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Clinical Role of Three-Dimensional Body Scanners in Presenting Direct Anthropometrics for Estimation of Body Composition: Three-Dimensional Body Scanner and Body Composition

ABSTRACT

Objective: Anthropometric quantities were calculated to evaluate the growth kinetics in children and health-related diseases in adults. Dual-energy x-ray absorptiometry is highly valuable to measure the effectiveness of three-dimensional body image. This study aims to investigate the clinical relevance of the three-dimensional body scanners in providing direct anthropometrics for estimations related to body composition.

Methods: In this analytical cross-sectional study, 2 significant groups were recruited through purposive sampling. The first included the calibration group, where 38 participants were recruited based on the age groups between 20 and 60 years. Besides, age, body mass, height, and body mass index calculations were examined by using dual-energy x-ray absorptiometry and three-dimensional scans to provide valuable results.

Results: Differences in measurements were observed between the calibration group and the validation group. Linear models were used to predict dual-energy x-ray absorptiometry body composition from three-dimensional scan measurements. High clinical relevance for three-dimensional optical measurements related to height (0.02 m^2), right arm (0.02m^2), and left leg (0.05 m^2) was observed. The highest coefficient variation of 3.46% was achieved for the average left/right arm. The body mass index values were indicated by the mean values of 25.6 kg/m^2 and 24.5 kg/m^2, respectively.

Conclusions: The mass of individuals in both groups was provided at the mean values of 80.0 kg and 79.5 kg, respectively. Test–retest measurements showed a strong association for whole body fat, fat-free mass, and arms, legs, and trunk. Three-dimensional body scanners were found effective in clinical settings for treatment procedures.

Keywords: Body scanners, cross-sectional study, x-ray, absorptiometry, optical measurements

Introduction

Anthropometric quantities such as body weight, height, distance between body points, body circumference, and length of extremities are calculated through various techniques to treat patients suffering from obesity. Anthropometric quantities were calculated to evaluate the growth kinetics in children and health-related diseases in adults.[1] Several techniques have been used for anthropometric assessments regarding the amount and distribution of body fat among individuals such as caliper, tape measure, and stadiometer. This type of technique demands qualified staff to provide accurate measurements.[2] Therefore, development in scientific technologies has brought a suitable and cost-effective technique in the form of three-dimensional (3D) scan technologies. But in the present time, several complicated data regarding anthropometric issues have been collected by employing modern scanning technologies.[3]

Three-dimensional laser body scanners serve as an innovative and time-effective technique, providing better understanding between the direct contact of observer and patient. It further provides computerized measurement protocols while transferring electronic data into databases. The technique includes the emission of light rays on the human body, for complete body mass images presented through distorted patterns of light. The topography of 3D body surface is unique as it renders important body mass details through customized software. In line with this, Pleuss et al[4] illustrated the effectiveness of measuring body composition, and thus considered it a challenging process when compared to a conventional method.

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Other technologies, such as the dual-energy x-ray absorptiometry (DXA) are highly valuable to measure the effectiveness of 3D body image. For clinicians, the advent of an improvised technology such as the 3D scan has significantly contributed to providing effective treatments through accurate measurements of body masses.[1,5]

Similarly, Stewart et al[6] reported in their study that a number of muscular persons were misclassified by using body mass index (BMI) and Grith data predominantly at the waist with calculated total and visceral fatness recommend less favorable health status. However, the 3D scans probably were competent enough to describe the précised muscularity and revealed that irrespective of the lean physical appearance, the individuals were heavy and strong. Globally, a lot of data have already been established; however, very limited studies have been conducted in Saudi Arabia. Thus, by keeping this in view, the objective of the study was to apply the 3D scanner technique to healthy Saudi adults to determine their body composition. This study contributes by determining to investigate how this technique is helpful to establish the association of human body composition and diseases and its impact on health by predicting health risk, and in addition, how new indices predict the health status of individuals.

Materials and Methods

Study Design

This was an analytical cross-sectional study that investigated the effectiveness of 3D scans among healthy adults. The study was conducted in Riyadh from February 16, 2021, to July 30, 2021. The study was approved by the Ethics Committee of Roehampton University (Date: January 1, 2021; Decision No: ROB\0126\21) and informed consent was taken from the participants prior to the enrolment in the study.

The study involved 2 significant groups recruited through purposive sampling. The first included the calibration group, where 38 participants were recruited based on the age groups between 20 and 60 years. Besides, age, body mass, height, and BMI calculations were examined to provide valuable results. Participants who were mentally and physically active and were not dependent on their mobility were included. Participants undergoing pregnancy, joint replacement, history of body surgery, and missing limbs were excluded from the study. Participants belonging to the calibration group underwent a complete body DXA and 2 3D scans that were included simultaneously. Additionally, measurements related to height, weight, and waist were undertaken.

An expert anthropometrist carried out anthropometry using standard protocols. An anthropometer and a certified medical-level scale were used to assess body mass and height. A weighing machine was used to measure the weight. Biceps, triceps, subscapular, iliac crest, supraspinal, abdomen, thigh and calf elbow, hip, knee, ankle, upper arm, wrist, and waist were measured. A caliper with rounded ends was used to measure breadths, a non-stretchable narrow measuring tape was used to measure girths, and a calibrated skinfold caliper was used to measure skinfolds.

In the second group, the validation group, 36 participants underwent thorough body measurements in 5 fitness centers to self-assess their body weight. Furthermore, BMI fat measurement test for each participant was undertaken. The 3D images of 360° were acquired through a complete rotation. Besides, circumferences in relation to the measurement of the waist, hips, biceps, forearm, thigh, and calf were undertaken. Participants belonging to the first group were scanned twice by involving the repositioning of each individual. A standard DXA result included the overall mass of the body, percent fats, lean mass, and fat mass. In addition, regional and the overall volume of the body were derived for different regions and thus were indicated on the DXA report.

Three-Dimensional Surface Scans

Body volume, surface area, and circumference were measured by 3D scans. According to a standard protocol, a Fit3D Pro-scanner (Fit3D Inc., Redwood City, Calif, USA) was used to acquire 3D surface scans. A rotating platform and a 3D optical light-coding camera were comprised in a device in a tower 2 m from the center of a platform. Adjustable handles mounted on the platform were grasped by users such that their arms were relaxed and straight, seized from the body. A 360° 3D image was obtained while the platform rotated once around in almost 40 seconds when buttons on the scanner handles were depressed by the user. A total of 476 anthropometric measurements were automatically derived and stored in a proprietary database even though merely 11 circumferences were reported to the end users. Generally, feet, hands, and the head were excluded from all surface area, volume, and circumference calculations. This study has selected the Fit3D system over other models as almost 100 of these systems were available to the audience.

Each calibration participant was scanned twice with repositioning. Each participant was provided with a swim cap and form-fitting boxer briefs. Each validation participant was scanned once with long hair tied above the neck, in personal form-fitting clothing. The Fit3D was used to transfer 3D scan data and measurements to the University of California, San Francisco Medical Center. High long-term stability was reported between 0.21% and 1.1% for chest, waist circumference, thigh, hip, and total body volume.

Dual Energy X-ray Absorptiometry

Anthropometric measurement was done through DXA as well and the difference was observed. A DXA scan was provided to only calibration participants considering the criterion method for body composition. A Hologic Discovery/W or Horizon/A system was used to obtain whole-body scans. A single International Society for Clinical Densitometry-certified technologist was used to analyze centrally all scans via National Health and Nutrition Examination Survey calibration and Hologic Apex software. Participants were scanned without shoes in examination gowns. Considering the standard protocols of the manufacturer, participants were positioned on the scanner table with hands flat on the table, feet in planar-flex position, and arms out to the side. Percent fat, lean mass, total mass for the whole body,

MAIN POINTS

- This study aims to investigate the clinical relevance of the three-dimensional (3D) body scanners in anthropometrics for estimations related to the body composition
- In this analytical cross-sectional study, 38 healthy adults were stratified by age, height, and body mass index using dual-energy x-ray absorptiometry and 3D scans.
- High clinical relevance for 3D optical measurements related to height (0.02 m^2), right arm (0.02 m^2), and left leg (0.05 m^2) was observed.
- The highest coefficient variation of 3.46% was achieved for the average left/right arm

and fat mass were included in the standard DXA output. Additionally, each region derives the total and regional body volumes on the DXA report.

Statistical Methods

Data were analyzed through Statistical Package for the Social Sciences version 23.0. (IBM SPSS Corp.; Armonk, NY, USA). Shapiro–Wilk test was conducted and data were found normally distributed. Mean and standard deviation were computed for quantitative variables. Significant measurement biases between criterion methods and 3D measurements were detected through Student's *t*-tests. Univariate linear regressions were conducted to evaluate the agreement of selected clinically appropriate anthropometric measurements obtained on the 3D scanner as compared to criterion methods, body surface area, and hip and waist circumference tape measurements. The matched test–retest measurements were measured through % coefficient of variance (%CV) and root mean square error from the 3D optical scanner. A *P*-value of <.05 was considered statistically significant.

Predictive equations were presented for regional DXA body composition and whole-body DXA composition variables based on visceral fat mass, fat mass, and percent fat. The ratio of waist girth to waist width was used as an alternative for central obesity depth. Similarly, waist width and girth were used as alternatives for central obesity width. In each compartment, predictive equations were derived for fat-free mass through the same parameters as the fat mass equation. Linear regression was used to derive the equations. Covariate analysis on each equation was performed for determining whether cross-calibration was essential as DXA scans were obtained on 2 different systems. No significant differences were observed for all predicted variables between the 2 scanners after adjusting for height, weight, and age.

Results

Table 1 provides details regarding the statistical model for calibration and validation groups by using DXA along with different variables associated with it. The age of participants was divided into calibration and validation groups, with mean values of 42.1 and 44.5, respectively. The height of the participants ranges from 167.3 cm to 172.4 cm in both the calibration group and validation group. The BMI values were indicated by the mean values of 25.6 kg/m^2 and 24.5 kg/m^2, respectively. Mass of individuals in both groups was provided at the mean values of 80.0 kg and 79.5 kg, respectively.

Particulars related to the 3D body scan measures of participants in calibration and validation groups were also presented in Table 1. However, the following measurements in circumference were provided for the given regions, including waist (92.3 cm and 90.8 cm), hips (102.6 cm and 107.1 cm), biceps (35.2 cm and 33.2 cm), forearm (25.9 cm and 27.9 cm), thigh (59.8 cm and 63.4 cm), and calf (39.5 cm and 40.0 cm).

Furthermore, 3D optical measurements in the area (m^2) indicated for both calibration and validation groups included torso (0.658 m^2 and 0.660 m^2), left arm (0.179 m^2 and 0.138 m^2), right arm (0.127 m^2 and 0.129 m^2), left leg (0.265 m^2 and 0.270 m^2), and right leg (0.272 m^2 and 0.191 m^2). Table 1 also provides 3D optical measurements in volume (L), that is, whole body (77.0 L and 75.8 L), left arm (3.58 L and 3.86 L), right arm (3.52 L and 3.69 L), left leg (8.69 L and 8.98 L), and right leg (8.63 L and 9.36 L). Furthermore, the obesity indices among both groups were also presented. According to the results, the achieved values of the waist–hip ratio for both groups were 0.76 and 0.85, respectively. Whereas, 0.59 and 0.60 were the values achieved for the waist–height ratio in both groups. Therefore, results indicated the highest clinical relevance of 3D optical measurements for height (0.02 m^2), right arm (0.02 m^2), and left leg (0.02 m^2).

Table 2 presents test–retest measurements obtained by using the 3D optical scanner. The %CV was higher for biceps, that is, 2.20%. The second highest value was obtained for the forearm (1.85%). Other values of variation include 1.48%, 0.96%, 0.90%, and 0.78% for waist, thigh, calf, and hips, respectively. Measurements of test–retest indicated in surface area were also included. Findings revealed that the highest %CV of 3.46% was obtained for the average left/right (L/R) arm. Other significant values include 2.56% for average L/R leg, 1.35% for whole body, and 0.71% for Torso.

Similarly, results obtained from test–retest in measured volume provided the highest %CV (4.48%), the second highest value (2.61%) was obtained for average L/R leg, while, the minimum value (0.74%) was provided for whole body. Table 2 provides results regarding derived fat and fat-free mass in (kg). The highest value of 10.95% was obtained

Table 1. Statistics of the Model for Calibration and Validation Group Using Dual Energy X-ray Absorptiometry

	Calibration Group (n = 38)		Validation Group (n = 36)		
Variables	Mean	Standard Deviation	Mean	Standard Deviation	*P*
Age (years)	42.1	14.3	44.5	15.2	.62
Height (cm)	167.3	9.4	172.4	8.0	.02a
Body mass index (kg/m^2)	25.6	5.4	24.5	2.0	.34
Mass (kg)	80.0	18.0	79.5	9.1	.34
Three-dimensional optical measures in circumference (cm)					
Waist	92.3	12.2	90.8	7.0	.48
Hips	102.6	10.5	107.1	7.5	.69
Biceps	35.2	4.8	33.2	2.9	.46
Forearm	25.9	2.5	27.9	2.1	.42
Thigh	59.8	5.0	63.4	6.0	.70
Calf	39.5	3.4	40.0	2.5	.85
Three-dimensional optical measures in area (m^2)					
Torso	0.658	0.082	0.660	0.068	.63
Left arm	0.179	0.015	0.138	0.018	.10
Right arm	0.127	0.014	0.129	0.0111	.02a
Left leg	0.265	0.027	0.270	0.018	.05a
Right leg	0.272	0.030	0.191	0.018	.04
Three-dimensional optical measures in volume (L)					
Whole body	77.0	16.8	75.8	17.2	.73
Left arm	3.58	0.75	3.86	0.70	.50
Right arm	3.52	0.75	3.69	0.60	.11
Left leg	8.69	1.78	8.98	1.62	.21
Right leg	8.63	1.46	9.36	1.30	.12
Obesity indices					
Waist–Hip ratio	0.76	0.05	0.85	0.06	.47
Waist–height ratio	0.59	0.06	0.60	0.03	.11

Table 2. Test–Retest Measurements Using Three-Dimensional Optical Scanners

Measurement Type	Variable	Coefficient of Variation (%)	Root Mean Square Error
Circumference (cm)	Waist	1.48%	1.40
	Hips	0.78%	0.75
	Biceps	2.20%	0.75
	Forearm	1.85%	0.52
	Thigh	0.96%	0.57
	Calf	0.90%	0.35
Surface area (m^2)	Whole body	1.35%	0.018
	Torso	0.71%	0.0053
	Average L/R arm	3.46%	0.0038
	Average L/R leg	2.56%	0.0069
Measured volume (L)	Whole body	0.74%	0.56
	Average L/R arm	4.48%	0.17
	Average L/R leg	2.61%	0.22
Derived fat/fat-free mass (kg)	Whole body fat	1.89%	0.52
	Whole body fat-free mass	0.94%	0.48
	Visceral fat mass	6.52%	0.02
	Arms fat	10.95%	0.28
	Arms fat-free mass	3.42%	0.41
	Legs fat	1.21%	0.07
	Legs fat-free mass	1.87%	0.35

L/R, left/right.

for arms fat, while other values include legs fat (1.21%), whole body fat (1.89%), and visceral fat mass (6.52%). Other values were related to the fat-free mass, where the highest coefficient value (3.42%) was obtained for arms fat-free mass, while others include whole body fat-free mass (0.94%) and legs fat-free mass (1.87%).

Discussion

Results indicated the highest significant values for height, right arm, and left leg. Other similar associations were related to the estimated value of DXA volume and body volume and full body surface area to the Du Bois model. Three-dimensional measures were involved to provide the composition of the whole body and regional body. The estimations were provided including a sample of different ages and BMI measurements. The accuracy and effectiveness of the body composition approximations were approved through a separate data set that employs Body Mass Analysis (BMA). Despite biasness in the anthropometrics to a certain extent, the study values the use of 3D scanning technology in clinical settings since it is precise and accurate and highly effective in comparison to tape measurements.

Maximum accuracy of 3D scanner was obtained in the study of Tikuisis et al[7] that provided 6 different equations of height and weight related to the surface area and also indicated that the method was highly effective since no other standard method has been recognized in comparison to the 3D body scanners. The method helps in modeling the loss of water among serious burn injuries,[8] and medicine dosage related to chemotherapy can be further calculated.[9] Besides, models of body composition attained through adjusted 3D features were well corroborated by using DXA data. The results were similar to those proposed by Lee et al.[10,11] providing specific measurements of body composition using MRI and DXA data.

Pedroli et al[12] reported that it has become a common tool for clinicians in providing virtual measurements for each angle of the human body. The quantitative examination of human morphology was provided through body volume which serves as a basic determinant of anthropology. For some chronic diseases like cancer and diabetes, calculations regarding body volume were highly essential and thus were conducted through 3D scan technology in clinical medicine. Patients undergoing external radiography for cancer treatments usually experience the given process to speculate the impact of surgery and medication.[13] Previously, calculation for anthropometric measurements were held manually, which was time-consuming and included a maximum probability of human error.[2]

Lu and Wang[14] proposed an automated anthropometric data system of data collection and provided a reflection of the important steps to be undertaken while conducting a 3D image analysis. The first part was to segment different body parts to analyze the two-dimensional silhouette. Next, include the estimation of approximate locations used for conducting a reference point to conduct initial searches. Four different algorithms including the approximation of minimum circumference, silhouette analysis, contour plots of the human body, and grayscale detection were developed for the extraction of 12 landmarks along with 3 different characteristic lines found on the human body. This automated land-marking resulted in the provision of 104 anthropometric data.

Stančić et al[15] proposed a 3D body scanner consisting of structured light that was primarily effective for the measurements of the volume distribution and scan body segments. The system turned out to be effective in comparison to the non-homogenous subject surfaces without any compulsion of using the special clothes. Other important issues such as movement of the small subjects during scanning, reflection of the nearby objects was not applicable with the newly developed 3D light scanners. These scanners were considerably compatible in providing images with high scanning resolution. The given quality of 3D scanners was achieved through the integration of novel and dynamic binary coding of structured light. Ng et al[16] provided important correlations between anthropometric measures achieved through 3D technology and metabolic risk factors, and results indicated that the technology was successful in providing accurate measurements regarding regional and whole-body fat mass.

Stančić et al[15] indicated certain issues provided by the 3D body scanners and recommended the usage of 2 scanner units consisting of different color patterns and incorporating the usage of better camera such as the passive sensor along with active sensor or projector was further suggested including the implementation of sub-pixel accuracy algorithm. These improvements will help in providing better results for segment central axis detection leading toward the improvised system resolution. Wei and Jensen[17] further added the advantages of 3D scanning in estimating segment parameters. However, the application of human segment density profiles may also help in improving the accuracy of mass measurements.

Some advantages and disadvantages of 3D scanners have been observed to be strengthened after the implication of 3D scanners. Three-dimensional body scanning is a radiation-free diagnostic method, authenticated measurement of size and shape can be achieved through 3D scanner, and it can transform epidemiology of certain diseases and the dependency on BMI can be minimized.[18,19] Researchers are interested in investigating central adiposity and is potentially associated with risk of diseases acquired from sedentary lifestyles.[18] Dose calculation, chemotherapy dose, dialysis rates, and similar treatments can be done by estimating the body surface area. The three-dimensional technique scans the whole-body surface area with a single attempt.[18] Three-dimensional scans of anorexic women were taken, and the results revealed the possibility of integrating 3D scanning and computer-generated imagery (CGI) technology to build customized realistic avatars of specific patients to directly measure their body image perception.[19] It is also helpful in cosmetic surgery. Medical experts can use 3D scanning to highlight certain surface shape changes over time in patients, enabling clinicians to track treatment effectiveness while simultaneously considering the patient's interest and increase motivation.[20]

However, some authors have criticized this technique as it was unsuccessful to identify a percentage of children who test positive using a scoliometer,[21-23] had ethical and cost reservations.[22] It needs a subject to rotate 360° that can be difficult for children and elderly individuals. Moreover, the direct comparison of 3D data with existing large data sheets is compromised due to the land-marking and cut-off point discrepancies.[24,25] The construction of 3D scan has some holes and gaps to view the extremities such as the top of the head, between the legs, and under the arms; it may impact the authenticity of achieved data.[20] According to Heymsfield et al.[22] 3D scanner can only be used in a laboratory setting.

Limitations

The study has a few limitations. This was a cross-sectional study and further longitudinal study with ample size and stringent sampling technique should be conducted in this regard. The divisions in the form of participant's age, BMI values, and height and mass values were represented. Second, the validation information only contains body composition data of bio-electrical impedance analysis (BIA) instead of DXA data. The BIA data, however, were provided by users other than the well-trained technicians followed by a systematic protocol. Regardless of these limitations, the results suggested that the predictive models were effective when implemented in real environments such as clinical settings.

Future Implications

The study has shown the value of 3D surface scanning as a cutting-edge, reasonably priced technology for the analysis of metabolic health. Additionally, 3D scanning technology has a variety of therapeutic uses and was essential in providing estimations for the composition of different body types. The study is significant because it offers relative information about the common use of modern technology. It also talks about important improvements in patient treatment outcomes that used 3D anthropometric scanning rather than conventional techniques. The study significantly adds to the corpus of knowledge and can be used by different practitioners to judge how effective 3D body scanners are at treating chronic diseases. Academics as well as patients who are obese can benefit from anthropometrics.

Conclusions

It is concluded from the earlier discussion and study results; 3D surface scanners were effective in providing a strong modality in clinical anthropometry. The technique was important in that it offered a productive platform for timely body measurements as well as regional and global analyses of body composition. Lastly, the findings of this study were proposed by involving a healthy population that was dependent on identified conditions. These conditions were effective in altering the relationship between body composition and 3D body compositions including malnutrition or sarcopenia. Future researchers were suggested to conduct follow-up studies by involving individuals belonging to different age, sex, and BMI and ethnicity group among samples with different metabolic activities.

Data Availability: The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Roehampton University (Date: January 1, 2021; Decision No: ROB\0126\21).

Informed Consent: Written informed consent was obtained from all participants who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – M.A.A., A.T.A., H.G.A.; Design – M.A.A., A.T.A., H.G.A.; Supervision – M.A.A., A.T.A., H.G.A.; Resources – M.A.A., A.T.A., H.G.A.; Materials – M.A.A., A.T.A., H.G.A.; Data Collection and/or Processing – M.A.A., A.T.A., H.G.A.; Analysis and/or Interpretation – M.A.A., A.T.A., H.G.A.; Literature Search – M.A.A., A.T.A., H.G.A.; Writing Manuscript – M.A.A., A.T.A., H.G.A.; Critical Review – M.A.A., A.T.A., H.G.A.

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