# Development of a fitting-ensured men's garment block pattern prediction model for people with convex belly (PWCB)

**DOI: 10.35530/IT.076.02.202487**

MENGSHU DING
TIANYU LUO
YAN HONG

**ABSTRACT – REZUMAT**

**Development of a fitting-ensured men's garment block pattern prediction model for people with convex belly (PWCB)**

*The prevalence of People with a Convex Belly (PWCB) has been steadily increasing due to dietary and lifestyle changes. Standard garments available in the market are unsuitable for individuals with visible belly protrusion. While adapting patterns designed for individuals with normal morphology may be a potential solution, the design efficiency is currently inadequate. The purpose of this study is to propose the development of a Garment Block Pattern Prediction model to efficiently design fitting-ensured patterns for PWCB. This model aims to generate garment patterns that ensure a proper fit based on morphological data specific to PWCB. To achieve this objective, we simulate the mapping relationship between the body dimensions of PWCB and the dimensions of garment block patterns, which are adjusted to ensure a proper fit. Firstly, we identify key morphological dimensions of PWCB's bodies and determine the dimensions of garment block patterns using traditional garment pattern formulas. Secondly, we develop 130 fitting-ensured garment samples using CLO 3D software. Subsequently, we establish the mapping relationship using a linear regression model. The proposed prediction model in this study successfully enables the realization of personalized fitting-ensured garment block patterns for PWCB. This research significantly enhances the efficiency of pattern-making for PWCB and establishes a foundation for the automation and intelligence of garment pattern-making specifically tailored to PWCB's needs.*

***Keywords:*** *prediction model, convex belly, garment block pattern, pattern-making*

**Dezvoltarea unui model de predicție a tiparelor de blocuri de îmbrăcăminte pentru bărbați cu ajustare garantată pentru persoanele cu abdomen proeminent (PWCB)**

*Prevalența persoanelor cu abdomen proeminent (PWCB) a crescut constant, ca urmare a schimbărilor alimentare și ale stilului de viață. Articolele de îmbrăcăminte standard disponibile pe piață sunt inadecvate pentru persoanele cu proeminențe vizibile ale abdomenului. Deși adaptarea modelelor concepute pentru persoanele cu morfologie normală poate fi o soluție potențială, eficiența designului este în prezent inadecvată. Scopul acestui studiu este de a propune dezvoltarea unui model de predicție a tiparelor de blocuri de îmbrăcăminte pentru a proiecta în mod eficient tipare care asigură potrivirea pentru PWCB. Acest model urmărește să genereze tipare de îmbrăcăminte care să asigure o potrivire corespunzătoare pe baza datelor morfologice specifice PWCB. Pentru a atinge acest obiectiv, a fost simulată relația de corespondență dintre dimensiunile corporale ale PWCB și dimensiunile modelelor blocurilor de îmbrăcăminte, care sunt ajustate pentru a asigura o potrivire corespunzătoare. În primul rând, au fost identificate dimensiunile morfologice cheie ale corpurilor PWCB și determinate dimensiunile tiparelor blocurilor de îmbrăcăminte utilizând formulele tiparelor de îmbrăcăminte convenționale. În al doilea rând, au fost dezvoltate 130 de eșantioane de îmbrăcăminte cu potrivire garantată utilizând software-ul CLO 3D. Ulterior, a fost stabilită relația de corespondență utilizând un model de regresie liniară. Modelul de predicție propus în acest studiu permite realizarea cu succes a tiparelor personalizate de blocuri de îmbrăcăminte cu potrivire garantată pentru PWCB. Acest studiu îmbunătățește semnificativ eficiența realizării tiparelor pentru PWCB și stabilește o bază pentru automatizarea și inteligența realizării tiparelor de îmbrăcăminte special adaptate nevoilor PWCB.*

***Cuvinte-cheie****: model de predicție, abdomen proeminent, tipar bloc de îmbrăcăminte, proiectarea tiparelor*

## INTRODUCTION

During the recent years, obesity has increased in societies due to the reasons such as increasing stressful life, working long hours at desks and unhealthy nutrition [1]. The impact of trans fatty acids on the body's metabolism can result in fat accumulation, leading to a rising prevalence of the convex belly body type (PWCB) each year, which has become the most prevalent special body type [2]. The convex belly body type is characterized by a wider chest width compared to the back width, a longer front waist compared to the back waist length, a waist circumference that is close to or larger than the chest circumference, and a protruding belly [3–5].

Consequently, individuals with PWCB, particularly in the upper body region, do not fit into standard garment sizes available in stores, necessitating personalized products to cater to their unique needs in the consumer market [6].

In this particular scenario, the adaptation of ready-to-wear (RTW) garments to accommodate the morphology of PWCB is consistently required by this demographic. However, due to the complex geometric deformation of the body shape, the traditional 2D garment design process and associated design principles cannot be applied. The pattern-making phase, which plays a critical role in achieving proper garment fit, becomes a focal point for addressing convex belly-related issues [7, 8]. While straight lines can be determined using empirical formulas [9], the drawing of curves heavily relies on the expertise of pattern makers. Moreover, pattern makers encounter significant repetitive work during the pattern-making process, leading to time and energy wastage and diminished work efficiency. Currently, no efficient design solution catering specifically to PWCB is available in the market. In this context, the development of a prediction model capable of generating fitting-ensured garment patterns for individuals with convex bellies (PWCB) presents a potential solution.

In recent years, the field of garment pattern prediction has gained increasing attention from researchers. Liu et al. developed a system for the customization of jeans samples that utilizes both geometric and dimensional constraint parameters as inputs to generate the final product. The geometric constraints include the silhouette of the jeans, waist height, and trouser length, while the dimensional constraints encompass the individual's height, waist circumference, and hip circumference. This system features a sample modification process that facilitates interactive design and allows for real-time feedback [10]. In the realm of digital modeling, Abtew employed a technique to extract the body's surface contour by intersecting a cutting plane with the bust at its origin. This method involved the construction of a wireframe mesh, from which the volume of the breasts was determined using characteristic points on the mesh. This process enabled the simulation of a three-dimensional bra, which could subsequently be unfolded into a two-dimensional prototype [11]. Notable examples include Wang et al., who proposed a novel prediction model utilizing radial basis function (RBF) artificial neural networks (ANNs) to estimate body dimensions relevant to garment pattern-making [12]. Kolose et al.. employed a 3D body scanner to measure body dimensions from the New Zealand Defence Force Anthropometry Survey (NZDFAS) data and developed prediction models for shirt and trouser sizes using decision trees [13]. Additionally, Jin, SN et al. extracted human body sizes from body images and developed a system capable of automatically generating personalized patterns and style designs based on 2D human body images [14]. Numerous studies have demonstrated the existence of correlations between body dimensions and pattern dimensions, which can be effectively captured through prediction models. Such models have the potential to significantly enhance the efficiency of the garment pattern-making process. However, there is a dearth of research focusing on the prediction modeling of garment block patterns specifically tailored to PWCB. Thus, the objective of this paper is to develop a fitting-ensured garment block pattern prediction model for individuals with convex belly (PWCB), thereby improving the efficiency of pattern-making for this particular body type.

An effective garment pattern prediction model should align with classic pattern-making methods. Common methods include the proportion method, prototype method, and short-inch method, among others. The proportion method is suitable for simple garment styles, whereas the prototype method accommodates a broader range of garment styles. Therefore, in this study, the prototype method is adopted to establish the proposed prediction model. By employing the prototype method, diverse garment styles can be generated. To simplify the research problem, this study focuses solely on the garment block pattern. The garment block pattern serves as the foundation for pattern-making, representing the fundamental relationship between the garment and the morphology of the human body [15]. Various garment styles can be derived from garment block patterns. Hence, the key objective of realizing the proposed prediction model is to establish a matching relationship between morphological dimensions on the human body surface and garment block pattern dimensions under conditions that ensure a proper fit.

This study aims to investigate the relationship between garment block patterns and human body dimensions as a prediction model [16–18] to enhance the efficiency of garment pattern-making for PWCB. To achieve this objective, the following steps are undertaken. Firstly, a group of experienced pattern designers selects garment block patterns tailored to PWCB, considering key human body morphological dimensions. Secondly, a data set of 130 virtual PWCB with diverse morphology is created. In the virtual environment provided by CLO 3D, fitting-ensured garment block patterns are designed for each virtual PWCB. Subsequently, measurements of garment block dimensions and key human body morphological dimensions are obtained. These measurements serve as the basis for establishing their relationships using a linear regression model. Finally, an evaluation procedure is conducted to assess the accuracy and efficiency of the prediction model for clothing design, utilizing both virtual and physical fittings.

The study is structured into several chapters to address its research objectives comprehensively. 1st section provides an introduction to the background, purpose, and significance of the research topic and conducts a general review of the existing relevant literature. 2nd section outlines the methods and principles employed to derive the prediction model for this study. 3rd section constitutes the primary experiment of the research, employing appropriate methods and tools to obtain predictions of fitting garment block pattern dimensions based on key body dimensions. In the 4th section, the experimental results are rigorously validated and evaluated through both virtual fitting and physical fitting. 5th section encompasses the conclusion and outlook of the study, which summarizes the research findings, analyzes the innovative aspects, advantages, and limitations of the study, and suggests potential areas for future investigation.

## GENERAL INFORMATION

The primary aim of the study delineated within this article is to conceptualize and develop an automated system for the generation of tailored suit samples specifically designed for male individuals with a prominent abdominal region. Consequently, the subsequent section will elucidate the methodology and underlying theoretical framework that inform the construction of the proposed model.

### Principle of the proposed model

The objective of this study is to propose a prediction model for developing fit-ting-ensured garment block patterns using key human body morphological dimensions. The model's purpose is to facilitate the creation of a wider range of garment styles for individuals with a convex belly (PWCB). The proposed prediction model is constructed based on a digitalised convex belly body model within a virtual environment. It establishes a linkage between garment block patterns and the deformation of the human body surface. By leveraging key human body dimensions, the proposed model enables the efficient determination of fitting-ensured garment block pattern dimensions. As a result, the fitting-ensured garment block patterns can be effectively designed to accommodate a diverse selection of garment styles.

### Related concepts and tools of the proposed model

*CLO 3D software*

In the pattern-making process of the experimental study, the virtual software CLO 3D is utilized to obtain the PWCB mannequins and their fit-ensured garment block patterns. This is because the manual measurement of the real human body dimensions takes time, and it can easily cause errors [19]. The 3D body scanning could be a solution, but the cost is high [20]. The adoption of CLO 3D offers significant advantages in terms of efficiency compared to real clothing production [21] while also enabling the generation of diverse human body shapes with regular distribution [22, 23]. Hence, this research employs CLO 3D, which emphasizes the utilization of virtual draping as an alternative to physical draping [24–26].

*Linear regression model*

In the field of fashion, it is well-established that garment patterns are composed of a collection of lines and curves, each of which corresponds to a specific feature on the human body's surface (e.g., the collar girth and its corresponding neck girth) [27]. These lines and curves on both the human body and the garment pattern represent key human body morphological dimensions and pattern feature line segments, respectively. Within mathematical theory, any continuous curve can be mathematically represented by an equation.

*Fuzzy comprehensive evaluation method*

In the evaluation part of this study, the paper uses the fuzzy comprehensive evaluation method, which can ensure the accuracy of the data. The evaluation using a five-level Likert scale with a rubric set of V = {very ill-fitting, relatively well-fitting, average, relatively well-fitting, very well-fitting} and its assigned values of $\gamma$ = {1, 2, 3, 4, 5}, i.e., the values of *a, b, c, d*, and *e* are 1, 2, 3, 4, and 5, respectively. Experts evaluate the clothing fit according to the fitting degree judgment standard and the rubric set. Therefore, the affiliation function of this study is as in equations 1–5:

$$U_a(x, a, b) = \begin{cases} 1 & x \le 1 \\ (2-x)/(2-1) & 1 < x \le 2 \\ 0 & 2 < x \end{cases} \quad (1)$$

$$U_a(x, d, e) = \begin{cases} 0 & x \le 4 \\ (x-4)/(5-4) & 4 < x \le 5 \\ 1 & 5 < x \end{cases} \quad (2)$$

$$U_a(x, a, b, c) = \begin{cases} 0 & x \le 1 \\ (x-1)/(2-1) & 1 < x \le 2 \\ (3-x)/(3-2) & 2 < x \le 3 \\ 0 & 3 < x \end{cases} \quad (3)$$

$$U_a(x, b, c, d) = \begin{cases} 0 & x \le 2 \\ (x-2)/(3-2) & 2 < x \le 3 \\ (4-x)/(4-3) & 3 < x \le 4 \\ 0 & 4 < x \end{cases} \quad (4)$$

$$U_a(x, c, d, e) = \begin{cases} 0 & x \le 3 \\ (x-3)/(4-3) & 3 < x \le 4 \\ (5-x)/(5-4) & 4 < x \le 5 \\ 0 & 5 < x \end{cases} \quad (5)$$

## EXPERIMENT

In this study, a prediction model is proposed based on the deformation of the human body surface, aiming to develop fitting-ensured garment block patterns with appropriate ease values, taking into consideration the individual characteristics of men with convex bellies. To achieve this objective, a series of experiments are designed, as illustrated in figure 1, which outlines the general framework consisting of three phases.

In the first phase, relevant knowledge regarding human body morphological characteristics, specifically on body and pattern dimensions, is extracted and quantified. In the second phase, this quantified knowledge serves as the foundation for establishing a mapping relationship between key body dimensions and detailed body dimensions for men with convex bellies. Through the utilization of a linear regression model, the mapping relationship between the detailed dimensions of men with convex bellies and the pattern dimensions of fitting garment block

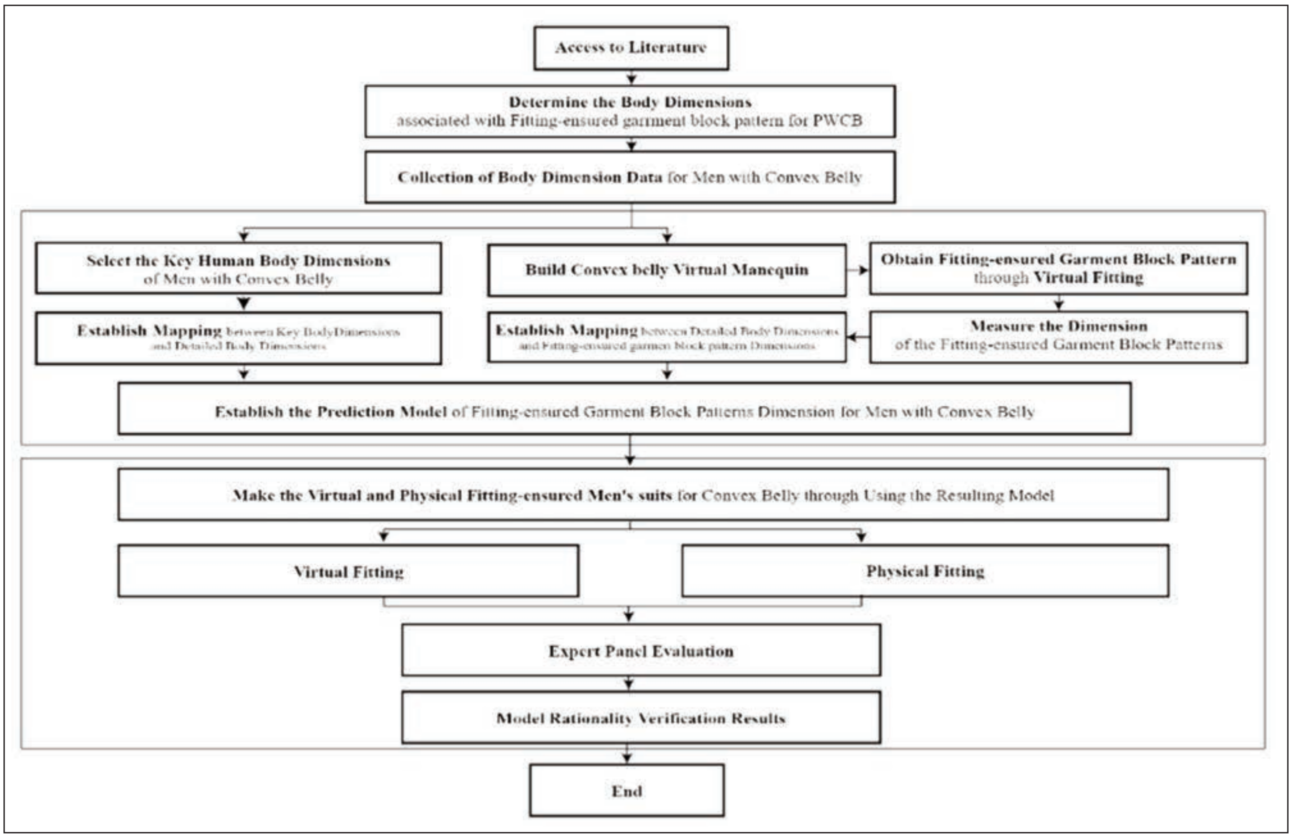



Fig. 1. General scheme for the development of a fitting-ensured men's garment block pattern prediction model

patterns is established. By combining these two relationships, a prediction model is derived for obtaining the pattern dimensions of fitting garment block patterns from key human body morphological dimensions. The prediction model is expressed through a set of linear regression equations. In the third phase, an evaluation is conducted, involving both virtual fitting and physical fitting methods [28]. This evaluation focuses on the fitting-ensured suits for individuals with convex bellies, aiming to validate the rationale behind the fitting-ensured Men's Garment Block Pattern Prediction Model for People with Convex Belly.

### Experiment I: Selection of key human body morphological dimensions

Given the multitude of morphological dimensions present on the human body surface, it is crucial to identify the dimensions that are directly relevant to pattern making. To address this, a cohort of 130 virtual subjects with diverse morphology, representative of People with Convex Belly (PWCB), is created within the virtual environment facilitated by CLO 3D. It should be noted that while certain dimensions, such as hip circumference, hold significance in pattern making, they may not be relevant to upper body pattern creation. Consequently, the accuracy of dimension selection heavily relies on the expertise of pattern designers. To ensure a standardized and objective approach, a rigorous evaluation process is undertaken to assess the selection of human body morphological dimensions subjectively, as illustrated in figure 2.

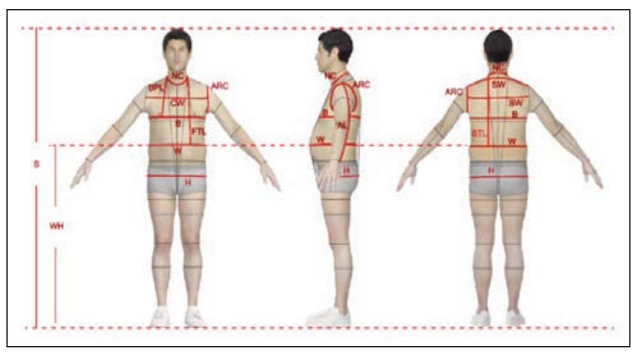


Fig. 2. Diagram of convex belly body anthropometric parts: Stature (S), Waist Height (WH), Back Length (BL), BP (Breast Point) Length (BPL), Arm Length (AL), Front Torso Length (FTL), Back Torso Length (BTL), Shoulder Width (SW), Chest Width (CW), Back Width (BW), Neck Circum-ference (NC), Arm Root Circumference (ARC), Bust (B), Waist (W), Hip (H)

We assembled a selection panel comprising ten experts in the pattern design field for this experiment. Before the selection process, the experts were provided with a comprehensive understanding of the experiment's objectives. Each panel member was tasked with compiling a list of human body morphological dimensions pertinent to their respective areas of expertise, encompassing factors such as height, length, width, and circumference of various body parts. The research object, namely the men's garment block pattern for individuals with convex bellies, was made available to the panelists as a point of reference during the selection process.

The panel engaged in detailed discussions to identify and eliminate redundant dimensions that lacked relevance to the pattern-making process specific to the men's garment block pattern for individuals with convex bellies. Employing a group decision-making approach, 14 human body morphological dimensions deemed integral to the men's garment block pattern for individuals with convex bellies were ultimately retained, which include Stature (S), Waist Height (WH), Back Length (BL), BP (Breast Point) Length (BPL), Arm Length (AL), Front Torso Length (FTL), Back Torso Length (BTL), Shoulder Width (SW), Chest Width (CW), Back Width (BW), Neck Circumference (NC), Arm Root Circumference (ARC), Bust (B), Waist (W), Hip (H).

**Experiment II: Select the fitting pattern dimension date**

Following the established research methodology, virtual fitting is conducted based on the acquired human body morphological dimensions. Subsequently, the fitting pattern is derived through expert perception evaluation.

*Criteria for virtual fitting clothing fit assessment*

To optimize cost, pattern adjustments are performed through virtual fitting [29, 30]. In this process, two key principles guide the evaluation of general clothing fit. Firstly, the clothing should exhibit a high degree of conformity to the human body, characterized by the absence of excess allowances and wrinkles. Secondly, considering the dynamic nature of the human body, the clothing should accommodate breathing and basic movement requirements while maintaining a certain degree of ease between the garment and the body surface.

In the experimental procedure, a panel of ten pattern design experts is assembled. The experts are provided with a clear explanation of the experiment's objectives. Each panelist is tasked with compiling a comprehensive list of garment fitting evaluation criteria based on their expertise. These criteria encompass the aspects influencing their assessment of the garment's fitting effect. Subsequently, all the proposed fitting evaluation criteria are presented to the panel for group discussion. Each panelist is then required to select the most suitable fitting evaluation criteria. As a result, two garment fitting evaluation criteria are identified: (1) "Overall" and (2) "Details". After that, similar processes are carried out to generate specific garment fitting evaluation positions for each garment fitting evaluation criterion. Finally, seven garment fitting evaluation positions are selected: Garment Length (GL), Bust Circumference (BC), Waist Circumference (WC), Hip circumference (HC), Collar Width (CW), Shoulder Width (SW), Armhole Depth (AD) and Back Collar Depth (BCD). For the "Overall" garment fitting evaluation criteria, "Garment Length", "Bust", "Waist", "Hip", and "Shoulder Width" are selected. For the "Details" garment fitting evaluation criteria, "Collar Width", "Back Collar Width", and "Armhole Depth" are selected. The criteria for determining the degree of the garment of men's tops with convex belly is as shown in table 1.

*Principle of virtual fitting pattern adjustment*

In this section, the initial step involves constructing a virtual human body model utilizing the available human body data, the flow is shown in figure 3. Subsequently, the initial garment block pattern is generated using traditional garment pattern formulas [31]. Following this, the garment block pattern is subjected to a try-on process, and the 2D pattern is adjusted based on the pressure, stress, and translucent diagrams observed in the 3D fitting analysis, as shown in figure 4 [32]. These adjustments continue until a consensus is reached among the expert panel. Ultimately, a modified garment block pattern is obtained, ensuring an appropriate fit.

To accommodate the adjustment of the garment block pattern for men's tops designed for individuals with a convex belly physique, several factors are considered. Firstly, the overall length of the garment is optimized to achieve proper fitting with the body surface. Emphasis is placed on achieving an ideal fit at the chest, shoulder blades, and shoulders.

Additionally, the front of the garment and the middle of the back should exhibit a flat and straight appearance. However, considering the protrusion of the convex belly, special attention is given to ensuring that the hem below the waist-line hangs vertically, remaining smooth and without any distortion. Moreover, sufficient breathing room is incorporated into the chest, waist, and hip areas of the garment. Lastly, when designing the collar arc and sleeve cagearc, care is taken to avoid tightness, allowing for adequate freedom of movement.

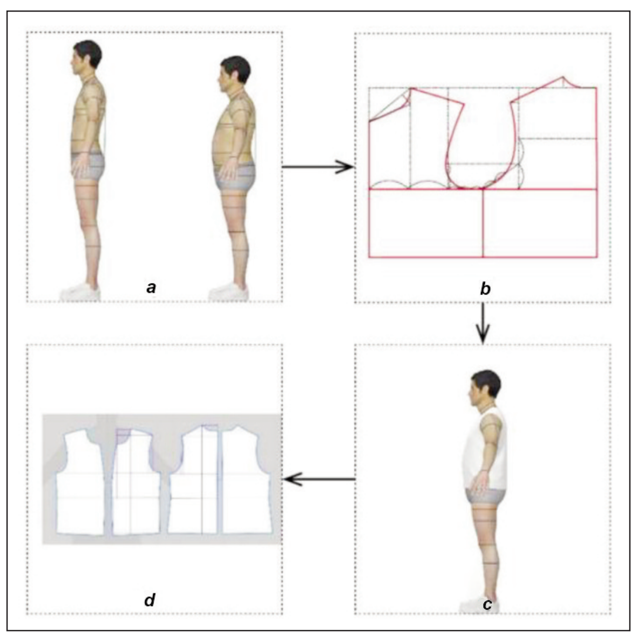



Fig. 3. Virtual fitting flowchart: *a* – adjustment of the standard body type virtual mannequin to a convex belly body mannequin; *b* – non-fit garment block pattern drawn according to the traditional formula; *c* – virtual fitting; *d* – obtaining a convex belly fitting garment block pattern

Table 1

<table>
<tr><th colspan="3">CRITERIA FOR DETERMINING THE DEGREE OF FITTING OF THE GARMENT BLOCK PATTERN OF MEN'S TOPS WITH CONVEX BELLY</th></tr>
<tr><th colspan="2">Site</th><th>Fitting criteria</th></tr>
<tr><td rowspan="5">Overall</td><td>Garment length</td><td>Try-on diagram: The length of the garment is aligned with the hip line, with the front and back hems at the same level. The front and back exhibit a rounded, smooth, and flat appearance without any elevation in the front hem.</td></tr>
<tr><td>Bust</td><td>Try-on diagram: The front piece of the garment fits the human chest without any excessive fabric, resulting in folds. It conforms to the contours of the chest and remains smooth at the shoulder blades of the back.<br>Perspective view: Upon observation, the chest and back sections of the garment exhibit a close fit to the body, with approximately 2 to 3 cm of ease between the underarm area and the body surface.<br>Stress diagram: The garment is predominantly displayed in green (indicating less stress) or blue (indicating very little stress), with white areas signifying no stress. However, the shoulder blade area, which bears stress due to gravity, is displayed in yellow (indicating more stress). If the stress reaches a significant level, it is indicated in red, suggesting a tight fit.</td></tr>
<tr><td>Waist</td><td>Try-on diagram: The waist and upper belly areas of the front piece show no excess fabric folding. They conform to the body's waist and upper belly, while the back waist area slightly tapers inward and remains relatively flat.<br>Perspective view: The waist and upper belly sections of the garment conform to the human body, with approximately 1–2 cm of ease between the side waist area and the body and approximately 3–5 cm of ease between the back waist area and the body surface.<br>Stress diagram: The stress display for the waist area should predominantly show green, blue, or white colors. If the stress display appears red, it indicates a very tight fit, while yellow suggests a tighter fit.</td></tr>
<tr><td>Hip</td><td>Try-on diagram: The garment exhibits no pleats formed by excessive fabric accumulation around the hips. It maintains a smooth and flattering appearance around the hip line, is neither tight nor flared, and remains as vertical to the ground as possible.<br>Perspective view: The hip area of the garment fits the body's surface, with approximately 3–5 cm of ease between the lower belly section of the garment and the body.<br>Stress diagram: The stress display for the hip area should predominantly show green, blue, or white colors. If the stress display appears red, it indicates a very tight fit, while yellow suggests a tighter fit.</td></tr>
<tr><td>Shoulder width</td><td>Try-on diagram: The shoulder point of the garment is near the human shoulder point, ensuring a smooth and non-constricting shoulder line.<br>Perspective view: There is approximately 1 cm of ease between the shoulder of the garment and the body surface.<br>Stress diagram: As the shoulder serves as the primary load-bearing part of the garment, the stress in this area is ideally displayed in shades of yellow, green, blue, or white. If the stress area appears red, it indicates a very tight shoulder fit.</td></tr>
<tr><td rowspan="3">Details</td><td>Collar width</td><td>Try-on diagram: The collar width is slightly wider than the straight-line distance between the left and right neck points.<br>Stress diagram: The stress display for the left and right neck points should predominantly show green, blue, or white colors. If the stress display appears red, it suggests a very tight collar circumference, while yellow suggests a tighter collar fit.</td></tr>
<tr><td>Back collar depth</td><td>Try-on diagram: The depth of the back collar is near the back neck point.<br>Stress diagram: The stress display for the back neck point should predominantly show green, blue, or white colors. If the stress display appears red, it indicates a very tight neckline, while yellow suggests a tighter neckline.</td></tr>
<tr><td>Armhole depth</td><td>Try-on diagram: The armhole should not be excessively wide, and the curve of the armhole should follow a basic pattern along the shoulder point, front and rear axillary points, and the bottom point of the cage from the axillary point has the ease of about 5 to 6 cm.<br>Stress diagram: The stress shown around the armhole should be green, blue or white. If the stress shows red, the armhole is very tight; if the stress shows yellow, the armhole is tighter.</td></tr>
</table>

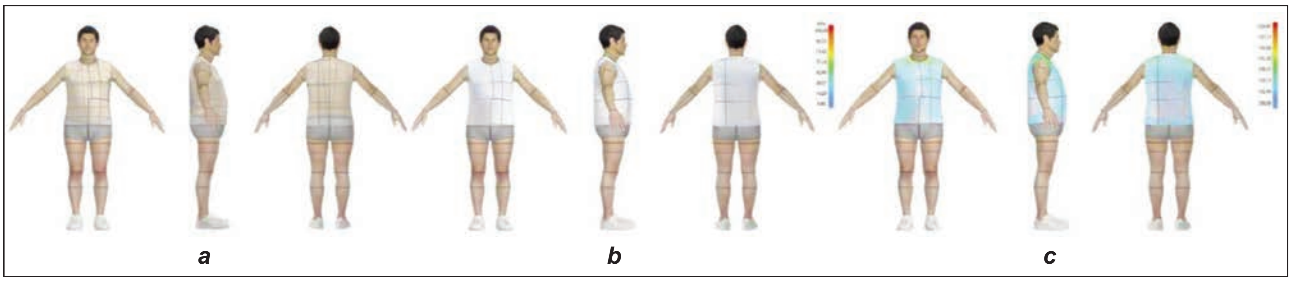


Fig. 4. Diagram of the adjustment details of the convex belly garment block pattern: *a* – perspective view (front, side, back); *b* – pressure diagram (front, side, back); *c* – stress diagram (front, side, back)

*Fitting pattern data collection*

Ten pattern design experts were invited to participate in a standardized subjective screening process aimed at identifying the pattern dimensions to be measured following the acquisition of fitting garment block patterns. The primary objective of the experiment was explained to the experts before their involvement. Subsequently, each panelist individually identified the characteristic lines that they deemed significant for pattern-making in men's garments designed for individuals with a convex belly physique. These characteristic lines encompassed the outlined line of the template, the structure line, and the auxiliary line. After the individual assessments, a group discussion was conducted to facilitate the selection of characteristic dimensions specifically tailored for men's garments intended for individuals with a convex belly physique. The convex belly fitting-ensured garment block pattern and diagram for measuring the characteristic dimensions of the convex belly fitting-ensured garment block pattern are as shown in figure 5.

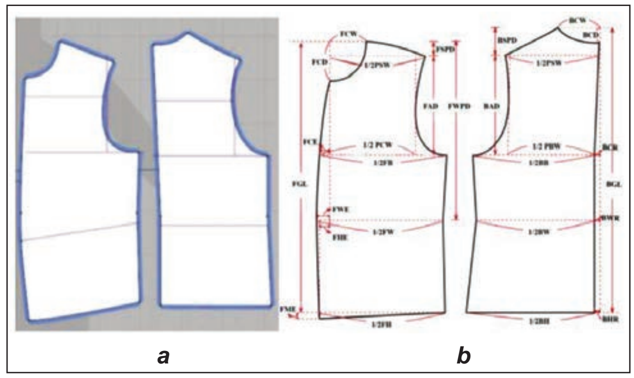


Fig. 5. The convex belly fitting-ensured garment block pattern and diagram for measuring the characteristic dimensions of the convex belly fitting-ensured garment block pattern: *a* – convex belly fitting-ensured garment block pattern obtained after virtual fitting, expert evaluation and adjustment; *b* – diagram for measuring the characteristic dimensions of the fitting-ensured garment block pattern of the convex belly

## Mapping and modeling the relationship between body dimensions and pattern dimensions

*Analysis of body dimensions data and extraction of key body dimensions*

Based on the findings from previous anthropometry studies, it is evident that human body morphological dimensions exhibit certain correlations [33]. For instance, changes in human height are known to influence various body dimensions, while the degree

Table 2

| CONVEX BELLY BODY TWO-BY-TWO DETAILED DIMENSIONS RELATED ANALYSIS RESULTS | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S | B | W | NC | ARC | H | SW | AL | BL | FTL | BTL | CW | BW | BPL | WH |
| S | 1 | 0.316 | 0.292 | 0.460 | 0.527* | 0.424 | 0.670* | 0.842* | 0.737** | 0.748** | 0.741** | 0.596* | 0.560* | 0.723* | 0.984** |
| B | 0.316 | 1 | 0.860* | 0.937** | 0.927** | 0.924** | 0.856* | 0.289 | 0.370 | 0.586* | 0.524* | 0.885** | 0.897** | 0.682* | 0.333 |
| W | 0.292 | 0.860* | 1 | 0.807* | 0.849* | 0.857* | 0.754* | 0.278 | 0.267 | 0.406 | 0.392 | 0.696* | 0.769* | 0.762* | 0.325 |
| NC | 0.460 | 0.937** | 0.807* | 1 | 0.930* | 0.898* | 0.899* | 0.402 | 0.462 | 0.665* | 0.611* | 0.895* | 0.885* | 0.769 | 0.469 |
| ARC | 0.527* | 0.927** | 0.849* | 0.930* | 1 | 0.905* | 0.914* | 0.444 | 0.507* | 0.668* | 0.639* | 0.882* | 0.909* | 0.813* | 0.542* |
| H | 0.424 | 0.924** | 0.857* | 0.898* | 0.905* | 1 | 0.855* | 0.377 | 0.410 | 0.619* | 0.544* | 0.854* | 0.868* | 0.752* | 0.438 |
| SW | 0.670* | 0.856* | 0.754* | 0.899* | 0.914* | 0.855* | 1 | 0.572* | 0.600* | 0.740* | 0.731* | 0.925* | 0.959* | 0.848** | 0.673* |
| AL | 0.842* | 0.289 | 0.278 | 0.402 | 0.444 | 0.377 | 0.572* | 1 | 0.635* | 0.649* | 0.634* | 0.526* | 0.497 | 0.621* | 0.827* |
| BL | 0.737** | 0.370 | 0.267 | 0.462 | 0.507* | 0.410 | 0.600* | 0.635* | 1 | 0.814* | 0.945* | 0.506* | 0.571* | 0.539* | 0.640* |
| FTL | 0.748** | 0.586* | 0.406 | 0.665* | 0.668* | 0.619* | 0.740* | 0.649 | 0.814* | 1 | 0.841* | 0.734* | 0.677* | 0.685* | 0.670* |
| BTL | 0.741** | 0.524* | 0.392 | 0.611* | 0.639* | 0.544* | 0.731* | 0.634* | 0.945* | 0.841* | 1 | 0.639* | 0.698* | 0.601* | 0.658* |
| CW | 0.596* | 0.885** | 0.696* | 0.895* | 0.882* | 0.854* | 0.925* | 0.526* | 0.506* | 0.734* | 0.639* | 1 | 0.907* | 0.755* | 0.605* |
| BW | 0.560* | 0.897** | 0.769* | 0.885* | 0.909* | 0.868* | 0.959* | 0.497* | 0.571* | 0.677* | 0.698* | 0.907* | 1 | 0.768* | 0.568* |
| BPL | 0.723* | 0.682* | 0.762* | 0.769 | 0.813* | 0.752* | 0.848** | 0.621* | 0.539* | 0.685* | 0.601* | 0.755* | 0.768* | 1 | 0.724* |
| WH | 0.984** | 0.333 | 0.325 | 0.469 | 0.542* | 0.438 | 0.673* | 0.827* | 0.640* | 0.670* | 0.658* | 0.605* | 0.568* | 0.724* | 1 |

of human obesity is associated with alterations in circumference dimensions in different directions. Consequently, modifications in individual body part dimensions correspond to changes in the corresponding dimensions of the clothing worn.

Apart from general trends, more specific quantitative relationships may exist among the aforementioned data. To identify correlated data and establish precise quantitative relationships between relevant variables, the present study employs the data analysis software SPSS to conduct correlation and regression analyses. As presented in table 2, the strength of correlation between two body dimensions is indicated by the magnitude of the correlation coefficient, which falls within the range of 0 to 1. A correlation coefficient of 1 signifies that the two body dimensions are identical. In the table, an asterisk (*) is used to denote a stronger correlation between two groups of body dimensions. Based on the data provided in the table, ten pattern design experts analyze and screen the data, considering both the magnitude of the correlation coefficient and other factors such as representativeness in a single dimension and ease of measurement. The final selection of key dimensions includes Stature (S), Bust (B), Shoulder Width (SW), Waist (W), Arm Length (AL), and their respective detailed dimensions, as outlined in table 3. The correlation of these selected dimensions with other detailed dimensions is denoted by a double asterisk (**).

Based on the data presented in the table, it is evident that the correlation coefficient between certain screened key body dimensions and their corresponding detailed dimensions is not the highest. Notably, the measurement of height has been widely employed as an indicator of the longitudinal length of the human body in both scientific research and everyday life. Height is a well-recognized and easily measurable dimension, making it more representative. Therefore, height is deemed a crucial body dimension and is selected as one of the key dimensions.

*Linear regression model for body dimension data*

As depicted in table 4, a linear regression analysis is conducted on the two sets of data, considering the relationship between the screened key body dimensions and the corresponding detailed body dimensions. The R-square value signifies the extent to which the selected independent variable can explain the dependent variable. A higher R-square value, closer to 1, indicates a stronger explanatory power of the independent variable over the dependent variable. The coefficients and constants of the linear regression model for back length and height are presented in table 5 as 0.225 and 7.351, respectively, with significance levels of 0.022 and 0.000 ($P$<0.05), thereby indicating the statistical significance of the linear regression analysis results. Figure 6, *a* illustrates that the independent variable (height) in the regression model approximates a normal distribution. The quality of the linear regression model fit can be assessed by examining the proximity of scattered points in the standardized residual normal *P-P* plot (figure 6, *b*) to the straight line, and the scatter and regularity of points in the scatter plot (figure 6, *c*).

Utilizing the aforementioned analyses, the linear regression equation is derived from the linear regression model, with the screened key body dimensions serving as the independent variable and the remaining detailed dimensions as the dependent variable. The obtained linear regression equation is presented in table 6. With this linear regression equation, it

Table 3

TABLE OF CORRELATION COEFFICIENTS OF SCREENED KEY BODY DIMENSION AND THE DETAILIED BODY DIMENSIONS THEY REPRESENT

| Key body dimensions | Detailed body dimensions | Correlation coefficient |
|---|---|---|
| Stature (S) | Back Length (BL) | 0.737 |
| | Front Torso Length (FTL) | 0.748 |
| | Back Torso Length (BTL) | 0.741 |
| | Waist Height (WH) | 0.984 |
| Bust (B) | Neck Circumference (NC) | 0.937 |
| | Hip (H) | 0.924 |
| | Arm root circumference (ARC) | 0.927 |
| | Chest Width (CW) | 0.885 |
| | Back Width (BW) | 0.897 |
| Shoulder width (SW) | Breast Point Length (BPL) | 0.848 |
| Waist (W) | - | - |
| Arm length (AL) | - | - |

Table 4

SUMMARY TABLE OF HEIGHT-BACK LENGTH LINEAR REGRESSION ANALYSIS MODEL

| Model | R | R-Squared | Adjusted R2 | Error in standard estimation | Change statistics | | | | | Durbin-Watson |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | R-squared change amount | F change amount | Freedom 1 | Freedom 2 | Significance F amount of change | |
| 1 | 0.737[a] | 0.544 | 0.540 | 1.1342 | 0.544 | 152.581 | 1 | 128 | 0.000 | 1.892 |

*Note:* a – predictive variables: (Constant), Height; b – dependent variable: Back length.

Table 5

| TABLE OF COEFFICIENTS OF HEIGHT-BACK LENGTH LINEAR REGRESSION ANALYSIS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Model** | **Unstandardized coefficient** | | **Standardized coefficient** | | **T** | **Significance** | **Covariance statistics** | |
| | **B** | | **Standard Error** | **Beta** | | | **Tolerances** | **VIF** |
| 1 | (Constant) | 7.351 | 3.163 | / | 2.324 | 0.022 | / | / |
| | Height | 0.225 | 0.018 | 0.737 | 12.352 | 0.000 | 1.000 | 1.000 |

*Note:* a – dependent variable: Back length.

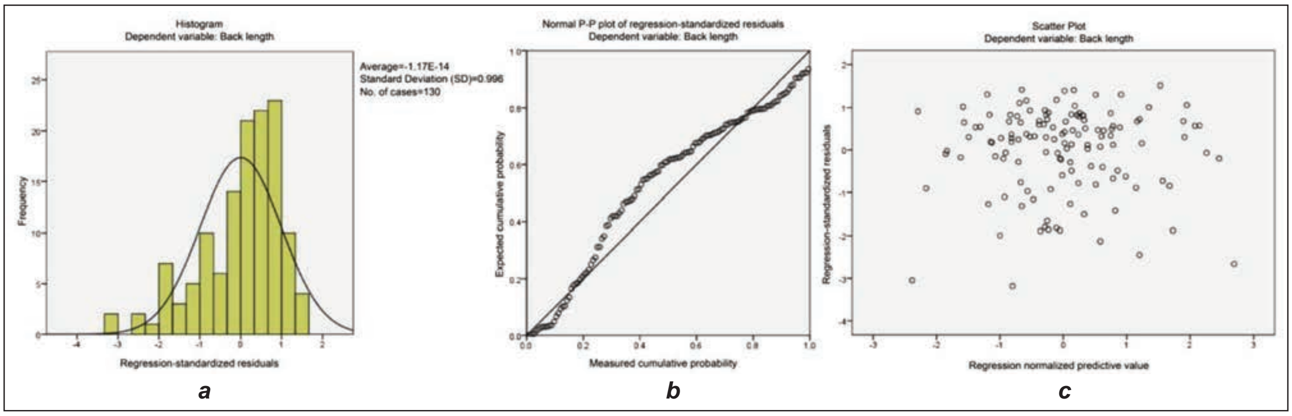



Fig. 6. Linear regression model for body dimension data: *a* – histogram of standardized residuals from height-back length regression; *b* – normal P-P plot of regression-standardized residuals; *c* – height-back length regression standardized predictive scatter plot

Table 6

| CONVEX BELLY KEY DIMENSION-DETAILED DIMENSION LINEAR REGRESSION EQUATION | |
|---|---|
| **Detailed dimension** | **Linear regression equation** |
| Back length (BL) | BL = 0.225S + 7.351 (S: height) |
| Front Torso Length (FTL) | FTL = 0.242S + 5.208 (S: height) |
| Back Torso Length (BTL) | BTL = 0.263S + 3.436 (S: height) |
| Waist Height (WH) | WH = 0.708S – 15.830 (S: height) |
| Chest Width (CW) | CW = 0.189B + 20.117 (B: bust) |
| Back Width (BW) | BW = 0.216B + 16.594 (B: bust) |
| Neck Circumference (NC) | NC = 0.279B + 13.120 (B: bust) |
| Hip (H) | H = 0.791B + 19.956 (B: bust) |
| Arm root circumference (ARC) | ARC = 0.542B – 7.985 (B: bust) |
| Breast Point Length (BPL) | BPL = 0.478SW + 6.834SW: shoulder width) |

becomes feasible to predict other detailed body dimensions based on the screened key body dimensions.

*Linear regression model of body dimension data and pattern dimension data*

In the case of the sleeve pattern, the traditional pattern formula is employed due to the minimal difference observed between the arm portion of individuals with convex belly body type and those with normal body type. By establishing a correlation between human data and pattern data, the necessary human detail dimensions required for constructing the regression analysis model of human data – pattern data can be obtained. The detailed dimensions encompass chest width (CW), back width (BW), neck circumference (NC), and waist height (WH). The regression models illustrating the relationships between these body-detailed dimensions and the key body dimensions are presented in table 7.

In this study, a comprehensive linear regression analysis is performed to investigate the relationship between human body dimensions and garment pattern dimensions. To illustrate this relationship, the linear regression model of human chest circumference and sample chest dimension is utilized as an exemplar. The model summary table (table 8) reveals an R-squared value approaching unity, indicating a strong ability of the independent variable (human chest circumference) to account for the variability observed in the dependent variable (pattern chest

| Table 7 | |
|---|---|
| LINEAR REGRESSION MODEL OF BODY DIMENSION DATA AND PATTERN DIMENSION DATA | |
| **Body dimension** | **Linear regression equation** |
| Chest Width (CW) | CW = 0.189B + 20.117 |
| Back Width (BW) | BW = 0.216B + 16.594 |
| Neck Circumference (NC) | NC = 0.279B + 13.120 |
| Waist Height (WH) | WH = 0.708S – 15.830 |

circumference). Examining the coefficient table (table 9), we find that the coefficients of the independent variables, namely bust and constant, are estimated to be 0.455 and 7.022, respectively. Moreover, their corresponding significance levels are determined to be 0.000, indicating statistical significance ($P$<0.05).

Figure 7, *a* exhibits a histogram representing the bust measurements, which demonstrates a favorable fit to the normal distribution curve. This observation suggests that the bust distribution among the experimental cases aligns closely with a normal distribution. Additionally, the regression normalized residuals normal P-P plot (figure 7, *b*) displays a satisfactory correspondence between the predicted accumulation probability and the observed accumulation probability, further indicating a normal distribution pattern within the pattern data. Furthermore, the scatter plot (figure 7, *c*) displays a random and irregular distribution of points, signifying a robust fit of the regression model.

According to the results presented in table 10, the linear regression analysis has enabled the determination of the final linear regression equation. This equation establishes the relationship between the independent variable of detailed body dimensions and the dependent variable of pattern dimensions. Furthermore, the linear regression equation between the fitting garment block pattern dimensions and the

Table 8

SUMMARY TABLE OF LINEAR REGRESSION ANALYSIS MODEL OF BODY CHEST CIRCUMFERENCE – PATTERN CHEST CIRCUMFERENCE

| Model | R | R-Squared | Adjusted R2 | Error in standard estimation | Change statistics | | | | | Durbin-Watson |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | R-squared change amount | F change amount | Freedom 1 | Freedom 2 | Significance F amount of change | |
| 1 | 0.975[a] | 0.950 | 0.950 | 0.6941 | 0.950 | 2427.915 | 1 | 128 | 0.000 | 1.957 |

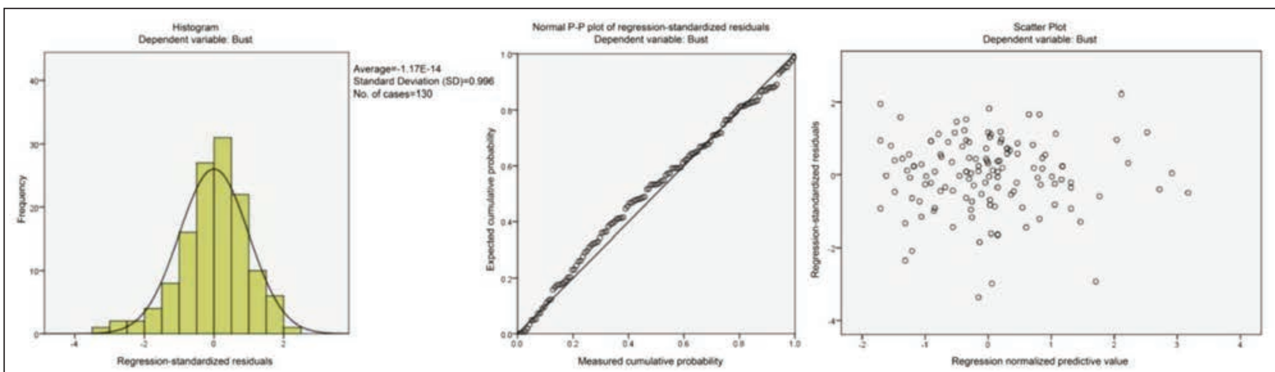
*Note:* a – predictive variables: (Constant), Bust; b – dependent variable: Bust.

Table 9

TABLE OF COEFFICIENTS FOR LINEAR REGRESSION ANALYSIS OF BODY CHEST CIRCUMFERENCE – PATTERN CHEST CIRCUMFERENCE

| Model | Unstandardized coefficient | | Standardized coefficient | | t | Significance | Covariance statistics | |
|---|---|---|---|---|---|---|---|---|
| | B | | Standard Error | Beta | | | Tolerances | VIF |
| 1 | (Constant) | 7.022 | 0.986 | / | 7.124 | 0.000 | / | / |
| | Bust | 0.455 | 0.009 | 0.975 | 49.274 | 0.000 | 1.000 | 1.000 |

*Note:* a – dependent variable: Bust.




*a* *b* *c*

Fig. 7. Linear Regression model of body dimension data and pattern dimension data: *a* – histogram of standardized residuals from body bust – pattern bust regression; *b* – normal P-P plot of regression-standardized residuals; *c* – body bust – pattern bust regression standardized predictive scatter plot

Table 10

| LINEAR REGRESSION EQUATION FOR KEY HUMAN BODY MORPHOLOGICAL DIMENSION-FITTING GARMENT BLOCK PATTERN DIMENSION | |
|---|---|
| **Pattern dimension** | **Linear regression equation** |
| Front garment length (FGL) | FGL = 0.345S + 2.504 |
| Back garment length (BGL) | BGL = 0.324S + 8.485 |
| 1/2 front bust (1/2FB) | 1/2FB = 0.455B + 7.022 |
| 1/2 back bust (1/2BB) | 1/2BB = 0.455B + 7.022 |
| 1/2 front waist (1/2FW) | 1/2FW = 0.438W + 9.043 |
| 1/2 back waist (1/2BW) | 1/2BW = 0.438W + 9.043 |
| 1/2 pattern chest width (1/2PCW) | 1/2PCW = 0.361CW + 4.958 = 0.068B + 12.220 |
| 1/2 pattern back width (1/2PBW) | 1/2PBW = 0.518BW – 1.421 = 0.112B + 8.596 |
| 1/2 front hem (1/2FH) | 1/2FH = 0.423W + 11.147 |
| 1/2 back hem (1/2BH) | 1/2BH = 0.423W + 11.147 |
| 1/2 pattern shoulder width (1/2PSW) | 1/2 PSW = 0.408SW + 3.493 |
| Front collar width (FCW) | FCW = 0.244NC – 0.630 = 0.068B + 2.571 |
| Front collar depth (FCD) | FCD = 0.222NC – 0.113 = 0.062B + 2.800 |
| Back collar width (BCW) | BCW = 0.276NC – 1.318 = 0.077B + 2.300 |
| Back collar depth (BCD) | BCD = 0.155NC – 2.341 = 0.043B – 0.307 |
| Front armhole depth (FAD) | FAD = 0.12B + 0.094S – 5.109 |
| Back armhole depth (BAD) | BAD = 0.125B + 0.104S – 6.919 |
| Front shoulder point depth (FSPD) | FSPD = 0.159SW – 2.957 |
| Back shoulder point depth (BSPD) | BSPD = 0.09SW + 1.881 |
| Front waist point depth (FWPD) | FWPD = 0.355S – 16.617 |
| Back waist receipt (BWR) | BWR = 0.098W – 10.403 |
| Back hem receipt (BHR) | BHR = 1.084BWR – 0.019 = 0.106W – 11.296 |
| Back chest receipt (BCR) | BCR = 0.603BWR + 0.002 = 0.059W + 6.293 |
| The front middle extension (FME) | FME = –0.033(B – W) + 2.714 |
| Front waist extension (FWE) | FWE = –0.052(B – W) + 1.444 |
| Front chest extension (FCE) | FCE = 0.652 FWE – 0.085 = – 0.037(B – W) + 0.932 |
| Front hem extension (FHE) | FHE = 1.268 FWE – 1.307 = – 0.066(B – W) + 0.524 |

key human body morphological dimensions is established based on the interconnection between the detailed body dimensions and the key body dimensions.

## RESULT AND DISCUSSION

In this section, we undertake the validation and evaluation of the findings obtained in the study. Employing the model developed in this paper, which predicts the dimensions of the garment block pattern based on key human body morphological dimensions, we construct a suit garment block pattern specifically designed for individuals with a convex belly. Subsequently, both virtual and physical fitting sessions are conducted to try on the fitting-ensured men's suits tailored using the extended model derived from this study. To ensure comprehensive evaluation, experts are invited to assess the fitting effect, while subjective feedback regarding the wearing experience is gathered from the individuals participating in the physical fitting. This comprehensive assessment aims to validate the feasibility and practicality of the study's outcomes.

For the research scope, this study focuses on the Japanese suit (H-type) characterized by a suitable amount of ease and a well-fitted design. Moreover, the specific suit style selected for investigation features flat lapels, a one-button closure, and no slits, as exemplified in figure 8 [34].

The linear regression model established in this study, which correlates key human body morphological dimensions with fitting garment block pattern dimensions, serves as an initial garment block pattern for patterned garments. To validate the feasibility of the study results, the pattern function model is to be reconfigured to accommodate the specific structure of the convex belly men's suit. As an example, the suit's sleeve pattern can be parametrically designed based on the functional relationship derived from the traditional empirical formula, considering the minimal difference between the convex belly body type and the normal body type in the arm region. Additionally, components such as the collar and pocket can also be parametrically designed using the traditional

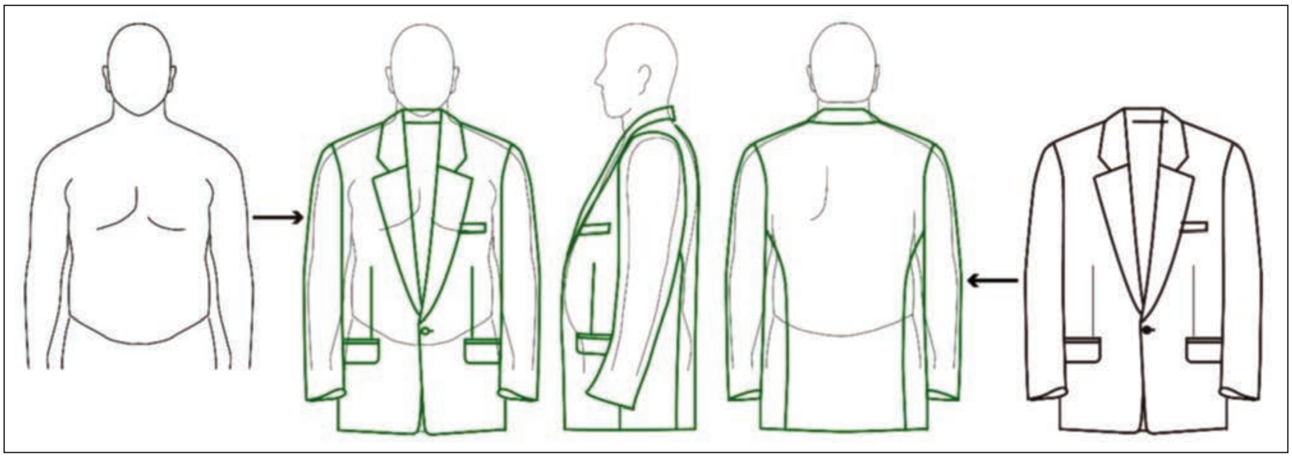


Fig. 8. Dress style diagram of H suit with a convex belly

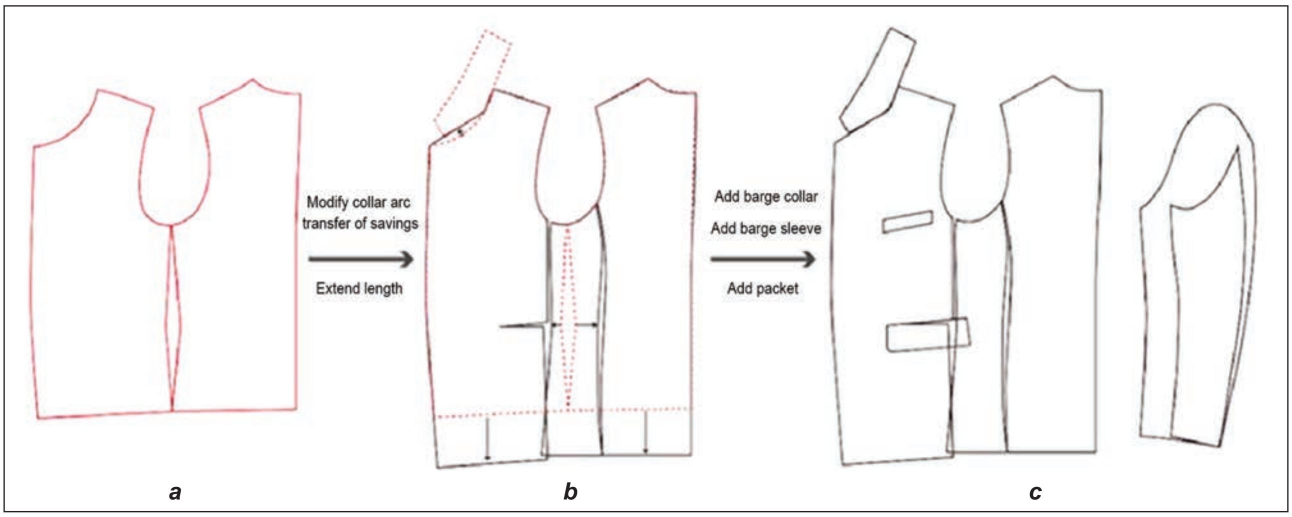



Fig. 9. The flow chart of transforming the fitting-ensured garment block pattern into the fitting-ensured suit pattern: *a* – fitting-ensured garment block pattern for convex belly; *b* – the suit pattern after modifying the front collar arc, transferring the dart, and lengthening the back of the garment; *c* – fitting-ensured suit pattern for convex belly

empirical formula. The outlined process is illustrated in figure 9.

In the virtual fitting evaluation session, a sample of ten subjects with convex belly body types is carefully selected, and their anthropometric measurements are conducted based on the key body dimensions identified in this study. Subsequently, ten virtual mannequins and ten sets of men's suit patterns are established within a virtual environment. These patterns are then tried on using virtual fitting software [16]. Figures 10 and 11 provide a comprehensive visual analysis through a tripartite presentation of Subject 10's virtual fitting process, juxtaposed with the subject's real-life depictions. Specifically, figure 10 elucidates the virtual fitting rendering, offering a perspective view alongside a stress diagram for Subject 10,

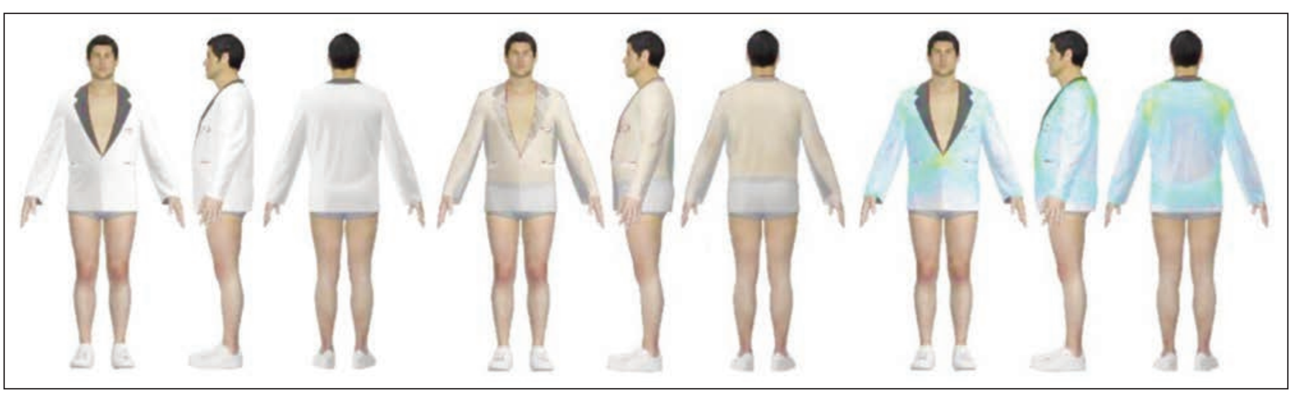


Fig. 10. Three views of the virtual fitting rendering, perspective view and stress diagram for subject 10

Fig. 11. Three views of subject 10 in real life

thereby facilitating a multifaceted understanding of the garment's virtual fit. Conversely, figure 11 presents three distinct real-life views of Subject 10, enabling a direct comparison between the simulated garment fit and its actual physical manifestation. This comparative visual documentation serves to underscore the fidelity and practical applicability of the virtual fitting process. Finally, a panel of 30 experts from the apparel field is invited to evaluate the fitting of the virtual garments.

During the physical fitting evaluation session, two subjects with convex belly body types are purposefully selected, and their five key human body morphological dimensions are accurately measured. Two sets of men's suit patterns are generated based on the findings of this research. The garments are constructed using non-elastic black suit fabric. Finally, a panel of 30 experts from the apparel field is invited to score the visual fit of the garments, while the subjects themselves evaluate the subjective comfort.

The evaluation process employs a five-level Likert scale, as previously mentioned. By combining the virtual fitting evaluation results with the fuzzy comprehensive evaluation method [35], ten sets of rubric affiliation are derived, constituting a judgment matrix.

$$R_1 = \begin{bmatrix} 0 & 0.0333 & 0.1 & 0.4333 & 0.4333 \\ 0 & 0 & 0.0333 & 0.5 & 0.4667 \\ 0 & 0.0333 & 0.1 & 0.6667 & 0.2 \\ 0 & 0 & 0.1667 & 0.5 & 0.3333 \\ 0 & 0 & 0.0333 & 0.6333 & 0.3333 \\ 0 & 0 & 0.1 & 0.5 & 0.4 \\ 0 & 0 & 0.1667 & 0.5 & 0.3333 \\ 0 & 0.0333 & 0.0333 & 0.5667 & 0.3667 \\ 0 & 0 & 0.1333 & 0.4333 & 0.4333 \\ 0 & 0 & 0.0667 & 0.4333 & 0.5 \end{bmatrix}$$

$$R_2 = \begin{bmatrix} 0 & 0.0667 & 0.0667 & 0.0667 & 0.2 \\ 0 & 0 & 0.1333 & 0.5 & 0.3667 \\ 0 & 0.0333 & 0.1 & 0.3667 & 0.5 \\ 0 & 0 & 0.1 & 0.4667 & 0.4333 \\ 0 & 0 & 0.0333 & 0.4 & 0.5667 \\ 0 & 0 & 0.1667 & 0.4 & 0.4333 \\ 0 & 0 & 0 & 0.5667 & 0.4333 \\ 0 & 0 & 0.1 & 0.5333 & 0.3667 \\ 0 & 0.0667 & 0.0667 & 0.4 & 0.4667 \\ 0 & 0.0333 & 0.1667 & 0.3333 & 0.4667 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0 & 0.0333 & 0.0333 & 0.4667 & 0.4667 \\ 0 & 0 & 0.1 & 0.5 & 0.4 \\ 0 & 0 & 0.2 & 0.4333 & 0.3667 \\ 0 & 0 & 0.1 & 0.5333 & 0.3667 \\ 0 & 0 & 0.0333 & 0.5 & 0.4667 \\ 0 & 0 & 0.1333 & 0.5667 & 0.3 \\ 0 & 0 & 0.0667 & 0.4667 & 0.4667 \\ 0 & 0 & 0.0667 & 0.4 & 0.5333 \\ 0 & 0.0333 & 0.1333 & 0.4333 & 0.3667 \\ 0 & 0.1 & 0.2333 & 0.3 & 0.3667 \end{bmatrix}$$

$$R_4 = \begin{bmatrix} 0 & 0.0333 & 0.1 & 0.4333 & 0.4333 \\ 0 & 0 & 0.0667 & 0.4667 & 0.4667 \\ 0.0333 & 0 & 0.0667 & 0.5667 & 0.3333 \\ 0.0333 & 0 & 0.0667 & 0.5333 & 0.3667 \\ 0 & 0 & 0.0667 & 0.4667 & 0.4667 \\ 0 & 0 & 0.0667 & 0.5 & 0.4333 \\ 0 & 0 & 0.0333 & 0.5667 & 0.4 \\ 0 & 0 & 0.0667 & 0.5 & 0.4333 \\ 0 & 0 & 0.1667 & 0.4667 & 0.3667 \\ 0 & 0.1 & 0.1 & 0.5 & 0.3 \end{bmatrix}$$

$$R_5 = \begin{bmatrix} 0 & 0.0333 & 0.0333 & 0.3333 & 0.6 \\ 0 & 0 & 0.1333 & 0.6333 & 0.2333 \\ 0 & 0 & 0.1 & 0.4333 & 0.4666 \\ 0 & 0 & 0 & 0.5333 & 0.4667 \\ 0 & 0 & 0.0333 & 0.5 & 0.4667 \\ 0 & 0 & 0.1 & 0.4333 & 0.4667 \\ 0 & 0 & 0.0667 & 0.4333 & 0.5 \\ 0 & 0 & 0.1667 & 0.4 & 0.4333 \\ 0 & 0 & 0.1667 & 0.4 & 0.4333 \\ 0 & 0.0667 & 0.1333 & 0.4 & 0.4 \end{bmatrix}$$

$$R_6 = \begin{bmatrix} 0 & 0.0333 & 0 & 0.4333 & 0.5333 \\ 0 & 0 & 0.0667 & 0.5 & 0.4333 \\ 0 & 0 & 0.1333 & 0.5333 & 0.3333 \\ 0 & 0.0333 & 0.2 & 0.4 & 0.3667 \\ 0 & 0 & 0.0667 & 0.4 & 0.5333 \\ 0 & 0 & 0.0667 & 0.5 & 0.4333 \\ 0 & 0.0333 & 0.0333 & 0.5333 & 0.4 \\ 0 & 0 & 0.1 & 0.5333 & 0.3667 \\ 0 & 0 & 0.1667 & 0.4 & 0.4333 \\ 0 & 0.0333 & 0.1 & 0.4667 & 0.4 \end{bmatrix}$$

$$R_7 = \begin{bmatrix} 0 & 0.0333 & 0.0667 & 0.4333 & 0.4667 \\ 0 & 0 & 0.1 & 0.5 & 0.4 \\ 0 & 0 & 0.0667 & 0.5 & 0.4333 \\ 0 & 0 & 0.1333 & 0.3667 & 0.5 \\ 0 & 0 & 0 & 0.4333 & 0.5667 \\ 0 & 0 & 0.0667 & 0.4 & 0.5333 \\ 0 & 0 & 0.0333 & 0.5 & 0.4667 \\ 0 & 0 & 0.1333 & 0.3667 & 0.5 \\ 0 & 0 & 0.1 & 0.4667 & 0.4333 \\ 0 & 0.0333 & 0.1 & 0.4333 & 0.4333 \end{bmatrix}$$

$$R_8 = \begin{bmatrix} 0 & 0.0333 & 0.0667 & 0.3333 & 0.5667 \\ 0 & 0 & 0.1333 & 0.5 & 0.3667 \\ 0 & 0 & 0.2667 & 0.4333 & 0.3 \\ 0 & 0 & 0.1 & 0.4667 & 0.4333 \\ 0 & 0 & 0.0667 & 0.3333 & 0.6 \\ 0 & 0 & 0.1 & 0.4 & 0.5 \\ 0 & 0 & 0.0333 & 0.4667 & 0.5 \\ 0 & 0 & 0.1667 & 0.3667 & 0.4667 \\ 0 & 0 & 0.0667 & 0.5667 & 0.3667 \\ 0 & 0.0333 & 0.0667 & 0.5333 & 0.3667 \end{bmatrix}$$

$$R_9 = \begin{bmatrix} 0 & 0.0667 & 0.0667 & 0.4 & 0.4667 \\ 0 & 0 & 0.1667 & 0.5333 & 0.3 \\ 0 & 0 & 0.1333 & 0.5 & 0.3667 \\ 0 & 0 & 0.1 & 0.4333 & 0.4667 \\ 0 & 0 & 0.0667 & 0.5 & 0.4333 \\ 0 & 0 & 0.1667 & 0.4333 & 0.4333 \\ 0 & 0 & 0 & 0.5 & 0.5333 \\ 0 & 0 & 0.0667 & 0.4 & 0.5333 \\ 0 & 0 & 0.2333 & 0.4667 & 0.3 \\ 0 & 0.0333 & 0.1333 & 0.5333 & 0.3 \end{bmatrix}$$

$$R_{10} = \begin{bmatrix} 0 & 0.0333 & 0.0333 & 0.4667 & 0.4667 \\ 0 & 0 & 0.3 & 0.3667 & 0.3333 \\ 0 & 0 & 0.1 & 0.6 & 0.3 \\ 0 & 0 & 0.2 & 0.2667 & 0.5333 \\ 0 & 0 & 0.0667 & 0.3667 & 0.5667 \\ 0 & 0.0333 & 0 & 0.5 & 0.4667 \\ 0 & 0 & 0.0667 & 0.5333 & 0.4 \\ 0 & 0.0333 & 0.1 & 0.4667 & 0.4 \\ 0 & 0.0333 & 0.1667 & 0.6333 & 0.1667 \\ 0 & 0.0667 & 0.2 & 0.4333 & 0.3 \end{bmatrix}$$

In this study, the Delphi method is used to interview five university teachers of fashion design and engineering to determine the weights of 10 apparel evaluation parts. The resulting weight set is *W={Garment length, Bust, Waist, Hip, Shoulder width, Collar width, Back collar fit, Armhole depth, Sleeve fat, Sleeve length}={0.15, 0.15, 0.15, 0.1, 0.1, 0.05, 0.05, 0.1, 0.05, 0.1}*. Thus, the ten sets of integrated affiliation vectors are as follows.

$B_1 = W \times R_1 =$
$= \{0, 0.013320, 0.084995, 0.524995, 0.376660\}$

$B_2 = W \times R_2 =$
$= \{0, 0.021665, 0.096670, 0.471675, 0.410010\}$

$B_3 = W \times R_3 =$
$= \{0.001665, 0.016660, 0.109990, 0.456665, 0.415020\}$

$B_4 = W \times R_4 =$
$= \{0.008325, 0.014995, 0.078355, 0.496675, 0.401665\}$

$B_5 = W \times R_5 =$
$= \{0, 0.011665, 0.089990, 0.4566450, 0.441670\}$

$B_6 = W \times R_6 =$
$= \{0, 0.013320, 0.090005, 0.471655, 0.424985\}$

$B_7 = W \times R_7 =$
$= \{0, 0.008325, 0.081670, 0.443330, 0.466665\}$

$B_8 = W \times R_8 =$
$= \{0, 0.008325, 0.120015, 0.431660, 0.440015\}$

$B_9 = W \times R_9 =$
$= \{0, 0.013335, 0.111675, 0.468325, 0.406670\}$

$B_{10} = W \times R_{10} =$
$= \{0, 0.018325, 0.133335, 0.451680, 0.396670\}$

The formula gives the final evaluation score of $Y_1 = 4.2649$, $Y_2 = 4.2701$, $Y_3 = 4.2667$, $Y_4 = 4.2684$, $Y_5 = 4.3282$, $Y_6 = 4.3082$, $Y_7 = 4.3683$, $Y_8 = 4.3034$, $Y_9 = 4.2683$ and $Y_{10} = 4.2267$. It can be seen that the virtual fitting results of the ten groups of virtual mannequins are between relatively fit and very fit, which indicates that the mathematical model proposed in this study has some rationality.

From the physical fitting evaluation results and fuzzy comprehensive evaluation method, we can obtain the following two groups of rubric affiliation consisting of a judgment matrix.

$$R_{11} = \begin{bmatrix} 0 & 0 & 0 & 0.3667 & 0.6333 \\ 0 & 0 & 0.0667 & 0.5000 & 0.4333 \\ 0 & 0 & 0.0667 & 0.4333 & 0.5000 \\ 0 & 0 & 0.0667 & 0.4000 & 0.5333 \\ 0 & 0 & 0.1667 & 0.5000 & 0.3333 \\ 0 & 0 & 0.0667 & 0.4333 & 0.5000 \\ 0 & 0 & 0 & 0.4667 & 0.5333 \\ 0 & 0 & 0.1667 & 0.5667 & 0.2667 \\ 0 & 0 & 0 & 0.6000 & 0.4000 \\ 0 & 0 & 0.0333 & 0.4000 & 0.5667 \end{bmatrix}$$

$$R_{12} = \begin{bmatrix} 0 & 0 & 0 & 0.7000 & 0.3000 \\ 0 & 0 & 0.1000 & 0.4667 & 0.4333 \\ 0 & 0 & 0.1000 & 0.5667 & 0.3333 \\ 0 & 0 & 0.0667 & 0.3667 & 0.5667 \\ 0 & 0 & 0.1333 & 0.5000 & 0.3667 \\ 0 & 0 & 0.0667 & 0.5000 & 0.4333 \\ 0 & 0 & 0.0333 & 0.3000 & 0.6667 \\ 0 & 0 & 0.1000 & 0.5667 & 0.3333 \\ 0 & 0 & 0.0667 & 0.7333 & 0.2000 \\ 0 & 0 & 0 & 0.5667 & 0.4333 \end{bmatrix}$$

Based on the weight set: *W={Garment length, Bust, Waist, Hip, Shoulder width, Collar width, Back collar fit, Armhole depth, Sleeve fat, Sleeve length}={0.15, 0.15, 0.15, 0.1, 0.1, 0.05, 0.05, 0.1, 0.05, 0.1}* determined by the Delphi method in the virtual fitting evaluation experiment, the affiliation vector for the visual evaluation of the fit of the real person fitting is calculated as follows.

$B_{11} = W \times R_{11} = \{0, 0, 0.066667, 0.456667, 0.476667\}$

$B_{12} = W \times R_{12} = \{0, 0, 0.068333, 0.536667, 0.395000\}$

The final evaluation scores are: $Y_{11} = 4.4100$; $Y_{12} = 4.3267$.

The results of the subjective comfort evaluation conducted with the subjects are presented in figure 12, *a* and *b*. The average scores for the subjective comfort

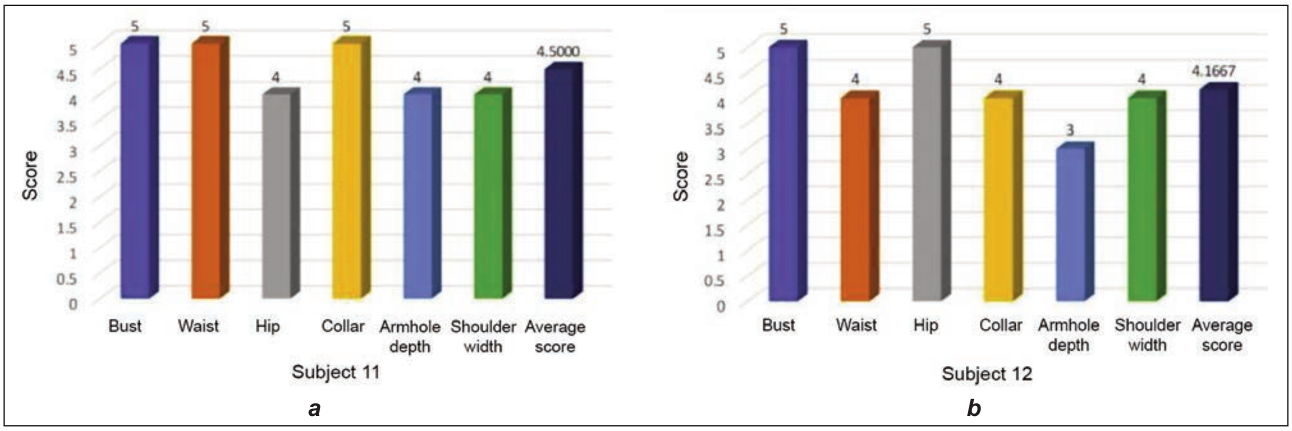



Fig. 12. The results of the subjective comfort evaluation conducted with the subjects: *a* – convex belly fitting-ensured suit subjective comfort evaluation experiment subject 11 evaluation results; *b* – convex belly fitting-ensured suit subjective comfort evaluation experiment subject 12 evaluation results

evaluation of the two types of suits are 4.5 and 4.1667, respectively. These scores, both exceeding 4, signify a high level of comfort. The comprehensive evaluation outcomes outlined above collectively demonstrate that the mathematical model developed in this study possesses a degree of rationality and practicality.

## CONCLUSIONS

This study presents a novel prediction model for developing fitting-ensured garment block patterns tailored to individuals with convex bellies (PWCB). The research begins by creating digitalized 3D human body models using CLO 3D software and analyzing them to extract crucial human body morphological dimensions and fitting-ensured garment block pattern dimensions. Subsequently, a linear regression model is employed to establish the mapping relationship between the identified human body morphological dimensions and the corresponding fitting-ensured garment block pattern dimensions. To evaluate the effectiveness of the model, a fuzzy comprehensive evaluation method is conducted, involving both virtual fitting and physical fitting to assess its accuracy and efficiency in clothing design. Throughout the entire modeling process, emphasis is placed on incorporating the unique characteristics of individuals with convex bellies (PWCB) and establishing the relationship between the human body and garment block patterns as fundamental guiding principles.

The current study is confined to the identification of a well-fitted men's suit for individuals with a protruding abdomen without establishing a comprehensive framework for generating suit samples that vary in fit, collar style, and lapel design. Future research endeavors will aim to systematically categorize and organize the drafting rules for suit samples that differ in terms of fit, collar types, and lapels. These rules will be meticulously compiled and integrated into an automated sample generation system. This enhancement will empower customers with the autonomy to select and combine different suit elements, thereby enabling the system to offer a more diverse array of suit sample designs to meet individual preferences and requirements [36].

## ACKNOWLEDGEMENTS

This research was funded by the National Natural Science Foundation of China (Grant Number: 61906129), the China Association for Science and Technology Youth Support Talent Project (Grant Number: 2021-298), and the Hong Kong Polytechnic University GBA Startup Postdoc Programme 2022 (Grant Number: SP-22-13).

## REFERENCES

[1] Acar, E., Ofluoğlu, P., Kanat, S., Ünal, Z.B., Atilgan, T., *Analyzing buying behavior of plus-size clothing consumers in e-commerce*, In: Industria Textila, 2017, 68, 5, 396–404, https://doi.org/10.35530/IT.068.05.1393

[2] Schneider R., *The Typical Irregularity of Virtual Convex Bodies,* In: Journal of Convex Analysis, 2018, 25, 1, 103–118

[3] Hong, Y., Zeng, X., Bruniaux, P., *Interactive virtual try-on based three-dimensional garment block design for disabled people of scoliosis type,* In: Textile Research Journal, 2017, 87, 10, 1261–1274

[4] Hong, Y., Bruniaux, P., Zeng, X., Liu, K., Curteza, A., Chen, Y., *Visual-simulation-based personalized garment block design method for physically disabled people with scoliosis (PDPS),* In: Autex Research Journal, 2018, 18, 1, 35–45

[5] Avadanei, M., Curteza, A., Dulgheriu, I., Ionesi, S.D., Viziteu, D., Loghin, E.C., *A digital-integrated solution for a customised 3D design process of garments*, In: Industria Textila, 2022, 73, 3, 333–338, http://doi.org/10.35530/IT.073.03.202171

[6] Cupar, A., Rudolf, A., *Construction of adapted garments for people with scoliosis using virtual prototyping and CASP method*, In: Industria Textila, 2016, 67, 141–149

[7] Olaru, S., Filipescu, E., Niculescu, C., Filipescu, E., *Morphological assessment of human body for clothing patterns design*, In: Industria Textila, 2013, 64, 5, 254–259
[8] Au, C.K., Ma, Y.S., *Garment pattern definition, development and application with associative feature approach*, In: Computers in Industry, 2010, 61, 6, 524–531
[9] Zhu, C., Liu, K., Wang, R., Wang, J., Bruniaux, P., Zeng, X., *The mathematical model of men's garment prototype*, In: International Journal of Clothing Science and Technology, 2022, 34, 6, 892–904
[10] Liu, K., Zhu, C., Tao, X., Bruniaux, P., Zeng, X., *Parametric design of garment pattern based on body dimensions,* In: International Journal of Industrial Ergonomics, 2019, 72, 212–221
[11] Abtew, M., Bruniaux, P., François, B., Loghin, C., Cristian, I., Chen, Y., *Development of comfortable and well-fitted bra pattern for customized female soft body armor through 3D design process of adaptive bust on virtual mannequin*, In: Computers in Industry, 2018,100, 7–20
[12] Wang, Z., Wang, J., Xing, Y.M., Yang, Y., Liu, K., *Estimating human body dimensions using RBF artificial neural networks technology and its application in activewear pattern making*, In: Applied Sciences, 2019, 9, 6, 1140
[13] Kolose, S., Stewart, T., Hume, P., Tomkinson, G.R., *Prediction of military combat clothing size using decision trees and 3D body scan data*, In: Applied Ergonomics, 2021, 95, 103435
[14] Jin, S.N., Gu, B.F., Zhang, B.B., Xia, Y.P., He, H.Z., *Pants design and pattern generation based on body images*, In: Industria Textila, 2023, 74, 1, 74–80, http://doi.org/10.35530/IT.074.01.20223
[15] Hong, Y., Bruniaux, P., Zeng, X., Curteza, A., Liu, K., *Design and evaluation of personalized garment block for atypical morphology using the knowledge-supported virtual simulation method*, In: Textile Research Journal, 2018, 88, 15, 1721–1734
[16] Liu, H., Jiang, G., Dong, Z., Xia, F., Cong, H., *The size prediction and auto-generation of garment template*, In: International Journal of Clothing Science and Technology, 2021, 33, 1, 74–92
[17] Wang, Z., Wang, J., Zeng, X., Tao, X., Xing, Y., Bruniaux, P., *Construction of Garment Pattern Design Knowledge Base Using Sensory Analysis, Ontology and Support Vector Regression Modeling*, In: Int. J. Comput. Intell. Syst., 2021, 14, 1, 1687–1699
[18] Wang, X., Xue, Y., Zhang, J., Hong, Y., Guo, S., Zeng, X., *A Sustainable Supply Chain Design for Personalized Customization in Industry 5.0 Era*, In: IEEE Transactions on Industrial Informatics, 2024
[19] Li, Y., Jiang, L., Li, X., Feng, W., *Non-contact clothing anthropometry based on two-dimensional image contour detection and feature point recognition*, In: Industria Textila, 2023, 74, 1, 67–73, http://doi.org/10.35530/IT.074.01.202279
[20] Popescu, G., Olaru, S., Niculescu, C., *Innovative technologies for the design and simulation of children's clothing products using anthropometric data obtained by 3D standardized scanning*, In: Industria Textila, 2017, 68, 2, 95-102, http://doi.org/10.35530/IT.068.02.1356
[21] Wang, J., Lu, G., Chen, L., Geng, Y., Deng, W., *Customer participating 3D garment design for mass personalization*, In: Textile Research Journal, 2011, 81, 2, 187–204
[22] Chen, J.Z., Guo, Z.Y., Li, T., Du, L., Zou, F.Y., *An undamaged pattern generation method from 3D scanned garment sample based on finite element approach*, In: Industria Textila, 2023, 74, 1, 35–41, http://doi.org/10.35530/IT.074.01.202185
[23] Irovan, M., Indrie, L., Frunze, V., Florea-Burduja, E. and Raru, A., *Digital methods in the development of adaptive clothing for people with disabilities*, In: Industria Textila, 2023, 74, 1, 28–34, http://doi.org/10.35530/IT.074.01.202295
[24] Li, J., Ye, J., Wang, Y., Bai, L., Lu, G., *Fitting 3D garment models onto individual human models*, In: Computers & graphics, 34, 6, 742–755
[25] Dai, X., Hong, Y., *Fabric mechanical parameters for 3D cloth simulation in apparel CAD: A systematic review*, In: Computer-Aided Design, 2023, 103638
[26] Huang, S., Huang, L., *CLO3D-Based 3D Virtual Fitting Technology of Down Jacket and Simulation Research on Dynamic Effect of Cloth*, In: Wireless Communications and Mobile Computing, 2022
[27] Ying, X., Liu, Z., Chen, G., Zou, F., *The impact of body surface convex angle on dressed waist ease*, In: International Journal of Clothing Science and Technology, 2020, 32, 4, 571-587
[28] Ancutiene, K., *Comparative analysis of real and virtual garment fit*, In: Industria Textila, 2014, 65, 3, 158–165
[29] Zhang, D., Liu, Y., Wang, J., Li, J., *An integrated method of 3D garment design*, In: The Journal of the Textile Institute, 2018, 109, 12, 1595–1605
[30] Volino, P., Cordier, F., Magnenat-Thalmann, N., *From early virtual garment simulation to interactive fashion design*, In: Computer-aided design, 2005, 37, 6, 593–608
[31] Hong, Y., Bruniaux, P., Zhang, J., Liu, K., Dong, M., Chen, Y., *Application of 3D-TO-2D garment design for atypical morphology: a design case for physically disabled people with scoliosis*, In: Industria Textila, 2018, 69, 1, 59–64, http://doi.org/10.35530/IT.069.01.1377
[32] Dianat, I., Molenbroek, J., Castellucci, H.I., *A review of the methodology and applications of anthropometry in ergonomics and product design*, In: Ergonomics, 2018, 61, 12, 1696–720
[33] Wang, C.C., Wang, Y., Yuen, M.M., *Feature based 3D garment design through 2D sketches*, In: Computer-aided Design, 2003, 35, 7, 659–672

[34] Zhou, X., Xu, Y., Chen, T., *Research on optimization design of men's suit considering users' perception*, In: International Journal of Clothing Science and Technology, 2022, 34, 3, 379–390

[35] Lin, Y.L., Wang, M.J.J., *The development of a clothing fit evaluation system under virtual environment*, In: Multimedia Tools and Applications, 2016, 75, 7575–7587

[36] Wei, L., Wang, X., Wang, T., Duan, Z., Hong, Y., He, X., Huang, H., *Recommendation systems for the metaverse*, In: Blockchains, 2023, 1, 19–33

**Authors:**

MENGSHU DING[1], TIANYU LUO[2], YAN HONG[1,2,3]

[1]School of Fashion, Henan University of Engineering, Zhengzhou, Henan, 451191, China

[2]College of Textile and Clothing Engineering, Soochow University, Suzhou 215021, China

[3]Department of Computing, The Hong Kong Polytechnic University, Hong Kong, China

**Corresponding author:**

YAN HONG
e-mail: hongyan@suda.edu.cn