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Anthropometric Dimensions of Foot in Northwestern Iran and Comparison with Other Populations

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Abstract

Background: Foot anthropometry will enhance the fit and comfort of shoes. There are limited published data on the foot anthropometry of Iranians. Therefore, this study aimed to collect foot anthropometric data in northwest Iran to compare dimensions between the two genders and also with the corresponding data from other populations.

Methods: A total of 21 dimensions of the right foot were measured in 290 males and 290 females using a digital caliper and a tape. Digital patterning and different percentile values were calculated. Independent t-test was applied to test the effect of gender on foot dimensions. Cohen's d was computed to express the magnitude of dimensional differences between the participants of the current study and others.

Results: The absolute foot dimensions of males were significantly larger than those of females. After normalization to the foot length, however, some foot dimensions of females were found to be larger. The relative proportion of digital patterning of I and II were 78% and 22% respectively. Digital patterning and the main dimensions such as foot length and width were different among the participants of the current study and those of other populations, especially the East Asian communities.

Conclusions: The data of this study could be utilized by local footwear designers. In accordance with the relative foot dimensions, the female foot was not a scale-down of the male foot. Therefore, women's data should be used in designing their footwear. Compared with other populations, the participants of this study had individual foot morphology, which should be considered in the design and import of footwear.

Keywords: Anthropometry, Foot, Female, Male, Shoes

1. Background

In designing any product for a specific population, anthropometric information is necessary. Anthropometric data of foot are important for footwear design and production (1). In practice, the design of a shoe starts with the design of how long the shoe will last, which is a wooden or metal model of human foot (2). The use of foot dimensions for construction of how long the shoe will last improves the fitness and comfort of the produced shoes (3).

A poorly designed or ill-fitting shoe can cause foot problems such as pain, discomfort, and foot deformity (4). Wearing uncomfortable shoes has been reported as the cause of foot pain in 60% of female and 30% of male subjects (5). Poorly fitted shoes, either too tight or too loose, can influence the comfort of the foot. In other words, a snug shoe could result in tissue compression while a larger one could cause slippage or friction (6). Wearing tight, narrow dress shoes with a constrictive toe box (toe area) might lead to the formation of a hallux valgus as a common foot deformity (7). From patients who underwent lesser toes surgery, 39 patients (62%) felt that their hammertoe deformity was related to ill-fitting shoe wear (8). The surgery costs imposed by ill-fitting shoes are noticeable. It is estimated that shoe-related foot disorders had a cost of approximately $3 billion in the US in 1991 (9). Therefore, designing of the footwear based on foot anthropometric dimensions will enhance the fit and comfort of shoes and reduce the shoe-related problems (2, 4, 10).

In anthropometric investigations of the foot, different data including physical morphology (size), shape, and plantar contour could be collected. Among these, foot sizes that are useful for the design of footwear could be measured using direct and indirect methods. In direct or manual methods, digital calipers and tapes are used to measure the foot dimensions. Three-dimensional (3D) scanning, photography methods, and footprint inks are commonly-used techniques in indirect data acquisition (11, 12). The direct method and 3D scanning, among indirect techniques, could provide all foot dimensions including length, width, height, and girth (3, 13). Although 3D foot scanners have been recently adopted to gather foot data (1, 12, 14), these devices are only used limitedly in developing countries due to their relatively high cost. Therefore, in the current study, data were manually collected by a digital caliper and a tape due to the lack of access to 3D scanners and also the need for the measurement of all important foot dimensions.

Some previous studies showed that the foot morphology may vary across populations. For example, significant differences were reported for foot morphology between Caucasian in North America and Japanese Korean males (15), Taiwanese and Japanese females (16), and French and Japanese males (17). The incidence of digital patterning also varied across nationalities (15, 18). Therefore, due to various foot morphologies among populations, country-specific data of the foot should be made available to designers.

A number of studies aimed at characterizing the variation of foot shape between genders. Several foot dimensions of Chinese women were significantly smaller than those of men (14). Similar findings were reported for Japanese adults (19) and U.S. army soldiers (20). In conclusion, data from these studies suggest that the footwear of each gender should be designed using their foot anthropometric data.

2. Objectives

A number of studies have recently reported the anthropometric dimensions of the Iranians (21-24), however, they measured only the limited number of dimensions such as foot length and width. Therefore, the current study aimed to measure the important dimensions of the foot for both genders in northwestern Iran and also to compare the means of the corresponding measurements using available data from other published studies.

3. Methods

3.1. Study Participants

The sample size of this cross-sectional study consisted of 580 (290 males and 290 females) university students. The sample size was calculated using the formula provided in ISO 15535, 2012: general requirements for establishing anthropometric databases (25) for a 95% confidence interval for the 5th and 95th percentiles:

$$n \geq \left(3.006 \times \frac{CV}{\alpha}\right)^2 \quad (1)$$

where, n: sample size, CV: coefficient of variation, α: the percentage of relative accuracy desired. Assuming a relative accuracy of 5%, and using the largest CV (CV = 28) obtained for HLM (Heel to lateral malleolus) from a pilot study on 40 participants (20 for each gender), the minimum sample size for each gender was calculated to be 284, however, it was increase to 290. On the other hand, the sample of the study consisted of 580 volunteers.

The criteria for selecting the subjects were (1) being the residence of Urmia, Iran and (2) the absence of any foot abnormality and foot illness. Therefore, among 3380 students of Urmia University of Medical Sciences, 2700 were eligible to participate in the study and the sample size was selected through a simple random sampling to collect the data. Weight, height, and 21 foot dimensions were measured for each participant during a time period of approximately 15 minutes. The study protocol was approved by the Scientific and Ethical Review Board of Urmia University of Medical Sciences (IR.UMSU.REC.1394.37). All participants signed a consent form prior to completing the foot measurements.

3.2. Foot Dimensions

In this study, 21 dimensions of the right foot including the length, width, height, and girth were measured (Figure 1). The measured dimensions were those most commonly measured in previous studies (13, 18) and their definitions were adapted from those used by Witana et al. (13).

3.3. Measuring Equipment

A digital vernier caliper (ASIMETO, Germany), with the resolution ratio of 0.01 mm, was used for measuring length, height, and width dimensions. A measuring tape (Seca 201 tape measure; Seca, Hamburg, Germany), accurate to the 0.1 cm level, was used to quantify the foot girths. Height and weight of the participants were measured with light indoor clothes and no shoes. Body weights were measured on a digital scale (Salus scale, Milan, Italy), to the nearest 0.1 kg and height to the nearest 0.5 cm using a stadiometer (Salus stadiometer, Milan, Italy).

3.4. Measurement Procedure

In this study, the anthropometric data were gathered from the right foot of the participants. In measurement of all dimensions except that of the girths, the full body weight was on the right foot while the left foot was rested on a 25 cm raised platform. To measure the girths, each participant was seated on a chair. Length measurements were performed parallel to the long axis of the foot, and height dimensions were measured in the vertical plane from the

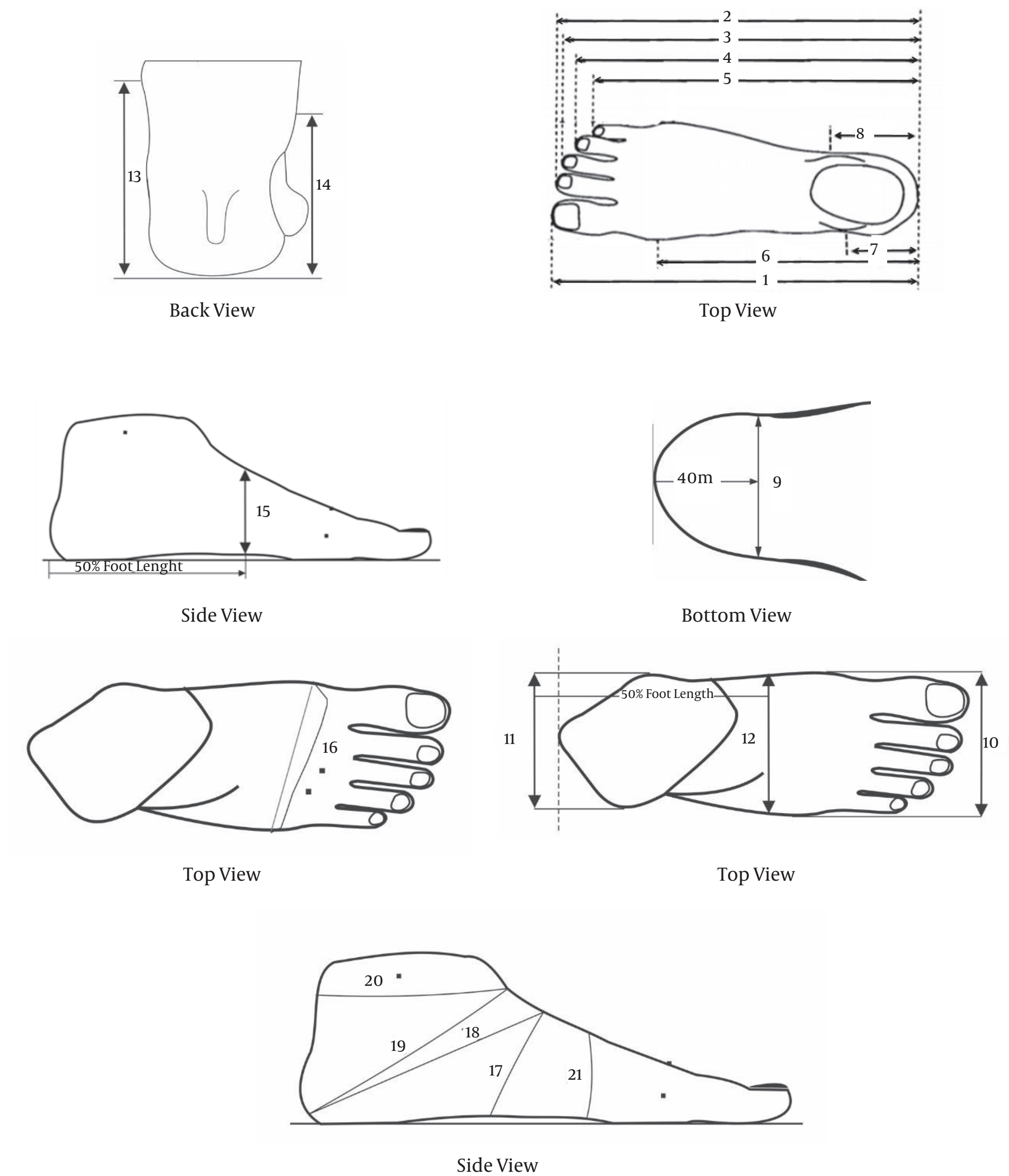

Figure 1. Foot dimensions; lengths (1 = FL (first toe length), 2 = FL2 (second toe length), 3 = FL3 (third toe length), 4 = FL4 (fourth toe length), 5 = FL5 (fifth toe length), 6 = AL (arch length), 7 = HMM (heel to medial malleolus), 8 = HLM (heel to lateral malleolus)), Widths (9 = HW (heel width), 10 = FW (foot width), 11 = BW (bimalleolar width), 12 = MFW (mid-foot width),13 = MMH (medial malleolus height)), heights (14 = LMH (lateral malleolus height), 15 = HFL (height at 50% foot length)),girths (16 = BG (ball girth), 17 = IG (instep girth), 18 = LHG (long heel girth instep girth), 19 = SHG (short heel girth), 20 = AG (ankle girth), 21 = WG (waist girth).

horizon to the landmark of the interest. Width measurements were made in the horizontal plane perpendicular to the long axis of the foot (18). All dimensions were measured by one operator. To ensure the consistency of measurements, the intra-operator reliability was assessed using intra-class correlation coefficient (ICC). The values of ICC ranged between 0.921 and 0.997 for different dimensions.

3.5. Statistical Analysis

Data were analyzed using the Statistical Package for Social Sciences (SPSS) version 16.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics and percentiles were calculated. Independent Student's t-test was applied to compare the mean values between genders. The significant level was set at $P < 0.05$. To compare the mean values of FL (foot length), FW (foot width), and BG (ball girth) of the participants of the current study with reference populations, Cohen's d was calculated applying the following equation;

$$Cohen\text{'}s\,d = \frac{M_1 - M_2}{\sqrt{\frac{S_1^2 + S_2^2}{2}}} \tag{2}$$

In this equation, M_1 and M_2 represent the mean value for the current study and for the other populations respectively. S_1 and S_2 also represent the SD of the respective populations. Cohen's d is interpreted as a very small effect (< 0.2), as a small effect (0.2 - 0.5), as a moderate effect (0.5 - 0.8), and as a large effect (> 0.8) (19).

4. Results

4.1. Participants and Foot Anthropometric Data

The participants of this study consisted of 580 (290 males and 290 females) University students serving as a representative sample of the northwest Iranian population. The participants were aged 18 to 30 years and their weight and height were between 40 - 103 kg and 150 - 194 cm, respectively. The percentile values (5th, 50th, and 95th) and SD of foot dimensions for males and females are shown in Table 1.

4.2. Absolute and Relative Foot Dimensions

The absolute and relative foot data of both genders are presented in Table 2. Not surprisingly, the absolute values for males were significantly larger than those for females (P value < 0.05), however, the relative data (standardized by foot length) were not always larger in males. In other words, in the same foot length, females could have the larger value in some dimensions such as FW and BG.

4.3. Digital Patterns

Common digital patterns (DP), such as DPI and DPII, can be determined by comparing the length of the first and second toes. In DPI, the order of digits in their size is 1 > 2 > 3 > 4 > 5, whereas in DPII the order is 2 > 1 > 3 > 4 > 5. In our sample, 78% and 22% of the participants' feet conformed to the DPI and DPII patterns respectively.

4.4. Comparison of Foot Dimensions

As the second aim of the study, some foot dimensions including FL, FW, and BG were compared with the corresponding ones from other populations of both genders. Table 3 summarizes the results of this comparison. Cohen's effect sizes were used to interpret the differences.

5. Discussion

In this study, 21 dimensions of the right foot were measured in 580 participants from northwest Iran. The calculated percentiles could be used as a guide for local footwear designers. The 5th - 95th percentiles cover 90% of people. Therefore, local manufacturers could produce comfortable products for a significant percentage of the population using the obtained dimensions.

According to the absolute data, males had larger foot dimensions than females. In some relative dimensions, however, females had larger ones. Our results were generally consistent with those of previous studies. For instance, Manna et al. (30) found that Indian females had significantly smaller values than males in all six measured foot dimensions. The analysis of length and width of foot in a study from Turkey also showed notable differences between the two genders (32).

In previous studies, some relative foot dimensions were larger in women than men. For instance, in U.S. Army personnel, all 26 absolute foot dimensions of men were larger than those of women, however, after normalization to FL, 10 dimensions of women were larger than men (20). Similarly, larger relative dimensions have been reported for Chinese (14) and German females (33). In our study, seven relative dimensions of females' feet were larger than those of males, from among which the four items of FW, HFL, SHG, and AG showed significant differences between the two genders (P value < 0.01). Three of these relative dimensions, that is, HFL, SHG, and AG, were reported by Wunderlich and Cavanagh as larger ones in females (20). Taken together, similar to other populations, absolute foot dimensions of females of this study were smaller than those of males. However, when standardized to FL, females had some larger dimensions than males. Due to this evidence, it is proposed that female feet and legs are not simply scaled-down versions of male feet. Consequently, in designing women's shoes, their own anthropometric data should be utilized.

In the forefoot, the digital patterning could affect the comfort and fit of the shoe. Among the current study population, the two common digital patterns, that is, DPI and DPII (78% vs. 22%), were close to the results obtained for the Caucasian North Americans (76% vs. 24%). This was while they were considerably different from those of the Japanese and Korean males (51% vs. 49%) (15). The DPI and DPII of Caucasian were 72% and 24%, respectively, which is again close to our findings (18). Therefore, the forefoot shape may be different or similar among populations and consequently, it should be considered by footwear producers and importers.

As the second aim of the present study, some foot di-

Table 1. Percentiles of Foot Dimensions, mm

Dimensions	Males				Females			
	Percentiles			SD	Percentiles			SD
	5th	50th	95th		5th	50th	95th	
FL	244.22	268.35	293.30	15.17	217.26	234.84	250.73	11.20
FL_2	240.70	266.08	291.50	15.57	206.81	230.84	248.93	12.58
FL_3	231.00	257.45	286.31	16.68	201.03	222.11	238.85	11.91
FL_4	220.00	245.41	281.51	18.64	192.58	211.50	227.68	10.79
FL_5	204.83	228.17	278.28	22.80	180.01	197.38	210.99	10.30
AL	177.90	195.58	222.70	15.12	145.18	162.67	180.27	10.94
HMM	66.42	85.31	94.26	7.74	42.70	52.69	66.71	8.23
HLM	56.70	71.18	82.82	8.01	32.79	42.49	55.54	7.25
FW	79.92	103.30	117.25	11.57	81.19	89.33	98.14	5.92
HW	60.27	70.25	84.02	7.28	45.32	52.38	59.22	4.38
BW	65.13	74.27	86.86	6.85	58.75	64.18	69.56	5.10
MFW	79.85	93.47	104.34	7.69	67.31	76.15	86.09	6.23
MMH	66.04	77.26	87.49	6.71	55.10	64.31	75.80	6.02
LMH	54.09	66.04	80.70	7.62	50.42	57.68	66.68	5.12
HFL	47.22	54.75	72.26	7.02	46.26	51.67	58.31	3.98
BG	225.00	250.00	270.00	12.58	200.55	217.00	237.00	11.18
IG	240.00	265.00	295.00	18.23	203.00	221.00	242.00	11.68
SHG	290.00	330.00	368.35	24.61	268.00	293.00	317.00	15.68
LHG	320.00	370.00	407.25	29.97	294.00	318.00	349.00	16.74
AG	206.10	235.00	275.00	21.59	193.00	213.00	239.00	13.11
WG	232.00	255.00	280.00	16.24	196.00	213.00	232.00	11.51

mensions including FL, FW, and BG were compared with the corresponding ones from other populations. According to Table 3, FL of males in our study was larger than all the other populations, except for Australians. The FL of our females was smaller than those of Hong Kong Chinese, Caucasians born in Italy, Taiwanese, Japanese, and Australians, however, larger than those of Malaysian, Chinese, and Indians. Similar to FL, FW of Australians was bigger than those of the population in this study. Unlike FL, FW of our males was smaller than those of Caucasians born in Italy, Taiwanese, and Japanese. The pattern of FW of females was similar to FL. The males of the current study had smaller BG than males of Taiwan, Japan, and North America. Similar to FL and FW, BG of Hong Kong Chinese, Taiwanese, and Japanese females were bigger than BG of our females. Generally, the males of the current study had longer feet than other Asian nationalities and Taiwanese and Japanese had wider feet than our participants. The differences discussed above show the foot morphology variations among countries or regions putting stress on the development of country-specific data for footwear design and production.

As it is clear in Table 3, that the mean and range of age were different among the participants of the current and reference studies in some cases. Consequently, the age-related changes of foot morphology could be a potential confounding factor. These changes have been investigated in some studies. In a study on 168 women (20 - 80 years old) divided into seven age categories, it was revealed that the foot length was not related to age (34) and it reaches its full length after the age of 20 (29, 35). Therefore, the foot length cannot significantly change with aging. In case of FW and BG, Tomassoni et al. (27) reported no significant difference in terms of FW and BG among young-adult (age 20 - 25) and adult (age 35 - 55) participants. It seems that the effect of age on FW and BG are almost similar to FL, hence the comparison of these dimensions among different age groups, made in this study, could not be a primary concern.

Table 2. The Mean of Absolute (in mm) and Relative (in %FL) Foot Dimensions for Both Genders[a]

Dimensions	Absolute Data (Mean)			Relative Data (Mean)		
	Male	Female	P Value	Male	Female	P Value
FL	270.03	234.35	0.001	-	-	-
FL_2	266.86	229.43	0.001	0.99	0.98	0.001
FL_3	258.47	221.31	0.001	0.96	0.94	0.001
FL_4	247.89	210.77	0.001	0.92	0.90	0.001
FL_5	233.23	196.12	0.001	0.86	0.84	0.001
AL	195.67	162.60	0.001	0.73	0.69	0.001
HMM	83.65	53.29	0.001	0.31	0.23	0.001
HLM	70.19	43.22	0.001	0.26	0.18	0.001
FW	100.44	89.17	0.001	0.37	0.38*	0.01
HW	70.71	52.18	0.001	0.26	0.23	0.001
BW	74.36	46.06	0.001	0.28	0.27	0.37
MFW	92.96	76.43	0.001	0.34	0.33	0.001
MMH	76.96	64.53	0.001	0.29	0.28	0.001
LMH	66.67	57.95	0.001	0.25	0.26*	0.88
HFL	55.96	52.02	0.001	0.21	0.22*	0.001
BG	248.71	217.68	0.001	0.92	0.93*	0.16
IG	264.65	221.87	0.001	0.98	0.95	0.001
SHG	328.71	292.93	0.001	1.22	1.25*	0.001
LHG	362.98	318.72	0.001	1.34	1.36*	0.13
AG	236.62	213.92	0.001	0.88	0.91*	0.001
WG	256.04	212.88	0.001	0.95	0.91	0.001

[a] *Females have larger value.

5.1. Conclusion

This study is among the limited research that attempted to measure the foot dimensions in northwest Iran, and the results of which can be used as a reference by local footwear designers. In agreement with previous investigations, females had larger values in some important relative dimensions. Our results further suggest the use of anthropometric data of females in designing their shoes. The forefoot shape, in terms of digital patterning, also showed the dimensional differences of foot among populations. The participants of the current study had longer but narrower feet than the East Asian communities. This study had some limitations in its sample size and measuring techniques. Therefore, another study with a larger sample size, with participants from various regions of Iran using a 3D scanning system is proposed.

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Footnotes

Authors' Contribution: Mohammad Hajaghazadeh and Teimour Allahyari conceptualized the study and designed data collection methodology. Roya Emamgholizadeh Minaei collected data. Mohammad Hajaghazadeh prepared the manuscript. Hamidreza Khalkhali conducted data analysis.

Conflict of Interests: None of the authors has any conflict of interest.

Ethical Approval: The study was approved by Vice-Chancellor for Research and Technology, Urmia University of Medical Sciences (IR.UMSU.REC.1394.37). All participants

Table 3. Comparison of Foot Dimensions Between the Populations of the Current Study and Other Previously Reported Studies, mm[a,b,c,d]

Population of Current Study vs.	Dimensions	Male				Female			
		No.	Age, y	Mean ± SD	Effect Size (Guide)	No.	Age, y	Mean ± SD	Effect Size (Guide)
Current study									
	FL		1830	270.03 ± 15.17			1930	234.35 ± 11.20	
	FW		22.07 ± 2.26	100.44 ± 11.57			21.97 ± 2.27	89.17 ± 5.92	
	BG			248.71 ± 12.85				217.68 ± 11.18	
Hong Kong Chines (26)		26				24			
	FL		1924	254.69 ± 12.16	1.12[*D]		1924	238 ± 12.56	0.30[B]
	FW		21.58 ± 1.17	96.71 ± 5.52	0.41[*B]		21.42 ± 1.32	90.42 ± 5.80	0.21[B]
	BG			243.23 ± 12.13	0.44[*B]			226.56 ± 13.72	0.71[C]
Italian Caucasians, (27)		130				128			
	FL		2025	261.7 ± 13	0.59[*C]		2025	233.7 ± 10.3	0.06
	FW		(NA)	101.7 ± 6.3	0.13[A]		(NA)	91.2 ± 5.2	0.36[B]
	BG			242.1 ± 17.4	0.43[*B]			217.2 ± 11.5	0.04[*A]
Taiwanese (1)		2000				1000			
	FL		1860	259.7 ± 11.7	0.76[*C]		2060	235.8 ± 10.5	0.13[A]
	FW		32.3 ± 10.1	103.9 ± 5.5	0.38[C]		30.6 ± 7.8	93.7 ± 4.8	0.84[D]
	BG			249.1 ± 12.7	0.03[A]			224.9 ± 12.9	0.59[C]
Japanese (28)		478				410			
	FL		NA	247.90 ± 10.40	1.70[*D]		NA	227.40 ± 9.02	0.68[C]
	FW		34.9 ± 10.66	101.90 ± 4.62	0.16[A]		33.7 ± 10.87	93.1 ± 4.38	0.75[C]
	BG			249.2 ± 10.66	2.58[D]			226.6 ± 9.61	0.85[D]
North America (18)		1197							
	FL		1885	263.2 ± 12.3	0.49[*B]				
	FW		35.47 ± 11.85	99.1 ± 5.7	0.15[*A]				
	BG			253.4 ± 13.0	0.36[B]				
Malaysian (29)		112				120			
	FL		2046	227 ± 9.8	3.36[*D]		2069	223 ± 5.0	1.31[*D]
	FW		28.27 ± 10.34	87.8 ± 3.1	1.49[*D]		25.1 ± 8.85	82 ± 3.4	1.48[*D]
Chinese (29)		107				106			
	FL		2069	222 ± 8.4	3.91[*D]		2067	212.2 ± 12.1	1.89[*D]
	FW		34.00 ± 14.50	87.4 ± 5.5	1.44[*D]		27.33 ± 9.23	82.6 ± 6.0	1.10[*D]
Indian (29)		102				102			
	FL		2063	223.9 ± 12	3.37[*D]		2064	220.5 ± 9.9	1.31
	FW		32.91 ± 11.17	86.2 ± 5.3	1.58[*D]		32.36 ± 11.11	82.5 ± 5.7	1.14[*D]
Bangalee (30)		200				100			
	FL		2035	244.7 ± 12.5	1.82[*D]		2035	229.8 ± 14.1	0.36[*B]
	FW		(NA)	98.2 ± 9.6	0.2[*B]		(NA)	85.5 ± 3.1	0.77[*C]
Australian (31)		87				108			
	FL		1868	273.4 ± 13.6	0.23[B]		1863	245.6 ± 12.1	0.96[D]
	FW		38.2	103.6 ± 6.3	0.34[B]		36.5	92.8 ± 5.5	0.63[C]

[a]Values are expressed as range or mean ± SD.
[b]*Larger in our study.
[c]A = very small, B = small, C = moderate, D = large.
[d]NA = Range of age was not available, (NA) = Mean ± SD of age was not available.

signed the consent form and confidentiality of data collection was ensured to all of them.

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