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Comparisons of Body Volumes and Dimensions Using Three-Dimensional Photonic Scanning in Adult Hispanic-Americans and Caucasian-Americans

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Abstract

Background:
We studied whether significant differences exist between Hispanic-Americans (H-A) and Caucasian-Americans (C-A) in body dimensions using a newly validated three-dimensional photonic scanner (3DPS).

Methods:
We compared two cohorts of 34 adult U.S.-based H-A (19 females) and 40 adult C-A (25 females) of similar age and body mass index (BMI, kg/m^2). We measured total body volume (TBV), trunk volume (TV), and other body dimensions, including waist and hip circumferences, estimated percentage body fat (%fat), calculated TV/TBV, and waist-to-hip ratio.

Results:
For female cohorts, there were no significant differences in age, weight, height, and 3DPS-measured variables between the two ethnic cohorts. For male cohorts, C-A had greater height ($p = 0.014$), but there were no significant differences in absolute or proportional volumes or dimensions between the two cohorts.

Conclusions:
Results demonstrate that, in these H-A and C-A cohorts of similar age and BMI, total and regional body volumes and dimensions, as well as their proportions, approximate each other very closely in both sexes; these variables also show similar relationships with %fat in each sex. This is in contradistinction to previous study reports using other measurement techniques.

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Abbreviations: (BMI) body mass index, (C-A) Caucasian-Americans, (CVD) coronary vascular disease, (H-A) Hispanic-Americans, (HC) hip circumferences, (TBV) total body volume, (TV) trunk volume

Keywords: body circumferences, ethnicity, ratio of trunk volume/total body volume, ratio of waist circumference/hip circumference

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Introduction

Various medical conditions and consequences associated with excess body fat make its measurement important in clinical settings. Obesity is associated with many diseases, including hypertension, diabetes mellitus, coronary vascular disease (CVD), dyslipidemia,[1–5] and disability.[6] Many studies have reported that percentage body fat (%fat) and body fat distribution vary by ethnicity.[7–11] Some studies have concluded that ethnicity should be taken into account when interpreting anthropometric measurements.[3,10,12,13] Numerous reports have stated that the higher risks of CVD in nonwhites compared with whites might be explained by their differing phenotypes.[4,9,14,15–17]

Ethnicity dependency becomes important in the United States where the population is very heterogeneous. Over the past 2 decades, the Hispanic population has increased faster than any other ethnic group (http://www.census.gov/compendia/statab/tables/06s0043.xls). However, there is little information on body volumes and dimensions in Hispanic-Americans (H-A). What is available is based on traditional tape measures or skin fold calipers, which require validation by other reliable techniques to confirm that the information is credible for assessing the health risk of the population.

Hamamatsu Photonics of Japan has developed scan systems using a digitized optical method and computer to generate a three-dimensional photonic image of the human body, and the technique has been used for measuring total and regional body volumes and dimensions. The newly developed three-dimensional photonic scanner (3DPS) system (Model C9036-02, Hamamatsu Photonics K.K., Hamamatsu, Japan) collects a maximum of 2,048,000 data points over a scan field (200 cm height × 100 cm width × 60 cm depth) in 10 seconds. We have cross validated this new technique using a traditional tape measure for the measurement of body sizes, including circumferences and dimensions, and using traditional underwater weighing for the measurement of body volume and body fat content in 93 subjects aged 6–83 years old, which has indicated that this newly developed technique measures body sizes and body fat accurately in humans.[18]

The aims of this study were to investigate the relationships between total and regional body volumes and their associations with body mass index (BMI), waist circumference (WC), and %fat in a group of H-A living in the New York City region and to compare the results to Caucasian-Americans (C-A).

Subjects and Methods

Subjects

Thirty-four H-A adults (19 females) and 40 Caucasian adults (25 females) living in the New York City region were recruited for the study. Inclusion criteria were that participants must be self-claimed Caucasian or Hispanic, >17 years old, free of diseases on medicine, have no amputation, able to perform the 3DPS scan, and present consent for the study. Study recruitment was conducted by direct personal contacts, through research coordinators, or postings in local public bulletins. The study was approved by the St. Luke's–Roosevelt Hospital Institutional Review Board. A written consent form was obtained from each participant.

Ethnicity

Ethnicity as H-A or C-A was determined by self-report, requiring a similar ethnic background of all parents and grandparents.

Methods of Measurement

Body weight was measured to the nearest 0.1 kilogram (Ohaus Champ General Purpose Bench Scale) and height to the nearest 2 millimeters using a stadiometer (Holtain) while subjects wore minimal underwear without shoes. Total body volume (TBV), trunk volume (TV), WC, and hip circumferences (HC) were measured by the 3DPS using the standard scan mode (10 seconds per scan)[18] using the newly improved protocols for preparation of a subject for the scan as described later.

Fit of Cap and Underwear

The fit of the cap and underwear was examined thoroughly before positioning the subject for the scan. A white-color, 1-inch wide surgical tape made of inelastic fiber was applied over the area of the cap to minimize airspace between the cap and the skull and applied over the underwear to minimize air pockets between the skin's surface and the underwear.

Standardized Positioning Subjects for Scan

Two new devices were added to the scanner to improve and standardize the positioning of the subject for scanning. (1) Two height-adjustable handlebars for standardizing positioning of the arms were added to the two poles at the left and right sides of the scanner. A ruler attached to the pole indicates the height of the handlebar. (2) A tape measure for standardizing the positioning of the feet was permanently glued on the floor of the scanner to indicate the position and the distance of the subject's heels from the center point of the scan floor.

Standardized Protocols for Positioning Subject for Scan

Legs. The subject was first instructed to stand at the center of the scanner and then to move both heels away to an equal distance from the center point along the tape until there was no contact between the legs.

Arms. The subject was instructed to hold the handlebars gently, and then both handlebars were adjusted at an equal height level so that the arms were abducted to the trunk of the body. The positions of the heels on the floor and the height of the hands on the poles were recorded in the database.

Scanning and Estimating Percentage Fat

After the subject was positioned as just described, a 10-second 3DPS scan was performed after a maximum expiration for total body volume measurement in order to overestimate the body volume due to air contained in the lungs over the residual lung volume so that this total body volume could be used for calculating %fat.[18] The scan was repeated three times for one subject measurement, and the average of the three scans was used in data analysis. Body density was calculated as body weight$_{kg}$/(total body volume measured after a maximum expiration – RLV)$_L$, where RLV (residual lung volume) was estimated using the Crapo equation.[19] Percentage of body fat by the 3DPS scan was estimated using the Siri equation.[20]

Figure 1 shows the body image produced by the 3DPS scan. The image has four regions: head, arms, trunk, and legs as indicated by different colors. The total body volume is the sum of all the regional volumes. Because anthropometric measurements are measured traditionally during a normal breathing condition, reported total and regional body volume values and WC for body volumes and dimensions for the study were measured at normal breathing.

The measurement reproducibility by the 3DPS was studied by repeated 3DPS measurements done three times on each day for 3 days in three volunteers: reliabilities for body volumes and circumferences are shown in **Table 1**. Sex or race had no influence on measurement reliability.

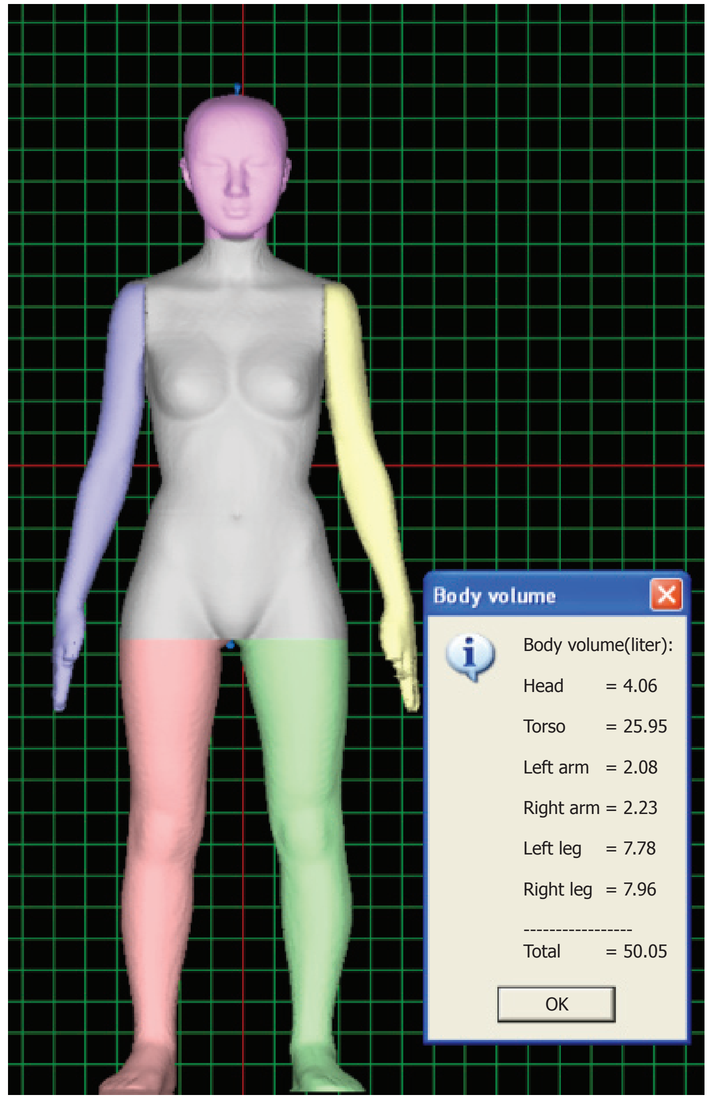

Figure 1. Image of a total body scan and definition of regional body volumes generated by the 3DPS scanner. Trunk volume is the total body volume subtracting volumes of head, left and right arms, and legs.

Statistical Analyses

The hypothesis was that body volumes and dimensions in adult H-A and C-A measured by 3DPS would be different. Descriptive statistics, mean and standard error, and significance level were tested by using unpaired *t* tests and were calculated by sex and by ethnicity for all variables. Linear regression models were used to identify significant relationships among body volumes, dimensions, and trunk volume to total body volume proportion (TV/TBV) and BMI from WC, WHR, and %fat. *p* values were considered significant at $p < 0.05$. Data were analyzed using the Excel program (Microsoft® Excel version 11.0, Dell Inc.).

Table 1.
Descriptive Statistics for 3DPS Reliability Study[a]

	Mean	Components of variance			Standard deviation		CV	Reliability
		Subject	Day	Error	Single reading	Error		
Chest circumference	114.50	163.6800	1.3102	0.3304	12.86	0.57	0.50	1.00
Waist circumference	109.97	315.2400	2.8941	0.2844	17.84	0.53	0.48	1.00
Hip circumference	113.67	73.2886	0.1689	0.1226	8.58	0.35	0.31	1.00
Right mid-thigh circumference	57.74	27.1894	0.0165	0.0500	5.22	0.22	0.39	1.00
Left mid-thigh circumference	57.92	27.1698	0.0853	0.0570	5.23	0.24	0.41	1.00
Right knee height	47.02	1.0696	0.0189	0.0100	1.05	0.10	0.21	0.99
Left knee height	47.27	1.0426	0.0264	0.0044	1.04	0.07	0.14	1.00
Total body volume	104.66	421.4700	0.8221	0.0858	20.55	0.29	0.28	1.00
Head volume	5.75	0.3133	0.0060	0.0125	0.58	0.11	1.94	0.96
Trunk volume	65.66	299.2000	1.9525	0.4205	17.37	0.65	0.99	1.00
Right arm volume	4.89	0.8279	0.0031	0.0034	0.91	0.06	1.19	1.00
Left arm volume	4.47	1.0038	0.0008	0.0008	1.00	0.03	0.63	1.00
Right leg volume	11.94	1.0301	0.1066	0.0508	1.09	0.23	1.89	0.96
Left leg volume	11.95	1.1399	0.0946	0.0489	1.13	0.22	1.85	0.96
Body percent fat	28.54	96.8838	0.3293	0.6759	9.89	0.82	2.88	0.99
Sagittal diameter	33.02	35.1897	0.5917	0.0189	5.98	0.14	0.42	1.00
Neck circumference	46.89	61.9562	0.9227	1.1030	8.00	1.05	2.24	0.98

[a] Measurement reliability by the 3DPS was established in three male subjects (age range 25, 33, and 46; BMI 28, 36, and 39 kg/m^2). Each subject was measured on 3 days and three times on each day. Standard deviation of single reading = sqrt (subject variance + day variance + error variance), standard deviation = sqrt(error variance), CV = 100*(standard deviation of error)/mean, reliability = (subject variance + day variance)/(subject variance + day variance + error variance).

Results

Physical characteristics of the participants are shown in **Table 2** for each sex in each ethnic group. There were no significant differences between H-A and C-A females. C-A males were taller than H-A males, however. **Table 3** presents 3DPS measured results for TV, TBV, TV/TBV, WC, HC, WHR, and %fat and comparisons between the two ethnic groups for each sex. There were no significant differences between the two ethnic groups for either sex for total and regional volumes and dimensions, or as proportional of total body value.

Table 4 presents linear relationships for body volumes with dimensions and %fat for females and males in each ethnic group. The highest coefficients (r^2 value) were between TV and WC in all four subgroups; the second highest coefficients were between TV and %fat. Correlations between WHR and %fat were similar by sex or ethnicity ($p = 0.28$, 0.17, 0.53) except in C-A females ($p = 0.004$).

Discussion

Variations in anthropometrics and body composition by age and gender have been well known for centuries. Recent studies have increasingly paid attention to ethnicity as a variable because of the increasing population heterogeneity as a consequence of the recent large migrations in the world. As a result, newly developed prediction equations using anthropometric variables, such as body circumferences or skin fold thickness, tend to be ethnic specific.[8,11,12,16,21–26] Several studies have suggested that people with an ethnic Hispanic background require different prediction equations for body fat content and distribution when anthropometric variables are used.[7,8,10,11,16,21,27] However, the present study found that the body volumes and dimensions measured using a newly validated state-of-the art 3DPS technique in a cohort of H-A adults living in the New York City region are not significantly different from values measured in a cohort of C-A adults of comparable age, weight, and body fatness. It is especially interesting to point out that

Table 2.
Physical Characteristics (Mean ± SD) of Participants in Four Subgroups Divided by Ethnicity and Sex

	Females			Males			Females vs males (*p*)	
	Caucasian	Hispanic	*p*	Caucasian	Hispanic	*p*	Caucasian	Hispanic
N	25	19		15	15			
Age (years)	40.4 ± 14.8	37.5 ± 12.2	0.479	40 ± 9.81	33.9 ± 13.4	0.119	0.927	0.412
Weight (kg)	94.2 ± 24.53	85.98 ± 20.08	0.227	101.3 ± 34.29	91.8 ± 23.6	0.387	0.492	0.440
Height (cm)	166.54 ± 8.52	166.31 ± 8.87	0.385	176.7 ± 0.07	170.6 ± 4.73	0.014	0.000	0.006
Body mass index (kg/m^2)	34.57± 9.1	32.47 ± 8.06	0.423	32.35 ± 9.92	31.8 ± 9.7	0.881	0.486	0.830

Table 3.
Comparisons between Study Groups Divided by Ethnicity and Sex for Body Volumes, Dimensions, and %Fat[a]

	Females			Males			Females vs males (*p*)	
	Caucasian	Hispanic	*p*	Caucasian	Hispanic	*p*	Caucasian	Hispanic
N	25	19		15	15			
TV (liter)	62.2 ± 20.49	57.2 ± 18.06	0.388	68.8 ± 27.09	60.3 ± 21.4	0.346	0.419	0.645
TBV (liter)	96.5 ± 25.99	88.5 ± 21.02	0.240	102.3 ± 35.30	87.1 ± 32.04	0.227	0.582	0.600
TV/TBV	0.63 ± 0.05	0.63 ± 0.06	0.817	0.66 ± 0.04	0.65 ± 0.05	0.314	0.065	0.735
WC (mm)	1029.7 ± 210.86	973.4 ± 180.14	0.346	1092.5 ± 232.3	1037.5 ± 180.8	0.475	0.399	0.311
HC (mm)	1230.8 ± 178.28	1165.2 ± 159.06	0.205	1138.6 ± 194.5	1099.9 ± 167.6	0.564	0.146	0.259
WHR	0.83 ± 0.075	0.83 ± 0.068	0.954	0.95 ± 0.09	0.94 ± 0.08	0.711	0.000	0.000
%fat	42.6 ± 10.2	38.6 ± 11.5	0.233	33.16 ± 9.01	25.2 ± 13.1	0.064	0.004	0.003

[a] Mean ± SD of body volumes (liter) and dimensions (mm); values are proportions of total body values measured by 3DPS in the four subgroups divided by ethnicity and sex. TBV and TV are total body and trunk volume (liter), respectively; WC and HC are waist and hip circumference (mm), respectively; and WHR is the waist-to-hip ratio.

the observed relationships between 3DPS measured body volumes and dimensions with %fat are similar in the two ethnic cohorts regardless of sex.

The linear relationships presented in **Table 4** indicate several important findings. TV and WC are highly correlated to each other in all subgroups, with the correlation coefficients being the highest of all the comparisons. One can argue that TV would be expected to have a significant relationship with WC. However, to our knowledge, there are no TV data in the literature on the relationship between TV and WC. This study documented such a relationship and indicates that the relationship is similar in H-A and C-A. Second, %fat is significantly correlated with TV and WC, but is less correlated with BMI in all subcohorts and is not significantly correlated with WHR in three of the four subcohorts. These results suggest that TV has the strongest influence on body fatness. These data also confirm data in the literature that WC can be used as a predictor for %fat, but that WHR cannot.[28–31]

The following several factors may have some degree of influence on the outcomes of our study.

Methodology

Most anthropometric data in the literature have been collected using tape measures or skin fold calipers. These traditional techniques vary by the measurement protocols and the observers' measurement skill. Our study used a 3DPS technique that is easy, fast, and accurate to determine total and regional body volumes and dimensions and to estimate mass distribution. Previous results, obtained in studies of mannequins, documented the great accuracy of the 3DPS compared to underwater weighing and tape measure techniques.[18]

The 3DPS technique has been used as a technology for measuring human body shape in the high fashion industry over the past decade. The technique was validated for total body volume and %fat in children and adults using underwater weighing and air displacement

Table 4.
Linear Relationships among Body Volumes, Dimensions, and %Fat in Each Subgroup[a]

	Ethnicity	Sex	Equation	R2	P	SEE
TV vs %fat	C-A	F	$y = 1.462x - 0.173$	0.528	0.000	14.3789
		M	$y = 2.270x - 6.4211$	0.571	0.001	18.4093
	H-A	F	$y = 1.319x + 6.188$	0.710	0.000	10.017
		M	$y = 1.248x + 28.847$	0.583	0.001	14.323
TV/TBV vs %fat	C-A	F	$y = 0.003x + 0.501$	0.376	0.001	0.042
		M	$y = 0.003x + 0.582$	0.429	0.008	0.034
	H-A	F	$y = 0.003x + 0.502$	0.436	0.002	0.048
		M	$y = 130.14x\ 58.725$	0.283	0.041	0.047
TV vs WC	C-A	F	$y = 0.094x - 34.765$	0.939	0.000	5.191
		M	$y = 0.1099x - 51219$	0.888	0.000	9.399
	H-A	F	$y = 0.010x - 36.974$	0.929	0.000	4.953
		M	$y = 0.111x - 55.092$	0.886	0.000	7.470
TV/TBV vs WHR	C-A	F	$y = 0.567x + 0.163$	0.674	0.000	149.158
		M	$y = 0.3319x + 0.3463$	0.483	0.004	170.930
	H-A	F	$y = 0.0568x + 0.166$	0.401	0.003	113.567
		M	$y = 0.877x + 0.378$	0.310	0.031	124.484
WC vs %fat	C-A	F	$y = 14.936x + 392.52$	0.521	0.000	6.752
		M	$y = 18.16x + 490.27$	0.497	0.003	7.541
	H-A	F	$y = 12.34x + 496.95$	0.625	0.000	5.210
		M	$y = 10.356x + 776.34$	0.560	0.001	7.205
BMI vs %fat	C-A	F	$y = 0.614x + 8.398$	0.472	0.000	0.064
		M	$y = 0.750x + 7.464$	0.464	0.005	0.091
	H-A	F	$y = 0.544x + 11.449$	0.606	0.000	0.067
		M	$y = 0.514x + 18.847$	0.483	0.004	0.086

[a] BMI is body mass index. TBV and TV are total body and trunk volume (liter), respectively; WC and HC are waist and hip circumference (mm) respectively; and WHR is the WC-to-HC ratio. SEE is standard error of estimate.

plethysmography techniques as standards.[32,33] The newly developed scan instrument used in this study, as described earlier, also generates values for regional body volumes and dimensions, as well as total body volume. The measurement reliability for body volumes and dimensions of 3DPS is the highest among the techniques currently available in the body composition field, as shown in **Table 1**.[34] However, the technique is similar to traditional underwater weighing when it is applied for estimating %fat.[18] The %fat estimation is based on the body density of the subject, which is calculated as the ratio of body weight/total body volume.[18] It does not provide the level of accuracy as obtained with dual-energy X-ray absorptiometry, computed tomography, or magnetic resonance imaging in measuring body fat and lean, especially when it is applied to a population with a body density that varies from the assumed constant body density used in the estimation of %fat.[34]

Ethnicity

"Hispanic" is considered a definition of ethnicity in the United States, not of race. Hispanic ethnicity is a broad term that encompasses persons originating or descending from Central America, Cuba, the Dominican Republic, Mexico, Puerto Rico, and South America. In some resources (Internet: http://blue.census.gov/prod/2001pubs/c2kbr01-3.pdf), it also includes Spain. However, although the common feature is the Spanish language, the Spanish come from a mostly differing anthropological root. In addition, ethnicity is usually reserved for classifying humans on the basis of characteristics related to culture, whereas race focuses on biologically based traits.[32] Taking this into account, Spaniards and populations coming from Argentina, Chile, and Uruguay that do not have much Indian blood are some times excluded from Hispanic ethnicity. In this study, the Hispanic persons assessed came from Central America, Cuba, the Dominican Republic, Mexico, Puerto Rico, and countries of South America that have a large proportion of American-Indian blood. American Indians are often shorter and tend to have larger WC than Caucasians.[8–10] Unfortunately, our information was such that we could not provide a breakdown of American-Indian blood in the cohort. The overall observed differences in height between females and males in each ethnic group were in the expected pattern in the literature.

Study Sample Size

The number of participants in each subcohort divided by ethnicity and sex in the study is small, raising a question of whether the results presented in this report are representative. Having this concern in mind, we specifically included C-A subjects of similar age and fatness to H-A in each sex so that no justification or multiple-regression analysis would be required to confirm the outcomes of the comparisons. The comparison of data in these H-A subjects with similar age and BMI to those of the C-A subjects of the same sex should be able to generate representative results. However, BMI is not a reliable predictor of %fat in studies involving subjects with wide ranges in body shape or fitness, especially with a small sample size. For example, our male H-A and C-A had similar BMI, but the male H-A had significantly lower %fat than the male C-A, as some of the male H-A used weight lifting as a way of exercise for many years. When adjusted for BMI, these weight lifters are leaner and less fat than other subjects. Therefore, additional studies with a larger sample size and close match in BMI and %fat should be conducted to confirm the outcomes of this study.

Conclusion

Results obtained using the newly validated 3DPS technique indicate that total and regional body volumes and their proportion of the total body in a sample of U.S.-based H-A compared with C-A of the same sex, age, and fatness are similar; they also have similar relationships with %fat. Although this study indicated that TV is significantly related with %fat, WC is a stronger predictor for %fat than TV, and WC is a much stronger predictor than BMI and WHR, a confirmation of previous literature. However, the study did not find any significant difference in WC or WHR between the two ethnic groups as suggested by previous studies.

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Disclosure:

There is a potential duality of interest in that the 3 DPS instrument was provided to us free of charge by the manufacturer, Hamamatsu Photonics KK.

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