Evaluation of Shock Absorbing Performance of Sports Bras

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Abstract: A scientific understanding on the reduction of breast displacements during activities will be necessary for the future development of optimal sports bras in order to prevent breast injury. This study aims to evaluate the shock absorbing performance of different sports bras, and to analyze the factors involved. Three healthy women were invited to participate in the experiments. They wore four types of sports bras of two different support levels and performed three different activities. Breast movements were recorded by a 6-camera Vicon motion capturing system. The breast displacement and the reduced percentage of controlled breast displacement (RBD) are proposed as the main parameters for evaluating the shock absorbing performance of sports bras. The naked breast displacement ranged from 1.01 to 4.37 cm. The breast displacement was the largest during stepping at the nipple. However, the RBD was larger at outer breast when wearing sports bras. The magnitude of shock absorption did not agree with the support levels claimed by the manufacturers. The encapsulation bras were more effective than compression bras in controlling breast displacement. The encapsulation bra EP-2 was the most effective shock absorber due to its higher content of polyamide, wider shoulder strap and higher neckline.

Keywords: Sports bra, shock absorption, displacement, breast.

1. Introduction

Breast pain is common among women and varies markedly in severity and clinical significance [1]. The reported prevalence of breast pain ranges from 41% to 79% [2-6]. A considerable percentage of the women worldwide have suffered from breast pain during activities. In 1998, the American Council on Exercise (ACE) reported that a majority of women experienced breast discomfort while exercising [7]. Lorentazn and Lawson found that 56% of 59 female volunteers experienced sports-related breast pain or discomfort [8]. Correlative report by Haycock in 1977 also concluded that 72% of the respondents indicated breast sore or tender after exercise [9]. In Shangold's study, 52% reported specific minor breast injuries [10]. Therefore, the prevention of breast pain and maintenance of breast health during women's daily life and exercise has become an important and urgent research topic.

Clinical experiments have shown that sports bras could provide good external support and relieve breast pain [11] as the bra absorbed the vibration energy and helped to reduce breast displacement and discomfort.

Although sports bras have been invented for more than 30 years, the factors influencing the bra performance in shock absorption still remains unclear.

Therefore, this paper aims to propose a new and unique performance indicator for evaluating the shock absorbing performance of various sports bras, to compare the effectiveness of different shock absorbing bras and to validate the manufacturers' claimed levels of bra support.

2. Methodology

2.1 Subjects

All recruited subjects were healthy, active, pre-menopausal adult females of breast sizes 34B, 34C or 36B. They were not breast feeding nor pregnant during the testing period. Those with a history of previous breast surgery, musculoskeletal disorder or pain were also excluded. The exclusive criteria were set to avoid the confounding factors such as variety of sex hormones and physical disability.

In this study, three healthy female volunteers with ages of 29 $\pm$ 5 years, height 159.67 $\pm$ 2.82 cm, weight 52.56 $\pm$ 4.98 kg, body mass index 20.46 $\pm$ 1.89 kg/m^2 were recruited to participate. Ethical approval was obtained from The Hong Kong Polytechnic University Human Ethics Committee prior to commencing the wear trial. Each participant was fully informed of all procedures and protocols prior to giving their written consents.

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2.2 Garment samples

Four sports bra styles (two compression type bras and two encapsulation type bras) of support levels 2 and 3 were sponsored by a major bra brand in France and tested in this study. The diagrams, fibre contents and design features are shown in Table 1.

Table 1 Sports bra samples

Bra code and type	Front view	Back view	Claimed Support level	Fiber content (%)				Design features
				Polyamide	Polyester	Elastane	Cotton	
CP-2 Compression sports bra			2	55		16	29	2-layer princess line top vest, racer back, adjustable hooks & eyes at the back
EP-2 Encapsulation sports bra			2	67	28	10	5	2-layer princess line top vest, racer back, adjustable hooks & eyes at both sides with removable pad in the inner cup
CP-3 Compression sports bra			3	42	53	5		2-layer princess line top vest, racer back, adjustable hooks & eyes at both sides
EP-3 Encapsulation sports bra			3	56	27	15	2	Moulded cups, titanium memory underwire, adjustable hooks & eyes at both sides

2.3 Activities

The experiments were carried out in the Human Locomotion Lab in the Hong Kong Polytechnic University with controlled temperature of 23 ± 0.5^0C and 65 ± 3% relative humidity.

The subjects were instructed to perform walking and running on a treadmill under two experimental conditions - bare breasted and wearing sports bra. Unlike other research, this work also studied the stepping motion on a 24 cm high platform.

The stride rate of exercise can influence breast motion [9]. Therefore, each subject first tried to walk, run and step at her own velocity deemed replicable. During this pilot test, the stride rate was timed and the norm was set as the standard velocity to be controlled. A metronome was then set to ensure that the subjects walk, run and step for two minutes at the same stride rate in each experiment. The subjects were allowed to rest for five minutes between subsequent experiments.

2.4 Motion Analysis

The 3D body kinematics was recorded using a six-camera Vicon motion capturing system (Model: Pulnix 6701AN, Oxford Metrics, UK). The motion signals in terms of 3D coordinates of specified breast positions were recorded with 60 Hz sampling frequency. Both

static and dynamic calibration procedures of the motion capturing system were carried out before all experimental sessions with residuals of less than 1 mm.

Spherical retro-reflective markers were placed at seven different locations on the subjects' breast region. Every marker was 4 cm apart from the bust point along both horizontal and vertical directions on the left breast either with or without a bra. One reference marker (P0) was also placed at the front neck point as a base point in calculating the relative breast displacement to the body torso.

The positions of the reflective markers (P1 to P6) can be found in Figure 1. P1 is on inner breast, P2 is on lower breast, P3 is on outer breast, P4 is at bust point, P5 is on upper breast, and P6 is on the top breast.

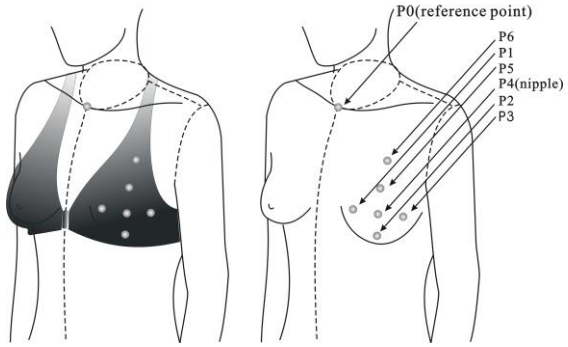

Figure 1 Positions of reflective markers

2.5 Data Analysis

The vertical breast displacements of the seven predetermined positions relative to the reference point (front neck point) were calculated, while the movement between the bra and the breast skin was neglected.

The displacement was analyzed based on the results of paired *t*-tests that determined whether the breast displacement differed significantly during various activities at a level of 0.05. All statistical data were computed using SPSS software (SPSS Inc, Illinois, USA).

The peak displacement at each stride of activity was determined as shown in Figure 2. Then the mean of the peak displacements during different strides was calculated for each experimental run.

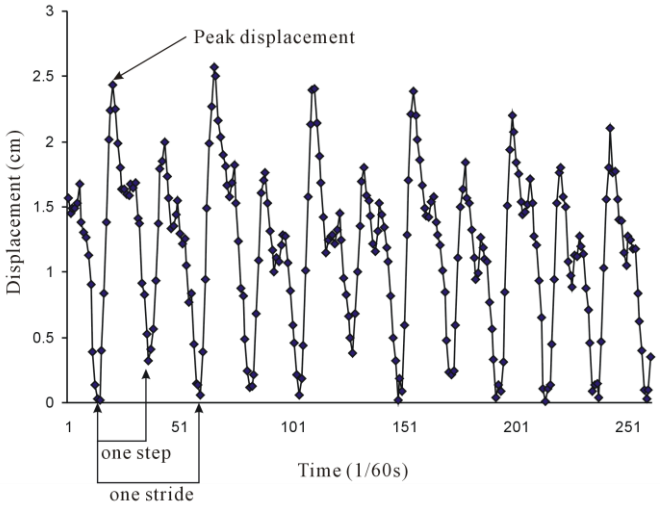

Figure 2 Determination of peak displacement along time

3. Findings and Discussion

3.1 Displacements at different breast positions and different activities

Figure 3 illustrates the mean and standard deviation of the peak vertical displacement in four types of bra conditions and one braless condition during three different activities (walking, running and stepping). Interesting findings are:

a) The breast displacement was always the largest during stepping when compared with the same position in other activities due to the strong intensity of breast movement during stepping. However, the displacement was the smallest during walking.
b) The displacement at P4 (nipple) was the greatest, whereas that at P6 (top breast) was the smallest during all the three activities. This infers that the highest intensity of breast movement occurs at the centre of the breast, rather than those positions far away on the upper, lower and side breast.
c) The displacements at all the six breast positions were reduced by wearing sports bras during different activities. This finding is consistent with previous studies [7, 12].

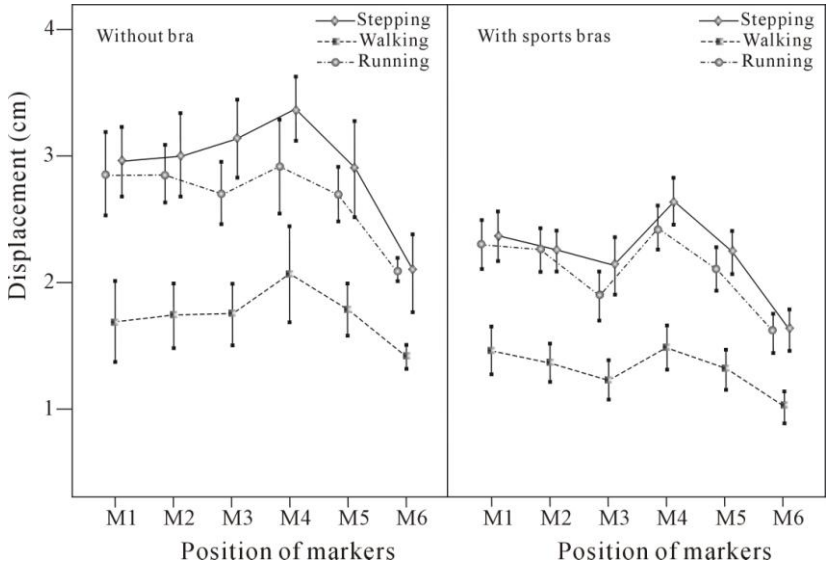

Figure 3 Mean of breast displacement at different positions with and without bras during activities

3.1.2 Displacements in different bras

As different sports bras may have different controls of breast displacement during activities, the mean and ranges of breast displacements in different bra conditions were presented in a box plot (Figure 4).

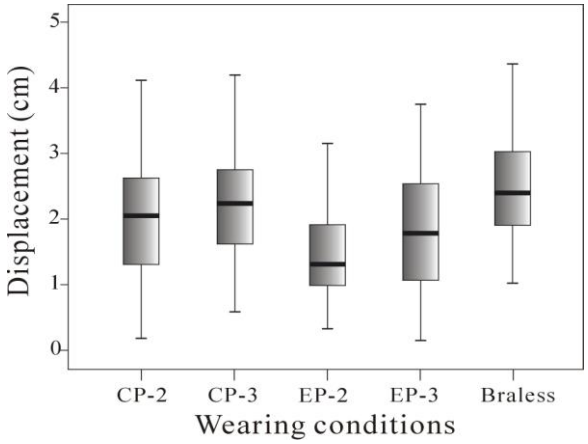

Figure 4 Breast displacements in different wearing conditions

The mean breast displacement under a braless condition was 2.47 cm (range = 1.01 - 4.37 cm), which was much smaller than the findings obtained by other western studies [13, 14]. The encapsulation bra EP -2 has successfully controlled it to 1.45 cm (range = 0.33 - 3.16 cm), while the compression bras CP-2 and CP-3 could only slightly brought the absorbing performance down to the mean displacement of 2.03 and 2.18 cm respectively.

3.1.3 Significance of differences

The results from paired *t*-test in the comparison among 4 different bras have shown the following findings.

a) The encapsulation bra EP-2 gave significantly smaller breast displacement ($p < 0.01$) than CP-2, CP-3 and EP-3 at all 6 positions during all 3 activities.
b) There was no significant difference ($p = 0.186 > 0.05$) in breast displacements when wearing two compression bras CP-2 and CP-3.
c) There is no significant difference in displacement of Points 1, 4 & 5 ($p>0.05$), and Point3 closes to Point5. Point6 shows significantly smaller values from that of other points ($p<0.02$).
d) The breast displacement was significant different ($p = 0 \sim 0.046$) among different activities.

We anticipated that sports bras with different designs would fit different activities because they could bring different breast displacements at different breast positions. Therefore, it is crucial to analyze the reduction of breast displacement in different scenarios.

3.2 Reduced percentage of breast displacement

To evaluate the effectiveness of sports bra in controlling the breast bouncing, a new and unique performance indicator "RBD" i.e. Reduced percentage of controlled breast displacement is proposed and defined in Equation (1).

$$RBD = \frac{OD - CD}{OD} \times 100\% \quad (1)$$

OD stands for the breast displacement in a braless condition while CD stands for bra-controlled breast displacement at the same position during the same activity. The larger the RBD, the better the shock absorption performance of the bra has.

3.2.1 RBD of sports bras

As shown in Table 2, the sports bras have reduced the breast displacement most effectively at P3 outer breast (RBD = 30.35%) but the reduced displacement at P1 inner breast (RBD = 21.33%) was ranked the second smallest.

The most effective shock absorber was the encapsulation bra EP-2 (RBD=41.33%) while the weakest shock absorber was the compression bra CP-3 (RBD=10.43%). The descending order of effectiveness in reduced breast displacement was EP-2, EP-3, CP-2 and CP-3.

The finding shows that the encapsulation bras were more effective than compression bras in reducing breast displacement during all three activities. It is probably because the encapsulation bras contain moulded cups that separate the two breasts so as to stabilize them individually. On the contrast, the compression bras exert pressure on the two soft breasts when the front panels were tightly extended while wearing.

Table 2 RBD of different sports bras unit: %

Bra	Activity	Breast positions P1: inner	P2: lower	P3: outer	P4: nipple	P5: upper	P6: top	Mean	Overall mean	Rank
CP-2	Walking	9.9	13.1	31.1	30.8	25.0	22.4	22.05	17.25	3
	Running	6.3	8.0	25.0	6.8	15.1	18.6	13.30		
	Stepping	15.8	14.9	20.6	19.2	18.8	9.1	16.40		
EP-2	Walking	28.7	41.5	50.8	51.0	46.1	52.4	45.08	41.33	1
	Running	36.9	38.0	45.6	32.0	36.9	34.3	37.28		
	Stepping	31.0	43.7	53.3	37.8	42.8	41.1	41.62		
CP-3	Walking	3.5	11.9	12.4	13.9	13.3	13.3	11.38	10.43	4
	Running	4.9	11.5	17.3	7.1	11.1	8.6	10.08		
	Stepping	12.1	10.6	13.0	8.6	7.9	6.7	9.82		
EP-3	Walking	15.2	19.9	27.1	8.2	19.	23.1	18.82	24.79	2
	Running	36.9	30.3	32.4	25.5	26.6	34.8	31.08		
	Stepping	21.5	29.8	35.6	15.0	18.2	26.8	24.48		
Mean	Walking	13.5	21.6	29.4	27.4	25.6	27.3	24.13	23.39	
	Running	19.5	20.6	29.8	16.7	21.4	22.9	21.82		
	Stepping	19.5	24.8	31.7	21.5	22.6	21.1	23.53		
Overall mean	all activities	18.56	22.77	30.35	21.33	23.43	24.27	23.39		
Rank		6	4	1	5	3	2			

However, the higher support level 3 claimed by the manufacturer did not provide better shock absorption as expected. Instead, the RBD of EP-2 was larger than EP-3 probably due to its higher contents of polyamide and wider width of shoulder straps (3cm) than EP-3's (1.5cm). The RBD of CP-2 was also larger than CP-3.

It may be explained by the fact that the neckline of CP-2 is higher than that of CP-3, so that CP -2 compressed the breasts more tightly against the chest than CP- 3 did. Therefore, CP-2 can absorb breast shock more effectively.

4. Conclusion

This study has objectively measured the displacement of 6 different positions on the breast of female subjects who had different breast sizes, wore two different kinds of sports bras (compression and encapsulation) of two levels (level 2 and 3) during three types of activities (walking, running and stepping). We comprehensively analyzed the pattern of breast vertical displacement relative to the front neck point. Then the

displacements of different positions at different conditions were compared and the significance of difference was tested.

A new index "RBD" (Reduced % of breast displacement) was used to evaluate the effectiveness of bra in shock absorption performance. It can be concluded that

1) The largest breast displacement occurred at the bust point and decreased from centre to outside during different activities;
2) The RBD was the greatest at the outer breast (but not bust point), and the smallest at the inner breast;
3) The encapsulation bras are more effective than compression bras in reducing the breast movement;
4) A higher content of polyamide and wider shoulder strap was more effective in limiting breast movement;
5) A higher bra neckline gave more tight compression on the breasts, so more effectively absorbed breast shock;
6) The magnitude of shock absorption did not agree with the support levels claimed by the manufacturers.

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