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Reliability of a 3D Body Scanner for Anthropometric Measurements of Central Obesity

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Abstract

Background: Central obesity poses a significant risk for cardiovascular diseases, but the reproducibility of manual measurements of waist and hip circumferences has been questioned. An automated 3D body scanner that uses white light rays could potentially increase the reliability of these anthropometric measurements.

Methods: We assessed the reproducibility of anthropometric measurements performed manually and using a 3D-scanner in 83 adult volunteers. Manual measures of WC and HC were obtained using unmarked, non-elastic ribbons in order to avoid observer and confirmation bias. The 3D-scanner was used to create body images and to obtain WC and HC measurements in an automated fashion.

Results: The inter-observer mean differences were 3.9 ± 2.4 cm for WC; 2.7 ± 2.4 cm, for HC, and 0.006 ± 0.02 cm for WHR. Intra-observer mean differences for manual measurements were 3.1 ± 1.9 cm for WC, 1.8 ± 2.2 cm for HC and 0.11 ± 0.1 cm for WHR. The 3D-scanner variability for WC was 1.3 ± 0.9 cm, for HC was 0.8 ± 0.1 and 0.005 ± 0.01 cm for WHR. All means were significantly different ($p<0.05$) between manual and automated methods.

Conclusion: The 3D-scanner is a more reliable and reproducible method for measuring WC, HC and WHR to detect central obesity.

Keywords: Obesity; Central obesity; 3D-scanner; Waist circumference; Hip circumference; Waist-to-hip ratio

Abbreviations: CV: Cardiovascular; WC: Waist circumference; HC: Hip Circumference; WHR: Waist to Hip Ratio

Introduction

Central obesity is a significant risk factor for cardiovascular (CV) events, diabetes, and a shorter lifespan [1-7]. Waist circumference (WC) and waist-to-hip ratio (WHR) are arguably the most widely used methods to define central obesity [8,9]. Nonetheless, guideline recommendations range from omission of recommendations to formal inclusion in risk factor assessment, this disparity might indicate uncertainty in data from available epidemiological studies [8,10,11]. Several studies have questioned the reliability of manual measurement of WC and hip circumference (HC) [12-15], as manual measurements are prone to error not only in determining the precise place of measurement but also the consistency of measures in the same plane. These differences and errors may translate into misclassification of central obesity, affecting a key diagnostic criterion for metabolic syndrome [16]. Poor reproducibility with a wide inter- and intra-observer variation when measuring WC or HC may lead to systematic errors that could lead to miscalculation of the true risk associated with central obesity. The perceived low reproducibility by providers may also affect the wide implementation of measurements of central obesity in clinical practice. Few studies have tested the utility of automated methods to perform these anthropometric measurements for obesity research purposes or for interpretation in clinical practice [17,18]. Automated anthropometric measurements could become useful and potentially portable tools for epidemiologists and clinicians alike in the assessment of central obesity but the reproducibility of automated measurements has not been compared to manual measurements. This study aimed to assess the reliability and reproducibility of a 3D-scanner in measuring anthropometric parameters of central obesity. We hypothesized that a 3D body scanner would increase the reproducibility of anthropometric measurements when compared to manual methods.

Methods

Study population

We included eighty-three healthy volunteers and patients attending a phase II cardiac rehabilitation program, older than 18 years of age. We excluded patients with claustrophobia or those unable to stand still. All subjects underwent standard anthropometric measurements including height and weight, and manual measurements of WC and HC, in addition to WC and WH measurements by a novel 3D body scanner. All measurements were performed the day of enrollment into the study.

Two graduate students previously trained for the purpose of this study carried out all the measurements. A physician (FLJ) with extensive expertise in research related to adiposity measures provided the training based on the World Health Organization (WHO) Anthropometric Guidelines [8]. Specific emphasis was made to adequately identify the anatomical sites for placing the measuring tape and common causes of measurement error such as inadequate tightness of the measuring tape, the subject's posture, the phase of respiration, abdominal tension, stomach contents and clothing. The HC was measured at the widest portion of the buttocks with the tape horizontal. The WC was obtained at the midpoint between the lower margin of the lowest palpable rib and the top of the iliac crest in the mid-axillary line. To avoid measurement bias, WC and HC were measured using colored, non-elastic, unmarked ribbons that were cut to the length of each measurement and then their lengths determined separately, thereby preventing bias in repetitive measurements. These ribbons were then measured against a metallic ruler to a tenth of a cm by a member of the team not involved in the direct measurement of participants. Observers were instructed not to ask participants about their pants size, or previous WC or HC measurements and were blinded to previous measurements or measurements performed by others. Participants were weighed on an electronic high-sensitivity scale (Tanita Corporation; Arlington Heights, IL) with ± 0.01 Kg accuracy rounded to nearest 0.1 Kg. Height without shoes was measured with a stadiometer (Seca; Hanover, MD) and rounded to the nearest 0.1 cm. The Institutional Review Board approved the study.

3D Scanning measurements

The 3D Body Volume Index (BVI) scanning system® manufactured by Select Research (Worcester, UK) [19], is a non-invasive optical scanner composed of 32 cameras, forming 16 sensors (located in 4 angles at 4 heights) of white light that collect a maximum of 1,600,000 data points over a scan field (2.1 m high × 1.2 m width × 0.6 m depth), weighing <500 pounds. It uses triangular mathematics to detect the actual position of the white light projected onto the surface of an object and reflected back to the sensor. The 3D computer software (Select Research BVI software V.1.3.21.0) uses the data points to produce a maximum of 400 measurements at each of the cross sections with a point accuracy of less than 1 mm and a circumferential accuracy of less than 3 mm over the 2 m^2 vertical scan field in 7 seconds. To calculate measures of anthropometry, the software finds the size of any cross section by computing all detected data points at this level and measures the distance between any 2 body surface points by totaling all data points on a line between the 2 points. For WC, the scanner takes four views: center back, center front, left and right side views and measures it at the level of 55% of height. HC is measured as the widest volume of the body under the waist (Figure 1).

To ensure consistency during the scan, the subject must be facing forward in a motionless anatomic standing position at the end of expiration, with both feet on standard landmarks (centered 60 cm from the front scanner wall) and holding adjustable side handles. The subject must also be wearing body fitting gray underwear and an elastic swim cap to reduce the amount of air between the hair and skull.

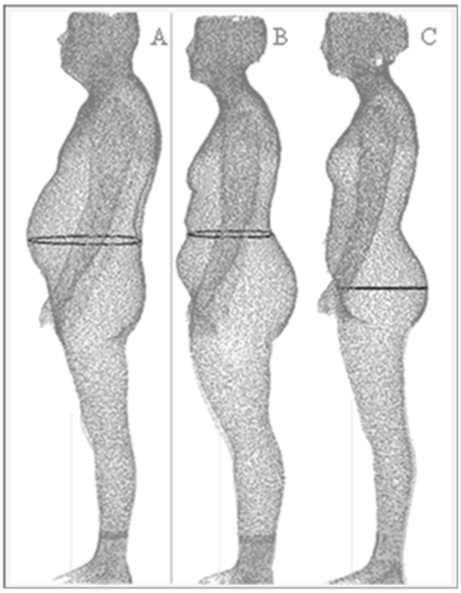

Figure 1: Image from 3D-scanner showing waist measurements in a man (A) and a woman (B). Hip circumference is measured in the widest area under the waist (C).

Proper calibration of the 3D-scanner was performed before each measurement session by using a cylinder with a known circumference per manufacturer standard. The pre-set rule was that whenever the scanner had an error of >0.1 cm during calibration, it would prompt a full recalibration process using standard spheres and a calibration cylinder.

Statistical analysis

To test the reproducibility of individual observations, we measured the intra- and inter-observer variability and used a paired *t*-test for statistical significance. To compare the mean difference between manual and automated difference in measurements, we used a non-paired *t*-test. Intraclass correlation indexes were calculated and Bland-Altman limits of agreements plots were created to illustrate the reproducibility of WC and HC measured manually versus using a 3D-scanner [20]. The level of statistical significance was set at 0.05 for all tests. All statistical analyses were performed using JMP®Version11.2.1 (SAS Institute Inc., Cary, NC).

Results

Of the eighty-three subjects that participated in this study, 48% were women, mean age ± SD 41.9 ± 18.1, ranging from 18 to 80 years, with a mean BMI of 25.9 ± 5.2 kg/m^2, ranging from 18.4 to 42.0 kg/m^2. The inter-observer mean difference for the manual circumference measures was 3.9 ± 2.4 cm for WC; 2.7 ± 2.4 cm, for HC, and 0.006 ± 0.02 cm for WHR. Intra-observer mean difference for manual measurements was 3.1 ± 1.9 cm for WC, 1.8 ± 2.2 cm for HC and 0.11 ± 0.1 cm for WHR. The 3D-scanner variability for WC was 1.3 ± 0.9 cm, and for HC was 0.8 ± 0.1 and 0.005 ± 0.01 cm for WHR. All p-values for the difference in means between manual and automated measurements were <0.05. Intraclass correlations in all cases had a value greater than 0.95. Bland-Altman plots illustrate the differences in the reproducibility of WC and HC when comparing manual measurements with the automated 3D-scanner measurements (Figure 2). Validation of the 3D-scanner showed a variation of less than 0.1 cm for circumferences using a standardized cylinder.

Discussion

This study reports on the reliability of a novel 3D-scanner to measure WC and HC, and compares it with manual measurements. We demonstrated that an automated scanner is a more reliable and reproducible way to measure anthropometric markers of central obesity as compared with manual measurements. This study also confirms what some other studies have shown, namely that manual measurements of WC and HC may have significant variability.

Indeed, manually measured WC and HC may remain unreliable, even after extensive personnel training [12-14,21]. The 3D-scanner by contrast showed less variation and more precision both by numerical and graphical methods for reliability assessment.

These differences may have important clinical implications. Waist circumference is an indirect one-dimensional estimation of abdominal fat- an error of 3.9 cm in WC would translate to about 3 pounds or 1.4 kg of abdominal fat. To estimate the relevance of the different variability between the manual method and the 3D-scanner, we calculated the difference in cross-sectional area of the abdomen of a hypothetical person with a WC of 100 cm, considering a measurement error of 3.9 cm, corresponding to the inter-observer variability or random error by the manual method. Assuming a circumferential shape, an error of 3.9 cm in WC would correspond to a cross-sectional area of ± 64.3 cm^2 (a radius of 15.9^2 for a WC of 100 cm × π, minus a radius of 16.5^2 for a WC of 103.9 × π).

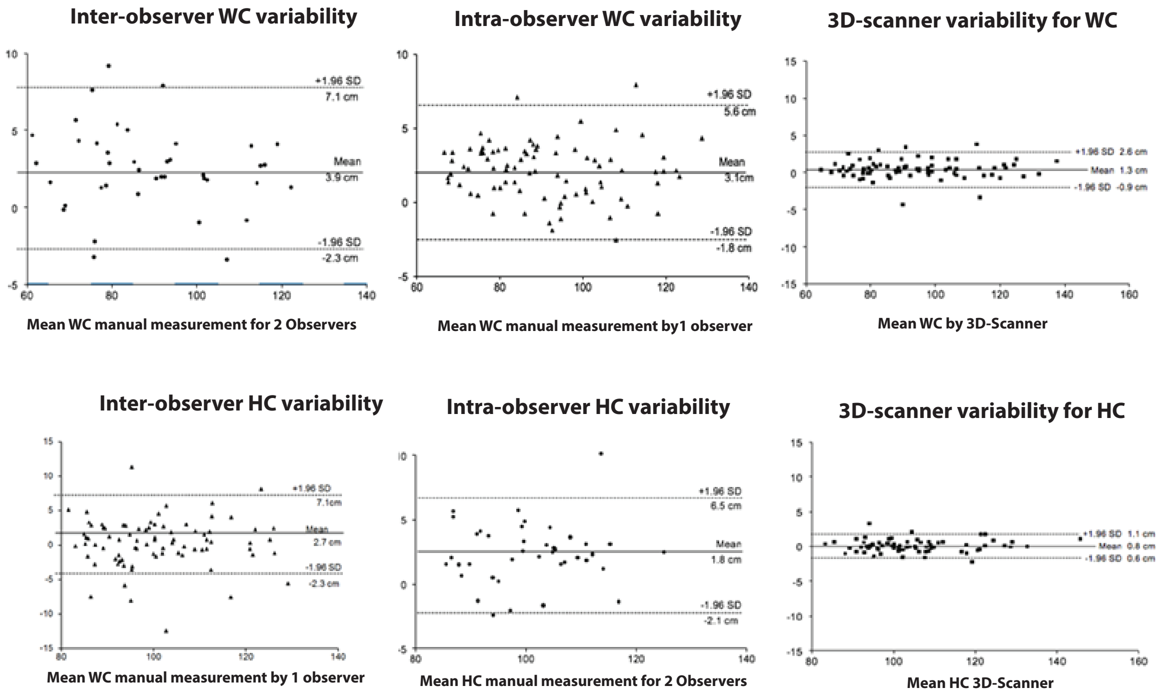

Figure 2: Bland-Altman Plots illustrating the differences in the reproducibility of WC and HC as measured manually versus using the 3D-scanner for all the subjects studied.

If translated into volume and assuming a cylindrical shape with a height of 20 cm, a measurement error of 3.9 linear cm of WC corresponds to a difference in volume of 1,285 cc. Therefore, this error is not trivial when measuring WC and HC. Experiments inducing weight gain and weight loss have shown that even small changes in visceral fat can affect glucose, lipid metabolism and endothelial function significantly [22].

The poor reproducibility of WC reported in other studies may have been underestimated because most studies evaluating the reliability of manual anthropometric measures did not blind observers to previous measurements. The awareness of previous WC values can naturally bias the estimation of a second measurement. Unconscious tightening or loosing of the measurement tape, according to the observer expectations, may lead to erroneous measurements and falsely decrease both intra- and inter-observer variability. To account for this in our study, we used non-elastic, unmarked ribbons when obtaining manual measurements, to prevent observers from knowing the first reading before performing the second measurement, can eliminate some of the measurement bias. Another potential source of bias would be the inclusion of both healthy volunteers and phase II cardiac rehabilitation program participants; this was intended in the design to attempt to include a broad range of WC and HC measures.

The lack of reproducibility of manual anthropometric measurements could be related to how the methodology is interpreted and executed by different observers. Another explanation for the poor reproducibility of anthropometric measures is that anatomical landmarks and the distances described in guidelines could be imprecise and confusing [21]. Mason and Katzmarzyk [13] showed that across different manual methods the variability and resulting misclassification of subjects as abdominally obese ranged from 23 to 34% in men and 31 to 55% in women.

Central adiposity has been proven to be a major CV risk factor. With the aid of new imaging technologies like computerized tomography and magnetic resonance imaging, researchers have been able to distinguish between different abdominal fat compartments, which are associated with specific cardiometabolic profiles. Visceral abdominal fat has been shown to be more deleterious than its subcutaneous counterpart [23]. Initially, WC was considered a good surrogate marker of visceral abdominal fat, but recent studies have shown that the correlation between WC and visceral abdominal fat is just modest [24]. This could be due to the measurement error when manual techniques are used to calculate WC. It is plausible that automated WC measurements may better correlate with visceral abdominal fat than manual measurements.

Conclusion

In conclusion, a 3D-scanner using white light is a simple and reproducible way to assess central obesity and has the potential to be used in epidemiological studies and in clinical trials where central obesity is a primary or secondary outcome.

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Conflicts of Interest

Select Research (Worcester, UK), the company that designed the 3D BVI body scanner and software provided without charge the scanner used for this and other studies taking place at Mayo Clinic. Select Research and Mayo Clinic are in ongoing discussions regarding collaborative arrangements.

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