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Morphological Classification of Female Abdominal-Hip and Crotch Regions for Menstrual Pants Design

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Abstract

Existing menstrual pants often suffer from poor fit, which can cause side leakage. While research on female lower-body is crucial for structural design, studies on abdominal and crotch morphology remain insufficient. This study therefore aims to analyze and classify the morphology of women's abdominal-hip and crotch regions. Anthropometric data were collected from 143 female subjects aged 18-50 years wearing size L menstrual pants. Factor analysis identified four key factors: circumference, crotch length, width, and crotch depth. Cluster analysis classified abdominal-hip morphologies into three types (flat abdomen-flat hip, thick abdomen-flat hip, slender abdomen-prominent hip) based on abdominal-hip difference and hip protrusion degree; and crotch morphologies into three types (H-shaped medium crotch, A-shaped short crotch, V-shaped long crotch) based on the crotch width-length index. The bottom crotch points were categorized into anterior type (51.75%) and posterior type (48.25%). These findings provide an anthropometric basis for the structural design of differentiated menstrual pants.

Keywords: Menstrual Pants; Crotch Width; Anthropometry; Body Shape Classification; Structural Research

1 Introduction

With the rapid development of the women's health industry, menstrual pants, as a new type of hygiene product, show explosive growth in market size [1]. A typical menstrual pant consists of a waist, abdomen, and hip area, and a crotch area. The waist-abdomen-hip area is mainly composed of elastic panel, mostly made of non-woven fabric. Elastic bands are set around the waist edge to fit the body. The crotch area consists of a liquid-permeable topsheet, a distribution layer for rapid liquid diffusion, an absorbent core, a leak-proof barrier layer, and barrier cuffs.

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Its main functions are to absorb menstrual blood, reduce leakage, and provide a comfortable, well-fitting wearing experience [2].

However, surveys find that over 80% of women experience side leakage during menstruation, with the proportion of lateral-posterior leakage reaching 87.14%. Furthermore, nearly half of such leakage results from insufficient fit between the crotch structure of menstrual pants and the human body [3-6]. The current national standard for menstrual pants is primarily based on hip circumference and uses the maximum waist circumference as a sizing reference. Meanwhile, most brands in the market provide weight recommendations in addition to the hip circumference sizes specified in the national standard, as a reference for purchasing. Taking size L as an example: the national standard specifies a hip circumference of 85-105 cm and a maximum waist circumference of 105 cm, while market guidelines suggest a weight range of 45-70 kg. As these sizing systems are primarily based on hip measurements rather than crotch measurements, they may contribute to inadequate fit in the crotch area of menstrual pants. Additionally, surveys reveal that menstrual pants also have issues with poor fit around the abdomen and hips. Against this backdrop, research focuses on the morphology of women's abdominal-hip and crotch regions. Hualei Chen collects data on the hip-crotch region from 98 women aged 20-28 years. Through analysis, she selects the hip protrusion angle as the clustering index and classifies the hip-crotch morphology of women during menstruation into 3 types [7]. Xia Yan randomly selects 200 female college students, extracts hip data using a 3D scanner, and obtains 4 types of gluteal region curves through clustering [8]. Kaixuan Liu et al. select 116 young women aged 20-30 years, extract 14 lower-limb anthropometric dimensions using 3D scanning, and classify lower-body morphologies into 3 categories based on the hip-waist difference [9]. Wu W selected 179 young women, obtained 85 lower body anthropometric data, chose the abdomen-hip differential of the second principal component as a key indicator, and classified the lower body into 9 types [10]. While the above studies explore the characteristics of women's lower-body shapes, current research primarily focuses on hip morphology and waist-hip differences, with insufficient attention to abdominal morphology. Only a limited number of studies have addressed abdominal morphology. For instance, Yijia Yan selected 165 Chinese women aged 50-59 years, obtained 23 characteristic parameters of abdominal convexity via 3D scanning, screened 133 samples with abdominal convexity, summarized five main morphological parameters, and classified abdominal morphology into four types [11]. Although this study provides an important reference for classifying abdominal morphology, its subjects were middle-aged and elderly women, whose age range differs from that of the main consumer group for menstrual pants. Thus, research on abdominal morphology among users of menstrual pants remains insufficient.

Furthermore, because the thighs and hips obstruct the crotch curve, existing menstrual pants are mostly modified versions of ordinary underwear. They focus on local adjustments such as lengthening the crotch panel and optimizing crotch width. But they lack research based on the morphological characteristics of the human crotch [12-17]. Moreover, menstrual pants, unlike regular underwear, must be able to absorb menstrual blood. Therefore, it is necessary to clarify the crotch morphology and the position of the vaginal opening. Based on this, this study uses custom measurement items for crotch length and width. This study combines a Martin measuring instrument and 3D scanning technology, with SPSS analysis software. It systematically analyzes and classifies the morphological characteristics of women's abdominal-hip and crotch regions. The goal is to provide a reference for the fit design of menstrual pants.

2 Methods

2.1 Experimental Subjects and Data Collection Methods

Before the experiment, it was necessary to determine the minimum sample size, which was set by the allowable error for this study. The formula for calculating the sample size is:

$$N = (U_{1-\alpha/2})^2 \times (\sigma/\Delta)^2 \tag{1}$$

In the formula, N represents the sample size; U represents the $\alpha/2$ quantile point of the standard normal distribution; σ represents the standard deviation; Δ represents the allowable error.

In industrial production and scientific research, the significance level is typically set at $\alpha = 0.05$ (95% confidence level), hence U = 1.96. This study focuses on the morphology of the abdominal-hip and crotch regions. According to the standard deviations and maximum allowable errors for relevant anthropometric dimensions stipulated in the national clothing size standards, the allowable error for hip circumference is 1.5 cm and the population standard deviation is 5.2 cm. Substituting these parameters into the formula yielded a minimum sample size of 46.

The experiment selected 143 females aged 18-50 years who fit into size L menstrual pants and collected body data via manual measurements and 3D scanning. A Martin measuring instrument was used to measure key circumferences and lengths. A 3DeVOK MT handheld 3D scanner acquired lower-body point cloud data to generate 3D models. For this study, the 'lower-body' is defined as the area from the waistline to above the knees, which corresponds to the coverage area of menstrual pants.

2.2 Measurement Specifications

According to standard human body measurement environmental requirements [18], the laboratory maintained relative humidity at (60±10)% and temperature at (24±2) °C. Subjects wore shorts, light-colored tight tops, no underwear, pants, and had their hair tied up. Related studies have demonstrated that 3D automatic and manual measurements significantly affect measurement data. Therefore, during 3D scanning, the scanning posture should be standardized according to research needs [19]. During Martin's measurements, subjects stood with feet together, arms hung naturally at their sides, palms faced inward. For 3D scanning, they stood with feet 600 mm apart, toes pointed straight forward, and arms held flat against the chest. The torso remained straight, and the head stayed level.

2.3 Measurement Projects

The study examined the morphological characteristics of the human crotch and reviewed and summarized relevant literature in this area. It identified 18 anthropometric items based on measurement standards, including GB/T 5703-2023 Basic Items for Human Body Measurement in Technical Design and GB/T 16160-2017 Dimensions and Methods for Human Body Measurement in Clothing [20-21]. These items mainly included: Height (Ht), Waist Circumference (WC), Umbilical Circumference (UmbC), Abdominal Circumference (AC), Hip Circumference (HC), Right Thigh Inclined Circumference (R. ThighIC), Right Thigh Root Circumference (R. ThighRC), Right Umbilical to Thigh Root Length (R. UTL), Anterior Mid-Length (AML), Base Crotch Length 1 (BCL1), Base Crotch Length 2 (BCL2), Front crotch length (FCrL), Posterior Crotch Length (PCrL), Perineal Crotch Length (PCL), Posterior Mid-Length 2 (PML2), Posterior Mid-Length 1 (PML1), Front Crotch Width (FCW), Hip Protrusion Spacing (HPS) ect. Hip protrusion spacing refers to the distance between the bilateral hip protrusion points. Specific positions of some items are shown in Fig. 1 [22]. The definitions of partial measurement items are shown in Table 1; items marked "Right" refer to measurements taken on the right side of the body.

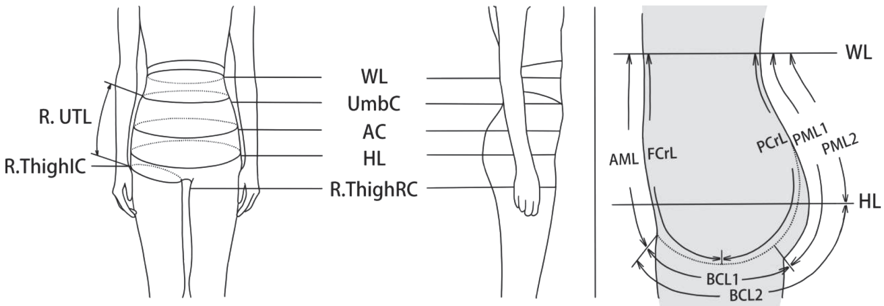

Fig. 1: Partial measurement items

Table 1: Definitions of some measurement items

Project	Definition
Umbilical Circumference (UmbC)	Horizontal circumference measured at the level of the umbilicus
Right Thigh Inclined Circumference (R. ThighIC)	Oblique circumference measured along the inguinal crease around the thigh root
Right Thigh Root Circumference (R. ThighRC)	Horizontal circumference at the thigh root
Right Umbilical to Thigh Root Length (R. UTL)	Curvilinear length from the lateral umbilical point to the lateral thigh root point along the body surface
Anterior Mid-Length (AML)	Curvilinear length on the anterior midline from the waistline to the pubic symphysis point
Base Crotch Length 1 (BCL1)	Curvilinear length from the pubic symphysis point to the anal point.
Base Crotch Length 2 (BCL2)	Curvilinear length on the body midline from the pubic symphysis point to the posterior hip point
Front Crotch Length (FCrL)	Curvilinear length on the anterior midline from the waistline to the bottom crotch point
Posterior Crotch Length (PCrL)	Curvilinear length on the posterior midline from the bottom crotch point to the waistline
Perineal Crotch Length (PCL)	Curvilinear length on the body midline from the anterior waist point, through the bottom crotch point, to the posterior waist point
Posterior Mid-Length 2 (PML2)	Curvilinear length on the posterior midline from the waistline to the hip point
Posterior Mid-Length 1 (PML1)	Curvilinear length on the posterior midline from the waistline to the anal point
Front Crotch Width (FCW)	Linear distance between the intersections of the horizontal line at the pubic symphysis point with the inguinal creases
Hip Protrusion Spacing (HPS)	Horizontal linear distance between the bilateral hip protrusion points

3 Results

3.1 Data Preprocessing

When using a Martin measuring instrument or a 3D scanner for data collection, errors may occur during measurement, data entry, and data extraction. Therefore, the original data must be preprocessed after data collection and before analysis to ensure data quality.

Firstly, outlier testing was performed. The study employed box plots to examine the 18 basic dimension data. According to the box plot method, values that exceed 1.5 times the interquartile range (IQR) are classified as outliers, and those greater than 3 times the IQR are categorized as extreme outliers. The test results indicated that all data points were within reasonable intervals, and no extreme values requiring elimination were found. The step effectively identified and excluded outliers arising from measurement or recording errors, providing a clean and reliable data set for subsequent analysis.

Secondly, normality tests were conducted (Table 2). The normality test can typically be performed using the non-parametric K-S (Kolmogorov-Smirnov) test (applicable when the sample size is greater than 50) or the S-W (Shapiro-Wilk) test (applicable when the sample size is less than 50). Given that the sample size of this study was relatively large (n = 143), the K-S test

Table 2: K-S normality test

Project	statistics	df	Sig.
Height (Ht)	.044	143	.200
Waist Circumference (WC)	.064	143	.200
Umbilical Circumference (UmbC)	.074	143	.055
Abdominal Circumference (AC)	.068	143	.200
Hip Circumference (HC)	.058	143	.200
Right Thigh Inclined Circumference (R. ThighIC)	.045	143	.200
Right Thigh Root Circumference (R. ThighRC)	.063	143	.200
Right Umbilical to Thigh Root Length (R. UTL)	.072	143	.068
Anterior Mid-Length (AML)	.047	143	.200
Base Crotch Length 1 (BCL1)	.073	143	.058
Base Crotch Length 2 (BCL2)	.064	143	.200
Front Crotch Length (FCrL)	.055	143	.200
Posterior Crotch Length (PCrL)	.052	143	.200
Perineal Crotch Length (PCL)	.043	143	.200
Posterior Mid-Length 2 (PML2)	.049	143	.200
Posterior Mid-Length 1 (PML1)	.057	143	.200
Front Crotch Width (FCW)	.043	143	.200
Hip Protrusion Spacing (HPS)	.080	143	.026
Logarithmic Conversion of Hip Protrusion Spacing	.061	143	.200

in SPSS ($\alpha = 0.05$) was used to assess normality. For any data found to be non-normally distributed, a logarithmic transformation could be performed, followed by retesting.The test results showed that the original Hip Protrusion Spacing (HPS) data yielded a p-value of 0.026 ($p < 0.05$). After logarithmic transformation, its p-value increased to 0.200 ($p > 0.05$). Thus, after necessary data transformation, the normality of all sample data was ensured, meeting the prerequisite for subsequent correlation analysis and factor analysis.

3.2 Descriptive Analysis

The study analyzed the data using SPSS statistical software. Table 2 presents descriptive statistics including mean, range, standard deviation, skewness, kurtosis, and coefficient of variation. The formula used for calculating the coefficient of variation is:

$$CV = \sigma/\mu \tag{2}$$

In the formula, CV represents the coefficient of variation; σ represents the standard deviation; μ represents the mean.

The results of descriptive analysis is shown in Table 3. The results revealed that the standard deviation of the circumference measurements was generally large (4.0-6.7 cm). Notably, the standard deviations for Umbilical Circumference (UmbC), Waist Circumference (WC), and

Table 3: Descriptive analysis

	Mean [cm]	Max [cm]	Min [cm]	Range [cm]	SD [cm]	CV	Skew	Kurt
Ht	165.4	179.4	151.0	28.4	5.4	3.26%	0.0	−0.3
WC	68.3	85.7	56.9	28.8	5.6	8.24%	0.5	0.0
UmbC	75.0	91.8	59.8	32	6.7	8.98%	0.4	−0.4
AC	85.6	98.8	73.2	25.6	5.2	6.07%	0.2	−0.3
HC	92.8	104.7	85.2	19.5	4.5	4.81%	0.3	−0.6
R. ThighIC	62.6	73.0	53.0	20	4.0	6.41%	0.2	−0.3
R. ThighRC	54.7	66.8	47.0	19.8	4.0	7.24%	0.5	0.0
R. UTL	11.9	17.2	6.7	10.5	2.1	17.45%	0.4	0.1
AML	19.3	25.0	15.0	10	1.6	8.50%	0.1	0.8
BCL1	15.7	23.6	7.4	16.2	2.7	17.31%	0.2	0.7
BCL2	26.6	35.4	20.3	15.1	2.4	9.13%	0.5	0.9
FCrL	28.4	33.6	21.1	12.5	2.2	7.91%	−0.2	0.4
PCrL	33.0	42.7	27.0	15.7	2.8	8.39%	0.6	1.0
PCL	61.4	69.9	54.2	14.7	3.1	5.07%	0.2	−0.1
PML2	15.5	19.1	11.5	7.6	1.6	10.47%	−0.1	−0.3
PML1	26.4	34.0	20.7	13.3	2.3	8.56%	0.2	0.2
FCW	11.1	15.2	6.5	8.7	1.8	16.34%	−0.1	−0.2
HPS	11.9	17.0	9.0	8	1.5	12.32%	0.4	−0.2

Abdominal Circumference (AC) exceeded 5 cm, and their ranges surpassed 25 cm. Among all items, Umbilical Circumference (UmbC) showed the greatest standard deviation and range, with values of 6.7 cm and 32.0 cm, respectively. The average CV for all circumference measurements was 6.95%, indicating considerable individual differences. Waist Circumference (WC), Umbilical Circumference (UmbC), and Right Thigh Root Circumference (R. ThighRC) had particularly high CVs of 8.24%, 8.98%, and 7.24%, respectively.

In contrast, the standard deviations for longitudinal measurements were generally small, revealing a relatively low absolute degree of dispersion. However, their CVs for relative dispersion showed exceptionally high values in several cases. Right Umbilical to Thigh Root Length (R. UTL), Base Crotch Length 1 (BCL1) and Front Crotch Width (FCW) had the highest CVs of 17.45%, 17.31%, and 16.34%, respectively, all significantly exceeding the CVs of other measurements. It indicates that in key areas such as the crotch and thigh root, there is considerable inter-individual variation in morphology. These are the main areas that cause fit issues under a uniform size. The CVs for Hip Protrusion Spacing (HPS), Posterior Mid-Length 1 (PML1), and Base Crotch Length 2 (BCL2) were also high, at 12.32%, 10.47%, and 9.13%, respectively. Furthermore, the difference between the maximum height (179.4 cm) and the minimum (165.4 cm) was 28.4 cm, illustrating the considerable variation in stature within this size category.

The distribution shapes of most variables showed skewness and kurtosis coefficients approaching zero, indicating that the data largely conformed to a normal distribution. This confirmed the results of the normality tests in Section 3.1. Most dimensions exhibited positive skewness. The top three kurtosis coefficients occurred in Base Crotch Length 2 (BCL2), Anterior Mid-Length (AML), and Base Crotch Length 1 (BCL1). Kurtosis coefficients tended to be negative for circumferences but positive for lengths, highlighting a contrast in distribution patterns.

3.3 Correlation Analysis

Correlation analysis examines the interdependence between variables. The correlation coefficient r quantifies this relationship. Given that the data met the normality assumption, Pearson correlation analysis was employed (Table 4). The results revealed strong mutual correlations among the three core trunk circumferences, namely Waist Circumference (WC), Umbilical Circumference (UmbC), and Abdominal Circumference (AC).Furthermore, Hip Circumference (HC) was not only highly correlated with Abdominal Circumference (AC), but also showed moderate correlations with Waist Circumference (WC), Umbilical Circumference (UmbC), and the thigh dimensions (Right Thigh Inclined Circumference, R. ThighIC; Right Thigh Root Circumference, R. ThighRC). This suggested that there was a co-variation trend between the hip circumference and both the abdominal-waist circumferences and the thigh circumferences. In contrast, It revealed low correlations between Height, Right Umbilical to Thigh Root Length (R. UTL), Anterior Mid-Length (AML)1, Front Crotch Width (FCW), Hip Protrusion Spacing (HPS), and other variables in the overall correlation matrix.

3.4 Factor Analysis

Factor analysis aims to reduce data dimensionality by identifying a few common factors that explain most of the information in the original variables, thereby establishing the core dimensions for body type classification. Before factor analysis, the suitability of the 18 anthropometric

Table 4: Pearson correlation coefficient between some variables

		WC	UmbC	AC	HC	R. ThighIC	R. ThighRC
WC	r	1	0.905	0.821	0.752	0.650	0.665
	Sig.		0.000	0.000	0.000	0.000	0.000
UmbC	r	0.905	1	0.853	0.713	0.628	0.639
	Sig.	0.000		0.000	0.000	0.000	0.000
AC	r	0.821	0.853	1	0.826	0.691	0.666
	Sig.	0.000	0.000		0.000	0.000	0.000
HC	r	0.752	0.713	0.826	1	0.764	0.788
	Sig.	0.000	0.000	0.000		0.000	0.000
R. ThighIC	r	0.650	0.628	0.691	0.764	1	0.646
	Sig.	0.000	0.000	0.000	0.000		0.000
R. ThighRC	r	0.665	0.639	0.666	0.788	0.646	1
	Sig.	0.000	0.000	0.000	0.000	0.000	

variables was assessed using the KMO (Kaiser-Meyer-Olkin) and Bartlett's tests. As presented in Table 5, the KMO measure was 0.795 (exceeding 0.5), and Bartlett's test was significant (*p* < .005), indicating strong inter-variable correlations. These results confirmed that the data were suitable for factor analysis.

Table 5: KMO and Bartlett inspection

KMO Sampling Suitability Scale		.795
Bartlett sphericity test	approximate chi-square	1500.60
	Degree of Freedom	78
	Significance	.000

Principal component factor analysis was conducted on the 18 variables. As shown in Table 6, the first four factors had eigenvalues greater than 1, and their cumulative variance explained accounted for 71.416%, indicating that these factors captured most of the information from the original variables.

Varimax rotation was applied to obtain a rotated factor matrix with a simpler structure (Table 7). The study named components based on variable commonalities within each. The rotated component matrix showed:

Component 1 had high loadings on circumferential measurements (Umbilical, waist, abdominal, hip, right thigh root oblique/circumference, base crotch length 2) and was named the circumference factor. Component 2 loaded strongly on crotch length variables (perineal crotch length, posterior mid-length 2, posterior mid-length 1, posterior crotch length) and was named the crotch length factor. Component 3 had high loadings on crotch-width metrics (front crotch width, hip protrusion spacing) and was named the crotch-width factor. Component 4 loaded significantly on the front mid-length lower point to crotch length and was named the crotch depth factor. Among them front mid-length lower point to crotch length refers to the curvilinear length from the pubic

Table 6: Total Variance Explained

components	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	Percentage of Variance (%)	Cumulative Percentage (%)	Total	Percentage of Variance (%)	Cumulative Percentage (%)
1	4.382	31.299	31.299	3.765	26.896	26.896
2	3.327	23.764	55.063	3.520	25.143	52.039
3	1.205	8.605	63.668	1.578	11.268	63.307
4	1.085	7.748	71.416	1.135	8.109	71.416

Table 7: Rotated Component Matrix

	components			
	1	2	3	4
Umbilical Circumference (UmbC)	0.928	−0.159	0.092	−0.045
Waist Circumference (WC)	0.919	0.011	0.061	−0.039
Abdominal Circumference (AC)	0.916	0.024	0.035	−0.045
Hip Circumference (HC)	0.864	0.311	−0.051	−0.014
Right Thigh Inclined Circumference (R. ThighIC)	0.783	0.253	−0.034	−0.038
Right Thigh Root Circumference (R. ThighRC)	0.771	0.345	−0.026	0.100
Base Crotch Length 2(BCL2)	0.683	0.218	0.467	−0.068
Perineal Crotch Length (PCL)	0.432	0.817	−0.034	−0.034
Posterior Mid-Length 2(PML2)	−0.122	0.811	−0.250	−0.035
Posterior Mid-Length 1(PML1)	0.019	0.715	0.122	0.052
Posterior Crotch Length (PCrL)	0.455	0.652	0.121	0.013
Front Crotch Width (FCW)	0.238	0.087	0.770	−0.168
Hip Protrusion Spacing (HPS)	0.301	0.207	−0.611	−0.256
Front Mid-Length Lower Point to Crotch Length (FML-Crotch Length)	−0.005	0.034	−0.021	0.968

symphysis point to the bottom crotch point.

Among them, Component 1, the circumference factor, exhibits the highest variance contribution rate and is the primary factor influencing differences in sample body shape.

The measurement items included in each factor can reveal the significance of each factor in the structural design of menstrual pants: the circumference factor corresponds to size grading and elastic zoning; the crotch length factor influences crotch panel length and posterior crotch height; the crotch width factor relates to crotch panel width and barrier cuff placement; and the crotch depth factor determines the positioning of the front end of the absorbent core. Together, these four factors provide an anthropometric support for the structural design of menstrual pants from different dimensions.

3.5 Cluster Analysis

The study integrates multiple variables into key body-type indicators to enable efficient classification. Based on the practical requirements of menstrual pant structural design, the study selected abdominal and hip circumferences. It used the abdominal-hip difference (i.e., hip circumference minus abdominal circumference) to characterize the morphological features of the abdominal-hip region. Hip protrusion is measured via the proportional relationship between posterior mid-length 2, posterior mid-length 1. The ratio of the distance from the lower point of the front mid-length to the crotch point to the crotch length 2 determines the position of the crotch point.This study defined the crotch point as the point at which menstrual blood exits. The following was the body type classification based on these characteristic variables.

3.5.1 Analysis of Abdominal-Hip Morphology

The study combined extracted anthropometric feature variables to derive the abdomen-hip difference. It used the ratio of posterior mid-length 2 to posterior mid-length 1 as a feature variable to describe the abdomen-hip shape. Using hierarchical clustering (Table 8), the study determined the optimal number of clusters to be 3, with the abdomen-hip difference and the posterior mid-length-to-2 ratio as clustering indicators. It then applied K-means clustering to obtain final cluster centers and inter-cluster sample proportions.The formula used for calculating the buttock convexity is:

$$\text{Bc} = \text{PML2}/\text{PML1} \tag{3}$$

Table 8: Results of Abdomen-Hip Morphology Cluster Analysis

	flat abdomen and flat hip	thick abdomen and flat hip	thin abdomen and perky hip
abdomen-hip difference	8.02	4.17	12.22
buttock convexity	0.59	0.58	0.62
sample proportion	50.35%	36.36%	13.29%

In the formula, Bc represents the buttock convexity; PML2 represents the posterior mid-length 2; PML1 represents the posterior mid-length 1.

Based on the final cluster centers, the following described the morphology of the female abdomen and hip. The first cluster, accounting for 50.35% of the samples, had a moderate abdomen-buttock difference and a mid-level degree of buttock convexity among the three types. It was named the “flat abdomen and flat hip” type. The second cluster, comprising 36.36% of the samples, showed the smallest abdomen-to-buttock difference and the least buttock convexity, with a flatter hip. It was named the “thick abdomen and flat hip” type. The third cluster, representing 13.29% of the samples, exhibited the largest abdomen-to-buttock difference and the highest degree of buttock convexity, with fuller hips. It was named the “thin abdomen and perky hip” type.

3.5.2 Cluster Analysis of Crotch Morphology

The crotch area morphology was mainly defined by front crotch width, hip protrusion spacing, and posterior mid- length 2, using these as variables for cluster analysis. First, it applied hierarchical clustering to these three variables. Three inflection points in the dendrogram indicated that the optimal number of clusters was 3. Then, the study used the K-means clustering method to group front crotch width, hip protrusion spacing, and base length (Table 9).

Table 9: Results of Crotch Morphology Cluster Analysis

	H-shaped crotch	A-type short crotch	V-type long crotch
front crotch width	11.8	9.9	12.9
Hip Protrusion Spacing	11.8	12.1	12.1
posterior mid-length 2	27.4	24.7	31.5
sample proportion	48.25%	41.96%	9.79%

Based on the final cluster centers, the crotch morphology of the female lower body was described. The first cluster, accounting for 48.25% of the samples, had equal front-crotch width and hip-protrusion spacing values at the cluster center. With a posterior mid-length 2 of 27.4 cm, it was named the “H-shaped crotch”. The second cluster, representing 41.96% of the samples, featured a posterior mid-length 2 of 24.7 cm. As this length was the shortest and the front crotch width was narrower than the hip-protrusion spacing, it was called the “A-type short crotch”.

The third cluster, comprising 9.79% of the samples, showed a posterior mid-length of 2 of 31.5 cm. Given the longest posterior mid-length 2 and a front crotch width wider than the hip protrusion spacing, it was named the “V-type long crotch”.

3.5.3 Cluster Analysis of Crotch Point Position

The study used the same method as above: the ratio of the distance from the lower point of the front mid-length to the crotch point, divided by the crotch length 2, was selected for hierarchical clustering of crotch point positions, with the optimal number of clusters determined as 2. K-means clustering was then applied for classification.The formula used for calculating the crotch point position is:

$$\mathrm{CPP} = (\mathrm{FML} - \mathrm{CrotchLength})/\mathrm{BCL2} \tag{4}$$

In the formula, CPP represents the crotch point position; FML-Crotch Length represents the Front Mid-Length Lower Point to Crotch Length; BCL2 represents the Base Crotch Length 2.

Based on the clustering results (Table 10), the female base crotch points were described as follows. The first type, accounting for a smaller proportion, had crotch points positioned posteriorly and was thus named the posterior type. The second type, with a larger proportion, had crotch points positioned anteriorly and was thus named the anterior type.

Table 10: Results of Crotch Point Cluster Analysis

	The posterior type	The anterior type
crotch point position	0.40	0.29
Sample proportion	48.25%	51.75%

4 Disscusion

(1) In recent years, significant progress has been made in the classification of female body shapes, particularly in the morphological classification of the upper body in young as well as middle-aged and elderly women, the torso shape classification based on body surface curve features, and the abdominal convexity morphology in middle-aged and elderly women, providing methodological references for the present study [11, 23-25]. However, existing research has largely focused on the upper body or overall body shape, with limited attention to the crotch region and no body shape analysis targeting menstrual pants users. This study focuses on females aged 18-50 years who fit size L menstrual pants. Based on the structural design requirements of menstrual pants, it classifies female abdominal-hip and crotch morphology and, for the first time, proposes an analysis of bottom crotch point position, thereby providing anthropometric support for the differentiated design of menstrual pants.

(2) Based on relevant literature and standards, 18 measurement items were selected to capture the necessary lower-body anthropometric data for the design of menstrual pants.The study presents the distribution of data across various sizes through descriptive analysis and finds that women within the same size range exhibit significant variation in abdominal circumference, hip circumference, and other related measurements. Through cluster analysis of abdominal-hip morphology, this study finds that abdominal shapes include slender and thick abdomens, while hip shapes include flat and raised hips. Previous studies on female abdominal morphology were limited, and abdominal-hip morphologies varied across age groups [26]. This study investigated abdominal-hip morphologies among women fitting the same size and found significant differences in their abdomen-hip differentials. Some scholars reconstructed the three-dimensional morphology of women's upper bodies by establishing models and described differences in abdominal-hip morphologies among women of different age groups.

(3) Descriptive analysis of crotch length, width, and other parameters reveals that the coefficient of variation for crotch length is relatively large, indicating significant differences in the length dimension of women's crotch morphology. Cluster analysis classifies crotch morphologies and crotch base point positions, identifying distinct crotch shapes such as "A", "V", and "H". Research demonstrates that crotch morphologies also exhibit obvious differences. For instance, Luo, YX et al. [12] find that crotch morphologies vary individually across different body types, further verifying the differences in women's lower-body morphologies.

(4) Relevant studies indicate that over 80% of women experience menstrual blood leakage, and existing products have structural deficiencies [12]. Against this backdrop, given the high coefficient of variation in abdominal and hip circumference data, gradient elastic fabric with zoned elasticity adapts to body-type differences in circumferences. They ensure a waist fit and fixation, providing stronger hip support to reduce issues such as waist creasing or hip looseness caused by uniform elasticity. Crotch shapes and absorbent positions are tailored to body type-specific crotch morphology: for the curvy hip type, the inclination angle of the back crotch line, back rise,

and posterior mid-length should be appropriately increased, and curved 3D crotch panels with front-shifted absorbent cores are used to match protrusions; for V-shaped long crotches, crotch width and length should be appropriately increased while posterior mid-length should be reduced, and wide trapezoidal crotch panels with rear-shifted and widened absorbent cores are used to enhance back leak-proofing; for the anterior and posterior crotch point types, the absorbent core should be correspondingly shifted forward or backward to ensure effective coverage of the bottom crotch point region, thereby balancing production costs with practical needs. On existing size systems, new body type labels for raised hip (Q), flat hip (P), and thick flat hip (B) are added to pair with traditional sizing (e.g., "L size-P type"), breaking the single waist-hip circumference classification and integrating body type into the size system. Future research should further quantify these design modifications to ensure that the improved menstrual pants achieve superior leakage protection and wearing comfort for different body types.

(5) The present study has several limitations. Due to experimental constraints, the sample only included females aged 18–50 years who wear size L menstrual pants. Therefore, the findings can effectively reflect the body shape characteristics of this specific group and provide a valid basis for analysis within this size category. Still, they may not be fully applicable to other size groups. Moreover, the sample's age range did not encompass a broader range of menstrual-age women, such as adolescents and menopausal women. In view of the above limitations, future research should further expand the sample to include sizes ranging from S to XL and extend the age range, thereby constructing a more comprehensive classification system for female lower-body morphology and providing an anthropometric basis for the differentiated design of menstrual pants.

5 Conclusion

To address the issue that existing menstrual pant designs fail to fully account for differences in women's body types, this study aims to clarify abdominal-hip and crotch morphological characteristics, providing references for structural design.It selects 143 size L users, uses 3D scanning combined with manual measurement to obtain lower-body data, and, through descriptive analysis, finds significant variations in abdominal and hip circumferences and large coefficients of variation in crotch length.Cluster analysis of crotch morphology and base point positions reveals marked differences, indicating distinct abdominal-hip and crotch shapes among same-size users.The research uncovers their characteristics and classifications, offers anthropometric support for differentiated designs, and matters for advancing feminine hygiene products and women's health industry.

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References

[1] Phan E, Kim J, Gam H, Hawley J. The Acceptance and Usage Intention of Menstrual Underwear, International Textile and Apparel Association Annual Conference Proceedings: 77 (1).

[2] Kavinkumar M, Saravanakumar A, Parithiban P. Sanitary towels, their menace, and the ministration of herbalism: An overview of the feminine pad patron mad Mady. International Journal of Innovative Research in Technology: 2023; 10: 1026-1040.

[3] 14 Chen HL, Gu MY, Zhang YZ, et al. Investigation and Analysis on Women's Consumption Experience and Demand of Underwear During Menstruation. Advances in Social Science, Education and Humanities Research: 2020; 30: 158-162.

[4] Gupta P, Roy A. Exploring challenges encountered by plus size women in the selection of lingerie: A comprehensive study. International Journal of Home Science: 2024; 10 (1): 200-203.

[5] Zhuang ML, Qu YJ, Wang JY. Design of Women's Physiological Underwear Based on Sanitary Napkin Consumption. Journal of Clothing Research: 2019; 4 (2): 153-157.

[6] Chen S. Seamless Knitted Fabric Design and Performance Research of Women's Functional Menstrual Underwear [D]. Zhejiang Sci-Tech University: 2023.

[7] Chen HL, Wang LL, Xiao AM. Analysis of Crotch Structure Curve of Women's Pantsuit During Menstrual Period. Wool Textile Journal: 2023; 51 (5): 69-75.

[8] Xia Y, Shi XQ, Wang HF. Analysis of Hip Convex Curve of Young Women and Structure of Rear Piece of Trousers. Journal of Textile Research: 2015; 36 (11): 115-120.

[9] Li KX, Liu JW, Xu XT, et al. Fuzzy classification of young women's lower body based on anthropometric measurement. International Journal of Industrial Ergonomics: 2016; 55: 60-68.

[10] Wu W, Zheng R, Zhang YC. Lower Body Classification of Young Women for Pants Size Optimization. Journal of Fiber Bioengineering and Informatics: 2013; 6: 453-465.

[11] Yan YJ, Zhong AH, Tu JW. Classi?cation and Regression Modelling of Abdominal Convexity Morphology in Middle-aged and Elderly Women. Journal of Fiber Bioengineering and Informatics: 2023; 16(1): 49-59.

[12] Luo YX, Ma XY, Ji YH, et al. Development and evaluation of multifunctional physiological underwear for women. Fashion Designer: 2024; (12): 65-71.

[13] Ji YH, Zhang W, Fu HH, et al. Optimal design and pressure comfort evaluation of physiological underwear for women. Knitting Industry: 2024; (10): 70-75.

[14] Xu FN, Fu HH, Zhang CJ, et al. Demand survey and optimal design of underwear for young women during menstruation. Knitting Industry: 2022; (9): 60-65.

[15] Xu FN, Ji YH, Ge Y, et al. Influence of structural factors on wearing comfort of female physiological underwear. Journal of Clothing: 2022; 7 (3): 209-217.

[16] Chen HL, Wang LL, Xiao AM. Analysis of the crotch structure curve of female physiological pants. Wool Textile Journal: 2023; 51(5): 69-75.

[17] GB/T 23698-2009.General requirements for 3D scanning anthropometric methods[S]. Beijing: China Standard Publishing, 2010.

[18] National Administration for Market Regulation, Standardization Administration of the People's Republic of China. 2023. GB/T 5703-2023: Basic Human Body Measurements for Technological Design [S].

[19] Qi J, Zhang X, Ying B, Lü F. Comparison of Human Body Sizing Measurement Data by Using Manual and 3D Scanning Measuring Techniques. Journal of Fiber Bioengineering and Informatics: 2011; 4: 83-95.

[20] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Standardization Administration of the People's Republic of China. 2017. GB/T 16160-2017: Size Definition and Methods of Anthropometry for Clothing [S].

[21] Wang J, Li X, Pan L, others. 2021. Parametric 3D modeling of young women's lower bodies based on shape classification. International Journal of Industrial Ergonomics: 84: 103-141.

[22] Liu HX, et al. Structural Design of Menstrual Pants Based on Crotch Morphology of Females. Textile Bioengineering and Informatics Symposium Proceedings 2025: 2025; 294-302.

[23] Pan RX, Yu C, Guo RL. Classification and identification model of young women's torso shape based on human surface curve features. Journal of Fiber Bioengineering and Informatics: 2023; 16(1): 29-47.

[24] Ling YL, Zhong AH. Research on the classification of body type and prototype of middle-aged women based on 3D scanning. Journal of Fiber Bioengineering and Informatics: 2020; 13(3): 161-167.

[25] Pang RD, Cui MH, Xu YX. A body shape study based on 3D body data for top size analysis of women aged 18-25 years. Textile Bioengineering and Informatics Symposium Proceedings: 2024; 69-78.

[26] Ling YL, Zhong AH. Research on the Classification of Body Type and Prototype of Middle-aged Women based on 3D Scanning. Journal of Fiber Bioengineering and Informatics; 13: 161-167.