The Use of 3D Body Scanner in Medicine and Psychology: A Narrative Review

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Abstract. In this narrative review several articles that explain the application of 3D Body Scanner were analyzed. Among all published articles in the last 10 years only 14 met the inclusion criteria. There are several fields of application of this technology: Body shape and posture analysis, pediatrics, metrical analysis, and forensic medicine. The results indicate that 3D Body Scanner is a promising technology that could help clinicians and researchers to improve their work both in term of quality and time saving.

Keywords: 3D Body Scanner · Medicine · Psychology · Review

1 Introduction

Body scanning technology has been increasingly used in health research in the past years, extending its use from clothing industry. This technology allows researchers and clinicians to evaluate and obtain body shapes, sizes and great amount of data that can also be visualized thanks to an avatar. Traditionally, doctors have measured body parts by hand and use a sophisticated technology to produce 3D internal images of a patient's body. 3D body scanner can fill the gap and would enable clinicians to acquire complete 3D information of both inside and outside of patients. Three-dimensional body scanners used to capture anthropometric measurements are now becoming a common research tool because it is simultaneously efficient, cheap and provides virtually infinite number of measurements of every angle of the human body [1, 2].

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Technically, 3D body scanner is a device that generates a 3-D "point cloud" from the subject's body a constellation of 100 000–200 000 points produced by the body's surface. These data are saved into a simple digital format and can easily be converted to the most common computer-aided design formats [3]. There are different kinds of body scanner techniques, such as laser scanning and white or structured light scanning. Besides, there are diverse type of scanners, including Human Solutions, Cyberware, Wicks and Wilson, Telmat or [TC]2 Body Measurement System [4]. Laser scanners sees light and couple charged device to detect light changes on surface, whereas white/structured light scanning requires projectors as a source of light and is faster than laser-based systems. This method uses stripes of white light on the subject and cameras to capture body shapes changes. Scanners adopt different techniques to extract data. For instance, Human Solutions scanner (e.g., Vitus Smart LC3) implements a system of laser triangulation, whilst Cyberware (e.g., Model WBX) using a patented Cyberware technology provides data thanks to four scanners. Wicks and Wilson (e.g., TriFormTM/TriBody) scanners use white light and eight cameras views to extract the shape. Telmat and its turbo flash 3D system SYMCAD (System for Measuring and Creating Anthropometric Database) utilizes structured light projected on the body and cameras.

Finally, [TC]2 Body Measurement System, based on white light system, provides a digital copy due to optical lenses. According to products reviewed on www.aniwaa.com the SYMCAD III (TELEMAT Industrie) utilizes near-IR structured light and takes only 1.5 s to scan the body, whereas the aforementioned scanners require 8–15 s. The Twinstant Mobile scanner allows to scan one to five bodies simultaneously as a result of the structured light and photogrammetry technologies. The cost varies on an average range of 10.000$–30.000$, as reported by www.aniwaa.com on the top 3D full body scanners chart. Despite differences in the way data are extracted, these scanners enable to create anthropometric models. Finally, avatar can be experienced by means of immersive technologies, such as motion capture and head mounted displays, allowing the user to have an illusion of embodiment in the avatar and the feeling of presence in the virtual environment [5].

2 Methods

2.1 Search Strategy

In 2007 two reviews about the clinical use of 3D body scanner were published [3, 6]. In one these articles authors described the Healthcare Applications of 3D Body Scanner in several field: epidemiology, diagnosis, treatment, and monitoring [6]. The other one is a literature survey of research work on HBS data segmentation and modeling [3]. That is the reason why the current article starts analyzing published article since then on.

To pursue this goal, a computer-based search in two databases was performed to retrieve relevant publications. Databases used for the search were: PubMed and Google Scholar. The search string was: "3D Body Scanner" AND ["Clinical" OR "Clinical Application"]. The articles were individually scanned to elaborate whether they fulfill the following inclusion criteria: (a) research article; (b) in the field of clinical application; and (c) published in English.

3 Results

In the current review, we aim to provide an initial review of the state-of-the-art studies from 2007 to 2017 focused on the use of 3D Body Scanner in medical and clinical application. In total, 14 studies met the inclusion criteria, which were critically reviewed, and are summarized in Table 1. In the following paragraphs, we reviewed the selected studies by dividing them according to the field of application of the technology: (1) body shape and posture analysis; (2) pediatric use; (3) metrical analysis; and (4) other applications.

Table 1. Characteristics of included studies

References	Scope	3D scanner type	Outcomes
Wells et al. [7]	Investigate the relation of shape and BMI and to examine associations between age, sex, and shape	3D whole body scanner, TC2 model	Relations between BMI and shape differed significantly between the sexes, particularly with regard to age. The inverse association between height and waist in men suggests either a genetic contribution or a link between early growth pattern and predisposition to obesity
Ashdown and Na [10]	Quantify the differences in posture and the differences in the amount of bilateral variation between the older and younger woman	Human Solutions VITUS/smart 3D body scanner	Of the 36 body taken measurements, 21 were significantly different between the two groups. The changes in linear measurements and angle measurement between the younger and older women indicate that there are significant differences in posture and in the amount of bilateral variation between the two groups. These differences will affect the fit of clothing
Bretschneider et al. [15]	Determine the precision and reproducibility of the body scanner for further applications	VITUS XXL 3D body scanner	The precision of the measurements of the circumferences of a truncated cone and a column was within 1 mm of the actual values (0.29%). These results show that the body scanner can accurately, precisely and reproducibly measure the circumference of objects and human body parts
Schloesser et al. [12]	Determine the BSA in healthy term neonates by 3D scanning	Prototype scanner constructed by 3D-Shape	3D scanning is an accurate and practical method to estimate BSA in newborns. One mathematical formula (Du Bois and Du Bois) showed a distinct underestimation of BSA compared to 3D scanning, the others an overestimation
Choi and Ashdown [1]	Test the accuracy and reliability of 3D measurements when taken on active body postures and analyze the change	Human Solutions VITUS XXL 3D whole body scanner	Results of calculating the body surface change rates for the lower body showed significant changes among the active postures. The analysis of the scan measurements demonstrated that the change in sitting posture generated the largest differences. These

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References	Scope	3D scanner type	Outcomes
	in lower body surface measurements		findings show the active changes in body measurements that occur with different postures for young women with hip measurements between 95 and 105 cm
Tomkinson and Shaw [16]	Used in the clinical setting as part of the examination process to assess musculoskeletal conditions	Vitus Smart 3D whole body scanner	Most standing postural measurements demonstrated good repeatability. However, head and neck postures demonstrated poor repeatability due to large random errors brought about by large postural errors. Overall, most of the error was due to postural error rather than technical error. The relatively small technical errors highlight that this 3D measurement process is generally repeatable, while the relatively large postural errors related to the head and neck suggest that these postures probably lack the precision to be clinically useful using this procedure
Daniell et al. [8]	Quantify shape differences associated with BMI	Vitus Smart 3D whole body scanner	There were nearly perfect correlations between WBV and BMI when analyzed by sex, with WBV increasing by about 3 l for every unit of BMI. While all segmental volumes increased significantly as BMI increased, the BMI-related patterns of increase varied among different body segments. Body shape changes due to variations in body volume could have important implications in a range of fields that currently use 1D anthropometric measurements that do not capture body shape differences in the same detail
Wells et al. [13]	Information on body size and shape used for interpretation of aspects of physiology in children, including nutritional status, cardio-metabolic risk and lung function	3D-PS	3D-PS is acceptable in children aged >5 years, though with current hardware/software, and body movement artefacts, approximately one third of scans may be unsuccessful. The technique had poorer technical success than manual measurements, and had poorer precision when the measurements were viable. Compared to manual measurements, 3D-PS showed modest average biases but acceptable limits of agreement for large surveys, and little evidence that bias varied substantially with size
Lee et al. [17]	Develop and validate a method for TBI treatment planning and compensator fabrication	Scan a RANDO™ phantom positioned in a TBI treatment	In vivo measurements for an end-to-end test showed that overall dose differences were within 5%. A technique for planning and fabricating a compensator for TBI treatment using a depth camera equipped tablet and a 3D printer was demonstrated to be sufficiently accurate to be considered for further investigation

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References	Scope	3D scanner type	Outcomes
Ng et al. [14]	Investigation for clinically relevant direct anthropometrics and body composition measurement	3D surface scan	Strong associations of waist and hip circumference to tape-measured values, body surface area to the Du Bois model and body volumes to DXA volume estimates. 3D surface scanners offer precise and stable automated measurements of body shape and composition. Software updates may be needed to resolve measurement biases resulting from landmark positioning discrepancies
Serino et al. [9]	Representation of the body, in terms of body size estimations, with VR (Virtual Reality) body swapping	Size Stream 3D body scanner	After participants embodied a virtual body with a skinny belly (independently of the type of visuo-tactile stimulation), there was an update of the stored representation of the body: participants reported a decrease in the ratio between estimated and actual body measures for most of the body parts considered. Scanner is used to collect measures
Liu et al. [2]	Develop estimation formulae for the total human body volume (BV) of adult males using anthropometric measurements based on a 3D scanning technique	Three-dimensional (3D) scanner	The linear model based on human weight was recommended as the most optimal due to its simplicity and high efficiency. The proposed estimation formulae are valuable for estimating total body volume in circumstances in which traditional underwater weighing or air displacement plethysmography is not applicable or accessible
Cornelissen et al. [11]	Body image distortion in Anorexia Nervosa	Size Stream 3D body scanner	Women who are in treatment for ANSD show an over-estimation of body size which rapidly increases as their own BMI does. By contrast, the women acting as healthy controls can accurately estimate their body size irrespective of their own BMI
Kottner et al. [18]	Forensic imaging investigations	VirtoScan: mobile, multi-camera rig based on close-range photogrammetry	A surface model comparison between the high-resolution output from our in-house standard and a high-resolution model from the multi-camera rig showed a mean surface deviation of 0.36 mm for the whole body scan and 0.13 mm for a second comparison of a detailed section of the scan. The use of the multi-camera rig reduces the acquisition time for whole-body surface documentations in medicolegal examinations and provides a low-cost 3D surface scanning alternative for forensic investigations

3.1 Body Shape and Posture Analysis

Four articles are categorized into this area. In particular, two of them connect the analysis of the body scan with the Body Mass Index (BMI) [7, 8]. This index is a common indicator in many medical fields. Developing a system to calculate precisely BMI could be an interesting research topic.

Wells and colleagues [7] investigated the relation of shape and BMI, examining associations between age, sex, and shape in a group of 9617 adults. They used a 3D Body Scanner TC2 model ([TC]2, Cary, NC) for the acquisitions of the shape, body girths and their ratios; authors also collect weight and height to obtain BMI. The results of this wide study are several and specific for age and sex. While in men BMI was associated with chest and waist girths; in women, the BMI is related to the measures of hips and bust. These associations are more valid in early adulthood and they tend to decrease with age. In women, waist girths increase with age while thigh girths decreased; in men, all the measures remained stable. The authors also reported that after adjustment for other girths, particularly for men, waist was significantly and inversely associated with height [7].

The second article tried to quantify differences in body shape among people with different BMI [8]. With that aim, they used the Vitus Smart whole-body scanner (Human Solutions, Kaiserslautern, Germany) and the data analysis was made using ScanWorx Editor and translated into a readable format for use in the CySlice v.3.4 (Headus, Perth, Australia) measurement extraction software. The authors analyzed eight segmental volumes: Neck, Shoulder, Elbow, Thorax, Abdominal, Hip and Knee in 340 young adults. The authors showed that while both segmental volumes and BMI increased significantly, the BMI-related patterns of increase varied among the different body parts analyzed. Accordingly, authors who underline the importance of understanding this relationship in order to develop a Body Volume Index or Surface Area Index may provide a tool that is more strongly associated with shape changes than BMI [8].

Another research group uses a 3D body scanner technology in order to obtain much precise measures, as well as to calculate BMI [9]. The authors aimed to investigate if an innovative virtual reality (VR) system for the body swapping illusion can be an effective for modifying the enduring memory of the body. Results showed that after the illusion there was an update of the stored representation of the body; participants reported a decrease in the ratio between estimated and actual body measures for most of the body parts considered. These findings provide first evidence that VR body swapping can induce a change in the memory of the body. The use of the Size Stream 3D Body Scanner allows the researcher to obtain a more precise measurement of the subjects' body to be compared with the other data [9].

Ashdown and colleague [10] use 3D body scanner to analyzed posture to assess the change over the age in a sample of women. These changes have been documented in many studies and in this study these results are validate. Using 3D measurements, the authors try to quantify the differences in posture and the differences in the amount of bilateral variation between the older and younger women. An important result emerged indicating an asymmetrical body configuration for the group of older women compared to the young one. The authors recorded 36 body measurements and find that 21 were significantly different between the two groups of women. These results are important both for the clothing industries and the health field [10].

In the last article of this section authors [11] used 3D Body Scanner to obtain an avatar of the patients. The authors modified the body shape of the avatars with the aim of quantifying over-estimation of the body in anorexic patients and healthy women. Before the implementation of 3D Body Scanner and CGI technology this process would not have been possible; the authors combine these two tools to create an innovative system. The results demonstrate the great utility of the system proposed to create personalized avatars of patients to assess their body image perception [11].

3.2 Pediatric Use

Two articles analyzed the possible use of the 3D Body Scanner with children in two different age sample.

In the first article authors [12] try to determinate the Body Surface Area (BSA) in healthy term and near-term neonates using the 3D body scanner technology. The authors developed and use a prototype constructed especially for the study by 3D-Shape, Erlangen, Germany because no commercial scanners are suitable to use with neonates. On 209 infants analyzed, only 53 acceptable images are collected. Despite this, the authors conclude that 3D scanning is an accurate and practical method to estimate BSA in neonates because allow to obtain individual day to day measures [12].

Wells and colleagues analyzed the Acceptability, Precision and Accuracy of 3D Photonic Scanning obtained with NX16 instrumentation ([TC]2, Cary, North Carolina) [13]. They collect measures manually and by 3D-PS in a multi-ethnic sample of 1484 child. Manual measurements were successful in all cases. Although successful scans were only obtained in 70.7%, mostly because of the movement of children. Compared to manual measurements, 3D body scanner measures had modest average biases but acceptable limits of agreement for large surveys, and little evidence that bias varied substantially with size.

3.3 Metrical Analysis

Measurement repeatability has important decision-making implications for clinicians and researchers when assessing individuals.

In their research Ng and colleagues [14] investigated if 3D body surface scanners can provide interested clinically direct anthropometrics and body composition estimates. They analyzed thirty-nine healthy adults with different age, sex and BMI with a Fit3D Proscanner (Fit3D Inc., Redwood City, CA, USA), dual energy X-ray absorptiometry (DXA), air displacement plethysmography (ADP), and tape measurements. The authors concluded that 3D surface scanners offer precise and stable automated measurements of body shape and composition. In particular, the use of 3D surface scanning is an accurate, precise and automated substitute to other methods such as measuring tape, ADP and DXA [14].

In the second paper analyzed by the authors [15], they try to establish how the measurements obtained with VITUS XXL 3D body scanner are precise and reproducible. Bretschneider and colleagues compared geometric shapes and human body parts using a measuring tape and the body scanner. Accordingly with the expectations, the results show that the measurements obtained with 3D body scanner are accurate, precise, and reproducible both for the circumference of objects and human body parts [15].

Choi and colleagues [1] used 3D scans to measure and analyze lower body measurement change for various active body positions. They compared the measurements from each posture to a standing posture and tested the reliability of the 3D measurements on active postures. Also, authors compare 3D scan measurements using virtual tools on the computer screen with traditional manual anthropometric measurements. The measurement obtained from 3D scans constitutes a reliable and appropriate method for comparative measurements between active body positions, contrary to standard anthropometric methods [1].

Four articles about the accuracy of the 3D body scanner measurement were published in 2013 by Tomkinson and Shaw [16]. The aims of the study were to quantify both the repeatability of direct measurements of standing posture as well as the characteristics of the postural and technical errors. During the process emerged that most of the error arose from postural error rather than technical ones. Accordingly, the authors concluded that 3D measurement process is repeatable, while the problem was related to the head and neck postures required during the process [16].

The last study of this section aimed to develop estimation formulae for the total human body volume (BV) of adult males [2]. To do that, the authors used measurements collected through a 3D body scanner technique. A regression analysis of BV based on four key measurements was conducted and eight total models of human BV show that the predicted results fitted by the regression models. So, the proposed estimation formulae are useful in estimating total body volume instead of classical measurement techniques [2].

3.4 Other Applications

Another interesting application of 3D body scanner technology is presented by Lee and colleagues [17]. They studied an innovative system to create a compensator in order to allow a better and uniform distribution throughout the body during a session of total body irradiation (TBI). Using depth-sensing cameras (Project Tango Developer Kit, Google, Inc., Mountain View, CA, USA) and 3D printing authors create a tablet to scan the body and elaborate and sending the data to the printing. The characteristics of the process and of the compensator allow to consider this prototype an interesting subject for future investigations [17].

3D body scanning techniques could be used profitably also in the forensic field. Kottner and colleagues [18] present an application of VirtoScan, a mobile, multi-camera rig based on close-range photogrammetry, for this kind of analysis. The aim is to add this measurements with other post-mortem investigations like post-mortem computed tomography (PMCT) and post-mortem magnetic resonance imaging (PMMR). The system presented allows to dramatically reduce the acquisition time for the whole-body surface during the medicolegal examinations providing a detailed low-cost 3D surface scanning for forensic investigations.

4 Discussion

Within the analyzed articles, it emerged that 3D body Scanner is a valid instrument that allows to research and clinicians to acquire easily a lot of information about their patients.

The fields of application in medicine for this technology are many and in each of these the implementation of the scanner can bring benefits.

The scanner was used to took measures in several research papers, most of the time to obtain precision and saving time, both for adults and children, even neonates. On the one hand, the possibility of obtaining several body indicators in a short amount of time encourage the researcher to use this toll. On the other hand, the cost of the technology and problem of space could not entice the clinicians to use the scanner.

Despite this, the use with children requires to overcome some problems, especially regarding the movement of the sample. Realistically, most of these limitations could be addressed through further technological development, turning this technology into a gold standard in the pediatric analysis.

The analysis performed to control the stability and the accuracy of the 3D body scanner technology reported very interesting and positive results. All the articles report that this tool is much more precise, fast and accurate than classical measurement systems.

Finally, the advantages of the use of the 3D body scanner overcome the problems and limitations identified in the analysis. Thus, this technology constitutes a useful tool for several applications in medicine and the clinical field.

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