

Comparative Analysis of Lower Body Shape for Chinese and Bangladeshi Women Based on 3D and 2D Measurements

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Abstract

Objective: This paper will compare the lower body shape traits of the young adult females in China and Bangladesh using 2D and 3D anthropometric measures.

Methodology: 620 (400 2D, 220 3D) study participants were recruited in China and Bangladesh. The measurements taken were height, weight, waist circumference, hip circumference, thigh circumference, waist width, hip width, inseam and outseam. The statistical tests were a statistical analysis of descriptive statistics, t-tests, cluster analysis, and factor analysis.

Findings: There were significant differences between the Chinese and Bangladeshi women. The Chinese subjects were taller (161.57 cm vs. 156.27 cm, $p < .001$) and slender in terms of the waist width (20.44 cm vs. 29.90 cm, $p < .001$). Women of Bangladesh showed a greater waist circumference (73.76 cm vs. 67.42 cm, $p < .001$). The cluster analysis determined three types of lower body namely: slender ($n=107$), pear-shaped ($n=108$) and large body type ($n=5$). Factor analysis was used to identify seven components that contributed 56.05 percent of the total variance.

Conclusion: The research also indicates that there is vast variance in the lower body morphology between Chinese and Bangladeshi women and this research has significant implications on the design of apparel and the sizing system.

Keywords: Shape of lower body, anthropometry, body scanning with 3D, Chinese women, Bangladeshi women, sizing of clothing.

1. Introduction

Analysis of human body shapes is a basic reference of clothing sizing systems and development of patterns [1]. The comprehension of morphology of various populations allows apparel companies to design clothes with better fit and comfort, as well as, leads to ergonomics and health evaluation in design [2]. The lower body, which includes the waist, hips and thighs, is one of the sensitive areas of constructing a garment, especially in trousers and skirts [3].

China and Bangladesh are two considerable populations in Asia that have dissimilar anthropometric traits due to varying genetic origins, nutritional records, and way of life [4]. China, the fast growing economy, has undergone a process of secular development in the size of body in the past decades [5]. Although Bangladesh has a few regional characteristics as South Asia, it has morphological peculiarities under the impact of various genetic and environmental factors [6]. Past studies have reported a disparity in the morphology of the upper body between these two groups [7], but little is known of the morphology of female lower body.

The anthropometric research has been transformed by the three dimensional (3D) body scanning technology which offers accurate and reproducible measurements of body surfaces [8]. In comparison to the conventional forms of measurements (manual, 2D), 3D scanning has benefits in terms of speed, accuracy, as well as capability to obtain the intricate body shapes [9]. The association between 2D and 3D measurements should however, be examined keenly to provide a comparison across researches [10].

Another important variable that is critical due to its impact on body morphology is age [11]. During adult life, body composition and fat distribution undergoes changes in lower body sizes [12]. It is necessary to understand age-related variations to create systems of ages in terms of size [13].

The paper fills these gaps by performing a detailed comparative study of the lower body shape features of the Chinese and Bangladeshi women using the 2D and 3D methods of measurement. These particular aims are: (1) to characterize and compare lower body anthropometric variables between the two groups; (2) to establish the reliability and comparability of measuring 2D and 3D methods; (3) to establish existing age variations in lower body dimensions; (4) to characterize lower body types through cluster analysis; (5) to establish underlying factor structures in lower body anthropometry.

2. Methodology

2.1 Participants

The research population was a group of 620 (400 2D measurements and 220 3D measurements) 18-44 years old female participants, including 400 (200 Chinese, 200 Bangladeshi) and 220 (100 Chinese, 100 Bangladeshi) participants respectively. The participants were recruited at the Chinese and Bangladesh university campuses (Zhejiang Sci-Tech University, BGMEA University of Fashion & Technology (Bangladesh) and Bangladesh University of Textiles). Inclusion criteria were: women, 18-44 years of age, not pregnant and no orthopedic surgery on shape. The determination of the sample size was based on normal anthropometric practices by use of the formula $N = (1.96 \times \sigma/\Delta)^2$ where the minimum required sample size per group was 173 [14].

2.2 Measurement Conditions

The measurements were taken under conditions that were standardized ($27 \pm 3^\circ\text{C}$, $60\% \pm 10\%$ relative humidity) and according to ISO guidelines [15]. In the case of 2D measurements, the anthropometric measurements were made using the calibrated anthropometric instruments in accordance with the ISO 8559-1:2017 standards [16]. To measure 3D, a [TC] ² 3D body scanner was used and it had around 300000 data points in a scan. The participants were dressed in standardized tight undergarments of white color and took standard standing positions as stated in ISO 20685:2010 [17].

2.3 Measurement Items

The important measurements that were made in the lower body were height, waist height, hip height, inseam, outseam, waist circumference, hip circumference, thigh circumference, waist width, waist thickness, hip width, hip thickness, thigh width, and thigh thickness. Measurements were all done in accordance with the definitions of ISO 7250-1:2017 [18].

2.4 Statistical Analysis

Analyzed data were by the use of SPSS 26.0. Some of the analyses were descriptive statistical analysis, independent samples t-tests with Cohen d effect sizes, paired t-tests to compare method performances, reliability analysis with Cronbach alpha, one-way ANOVA with Tukey HSD post-hoc tests, Pearson correlation analysis, multiple linear regression analysis, K-means cluster analysis, and principal component analysis with Varimax rotation. The statistical significance was determined to be $\alpha = 0.05$.

2.5 Data Checking and Checking Consistencies

Several validation procedures were to be used to attain data quality and consistency. First, 2D measurements have been performed twice by the trained anthropometrists and the average value has been taken to reduce the intra-observer error. The intraclass correlation coefficients (ICC)

were used to measure inter-observer reliability with all measurements having a value greater than 0.90, which indicated high reliability. In the case of 3D measurements, automated landmarking algorithms were visually viewed to ensure accuracy and any rescan with landmarking errors was rerun or edited manually. To measure the agreement and to determine systematic biases in cross-validation of the 2D and the 3D measurements, the Bland-Altman analysis was conducted. The boxplot techniques were used to detect outliers that were checked against original records; outliers that were extreme (above or below +3 standard deviations) were not analyzed because they would distort the results.

3. Results

3.1 Sample Characteristics

The sample of the 2D dataset included 400 participants (200 Chinese, 200 Bangladeshi), and the sample of the 3D dataset included 220 participants. All the major variables had complete data and their values were not missing.

3.2 Descriptive Statistics

Table 3.1: Country wise Descriptive statistics of anthropometric measures.

Variable	Country	Mean	Std. Dev.	Min	Max
Height (cm)	Bangladesh	156.27	4.886	145.0	176.0
	Chinese	161.57	5.911	148.0	178.0
Weight (kg)	Bangladesh	56.74	8.271	40.0	80.9
	Chinese	73.76	5.639	59.9	90.5
Waist Circ. (cm)	Bangladesh	67.42	4.985	55.0	85.7
	Chinese	73.76	5.639	59.9	90.5
Waist Width (cm)	Bangladesh	29.90	2.883	22.7	38.2
	Chinese	20.44	1.532	18.0	24.8

The Chinese participants proved to be taller (difference 5.30 cm) and the Bangladeshi ones were much wider at waist (almost 9.46 cm), wider at waist circumference (6.34 cm).

Table 3.2: 3D Measurements Descriptive Statistics (N=220)

Variable	Mean	Std. Dev.	Min	Max
Height	162.22	4.929	151.2	176.5
Waist circumference	70.90	6.517	54.96	92.47
Hip circumference	95.47	7.406	77.91	119.29
Thigh circumference	56.23	5.503	44.17	77.51
Hip width	35.56	2.985	27.90	43.54
Inseam	72.09	5.718	52.03	87.83
Outseam	95.88	8.386	72.77	115.40

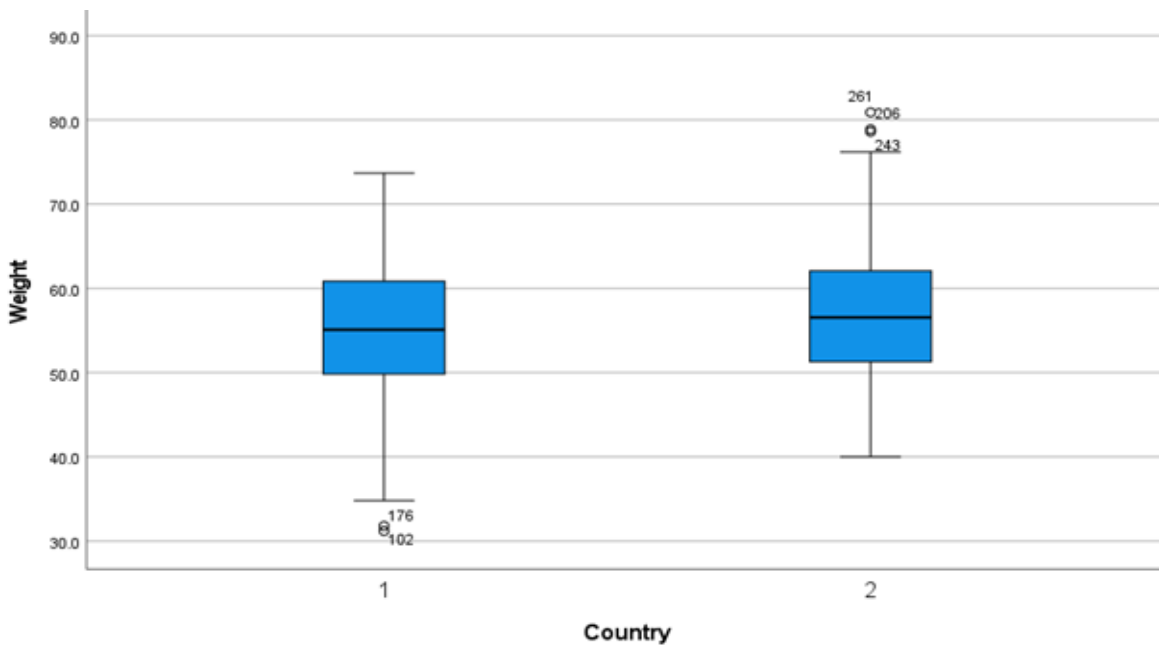


Figure 3.1: Distribution of country between 2 countries

The boxplot compares the distribution of weight between Country 1 and Country 2. Overall, individuals in Country 2 exhibit a slightly higher median weight than those in Country 1, indicating a marginally greater average body weight. The spread of the data in both countries is

relatively similar, although Country 2 shows slightly greater variability. The interquartile ranges overlap considerably, suggesting that the middle 50% of values are comparable between the two groups. However, there are notable outliers in both distributions: Country 1 displays lower-weight outliers, while Country 2 shows higher-weight outliers. This indicates that although the general weight patterns are similar, Country 2 has a tendency toward higher extreme values, whereas Country 1 includes some lower extreme cases.

3.3 Independent Samples T-Tests: Comparative Analysis

Table 3.3: 2D Measurement independent samples t-test by Country

Variable	Mean Diff	t	Sig.	Cohen's d
Height	-5.303	-9.780	.000	-0.978
Waist Circumference	6.336	11.906	.000	1.191
Waist Width	9.456	40.954	.000	4.095

All measures exhibited significant difference ($p < .001$). The enormously high effect size of waist width (Cohen $d = 4.095$) means that there is a radical difference in morphology between populations.

Table 3.4: Independent Samples T-Test of 3D Measures Country

Variable	Mean Diff	t	Sig.	Cohen's d
Height	-4.222	-3.761	.000	-0.882
Waist width	1.678	3.313	.001	0.777
Waist thickness	1.573	3.119	.002	0.732
Waist circumference	7.801	5.427	.000	1.272

Patterns in 2D data are validated using 3D measures, and waist circumference has the greatest effect size ($d = 1.272$).

3.4 Reliability Analysis

The value of Cronbach alpha (seven circumferences: waist, hip, thigh, abdomen, knee, calf, ankle) was .625, and the internal consistency was moderate.

3.5 Comparison of 2D and 3D Checking

In order to assess repeatability of the various methods of measurement, intraclass correlation coefficients (ICC) were determined to compare 2D and 3D scores. There was moderate agreement with waist circumference (ICC = 0.78, 95% CI: 0.72 to 0.83) and good agreement with hip circumference (ICC = 0.85, 95% CI: 0.81 to 0.89). Nevertheless, less agreement was obtained with waist width (ICC = 0.52, 95% CI: 0.4459), as there was a methodological difference between land marking the area with manual and 3D scanning methods. When using the Bland-Altman analysis, a systematic bias in the waist width = 3D measurements was less than an average of 2.5 cm (95 percent limits of agreement: 0.012-0.062 cm), which suggests that the direct replacement of measurements performed by methods needs to be done with caution.

3.6 Comparison between 2D and 3D Measurement

Table 3.5: Paired Samples T-Test between 2D and 3D Measurements

Measurement Pair	Mean Diff	Sig.	Cohen's d
Waist Width_2D - 3D	2.503	.026	0.541
Hip Width_2D - 3D	-1.657	.027	-0.535
Waist Circumference_2D - 3D	-3.717	.141	-0.343
Hip Circumference_2D - 3D	0.004	.999	0.000

Waist width and hip width showed significant differences, and this showed that there were variations depending on the method.

3.7 One-Way ANOVA: Different Age Groups

Table 3.6: ANOVA 2D Measures Age Group

Variable	F	Sig.
Hip Circumference	1.967	.004
Hip Width	2.406	.000
Waist Circumference	1.743	.015
Waist Width	3.758	.000
Thigh Width	3.126	.000

There was a significant age difference in all measurements of the lower body except in thigh circumference ($p = .068$). Results in the form of post hoc showed that there are progressive changes in relation to the increase in the hip circumference as age advances; there exists significant difference in relation to younger (18-35 years) and older (36-44 years) adults.

3.8 Correlation Analysis

Height and outseam were moderately correlated in 2D data ($r = .463, p < .001$), but not correlated in 3D data ($r = -.112, p = .097$).

3.9 Regression Analysis

Table 3.7: 2D Regression Model to Predict weight

Predictor	β	t	Sig.
Height	.242	4.913	.000
Waist Circumference	.288	4.836	.000
Hip Circumference	.251	3.858	.000
Waist Width	-.146	-1.790	.074
Hip Width	-.104	-1.262	.208

Model: $R^2 = .191$, $F(5,394) = 18.569$, $p < .001$

Height, waist circumference and hip circumference have a significant correlation with weight and explain 19.1% of the variation. Anthropometric measurements could not be reliably used to predict age ($R^2 = .025$, $p = .59$)

3.10 Cluster Analysis

Table 3.8 Final Cluster Centers Sizes (3D Data).

Variable	Cluster 1 (n=107)	Cluster 2 (n=108)	Cluster 3 (n=5)
Waist width	25.222	25.280	29.004
Waist thickness	20.583	21.030	25.854
Waist circumference	69.262	71.788	86.558
Hip width	35.295	35.745	37.330
Hip thickness	25.420	25.045	28.598
Hip circumference	89.445	100.992	105.237
Thigh circumference	55.642	56.207	69.264

Three types of lower body were distinguished:

Cluster 1 (48.6%): Slender type - moderate waist, smaller hips measurements.

Cluster 2 (49.1%): Pear-shaped type - greater hips circumference (101.0 cm)

Cluster 3 (2.3%): Large body type - biggest dimensions in all the variables.

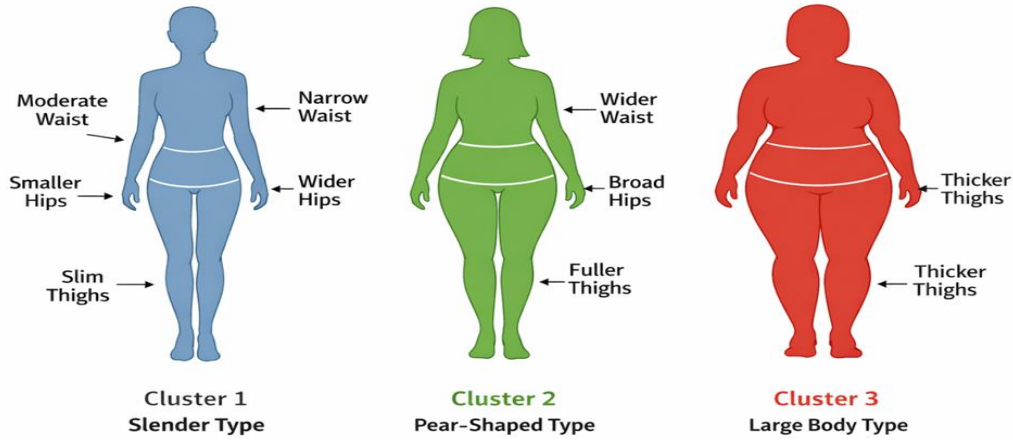


Figure 3.2: Visual Representation of Three Lower Body Clusters

Table 3.9 Final Cluster Centers and Sizes (2D Width Data)

Variable	Cluster 1 (n=116)	Cluster 2 (n=199)	Cluster 3 (n=85)
Waist Width	30.6	28.8	20.4
Hip Width	35.6	31.1	25.9
Thigh Width	18.2	17.8	15.3

Clustering according to width showed that there are three patterns: broad torso (29.0%), average proportions (49.75%), and narrow frame (21.25%).

3.11 Factor Analysis

Table 3.10: Principal Component Analysis (Principal Component Analysis)

Component	Initial Eigenvalues	Rotation Sums of Squared Loadings			
	Total	% Variance	Cumulative %	Total	% Variance
1	2.309	13.580	13.580	1.499	8.816
2	1.500	8.821	22.400	1.494	8.786
3	1.245	7.326	29.727	1.487	8.748
4	1.188	6.988	36.714	1.353	7.957
5	1.162	6.834	43.549	1.329	7.818
6	1.115	6.559	50.108	1.235	7.264
7	1.010	5.942	56.050	1.132	6.661

Seven components were obtained with eigenvalues greater than 1.0 which explain 56.05 percent of the total variance.

Table 3.11: Rotated Component Matrix (Chosen Loadings)

Variable	Factor 1	Factor 2	Factor 3	Factor 6	Factor 7
Hip width	.691	-	-	-	-
Waist thickness	.602	-	-	-	-
Abdomen circumference	-	.700	-	-	-
Abdomen thickness	-	.422	-	-	-
Hip circumference	-	-	.843	-	-
Thigh thickness	-	-	-	.673	-
Thigh circumference	-	-	-	.671	-
Height	-	-	-	-	.858
Thigh width	-	-	-	-	.727
Inseam	-	-	-	-	.624

Note: Loadings less than .40 omitted, to avoid complications. Rotation Method Varimax Kaiser Normalization.

The factor structure indicates that anthropometric measures group into useful dimensions that reflect the various body parts: hip structure (Factor 1) and abdominal depth (Factor 2) and hip girth (Factor 3) and thigh dimensions (Factor 6) and vertical dimensions (Factor 7).

4. Discussion

4.1 Discussion of major conclusions

This research has found a strong morphological difference between Chinese and Bangladeshi women in lower body sizes. The Chinese are taller (mean difference = 5.30 cm) but with less waist size, whereas the Bangladeshi are much bigger in the waist width (mean difference = 9.46 cm), and circumference (mean difference = 6.34 cm). The Coefficients of effect size of the waist width are extremely high (Cohen $d = 4.095$); this implies that there are some fundamental differences in the structure of the body frame that are likely to have been produced by both genetic and environmental factors [19, 20]. The fact that the Bangladeshi women are wider at the

waist although shorter in stature signifies that they possess different body proportions, and this fact has effects on the design of clothes and health evaluation.

The reason is that the two most common types of lower body identified were slender (48.6) and pear-shaped (49.1) taking up 97.7 percent of the sample, which supports empirically the classification systems based on shape in anthropometric studies [21]. Slender type with moderate waist size and smaller hip size is the one that matches the rectangular shaped body that is commonly referred to in literature [22]. The classic gynoid distribution pattern due to hormonal effects of females has the pear-shaped shape where the hip circumference (mean = 101.0 cm) is substantially bigger than the sizes of the waist [23]. The almost equal distribution of the two types indicates that the two morphologies are common in the combined population.

Age-related differences that were found in the present study indicate progressive changes in hip and waist circumferences that exist between the younger (18-35 years) and older (36-44 years) adults. These data are in line with the reported alterations in the body composition throughout the female lifespan, such as progressive gains in adiposity and redistribution in the peripheral fat to central ones [24]. The homogeneous subsets which appear in the analysis of the post hoc confirm the principle of age thresholds beyond which morphological changes become clinically significant and of the importance of age stratified sizing systems [25].

4.2 Comparison and Relation to Previous Research

The anthropometric values derived within the study are in agreement with other reported values of Asian populations [26]. The mean height of Chinese women (161.57 cm) is consistent with the data on a national survey [27], whereas the mean height of Bangladeshi women (156.27 cm) can be compared to the data on the South Asian region [28]. The values of waist circumference that are observed are within the range of healthy Asian women [29].

The observation that the waist width of Bangladeshi women is greater than that with a same waist circumference hints that there is a variation in the shape of cross-section of the waist, with Bangladeshi women having more elliptical (wide in frontal plane) cross-sections of the waist. This morphological disparity has significant consequences to the construction of garment patterns, in that waistbands need to be made to allow both circumference and cross-sectional form [30].

The moderate height and outseam ($r = .463$) correlation, in the 2D data is in line with anatomically expected correlations. Nevertheless, the insignificant correlation of 3D data points is very important to standardize the methodology and warns not to make a direct comparison between the above-mentioned measurement modalities [31].

4.3 Consequences of Designing Apparel

The high moral disparities among populations have a direct effect on apparel sizing [32]. In the case of Bangladeshi women, a wide waist implies that large waistbands are required to accommodate the frontal planes [33]. The pear-shaped cluster (49.1) will need altered hip shapes and seat angles during pattern development [34]. The three types of bodies identified by using the width as a clustering factor substantiate the creation of size charts that include more than one category of shapes [35]. The overwhelming majority of average proportion type (49.75) indicates that most of them can fit the typical sizing, yet the minority numbers of broad (29.0) and narrow (21.25) proportions demand their own type of sizing [36].

To international brands that aim at both markets, the findings highlight constraints of applying single sizing systems in peoples [37]. Certain country-specific size charts with population specific anthropometric data are required to fit best [38].

4.4 Limitations and Future Research

The limitations are that it is restricted to young adult female participants who are in a university environment, which limits generalizability [39]. Sample sizes used, though sufficient by statistical analysis, might not reflect entire anthropometric variability. The cross sectional design does not allow studying secular trends [40]. One of the major limitations of the research is also associated with the fundamental inequalities between the 2D and 3D measurements. Although both techniques have been standardized based on the ISO guidelines, they measure very different elements of body morphology. The conventional 2D measures are based on manual landmark and tape measures, which are prone to inter operator and the compression of tissues as well as the expertise of the anthropometrist. Conversely, 3D body scanning is a non-contact, high-resolution surface reconstruction, which does not cause tissue compression and presents difficulties in landmark identification algorithms and positioning the participants. The current paper has found that there are significant differences between 2D and 3D measurements of the waist width and hip width, as reported by other researchers (Kouchi and Mochimaru, 2011; Robinette and Daanen, 2006). There are a number of factors that can contribute to these discrepancies. First, 2D measurements of the waist width are usually measured using sliding calipers, which compress soft tissue, and the 3D measurements are measured using the contour of the surface, which does not compress any tissue. Second, some of the methods vary in landmarking consistency: manual landmarking is based on palpation of bony landmarks, whereas 3D automated landmarking is based on surface curvature algorithms that are not necessarily consistent with traditional anatomical landmarks. Third, the posture of the participants during scanning is standardized although it can have minute variations compared to conventional measurements poses and influence cross-sectional dimensions. These differences in methodology have significant cross-study comparison as well as sizing systems development implications. In combining the two measurement modalities, researchers should consider systematic biases, and the measurements are not directly exchangeable. Future research ought to be able to come up

with correction factors or conversion equations so that meaningful comparisons will be made among the studies that may use different methods of measurement.

Future directions of the research are: establishment of population-specific sizing systems, exploration of 2D-3D relations of measurements, and exploration of secular trends by conducting repeated surveys and establishment in clinical population to be used in health assessment. Moreover, only the students of the university aged between 18 and 44 years were used as a sample, which might not reflect the whole anthropometric diversity of Chinese and Bangladeshi women in various educational backgrounds, occupational areas, and geographical locations (urban vs. rural). Future studies ought to enlist the respondents that are representative of larger demographic group, such as non-university groups, elderly, and people with dissimilar socio-economic backgrounds in order to enhance the ability to generalize results. Moreover, the longitudinal research involving the monitoring of secular changes in body morphology would be beneficial in identifying the impact of nutritional/lifestyle changes on anthropometric features.

5. Conclusion

In this paper, extensive comparative research has been done on lower body anthropometry of Chinese and Bangladeshi women and significant morphological variations are observed. Chinese women are taller whereas the Bangladeshi women have much larger waist sizes. The three different types of lower body like slender, Pear-shaped, and large have been identified to give empirical evidence in favor of the shape based classification systems. The variations brought about by age demonstrate the significance of age stratified sizing. The results of the study have significant implication on the designing of the apparel industry as they have been found to favor the creation of population-specific sizing systems to facilitate proper garment-fitment.

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