring of breast motion. However the additional markers examined within this research enabled a more holistic understanding of the magnitudes and distributions of motion of previously unreported locations of the breast. In combination with the nipple marker, quantifying the multiplanar motion of a breast marker array may better inform sports bra design.

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