RESEARCH ARTICLE

Reliability of unconventional torso anthropometry using a three-dimensional scanner in Peruvian children and adolescents [version 1; peer review: 1 approved with reservations, 1 not approved]

Carlos Alberto Delgado ¹⁻³, Roberto Shimabuku^{2,3}, Erika Alarcón^{1,4}, Luis Huicho ^{2,3,5}, Augusto Cesar Ferreira De Moraes^{6,7}, SAYCARE Study Group

¹Instituto Nacional de Salud del Niño, Lima, Peru

²Department of Paediatrics, School of Medicine, Universidad Nacional Mayor de San Marcos, Lima, Peru

³Centro de Investigación en Salud Materna e Infantil (MAMAWAWA), Centro de Investigación para el Desarrollo Integral y Sostenible (CIDIS), Universidad Peruana Cayetano Heredia, Lima, Peru

⁴Instituto Superior de Ciencias Médicas, Universidad de la Habana, Havana, Cuba

⁵Department of Paediatrics, School of Medicine, Universidad Peruana Cayetano Heredia, Lima, Peru

⁶YCARE (Youth/Child cArdiovascular Risk and Environmental) Research Group, Department of Preventive Medicine, School of Medicine, University of São Paulo, São Paulo, Brazil

⁷Department of Epidemiology, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD, USA

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Abstract

Background: Three-dimensional (3D) scanners have made it possible to measure and display body surface and shape with high precision. These are fast measurements with minimum discomfort, which is especially useful when children are involved. The objective was to assess the reliability and validity of a 3D-scanner for measuring unconventional torso parameters in children and adolescents.

Methods: This is a sub-sample of the SAYCARE study, an observational multicentre research effort being conducted in six South American countries, aimed at developing methods to collect data on cardiovascular health biomarkers, lifestyles, and environmental, social and family risk factors. Images were captured using a portable scanner (iSense, Cubify, USA) attached to a Tablet 128Gb with OSX (Ipad-Air Apple, USA). Images were reshaped to exclude head, hair, arms and legs; area and volume were measured using 3D design software ((Rhinoceros for OSX, v5.02, USA).

Results: The sub-sample for our study comprised 54 girls and 46 boys, aged 6 to 17 years old, from two private schools in Lima, Peru. Out of 100 participants, 82 were scanned twice. There was strong reliability ($\rho_{c} > 0.80$) between first and second measurements of area and volume in boys of every age group. In girls, the reliability coefficient

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was moderate ($\rho_{c>0.70}$) only for area comparison in adolescents older than 10 years of age. The mean torso area was 0.55 m^2 (SD 0.08) in girls and 0.63 m^2 (SD 0.13) in boys. The overall mean torso volume was 24.4 l (SD 5.33) in girls and 31.47 l (SD 10.14) in boys. Area under ROC curve oscillates between 0.5707 and 0.6383 when volume/area ratio was compared to the selected “gold standard” (waist to height ratio > 0.5).

Conclusion: Use of portable and low cost 3D-scanners provides a reliable but inaccurate alternative for area and volume torso measurements in children and adolescents.

Keywords

Reliability, accuracy, three dimensional, 3D, scanner, anthropometry, torso, children, adolescents

Corresponding author: Carlos Alberto Delgado (cdelgadob1@unmsm.edu.pe)

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Introduction

Three-dimensional (3D) scanning is a time saving procedure and due to minimum discomfort it has become acceptable to use in children when body components and disease risk are being studied^{1,2}. Moreover, body mass index or head circumference may also be evaluated accurately through 3D scanners that capture three-dimensional images³⁻⁵.

Scanning devices that scan the body surface generating 3D images originated in the garment industry⁶. When adapted for computers or personal devices, 3D scanners can measure and display with precision the size and shape of a person's body and the surface of the skin, and offer great potential for medical applications^{7,8}.

Currently, there are several safe, accurate and reliable portable devices that perform their function in a few seconds^{4,9}. However, despite technological advances, there are few studies using 3D images in children. Pfeiffer *et al.*¹⁰ reported in 2006 the first study of prevalence of flatfoot in children using 3D measurements. Prieto *et al.*¹¹ reported a study measuring burnt skin area on different ages and Djordjevic *et al.*¹² reported on facial symmetry in adolescents.

Torso 3D measurements are reported in relation to breast position assessment for plastic surgery¹³ and scoliosis follow-up without x-ray exposure^{14,15}. Clinical or public health relevance for torso 3D measurements in relation to the obesity pandemic still requires additional research to define its usefulness.

Methods

Study design

This is a sub-sample of a larger project called South American Youth/Child cARdiovascular and Environmental Study (SAYCARE), an observational multicentre feasibility study based at public and private schools, aimed at developing methods for collecting reliable, comparable and validated data on cardiovascular health biomarkers, lifestyles, and environmental, social and family risk factors in children and adolescents. A detailed description of the SAYCARE sampling and recruitment methodology, data collection and quality control activities has been published elsewhere¹⁶.

Sample size calculation was performed considering a comparison between observed body surface area (BSA) mean obtained by a 3D scanner (2,139; SD=224) and a calculated BSA mean value using a mathematical formula (2,225), as reported by Schloesser *et al.*¹⁷. We included a type I error α of 0.05 and a type II error β of 0.95. The estimated sample size was 72, and was increased to 86 allowing an anticipated loss up to 20%. Thirty-six female and 46 male participants were recruited.

There were 66 adolescents (29 girls and 37 boys) and 16 children under 10 years old (7 girls and 9 boys).

For data collection, the schools were initially contacted and received a formal invitation with detailed information about the study. The schools were selected for their proximity to the institute and researchers in charge of the study, for being public or private, and because they had students in the required age groups. For the schools that agreed to participate, an information letter and a verbal explanation were provided to the potential participants and their parents or legal guardians.

Three-dimensional scan

Images were captured using a portable scanner (iSense, Cubify, USA) attached to a Tablet 128Gb with OSX (Ipad-Air Apple, USA). Special training was not required to use these devices. The training in the use of the scanner was carried out with the support of the local dealer technician during one morning. The training included information on safety, assembly, calibration and how to scan and export images with the scanner attached to the tablet. The scanner was operated by two authors (CD and EA). It allows scanning objects from 30cm to 3 meters in size. Images were capturing by rotating around the subject with the device focused towards the centre. Some training practical sessions by scanning objects were conducted before actually scanning people. The acquired images were rebuilt as objects without texture and processed with software ad-hoc for analysis and processing of digital images. The images were manually reshaped using the 3D design software Rhinoceros for OSX, v5.3.2 (Robert McNeel & Associates, USA) in order to exclude hair in girls or arms in boys and girls, retaining only the torso (Figure 1). Area and volume were measured using 3D design software (Rhinoceros for OSX, v5.3.2).

Body surface scanning was performed in a room with daylight, and with doors and windows closed. Girls were evaluated in a standing position, with their arms over their heads, holding their hair. Boys were evaluated in a standing position with the arms at the sides and the palms forward.

Statistical analysis

Descriptive analysis included mean, standard deviation and coefficient of variation. Reliability for area in m² and volume in litres¹ was made comparing the first and the second measurement, through the concordance correlation coefficient (rho_c). A new variable was constructed by dividing volume over area in order to apply a curve ROC analysis and estimate the accuracy, sensitivity and specificity for certain values of this method. The Waist-to-Height Ratio (WHtR) was considered as a "gold-standard" to measure obesity, considering

Figure 1. 3D torso scan images from two male teenagers. A: Waist to Height Ratio=0.4; **B** Waist to Height Ratio=0.6. In addition a 3D scan example is presented for **Figure 1 B** - Torso 3D scan: Model ID 3DPX-008635. Available from <https://3dprint.nih.gov/discover/3dpx-008635>.

a 0.5 as the cut-off point for abdominal obesity. We used a WHtR > 0.5 as gold standard for obesity classification, because this ratio has been reported as accurate in cross-sectional studies for children and adults¹⁸. Waist and height measurements were obtained by conventional anthropometric measurements during fieldwork. Expert anthropometrist hired for fieldwork took the anthropometric measures. The size was measured with a stadiometer with the feet not raised from the ground and with the head in the Frankfort plane. The waist was measured with a non-elastic and flexible tape measure, at the midpoint between the last rib and the iliac crest.

The statistical analyses were performed using the Stata software version 12.1 (StataCorp, College Station, Texas) and were stratified by sex and age group.

Results

Table 1 shows the descriptive values for first measurements of area, volume, waist, height and waist to height ratio (WHtR). The original sample comprised 54 girls and 46 boys. Images from 18 participants were excluded because they were incomplete or scanning could not be repeated twice. We obtained complete images for analysis from 36 girls and 46 boys. All 82 children studied were from two private schools in Lima.

Table 2 shows a descriptive analysis that includes the mean values for torso scanned area and volume measurements. It also shows the reliability coefficients for first and second area and volume measurement by sex and age group. In boys the reliability coefficients were strong ($\rho_c > 0.80$) in every comparison between first and second area and volume measurements

at any age group. In girls, this coefficient was moderate ($\rho_c > 0.70$) only for area comparison in adolescents older than 10 years of age.

Table 3 shows mean values for torso scanned area and volume measurements classified by WHtR and age group. It also shows the reliability coefficients for first and second area and volume measurement. The reliability coefficients for obesity were strong ($\rho_c > 0.80$) in every comparison between first and second area and volume measurements at any age group.

Figure 1 shows examples of 3D scanned images of the torso captured from two male teenagers with opposite values of WHtR. Both adolescents shown in **Figure 1** have similar age (both are 16 years-old) and height (both had a height around 1.7 m), but dissimilar WHtR (Image A=0.4 and Image B=0.6).

Figure 2 shows that the first and second three-dimensional torso area and volume measurements have a monotonic correlation.

Figure 3 shows the ROC curve for different cut-off points for volume/area ratios of 44 and 48. The area under the ROC curve ranged between 0.5707 and 0.6383 when volume/area ratio was compared to the cut-off point used as compared to the “gold standard” (WHtR > 0.5). In order to measure accuracy volume (in l)/area (in m²) ratio selected cut-off were 44 and 48. Sensitivity was higher (75%) than specificity (39%) when using the volume/area ratio = 44. Specificity was higher (80%) than sensitivity (47%) when using volume/area ratio = 48.

Table 1. First 3D torso and selected anthropometric measurements by age group and gender.

Age Group	Statistics	Girls					Boys				
		Area (m ²)	Volume (lt)	Waist (cm)	Height (cm)	W/H ratio	Area (m ²)	Volume (lt)	Waist (cm)	Height (cm)	W/H ratio
Children	N	7					9				
	Mean	0.47	19.08	65.00	132.50	0.49	0.50	22.42	69.37	132.58	0.52
	SD	0.07	4.49	7.96	11.72	0.05	0.11	7.35	10.00	11.13	0.04
	CV	0.16	8.22	12.00	24.70	0.10	0.11	5.04	14.00	15.40	0.08
11–14 years	N	16					27				
	Mean	0.54	23.96	72.54	151.83	0.48	0.60	29.72	74.78	151.70	0.49
	SD	0.06	3.63	7.13	8.09	0.05	0.07	5.51	12.64	7.34	0.08
	CV	0.10	5.77	5.50	8.25	0.11	0.08	8.06	11.20	12.00	0.16
15–18 years	N	13					10				
	Mean	0.60	27.81	75.08	158.55	0.47	0.80	44.32	84.10	173.89	0.48
	SD	0.07	5.19	5.00	3.92	0.03	0.10	10.19	12.70	6.70	0.07
	CV	0.08	6.78	6.50	6.00	0.06	0.15	20.64	16.00	4.80	0.14
Total	N	36					46				
	Mean	0.55	24.40	71.99	150.49	0.48	0.63	31.47	75.75	152.78	0.50
	SD	0.08	5.33	7.39	12.11	0.04	0.13	10.14	12.90	15.60	0.07
	CV	0.12	6.35	8.25	14.05	0.09	0.16	10.65	10.90	17.80	0.14

N=Number; SD=Standard Deviation; CV=Coefficient of Variation (SD/Mean); W/H ratio=Waist to Height ratio.

Table 2. Concordance correlation between 3D first and second measurement of torso area and volume, by gender.

Age Group	Statistics	Girls				Boys			
		Area-1 (m ²)	Area-2 (m ²)	rho_c	p	Area-1 (m ²)	Area-2 (m ²)	rho_c	p
Children	N	7		0.594	0.022	9		0.907	< 0.001
	Mean	0.47	0.45			0.50	0.50		
	SD	0.07	0.10			0.11	0.10		
11–14 years	N	16		0.778	< 0.001	27		0.855	< 0.001
	Mean	0.54	0.55			0.60	0.61		
	SD	0.06	0.05			0.07	0.07		
15–18 years	N	13		0.717	< 0.001	10		0.917	< 0.001
	Mean	0.60	0.60			0.80	0.80		
	SD	0.07	0.10			0.10	0.09		
Age Group	Statistics	Girls				Boys			
		Volume-1 (lt)	Volume-2 (lt)	rho_c	p	Volume-1 (lt)	Volume-2 (lt)	rho_c	p
Children	N	7		0.561	0.029	9		0.971	< 0.001
	Mean	19.08	17.79			22.42	22.64		
	SD	4.49	7.05			7.35	6.72		
11–14 years	N	16		0.572	0.001	27		0.938	< 0.001
	Mean	23.96	23.98			29.72	30.54		
	SD	3.63	2.87			5.51	6.02		
15–18 years	N	13		0.658	< 0.001	10		0.958	< 0.001
	Mean	27.81	27.33			44.32	45.66		
	SD	5.19	6.66			10.19	10.63		

Area-1=First area measurement, Area-2=Second area measurement, Volume-1=First volume measurement, Volume-2=Second volume measurement. rho_c= Concordance correlation coefficient, p=p-value

Table 3. Concordance correlation between 3D first and second measurement of torso area and volume, by Waist to Height ratio.

Age Group	Statistics	Waist to Height ratio ≤ 0.5				Waist to Height ratio > 0.5			
		Area-1 (m ²)	Area-2 (m ²)	rho_c	p	Area-1 (m ²)	Area-2 (m ²)	rho_c	p
Children	N	5		0.6000	0.2848	11		0.8455	0.0010
	Mean	0.42	0.45			0.51	0.49		
	SD	0.08	0.09			0.09	0.10		
11–14 years	N	24		0.5878	0.0025	19		0.9140	< 0.0001
	Mean	0.57	0.57			0.59	0.60		
	SD	0.06	0.05			0.08	0.09		
15–18 years	N	17		0.8137	0.0001	6		0.9429	0.0048
	Mean	0.65	0.65			0.80	0.80		
	SD	0.10	0.12			0.15	0.14		
Age Group	Statistics	Waist to Height ratio ≤ 0.5				Waist to Height ratio > 0.5			
		Volume-1 (lt)	Volume-2 (lt)	rho_c	p	Volume-1 (lt)	Volume-2 (lt)	rho_c	p
Children	N	5		0.879	< 0.001	11		0.817	< 0.001
	Mean	16.85	18.70			22.83	21.35		
	SD	4.68	6.12			6.22	7.61		
11–14 years	N	24		0.736	< 0.001	19		0.950	< 0.001
	Mean	25.52	25.79			30.18	31.01		
	SD	3.74	3.50			6.54	7.18		
15–18 years	N	17		0.817	< 0.001	6		0.984	< 0.001
	Mean	31.02	30.84			46.23	47.90		
	SD	6.96	8.27			14.13	14.58		

Area-1=First area measurement, Area-2=Second area measurement, Volume-1=First volume measurement, Volume-2=Second volume measurement. rho_c= Concordance correlation coefficient, p=p-value

Figure 2. Global concordance correlation between measurements. A: Area measurements; **B:** Volume measurements. Syntaxes used by STATA program included the command: **concord** to graph area and volume concordance.

Figure 3. Area under ROC curve for Obesity diagnosis. A: Volume to Area ratio = 44; Sensitivity 75%; Specificity 39%. **B:** Volume to Area ratio = 48; Sensitivity 47%; Specificity 80%. Syntaxes used by STATA program included the command: **roctab** to graph area and volume area under the curve.

Discussion

Portable scanners are reliable, time-saving devices, and are applicable in childhood nutritional research. Torso 3D measurements obtained by using low cost, portable scanners may increase unconventional anthropometric assessment in children and adolescents.

In this study, we showed strong reliability of 3D scanning images for torso area and volume measurements, particularly in boys and obese children. Our results are in line with previous reports showing that 3D scanner devices are reliable for different anthropometric measurements^{2,17,19}, and pave the way for further studies with larger numbers of participants.

To the best of our knowledge, we did not find published papers that used the iSense hand-held technology. However, Knoops *et al.*²⁰ compared four 3D scanning systems for describing facial form, including the Structure Sensor (Occipital Inc., San Francisco, CA, USA) that is similar to the scanning device used in our study. Those authors found that Structure Sensor performance was within a clinically acceptable range of 2 mm, showing fair agreement with systems more than tenfold its cost, therefore being of great promise for clinical use. For our study, we invested less than \$2,000 USD for each scanner attached to a tablet when purchased from local dealers. Portability and user-friendly performance are also important assets for fieldwork.

Of note, the reliability was higher in obese children and adolescents than in non-obese children and girls. As mentioned above in the Methods, images were manually reshaped to exclude head, hair, arms and legs, and then area and volume were measured using 3D software. It may be possible that the reshaping done after the capture of images introduced a bias, which can be more evident when dealing with smaller images.

Several authors assessed various 3D scanners in order to understand its usability for unconventional anthropometry.^{1,17} Santos *et al.*¹ studied 3350 Brazilian children at 6 years old with the aim to describe variation in childhood body shape and size by using three-dimensional photonic scanner using TC2 Three-Dimensional Photonic Scanner (TC2, Cary, NC, USA; www.tc2.com), traditional anthropometry and dual X-ray absorptiometry. These authors found that the component termed corpulence showed strong correlations with traditional anthropometric and body composition measures. Schloesser *et al.*¹⁷ determined the body surface area (BSA) in healthy term and near-term neonates by 3D scanning and compared their results with those from five mathematical formulae for each subject. These authors found that scanned BSA for a full-term new-born was slightly lower than that calculated by mathematical formulae.

In our study, Area and Volume 3D measurements have strong reliability, but Area to Volume ratio, which was tested as an empirical approach to a 3D diagnostic tool for obesity shows low accuracy. A possible explanation is related to bias linked to manually reshaping of images. Area and volume are not directly measurable by conventional anthropometry but could be

well-calculated using reconstruction algorithms from 3D surface imaging systems to assess obesity²¹. Obesity in children is a tractable condition, and if it is labelled as an epidemiologic pandemic²² or part of a bigger picture²³, highly sensitive tools including automatic processing for early diagnosis are required.

The capture of three-dimensional images using a low-cost portable scanner can be done in approximately 100 seconds with high reliability between measurements. However the scanner is extremely sensitive to movements, and if this happens, it is necessary to repeat the whole procedure. In addition, when scanning people with comparison purposes, it was observed that some uniformity is required in the amount of clothes that can be used to perform the body surface scans.

A major strength in our study is that we were able to assess the performance of a portable, low cost device to evaluate unconventional torso anthropometry in youths in a middle-income country, so we are adding to scientific literature with results from people and places not well studied.

Conclusions

The use of portable and low cost 3D scanners provides a reliable but inaccurate alternative for area and volume as unconventional anthropometric torso measurements in children and adolescents.

Data availability

Dataset 1: 3D-Scanner-Unconventional-Anthropometry_Database.

Available from: <https://dataverse.harvard.edu> Dataset Persistent ID doi:10.7910/DVN/BLH6BS

Data are available under the terms of the [Creative Commons Zero](https://creativecommons.org/licenses/by/4.0/) “No rights reserved” data waiver (CC0 1.0 Public domain dedication).

Ethics and consent

Institutional Research Ethic Committees approved the study protocol in each center where the SAYCARE team collected data: University of Buenos Aires (Argentina), National Institute for Child's Health at Lima (Peru), University of Antioquia (Colombia), Catholic University of Uruguay (Uruguay), University of Talca (Chile), University of Sao Paulo (Brazil), and Federal University of Piauí (Brazil).

For those who agreed to participate, informed written consent had to be signed by the parent. This had to be signed by a parent or legal guardian and by adolescent participants, before the enrolment. Adolescents, under 18 years-old are not legally able to consent alone. In addition, in Lima, children over 8 years of age were also asked to give their consent.

In Lima - Peru, the study was approved by the Review Board of the National Institute for Child's Health (Document number 00222-CEI-INSN-2015, February 25th, 2015). The informed consent was obtained from all participants and guardians of the children, clarifying doubts when needed, through written communications, telephone or face-to-face conversations.

Competing interests

No competing interests were disclosed.

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Markus Scholz

Institute for Medical Informatics, Statistics and Epidemiology (IMISE), Leipzig University, Leipzig, Germany

Major issues:

1. Abstract: The authors stated that the scanner is “inaccurate”. To my opinion this conclusion is far too general and not supported by the presented data.
2. The research question is not sufficiently motivated. Why are the authors interested in the torso?
3. Existing literature is not sufficiently discussed. Please consider Glock F et al. *Pediatr Res.* 2017 and Kuehnappel et al. *Sci Rep.* 2016
4. Sample Size calculation: What is the null-hypothesis used for the sample size calculation and how does it relate to the research question?
5. From the torso picture (figure 1), I conclude that the subjects are not undressed. This is unusual in anthropometric research. How does clothing impact your results?
6. I have concerns that scanning posture is different for girls and boys. What is the impact of scanning posture on results? Could this be a reason for the different reliability results in girls and boys?
7. The measure used for obesity is unusual to my opinion and should be better justified. WHtR is not a gold standard for defining obesity at least to my knowledge. Why not using BMISDS or WHR?
8. Figure 2: Should be replaced by Bland-Altman plots which are more informative.
9. Table 2: Confidence intervals of rho_c values are more relevant regarding reliability than p-values. Please replace.
10. Figure 3: ROC analysis is not carried out correctly. Please provide the complete ROC curve and its corresponding area. Alternatively, I would recommend removing the analysis since WHtR is not a gold standard of obesity diagnosis as far as I know.
11. Language polishing is required throughout the paper.

Minor issues:

1. Abstract: “Area under ROC curve oscillates...” This cannot be true. The area is fixed.
2. Methods page 3, col 1: SD=224 can hardly be true

3. Please provide times between first and second measurement.

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

Partly

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 04 May 2018

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Lina Jaeschke

Molecular Epidemiology Group, Helmholtz Association, Max Delbrück Center for Molecular Medicine, Berlin, Germany

Summary

The manuscript by Delgado et al. describes the application of a 3D scanner to assess body surface area and body volume in Peruvian children and adolescents in the age of 6 to 17 years. The study included 82 children and adolescents and authors used concordance correlation coefficients to assess 'reliability' of body surface area and body volume estimation, and ROC analyses to assess 'validity' of the volume-to-area ratio as compared to the manually measures waist-to-height ratio. Authors conclude that the 3D scanner 'provides a reliable but inaccurate alternative for area and volume torso measurement'.

With regard to the growing interest in finding new technologies and novel markers to assess the individual anthropometry as potential risk factor, the study deals with an interesting topic and promising measurement technique. However, there are major concerns about the study protocol used and the presentation of the study in the manuscript, especially in terms of the methods.

Please see detailed comments below.

Major comments

Introduction

1. Although touching an interesting field, i.e., the assessment of 3D body volume and body surface area, I think that the scientific impact and predictive value of assessing body surface area and volume, and, thus, the rationale for the study and the potential big advantage that 3D body scanners may possess, was not made clear. One decisive point is only mentioned shortly in the discussion section: the potential of 3D scanners to be a 'diagnostic tool for obesity'. In this respect, also the 'unconventionality' (see title) of the measures 'surface area' and 'volume' was unfortunately not pointed out, although this would clearly highlight the scientific relevance of the manuscript. Further, a short overview over current methods to assess body surface area and volume, and their shortcomings would underline the value of 3D body scanners.

2. The scanner technique used by the authors is different from many of the currently used stationary 3D body scanners (e.g., the Vitus Smart XXL), not only due to the portability of the scanner but also due to the technique underlying the scanner. However, in the introduction and discussion section, the authors cite studies using such other stationary scanning devices to point at the 'accuracy' and 'precision' of 3D scanners, and authors further compared their findings with other stationary scanning devices. Discussing differences between (and limitations of) the current (portable) and other (stationary) scanning techniques would help to point at the 'novelty' of the technology and further to meaningfully interpret the current findings.

Methods

3. Overall, the statistical methods used, are reported insufficiently, so that I believe that analyses presented are not reproducible by others.

4. Further, the scan protocol is not made clear. Persons were scanned twice – what was the time interval between measures? Some more information about the scanning technique is needed to understand the procedure and study (e.g. What kind of image is created? A whole body image? Which/how many anthropometric measures are determined? The authors mentioned using a 3D design software – is it specific for the body scanner? The authors report that scanning device captures pictures by 'rotating around the subject' – was rotating based on a manual movement by the study personnel or was it performed automatically by the device?).

5. Further, could the authors please explain how they defined reliability (short-term vs. long-term reliability, i.e., technical reliability of the device vs. true variability/stability of the measure) and validity? This is currently not made clear to the reader and, thus, the aim and methods are not really clear.

6. Why did the authors use rho_c to assess reliability and ROC analyses to investigate the

agreement of the volume-to-area and the waist-to-height ratio (which is their concept to proof validity)? Did the authors also thought about using ICC and Bland Altman plots instead?

7. Typically, persons being investigated are scanned with only wearing underwear and a bathing cap. In the present study, children and adolescents were scanned wearing loose clothing as presented in Figure 1. I am not sure if this makes sense, when aiming to investigate reliability and validity of the torso in terms of body surface area and volume. The authors themselves discuss that for 'comparison purposes [...] some uniformity is required in the amount of clothes'. Uniformity, however, was not fulfilled in the present study.

8. There were huge differences in the scanning procedures between sexes: boys were scanned 'in a standing position with the arms at the sides and the palms forward', while girls were scanned 'in a standing position, with their arms over their heads, holding their hair'. However, it is important to consider that previous studies indicate the significant impact of the arm position on abdominal measures assessed by 3D body scanners.

9. It is not clear to me, why captured 3D images were edited so extensively ('The acquired images were rebuilt as objects without texture [...] images were manually reshaped [...] in order to exclude hair in girls or arms in boys and girls, retaining only the torso'). Typically, researchers using 3D scanning techniques evaluate whole body images. Could the authors please explain the rational/need for this editing? Why was it not possible to evaluate the whole body image? Further, was there any standard operating procedure defining the 'manual' editing to make the process less subjectively and, therefore, reproducible?

10. Similarly, the differences in editing 3D images between sexes seem to be problematic in my point of view ('images were manually reshaped [...] in order to exclude hair in girls or arms in boys and girls'). Probably, authors wanted to account for (typically) longer/more voluminous hair in girls than in boys. However, did the authors consider excluding hair in both sexes or using bathing caps to reduce bias due to sex differences in data handling?

11. Regarding editing of images, in the methods the authors report that 'images were manually reshaped [...] in order to exclude hair in girls or arms in boys and girls', while in the abstract and discussion they say that 'images were manually reshaped to exclude head, hair, arms, and legs' – how was reshaping done? If heads were excluded, exclusion of hair (and the description of exclusion of hair in girls in the methods) seems to be unnecessary.

12. I am not sure about using the waist-to-height ratio as standard reference to assess validity of the 3D scanner-based volume-to-area ratio, since both ratios reflect different anthropometric information on body shape. However, what is the predictive value of the waist-to-height ratio in terms of health risk? Pointing at this issue may support the authors' use of this ratio to assess validity. Nevertheless, in my point of view, the concept used here may only assess validity indirectly, since the waist-to-height ratio is not a commonly used standard reference to assess body surface area or volume (for the latter, air displacement plethysmography may be the better 'gold standard'). Pointing at this limitation would be beneficial for the manuscript.

13. The ROC analysis is not quite clear to me. Figures show three dots for each curve only – could the authors please be more precise about the analyses, underlying data, and choosing cut points. What is meant by 'certain values of this method'? Typically, the ROC shows sensitivity and 1-

specificity over a range of cut points. However, in the results, figures suggest that the ROC is only shown for the cut points 44 and 48 for the volume-to-area ratio – or how can the figures be interpreted? Further, calculation of AUC is not reported in the methods section.

Results

14. Results are partly described sparsely and do not always represent the ‘whole picture’ of results shown in the tables (see minor comments for details).

15. The AUC observed is 0.5707 and 0.6383. An acceptable discrimination is typically considered for AUC >0.7. Could the authors provide an evaluation and interpretation of the observed AUC and an underlying definition for such evaluation?

Discussion

16. The discussion section would strongly improve, when authors may more discuss their own results. Currently, their own results are hardly discussed.

17. The authors did several sub-group analyses but did not really discuss differences found between measures, sexes, age groups, and ‘obesity’ groups, or probable reasons for different findings.

18. Strengths and limitations should be addressed in more detail, also with regard to the comments made on the scanning protocol and data handling.

19. Finally, I am not sure about the conclusion the authors made. It is concluded that 3D scanners provide “a reliable but inaccurate alternative” – Is it really an alternative if the measurement is inaccurate? Further, if at all, what it is an alternative for (see also comment #1)?

Abstract

20. In the background section, authors mention that 3D scanners allow measuring and displaying body surface and shape with ‘high precision’. However, is investigating the ‘precision’ not one of the aims of the authors’ study (in terms of reliability)?

21. In the background section, authors state that investigating ‘unconventional’ torso measures was one of the current aims? For me, it is not clear what is meant by ‘unconventional’. Probably, body area and volume are meant. However, both are first mentioned in the methods section. I would further recommend to shortly make clear the predictive value of measuring body surface area and volume, and, thus, the potential big advantage of 3D body scanners.

22. In the methods section, there is no information about statistics. Thus, the following results are hardly to follow and to interpret. E.g. What scan protocol was applied (obviously authors scanned persons twice – what was the time interval between measures)? How did the authors define reliability (short-term vs. long-term reliability, technical reliability of the device vs. true variability/stability of the measure) and how was it analyzed (obviously by using rho)? How was validity defined and analyzed (obviously by using ROC analyses with the waist-to-height ratio as standard reference)?

23. In the methods section, there is no information about age range and sample size included.

24. In the results section, I do not think that it is useful to report mean body surface area and volume as averaged over all ages, as ages included ranged from 6 to 17 years (as mentioned in the main text), therefore, encompassing a wide range of body weight, height, and shape.

25. Please refer to major comment #19.

Minor comments

Introduction

1. In the introduction section, authors say that 3D scanning is a 'time saving procedure' but in the discussion section they say that scanning requires around 100 seconds, with the scanner being 'extremely sensitive to movements'. In my point of view, 100 seconds is quite a long time for standing motionlessly, especially for children. Further, 'time saving' would only make sense for me if knowing the number of measures assessed in this time period and if knowing the time required for alternative measurements.

2. First paragraph, second sentence and elsewhere: '3D' instead of 'three-dimensional'

3. Second paragraph, first sentence: please check wording.

Methods

4. Second paragraph, first sentence: What do the numbers in parenthesis stand for? What data was the basis for the sample size calculation?

5. Second paragraph: Please check the numbers on participants recruited. In the abstract and results section, authors report to have recruited 100 participants (54 females and 46 males), while here, authors report to have recruited 82 participants (36 females and 46 males). Obviously, the difference may be explained by the 18 participants excluded due to incomplete pictures as mentioned in the results section. However, please align numbers on recruited (vs. included/assessed) participants.

6. Did the authors consider a selection bias due to the recruitment of participants from only 2 private schools being proximate to the institute/researchers in charge?

7. Fourth paragraph: I find it a bit confusing that authors say that training in usage of the scanner was not required, while reporting the way of training done in the present study at the same time.

8. Sixth paragraph: 'gold standard' instead of 'gold-standard'

9. How did the authors define 'accuracy'?

10. Was there any definition for interpreting rho_c, e.g., as 'poor' or 'good'?

11. Last paragraph: Analyses were also performed stratified by waist-to-height ratio.

Results

12. First paragraph: 'not be repeated' instead of 'not be repeated twice'

13. Obviously, only girls were excluded due to incomplete scanning – was there any reason for

that?

14. Second paragraph, last sentence: Maybe you want to add the information that for other comparisons (volume and younger ages) in girls, coefficients were weak.

15. Third paragraph: 'the reliability coefficient for area and volume' instead of 'the reliability coefficient for obesity' (since the term 'obesity' is used by the authors with regard to waist-to-height ratio)

16. Third paragraph, last sentence: Authors say that ρ_c was ' >0.8 in every comparison [...] at any age'. However, this is not true for several sub-group analyses, e.g., in children for area and waist-to-height ratio ≤ 0.5 , ρ_c was 0.6000.

17. Fourth paragraph: This finding is interesting but it is not further discussed. What is the implication of this result?

18. Table 1: Here, waist-to-height ratio is abbreviated by using 'W/H', while in the text, authors use 'WHtR'. Please align.

19. Tables 1 to 3: the highest age included is 17 years; thus, I would recommend changing age group '15-18 years' to '15-17 years'.

20. Tables 1 to 3: What do the p-values stand for?

21. In addition to figure 3, a table showing sensitivity, specificity and AUC for all assessed cut points for the volume-to-area ratio would help to interpret results.

22. Figures 2 and 3: Since all other analyses were made separately for sexes, age groups, and waist-to-height groups, I think that providing stratified figures for the different groups would be more in line with the other results and would, thus, help to interpret results as a whole.

Discussion

23. First paragraph: Does these statements are based on the authors' results or based on previous research?

24. Fourth paragraph: I would recommend to use 'waist-to-height ratio <0.5 ' or 'waist-to-height ratio ≤ 0.5 ' instead of 'obese' and 'non-obese', respectively, to facilitate following the discussion with regard to the results.

25. I do not understand the explanation that reshaping 'smaller images' may be more bias-sensitive and, thus, may have caused the finding that ρ_c was larger for waist-to-height ratios >0.5 than for ratios ≤ 0.5 . The editing of images was not made in the torso area and the differences in the size of the images may not have been that huge to fully explain differences in ρ_c between waist-to-height ratios >0.5 vs. ≤ 0.5 . Did the author thought about other reasons, why ρ_c was larger for waist-to-height ratios >0.5 than for ratios ≤ 0.5 ?

26. Did the authors thought about the generalizability of their findings, keeping in mind that the study population was recruited from 2 private schools in Lima?

27. Fifth paragraph: I do not think that this paragraph is that relevant for the discussion without putting these previous findings in context with the current findings; see major comment 2.

28. Sixth paragraph: 'Strong reliability' does not hold true for all sub-groups assessed in the current study, e.g., rho_c was mainly weak in girls and for waist-to-height ratios ≤ 0.5 .

29. Sixth paragraph, third sentence onwards: I would recommend moving this part into the background section, since it is the basic topic of the current study and highlights its scientific relevance.

30. Eighth paragraph: I do not think that this is a strength of the current study, since it was its aim.

Conclusion

31. First sentence: 'provide' instead of 'provides'

Abstract

32. In the methods section, last sentence, please delete one of the two left parentheses.

33. In the method section, please introduce the abbreviations rho_c, SD, and ROC.

Is the work clearly and accurately presented and does it cite the current literature?

No

Is the study design appropriate and is the work technically sound?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?

No

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

No

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

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