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Exploring the Impact of Body Shape on Bra Fit: Integrating 3D Body Scanning and Traditional Patternmaking Methods

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***Abstract*—**The issue of bra fitting has persisted throughout history despite advancements in molded bra cups. To gain a deeper understanding of the interaction between the breast and bra pattern, this study combines the art of traditional bra patternmaking with 3D body scanning technology. By employing a 2D bra pattern drafting method and analyzing the effect of body shape on the desired bra cup shape, the study focuses on the differentiation of the lower cup among bras designed for flat and round body-shaped breasts. The results shed light on the impact of body shape on bra fit and provide valuable insights for further research and improvements in bra design, pattern drafting, and fit. The integration of 3D body scanning technology enhances the accuracy and precision of measurements, allowing for a more comprehensive analysis of the unique contours and dimensions of the breast and body. Ultimately, the study aims to provide individuals with different body shapes a more comfortable and well-fitted bra-wearing experience, contributing to the ongoing efforts to alleviate the longstanding problem of bra fitting.

***Keywords*—**Breast shapes, bra fitting, 3D body scanning, bra patternmaking.

I. Introduction

IN today's era, women progressively prioritize their self-appearance and actively seeking out products that enhance their body shape. As a result, lingerie items, particularly bras, have become a significant investment [1]. Extensive research has focused on investigating design and production technologies in the realm of bra-making, aiming to develop an optimal bra that effectively addresses potential fit issues and provides adequate support for the breasts. However, despite these efforts, studies have shown that a considerable percentage of women, over 75%, still wear incorrectly sized bras [2]. Due to the heterogenous breasts among individuals, the persistent issue of poor bra fit remains unresolved as it is closely related to the misalignment of breast shape and the bra pad [3].

The intricate nature of breast morphology, coupled with the diverse range of sizes and shapes found among women, presents a formidable challenge when it comes to crafting intimate apparel that provides an optimal fit [4]. Body shape has a significant impact on the shape and characteristics of the breasts [5]. Previous studies have explored various factors influencing breast configuration, such as ethnicity [6], age [7], and other characteristics. These diversities highlight the natural and inherent differences in breast morphology, reflecting the uniqueness of every individual. The interplay between body shape and breast shape is a crucial factor to consider in bra design, as it directly influences the fit, support, and the comfort of the garment.

Understanding and appreciating the diversity in breast shape is essential in bra design. As the breast tissues are mounted on the rib cage, it is important to recognize that the shape of the rib cage directly impacts the distribution of the breast tissues [8]. The contours and dimensions of the rib cage serve as a foundation for the positioning and support of the breasts. Variations in rib cage shape can influence how the breast tissues are distributed across the chest, ultimately affecting the overall shape, projection, and appearance of the breasts. Therefore, understanding the relationship between rib cage shape and breast tissue distribution is crucial for developing bras that provide optimal support and enhance the natural contours of the breasts.

In recent years, there has been a growing interest in utilizing 3D body scanning methods to study breast anthropometric information. Earlier studies employ 3D scanning techniques to examine the cross-section of the breast [9], primarily for the purpose of gathering anthropometric data for sizing system evaluation and subsequently calculating breast volume. Later studies capture surface measurements and develop contour models for the breasts, which are then used to create corresponding molded cup contours [10], [11]. However, there is a lack of studies specifically investigating the relationship between different body shapes resulting from variations in rib cage structure and their influence on bra construction. This research aims to address this gap by investigating how the pattern drafting of a bra cup is influenced by different rib cage shapes, with the goal of providing a deeper understanding of the relationship between body shape and bra cup contour. By examining how variations in rib cage shape affect the construction of the bra cup, this research seeks to shed light on the intricacies of body shape and its impact on bra design. The findings of this study will contribute to a more comprehensive understanding of how to tailor bra cup contours to accommodate diverse rib cage shapes, ultimately leading to improved bra fit, comfort, and support for individuals with different body types.

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II. Methodology

A. Participants

Five Asian women with self-reported bra sized 38DD or above volunteered to take part in this study. The deliberate selection of larger bust sizes aimed to facilitate the observation and analysis of breast distribution patterns. The age range of participants in this study was between 21 and 56 years old, with a mean age of 32.2 years old. All participants were residents of Hong Kong at the time they were scanned. All participants were provided with a written informed consent sheet.

B. 3D Body Scanning

In this study, the 3D scanning process was conducted utilizing the Vitus 3D Body Scanner, whereby participants were scanned with their upper bodies remaining naked. Participants were instructed to maintain normal breathing patterns during the scanning process, as this helps capture the natural contours and dimensions of the upper body accurately. Additionally, a pre-manufactured foot pattern was provided on the 3D body scanner, guiding participants to place their feet in the designated position. This controlled foot positioning helps maintain consistency and ensures that measurements are taken from a standardized reference point across participants.

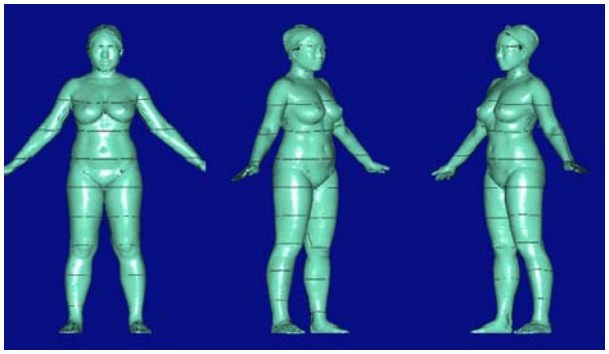


Fig. 1 Scanned body obtained by Vitus 3D body scanner

C. Body Slicing and Cross-Sectional View Analysis

After completing the scanning process, using Geomagic Wrap, a 3D digital engineering software, the scanned body data was further analyzed by slicing it at two specific levels: the full bust level and the underbust level, shown in Fig. 2. This slicing allowed for the extraction of cross-sectional view data. The full bust cross-sectional view provided information on the overall shape and fullness of the breasts, as in Fig. 3 (a). This view allowed for the visualization of the breast contour and the assessment of breast volume and distribution. On the other hand, the underbust cross-sectional view focused on the shape of the rib cage, as in Fig. 3 (b). This view revealed the structure and curvature of the rib cage, offering insights into the individual's unique rib cage shape and how it relates to the breast configuration.

To illustrate the relationship between breast tissues and rib cage shape, the sliced cross-sectional images were overlapped. In Fig. 3 (c), the overlapping of the cross-sectional images reveals the distribution of breast tissues and the shape of the rib cage. This visualization effectively demonstrates the actual volume of the breasts and the distribution pattern of the tissues.

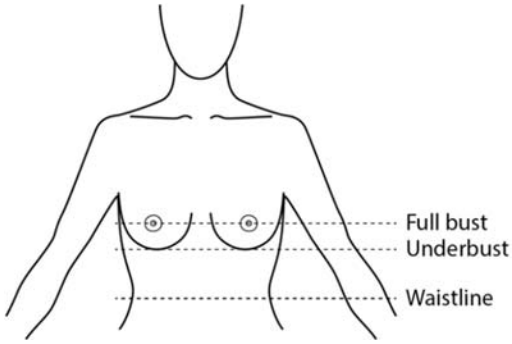
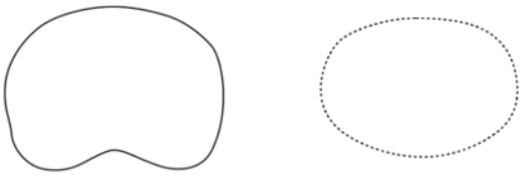
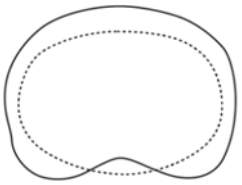


Fig. 2 Indication of full bust, underbust, and waistline level



(a) Cross section at full bust (b) Cross section at underbust



(c) Overlapping of (a) on (b)

Fig. 3 Sliced cross-sectional view at (a) full bust level and (b) underbust level; (c) overlapping of the cross-sectional images at full bust and underbust

With the sliced cross-sectional view images obtained, width, and depth of underbust of subjects were measured to calculate the underbust shape ratio, which is determined by dividing the underbust width by the underbust depth. The shape ratio serves as an indicator of body thickness. A high shape ratio corresponds to a flatter body thickness, indicating that the width across the underbust area is relatively greater compared to its depth. Conversely, a lower shape ratio suggests a rounder or more curved body thickness, where the width across the underbust area is proportionally smaller in relation to its depth. By quantifying the shape ratio for each subject, variations in body thickness and rib cage shape among subjects can be assessed. This information contributes to a better understanding of the interplay between body shape and bra cup contour, enabling the development of bras that accommodate different body types and provide optimal fit and support.

D. Flat Bra Cup Pattern Drafting

After determining the body shape ratio and categorizing participants into flatter and rounder body types, the next step in the study involved performing traditional 2D bra cup pattern drafting. The aim was to observe and analyze how the bra cup

patterns differ between these two body shapes. Using the body shape ratio as a criterion, participants were divided into respective groups based on their body type. The traditional 2D bra cup pattern drafting method was then applied to each group separately.

In this study, Shin's bra pattern drafting method was adopted, which introduces the concept of an intermediate block to streamline the process [12]. Unlike the traditional free-handed drafting of curves in industrial practice, Shin's method utilizes an intermediate lower cup block, shown in Fig. 4, to facilitate easier and faster manipulation of the bra pattern, allowing for efficient production and versatility in creating various bra styles. By comparing and analyzing the bra cup patterns generated for each body shape group, a deeper understanding of the unique characteristics and requirements of flatter and rounder body shapes in bra cup design can be gained. This analysis provided valuable information for improving bra fit and comfort for individuals with different body shapes, which contributes to the development of more inclusive and well-fitting bras that cater to the diverse needs and preferences of individuals with different body shapes and sizes.

Based on the drafted lower cups, a full set of slat patterns was developed according to the breast anthropometric measurement datasets. The patterns were used to manufacture actual bra samples using the same materials. Subjects were reinvited to participate in fitting sessions to assess the performance of the bra cups and evaluate the different pattern drafting methods.

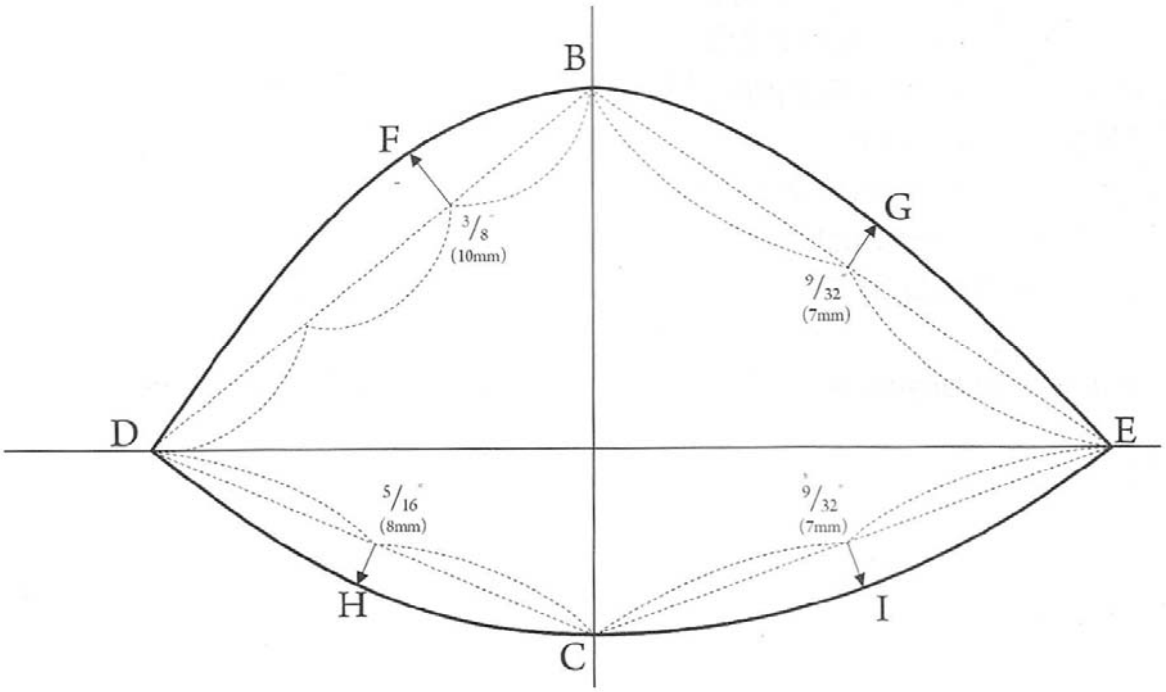


Fig. 4 Illustration of lower cup drafted by Shin's bra pattern drafting method

E. Fitting Assessment of Bra Cups

During the fitting sessions, the participants were asked to try on each bra one at a time, including the regular cup size 75E, the cup for the flat body shape, and the cup for the round body shape. The focus of the assessment was on the fit of the bra cups specifically. To ensure the bras were worn correctly and in the proper position, professional assistance was provided to the participants during the fitting process. After putting on each bra, the participants were asked to indicate the position of their bust point using a provided sticker. They were instructed to stand straight and breathe normally while the researchers observed the fit of the cups. The participants also provided comments on each bra, and the researchers noted these comments concurrently. In addition, photos were taken from different angles to review any fit problems that may have arisen.

By conducting these fitting sessions and gathering feedback from the participants, the study aimed to evaluate the effectiveness of the different pattern drafting methods for the bra cups. This process allowed for a comprehensive assessment of the fit and comfort of the bras on individuals with different body shapes, providing valuable insights for the development of more tailored and well-fitting bras.

III. Results and Discussion

A. Cross-Sectional View Analysis

Five sets of 3D body scanning data were collected and cross-sectional view at full bust and underbust were extracted using Geomagic Wrap, shown in Figs. 5 (a)-(e) respectively. From the cross-sections obtained from the body scans, different distributions of breast tissues can be observed among the five subjects. This allowed for the identification of various breast shapes, different sternum widths, and different projection directions of the breasts.

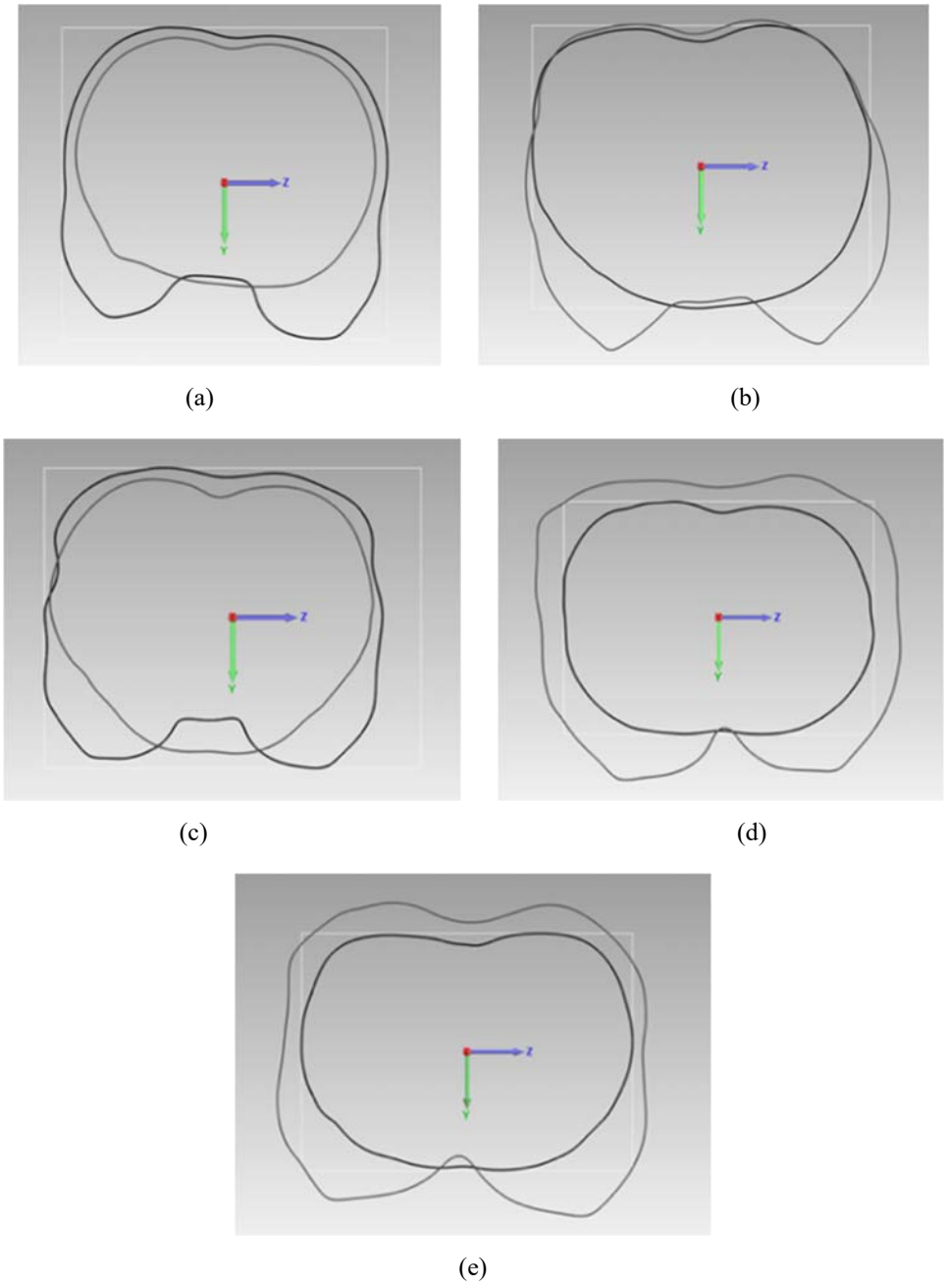


Fig. 5 Overlapping of cross-sections at full bust and underbust of (a) Subject 1; (b) Subject 2; (c) Subject 3; (d) Subject 4; and (e) Subject 5

TABLE I
UNDERBUST WIDTH, DEPTH, AND SHAPE RATIO

Subject	Underbust width (cm)	Underbust depth (cm)	Shape ratio
1	28.7	20.8	1.380
2	31.0	24.7	1.255
3	35.3	28.2	1.252
4	27.2	19.3	1.409
5	25.1	16.8	1.494

Furthermore, the body shape ratio for each subject was calculated by measuring the underbust width and underbust depth. The underbust shape ratios for each subject were presented in Table I. Based on the ratio calculation, subject 2 and subject 3 exhibited lower ratios, around 1.25, indicating a rounder body shape with a fuller body thickness. On the other hand, subject 1, subject 4, and subject 5 had higher ratios, with values of 1.380, 1.409, and 1.494, indicating a flatter body thickness.

These findings suggest that different body shapes exist within the same ethnicity, particularly among Asian plus-size females. It is noteworthy that these distinct body shapes were not intentionally recruited for the study but emerged naturally within the small number of participants. The fact that the differences in body shapes were effortlessly identified highlights the inherent diversity that exists among individuals, even within specific ethnic or size categories. This emphasizes the importance of considering and addressing these variations

in body shape and size when designing clothing, including bras, to ensure inclusivity and a proper fit for a wide range of individuals.

B. Body Measurements Extraction and Flat Pattern Drafting for Different Body Shapes

After identifying the two different body shapes among the subjects, one body measurement dataset from each body shape was selected for corresponding lower cup flat pattern drafting. Subject 1 and subject 3 were both determined to be the same bra size of 75E. From the scanned data, measurements of the breasts from these two subjects were extracted, representing the flatter and rounder body shapes, respectively. The measurements required for bra cup drafting were listed in Table II. Using Shin's bra drafting method, a regular lower cup pattern for bra size 75E was initially drafted, as shown in Fig. 6. With the collected measurements specific to each body shape, separate lower cup patterns were then drafted. The lower cup pattern for the flatter body shape (subject 1) was drafted and presented in Fig. 7. Similarly, the lower cup pattern for the rounder body shape (subject 3) was drafted and shown in Fig. 8.

TABLE II
BREAST ANTHROPOMETRIC INFORMATION FOR BRA FLAT PATTERN DRAFTING

Measurements	Subject 1 (Flat body shape)	Subject 3 (Round body shape)
Breast depth	6.99 cm	8.48 cm
Breast inner arc (LBIA)	9.9 cm	10.3 cm
Breast outer arc (LBOA)	10.8 cm	14.4 cm
Top cup	11.0 cm	10.2 cm
Bottom cup	9.2 cm	11.4 cm

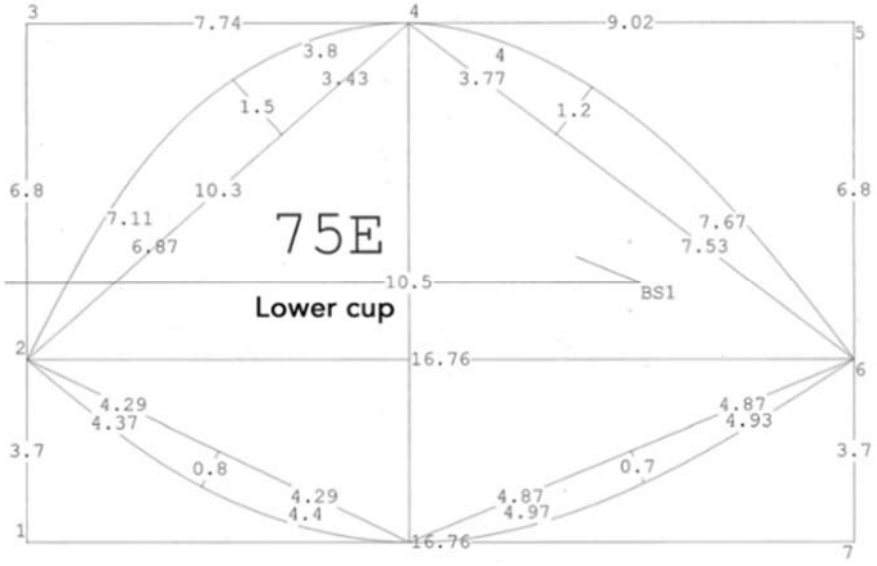


Fig. 6 Drafted lower cup for a regular size 75E according to Shin's bra drafting method

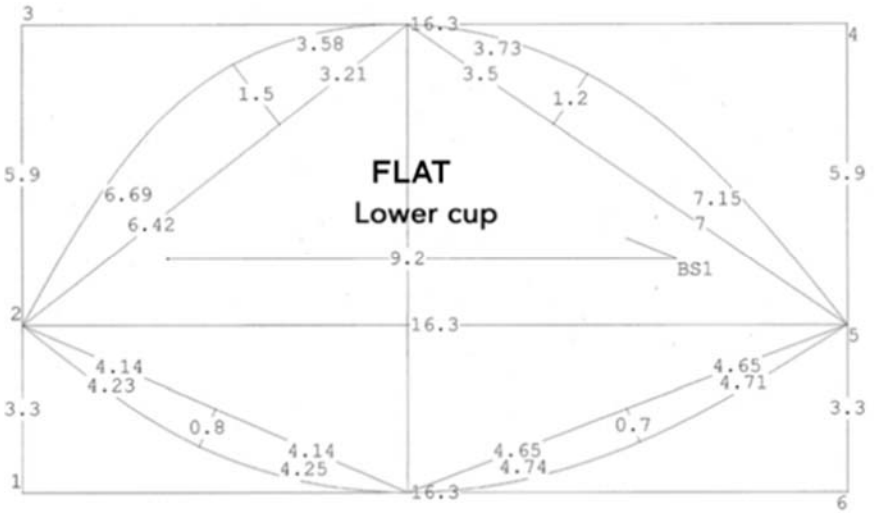


Fig. 7 Drafted lower cup for a flat body shape according to subject 1

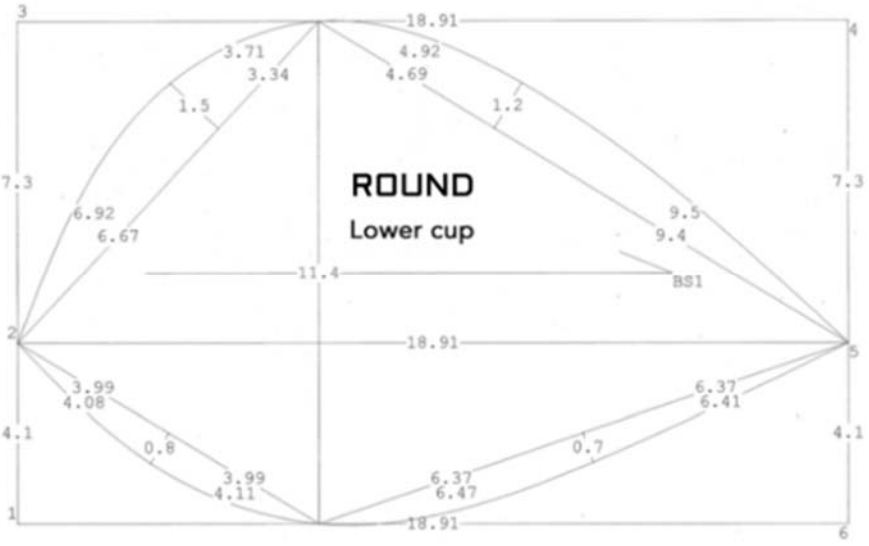


Fig. 8 Drafted lower cup for a round body shape according to subject 3

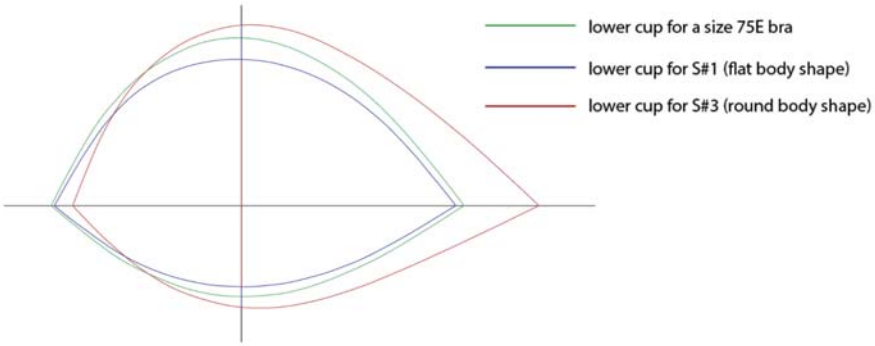


Fig. 9 Overlapping of the three drafted lower cups for comparison

The three lower cups differed in their shapes apparently in terms of width, height, and curvature. Fig. 9 illustrates the comparison of the drafted lower cups, highlighting their differences in shape, width, height, and curvature.

The lower cup for a size 75E bra displayed a more balanced shape, with the curve peak positioned in the middle. This peak represents the location of the bust point on the cup. The lines of this cup were curvier, resulting in a rounder shape overall.

The lower cup for the flat body shape resembled the 75E cup in terms of width, albeit slightly smaller. It maintained a balanced shape similar to the 75E cup but appeared flatter with a shorter height. Additionally, the overall size of this cup was smaller, resulting in a smaller volume for the breast.

In contrast, the lower cup for the round body shape exhibited more significant variations compared to the other two cups. It was noticeably wider, extending in a pointy shape on the outer side. This shape was a consequence of a longer outer breast arc. As a result, the bust point of this lower cup was not positioned in the middle but slightly more towards the inner bust, aligning with the breast configuration of the scanned subject.

By comparing these lower cups, it becomes evident how different body shapes can influence the width, height, curvature, and positioning of the cups. These observations highlight the importance of considering individual body variations and tailoring bra designs accordingly to ensure a proper and comfortable fit for diverse body shapes and sizes.

C. Bra Fitting Assessment

In the fitting assessment, the sample bras, developed based on the drafted lower cups and pattern drafting methods, were worn by subject 1 with a flatter body shape and subject 3 with a rounder body shape. The fitting results, as depicted in Fig. 10, likely illustrate the fit and appearance of the bras on both subjects. The figure may show how the bras conform to the unique body shapes of subject 1 and subject 3, highlighting any differences in the fit and performance of the T-cup bras for the two body shapes.

The fitting assessment results were listed as below.

A. Fitting Assessment of the 3 Bra Samples on Subject 1

i. Regular 75E Bra Cup According to Shin's Method

The bust point position of the subject was slightly lower and towards the left direction compared to the cup peak. This indicates that the positioning of the bust point on the bra cup may not be accurately aligned with the wearer's actual bust point. In Fig. 11, the neckline of the bra cup was pressing in towards the wearer's breast, resulting in the problem of "double breast." This suggests that the cup size or shape did not provide

adequate room or contouring for the breast tissue, causing spillage over the cup edge. The breast did not stay inside the cup and was being pushed out in the front. This may be attributed to excessive tension applied at the sides and insufficient coverage of the top cup. The cup design may not have properly accommodated the shape and volume of the wearer's breasts, resulting in a lack of containment and projection. Gapping was found at the underarm position, as shown in Fig. 12. This indicates that the cup size or shape may not be suitable for the wearer's body, leading to excess fabric and a lack of close fit in that area.

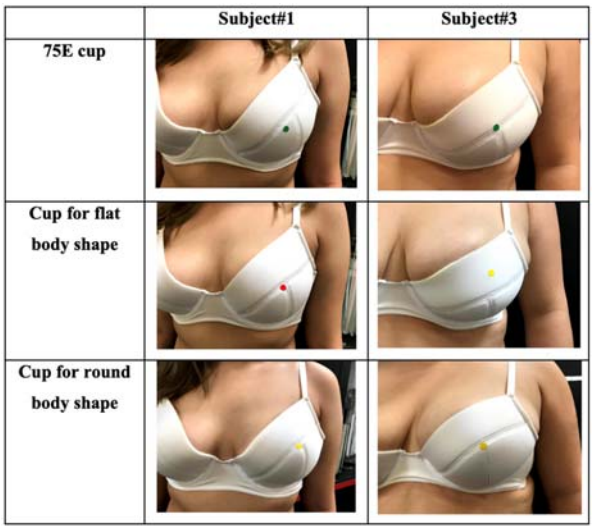


Fig. 10 Fitting of 3 bras on Subject 1 and Subject 3

Fig. 11 Budging at neckline in regular 75E bra sample on subject 1

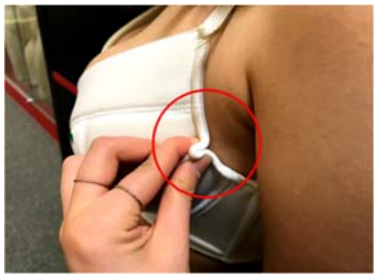


Fig. 12 Excessive fabric at underarm in regular 75E bra sample on subject 1

ii. Bra Cup for Flat Body Shape

The bra cup fitted nicely on the wearer's breast, indicating that the cup size and shape were appropriate for the individual. The bust point position matched with the cup peak as marked on the pattern, demonstrating accurate pattern drafting. According to Fig. 13, the neckline of the bra cup was positioned nicely on the wearer's breast, without any excess fabric or inward pressing. This suggests that the cup provided a good contour and coverage, creating a flattering appearance.

Fig. 14 shows that the breast stayed securely inside the bra cup without being pushed outwards. This indicates that the cup design and construction effectively held the breast in place, providing support and preventing any excessive movement. At the underarm position, no excess fabric was found, indicating a proper fit. The absence of tightness or bulging in this area suggests that the cup design and size were suitable for the wearer's body shape.

Fig. 13 Neckline of bra cup for flat body shape fitted well on subject 1

Fig. 14 Underarm of bra cup for flat body shape fitted well on subject 1

iii.Bra Cup for Round Body Shape

While the bra cup provided sufficient capacity for the wearer's breasts and the bust point position matched with the cup peak, the shape of the cup did not fit the breasts well. As shown in Fig. 15, gapping was observed on both the neckline and underarm areas of the bra. This indicates that the cup shape or size may not have been suitable for the wearer, resulting in a lack of proper coverage and fit. The underarm area of the bra was positioned too low on the wearer, and excessive fabric was present in that region. This led to a lack of coverage on the sides of the breasts, potentially causing discomfort and compromising the overall fit. The gapping problem in this bra cup was more serious than that observed in the regular size 75E bra cup. The gapping indicates that the cup shape or size did not conform closely to the wearer's breasts, resulting in loose or empty areas within the cup. The shape of the breasts in this bra appeared flattened, with extra room observed particularly in the

upper part of the breast. This suggests that the cup design or shape did not provide adequate lift or support, resulting in a less appealing breast shape.

Fig. 15. Gapping at neckline and underarm of bra cup for round body shape on subject 1

B. Fitting Assessment of the Three Bra Samples on Subject 3

i. Regular 75E Bra Cup According to Shin's Method

The bust point position indicated by wearer matched with the cup peak, the positioning of the bust point on the bra cup was accurate and aligned with the wearers' actual bust point. The neckline of the cup was pressing on the wearer's breast, causing a problem known as "double breast" as shown in Fig. 16. This indicates that the cup size or shape was not sufficient to properly contain the breast tissue, resulting in spillage over the cup edge. Bulging problems were observed in both the neckline and underarm areas of the cup. It is worth noting that unlike subject 1, subject 3 experienced bulging instead of gapping at the underarm. This indicates that the cup design or size may not have been suitable for subject 3's body shape, resulting in excess tissue being pushed towards the underarm area. In Fig. 17, the position of the underarm was shown to be too low on the wearer. This suggests that the underarm area of the cup might have been designed or positioned incorrectly, contributing to the fitting issues in that region.

Fig. 16 Bulging neckline shown in regular 75E bra cup on subject 3

Fig. 17 Underarm positioned too low in regular 75E bra cup on subject 3

ii. Bra Cup for Flat Body Shape

The positioning of the bust point on the bra cup was not aligned with the wearers' actual bust point. Serious bulging issues observed on both the neckline and underarm areas of the bras, as shown in Fig. 18. This indicates that the cups were not providing sufficient coverage or containment for the breast tissues, resulting in bulging and spillage. The height of lower cup was deemed insufficient for accommodating the volume of the breasts. This led to the breast tissues being pressed flat against the chest, resulting in an unflattering shape and lack of projection.

Fig. 18 Serious budging at neckline and underarm in bra cup for flat body shape on subject 3

iii. Bra Cup for Round Body Shape

The bust point position indicated by the wearer matched with the cup peak. This suggests that the cup was appropriately positioned to align with the natural placement of the wearer's bust point. The height of the lower cup was sufficient to accommodate the volume of the lower breast. This indicates that the cup size and shape were designed appropriately to provide ample coverage and support for the lower portion of the breast. In Fig. 19, the neckline of the bra cup stayed nicely on the wearer's breast without extra or lacking tension. This indicates that the tension of the fabric in the neckline area was well-balanced, creating a smooth and round curve and shape of

the breast. This contributes to a visually pleasing appearance. In Fig. 20, the underarm of the bra cup was in appropriate tension, avoiding any digging into the wearer's side breast. This suggests that the cup design and construction properly accommodated the underarm area, providing a comfortable fit. Despite the overall good fit, there is a suggestion to consider amending the position of the underarm to a higher position. This adjustment would provide more coverage on the side breast area.

Fig. 19 Neckline of bra cup for round body shape fitted well on subject 3

Fig. 20 Underarm of bra cup for round body shape fitted well on subject 3

Based on the information provided, it can be concluded that the regular 75E bra cup exhibited slight fitting problems on both subjects with different body shapes. This highlights the common fitting issues that exist with bras available in the market and the need for improved fit solutions.

With the modified pattern drafting and design specific to different body shapes, significant improvements in the fit of the bra cup were observed. For the bra cup drafted for the flat body shape of subject 1, the bra fitted well with no notable fit issues or discomfort reported. This indicates that the pattern drafting, and design adjustments effectively addressed the specific fit needs of the flat body shape, providing a secure fit, adequate coverage, and an appealing shape. Similarly, for the bra cup drafted for the round body shape of another subject, the fitting assessment indicated that the bra cup provided a nice appearance of the breast and offered appropriate support. This suggests that the modifications in pattern drafting, and design catered to the needs of the round body shape, resulting in a comfortable and visually appealing fit.

The study findings, although based on a small sample size of five participants, emphasize the significance of considering body shape as a key factor in achieving a proper fit for bras. The observed variations in the fitting assessment among individuals with different body shapes highlight the challenges in developing a universal fit solution. These differences underscore the need to understand and address the distinct fit requirements of individuals with diverse body shapes. Moreover, it is important to note that these variations in body shape are not exclusive to specific ethnicities but exist across different ethnic backgrounds. Therefore, in order to improve the fitting of bras available in the industry, it is crucial to recognize and accommodate these variations. By doing so, a better understanding of the unique fit criteria for different body shapes can be developed, leading to potential solutions for the long-standing issue of bra fitting problems.

In conclusion, this study emphasizes the importance of considering body shape as a significant factor in bra fit. Further research with a larger and more diverse sample size is warranted to validate and strengthen these findings. By understanding and addressing the unique fit requirements of individuals with diverse body shapes, the industry can work towards reducing bra fitting problems and improving the overall fit of bras available to consumers.

IV. Conclusion

The bra fitting problem has been a longstanding issue, and despite advancements in bra design, the fundamental art of bra patternmaking plays a crucial role in understanding the interaction between the breast and the bra pattern. With the addition of 3D body scanning technology alongside traditional bra patternmaking methods, this study offers a comprehensive approach to understanding the interaction between the breast and the bra pattern. By incorporating 3D body scanning, precise and detailed measurements of the subjects' bodies can be obtained, capturing the unique contours and dimensions in three dimensions. This data can then be combined with the 2D bra pattern drafting method to analyze the effect of body shape on the desired bra cup shape, particularly focusing on the differentiation in the lower cup for flat and round body shape breasts. The results of this study, which provide valuable insights into the relationship between body shape and bra fit, serve as a foundation for further research and improvements in the design, pattern drafting, and fit of bras. By better understanding how different body shapes influence bra fit, designers and manufacturers can develop bras that offer a more comfortable and well-fitted experience for individuals with varying body shapes.

Overall, the integration of 3D body scanning technology with traditional bra patternmaking methods in this study contributes to the advancement of bra design and fit solutions, ultimately aiming to address the long-standing bra fitting problem and provide individuals with different body shapes a more satisfying and supportive bra-wearing experience.

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