applied sciences

MDPI

Perspective

A Review of Commercially Available 3D Surface Imaging Systems for Body Composition Estimation

Alice May Bullas [1,*], Rebecca Greenwood [1], Michael Thelwell [2] and Simon Choppin [1]

[1] Sports Engineering Research Group, Sport and Physical Activity Research Centre, Sheffield Hallam University, Sheffield S1 1WB, UK
[2] Advanced Wellbeing Research Centre, Health Research Institute, Sheffield Hallam University, Olympic Legacy Park, 2 Old Hall Road, Sheffield S9 3TU, UK
* Correspondence: a.bullas@shu.ac.uk; Tel.: +44-(0)114-2554184

Featured Application: This review provides an overview of commercially available 3D surface imaging systems that provide body composition estimates for practitioners and researchers, encouragement for system manufacturers to increase the public availability of user and system details, and a call for standardisation within this field.

Abstract: Recent literature has suggested 3D surface imaging to be a potential method of estimating body composition. The aim of this study was to provide an overview of commercially available 3D surface imaging systems that provide body composition estimates. User and system details of complete commercially available whole body 3D surface imaging systems, which estimate body composition, were collated from May to June 2022. Six 3D body surface imaging systems were identified, each of which provided varying amounts of user and system details. As this information is necessary to ensure the correct selection of system, appropriate use, and interpretation of outputs, manufacturers should seek to publicly present more detailed user and system details, international standards groups and training associations should seek to encourage standardisation, and practitioners and researchers should request additional details where necessary and validate their system prior to use, and end users should cautiously interpret outputs without the availability of comprehensive user and system details.

Keywords: anthropometry; 3D body scanning; body measurement; kinanthropometry; body fat; digital; technology

check for updates

Citation: Bullas, A.M.; Greenwood, R.; Thelwell, M.; Choppin, S. A Review of Commercially Available 3D Surface Imaging Systems for Body Composition Estimation. *Appl. Sci.* **2022**, *12*, 8815. https://doi.org/10.3390/app12178815

Academic Editors: Antonio Jesús Sanchez-Oliver, Raul Domínguez Herrera, José Miguel Martínez-Sanz and Raquel Vaquero-Cristobal

Received: 18 July 2022
Accepted: 20 August 2022
Published: 1 September 2022

1. Introduction

Body composition describes and quantifies components of body mass [1]. It is regarded as a central element of health and sports practice and research due to the impact of body composition components on all physiological functions [2,3]. Consequently, body composition is regarded as essential in countless fields including growth, development, aging, sports performance and training, nutrition, obesity, malnutrition, pathology, and physical activity. Its descriptions can be broken down into five levels: atomic, molecular, cellular, tissue–organ, and whole body [4]. For each level, there are various models that consist of several components, whereby body mass is considered as the sum of all components of the model.

There are several methods through which the various levels and associated compartments of body composition can be estimated. These methods include:

- Direct: chemical carcass analysis and neutron carcass activation analysis [5],
- Indirect: using the relationship between cadaver data and other measurements such as densitometry, total body counting (40 K) measurements, dilution techniques, magnetic resonance imaging (MRI), and dual-energy X-ray absorptiometry (DEXA) [5],

- Doubly indirect: using the relationship between direct or indirect measurements and body parameters including anthropometry (such as skinfolds, weight, height, girths), bioelectrical impedance analysis (BIA), and ultrasound [5].

Reviews of these methods can be found within Heymsfield et al. [6] or Duren et al. [7]. In summary, there is an unmet need for an accurate, noninvasive, ionizing radiation-free body composition measurement suitable for regular use [8]—particularly when physical touch is culturally, practically, or socially unacceptable.

Recent literature has suggested three-dimensional (3D) surface imaging to be a possible method of estimating body composition [8–19]. 3D surface imaging (also known as 3D body, optical or photonic scanning) creates digital 3D images of the external geometry of the human body, which when stitched together creates a digital—to scale—representation, herein referred to as a humanoid (also known as a digital model, avatar, or twin) [18]. Using this technology, body composition is estimated through anthropometry using anthropometrics extracted from the humanoid. As such estimation of body composition through 3D surface imaging is a doubly indirect method; the prediction of body composition using regression algorithms of the relationship between anthropometrics and direct or indirect methods [5]. Thus, 3D surface imaging body composition estimations are dependent upon the accuracy of the humanoid mesh—and similar to body composition estimations through manual anthropometry—the accuracy of landmarking, anthropometry definitions, and the predictive regression algorithm [10,18]. This method provides the possibility of technician free, quick, contactless, ionizing radiation-free body composition measurement suitable for regular use [10,18]. Thereby making the technology suitable for when physical touch is culturally, practically, or socially unacceptable.

Previously, 3D surface imaging technology has been expensive and consequently inaccessible to many. However, the increasing usefulness of 3D surface imaging in entertainment, fashion, ergonomics, and health has bolstered the market [20], driving down prices and increasing accessibility. Each 3D surface imaging system uses different hardware, software, calibration techniques, anthropometric definitions, and data collection procedures—providing differing degrees of validity in body composition estimation [10,18]. Thus, to ensure the selection of the most suitable system, the appropriate use and correct interpretation of its outputs, clarity of user and system details are necessary. However, this information is inconsistently presented by system manufacturers, thereby risking incorrect selection of systems, inappropriate use, and misinterpretation of outputs—jeopardising the reputation and potential usefulness of this technology. The aim of this study was to provide an overview of commercially available complete whole body 3D surface imaging systems that provide body composition estimates.

2. Materials and Methods

This was a cross sectional descriptive study in which the user and system details of commercially available complete whole body 3D surface imaging systems were collected from the system manufacturers and publicly available information.

2.1. Sample

From March 2021 to March 2022 Sheffield Hallam University (SHU), UK, and Technische Universität (TU) Dresden, Germany, with the support of the IEEE 3D Body Processing Industry Connections group, collated a list of 3D surface imaging companies globally. From May to June 2022 each of these companies were explored, and those identified as providing commercially available complete whole body 3D surface imaging systems; including hardware and software, from which body composition measures could be extracted were included. Solely app-based systems were excluded, because of an increased prevalence of predicting the 3D mesh and thereby a greater prevalence of synthetic data (averages from population databases)/humanoid repair.

2.2. Data Collection

For each system the following 23 user and system details were collected:

1. Manufacturer name
2. Manufacturer location
3. System name
4. System description
5. Technology
6. Hardware cost (USD; excluding shipping)
7. Subscription cost (USD)
8. System volume (width × depth × height (cm))
9. Capture volume (width × depth × height (cm))
10. User mass minimum/maximum (kg)
11. User height minimum/maximum (cm)
12. Minimum age (years)
13. Capture duration (seconds)
14. Post processing duration (seconds)
15. Reported accuracy of humanoid mesh
16. How reported accuracy of humanoid mesh was established.
17. Reported accuracy of anthropometrics
18. How reported accuracy of anthropometrics was established.
19. Reported accuracy of body composition estimates
20. How reported accuracy of body composition estimates was established.
21. Estimated body composition components and estimation methods
22. Published validation studies on system
23. Use of data by company.

These details were deemed necessary for the selection, use, and interpretation of outputs from 3D surface imaging systems—based on previous reviews of 3D surface imaging systems [16,21]. This data was collected through the surveying of publicly available online information and direct communication with the system manufacturers. Each system manufacturer was contacted a maximum of 5 times by email and asked to provide the information before 30 June 2022. Ethical approval was sought and granted from Sheffield Hallam University (Ethic Review ID: ER43903722).

3. Results

Of the 52 3D surface imaging systems identified, six 3D body surface imaging system manufacturers were found to provide commercially available complete whole body 3D surface imaging systems from which body composition measures were estimated. The user and system details for each system are presented in Table 1, alongside the reported accuracy of the humanoid mesh, anthropometrics, and body composition estimates for each system in Table 2.

Table 1. The user and system details for 3D surface imaging systems with the body composition estimation capability, in which “-“ represents not reported.

System Name	**Bodygee Orbiter**	**Fit3D Proscanner**	**mPod**	**Naked**	**Shapescale**	**Styku S100X**
Manufacturer	Bodygee	Fit3D	mPort	Naked Labs	Shapescale	Styku
Manufacturer location	Switzerland	USA	Australia	USA	USA	USA
System name	Bodygee Orbiter	Fit3D Proscanner	mPod	Naked	Shapescale	Styku S100X
System description	Rotating platform and tablet	Rotating platform and instrumented tower.	Instrumented booth.	Rotating platform and Instrumented mirror.	Rotating instrumented tower.	Rotating platform
Technology	Structured light	Structured light	Structured light	Structured light	Structured light	Structured light
Website	https://bodygee.com (accessed 1 July 2022)	https://fit3d.com (accessed 1 July 2022)	https://mport.com (accessed 1 July 2022)	https://nakedlabs.com (accessed 1 July 2022)	https://shapescale.com (accessed 1 July 2022)	https://fit3d.com/ (accessed 1 September 2022)
Cost hardware (USD; exc. shipping)	$6500	$10,000	Hardware not for sale	$1395	$799	£4950
Cost subscription (annual)	-	No subscription costs	$35	No subscription costs	$9.99/$12.99	£799 per year (£79 per month)
System volume (w × d × h (cm))	150 × 150 × 200	91.44 × 182.88 × 180.34	180 × 170 × 240	76.5 × 90.5 × 158.8	120 × 120 × 145	131 × 185 × 117
Capture volume (w × d × h (cm))	-	-	-	-	-	-
User mass min./max. (kg)	None/200	-/272	-/200	-/150	11.3/160	23/250
User height min./max. (cm)	None/210	-/213	-	100/198	-/193	137/194
Min. age (years)	16+	13+	14+	18+	2+	18+
Capture duration (seconds)	60–90	35	7	15	<60	30–40
Post processing duration (minutes)	5–10	-	-	2–3	-	2

Table 2. The reported accuracy of the humanoid mesh, anthropometrics and body composition estimates for each 3D surface imaging system, in which "-" represents not reported.

System Name	Bodygee Orbiter	Fit3D Proscanner	mPod	Naked	Shapescale	Styku S100X
Reported accuracy of humanoid mesh (+/− mm/%)	-	-	10/-	~2.5/-	~1.6/1.5	-
How was accuracy of humanoid mesh established.	-	-	-	-	-	-
Reported accuracy of anthropometrics (+/− mm/%)	-	-	-	~5–15/-	-	~2.5–5/0.5
How was accuracy of anthropometrics established.	-	-	-	-	-	-
Body composition components estimated	Fat Mass (kg, %); Lean Mass (kg, %)	Fat Mass (kg, %); Lean Mass (kg, %)	Fat Mass (%); Lean Mass (kg, %)	Fat Mass (kg, %); Lean Mass (kg, %)	Fat Mass (%: absolute, regional); Lean Mass (%: absolute, regional)	Fat Mass (kg, %); Lean Mass (kg, %).
Method of body composition estimation	Friedl et al. [22] algorithm.	Proprietary algorithm: Fit3D v4.0 body fat.	-	Proprietary algorithm based on unspecified U.S. Navy formula.	-	Proprietary algorithm: Syku Phoenix.
How body composition estimate algorithms were created.	DEXA and anthropometry of 150 military trained women [22].	DEXA and anthropometry of 832 participants [23].	-	DEXA and anthropometry.	-	Advanced: DEXA and anthropometry Basic: BIA and anthropomerty.
Reported accuracy of body composition estimates (+/− kg/%)	-/<3	-/~5	-	-/2.5	-	-
How was accuracy of body composition estimates established.	-	DEXA and anthropometry of 832 participants [23].	-	-	-	-
Privacy policy	www.bodygee.com/privacy/ (accessed 1 July 2022)	www.fit3d.com/privacy (accessed 1 July 2022)	www.mport.com/privacy-policy.html (accessed 1 July 2022)	www.nakedlabs.com/privacy (accessed 1 July 2022)	www.shapescale.com/blog/privacy-policy/ (accessed 1 July 2022)	www.styku.com/privacy (accessed 1 July 2022)
Published body composition research using system.	None reported	[8,13,15,19,24–28]	None reported	[15,19]	[15,19]	[15,17,19,28,29]

4. Discussion

Six complete whole body commercially available 3D surface imaging systems that estimate body composition were identified, and the user and system details for each were collated. The results highlighted that commercially available whole body 3D surface imaging systems present a range of user and system details. Although the details collated are important for appropriate selection, use, and interpretation of outputs of each system, user and system details were not universally publicly available.

4.1. User Details

The commercially available 3D surface imaging systems reviewed in this paper reported minimum and maximum user height and weight of 0 (none) to 213 cm, and 0 (none) to 272 kg, respectively. This demonstrates that commercially available 3D surface imaging systems that estimate body composition can easily accommodate a variety of body sizes, unlike alternatives such as DEXA [30].

However, the validity of body composition estimations for different sizes, ethnicities, and races remains unknown, as few system manufacturers reported details regarding the population sample upon which their body composition estimation predictive algorithms are based upon, and of those that do, the majority use predictive algorithms based upon military personnel such as Hodgdon & Beckett [31] and Friedl et al. [22]. Furthermore, three system manufacturers; Fit3D, Naked Labs, and Styku, report developing their own proprietary predictive algorithms using DEXA for body composition estimation through partnerships with research groups, universities, and medical facilities. This is of concern when exploring the potential validity of systems for all, as it is suggested that DEXA demonstrates a scaling error when body size increases [32] and—as an indirect method—is also an estimation [33]. It is also worthwhile to note that, for system manufacturers that have their own proprietary predictive algorithms, they are often continuously developed and updated alongside their humanoid mesh and anthropometry code—as outlined on the Fit3D website; "As Fit3D aggregates additional and statistically relevant sets of data, we will continue to revise our body fat algorithm to ensure that we are providing the most accurate assessment of body composition possible through anthropometric measurements . . . As Fit3D publishes its research and updates/upgrades its models, we integrate the research and models into the product" [23]. Thus, whilst this may result in more representative algorithms, it is vital to know which version of the algorithm is used, as it is possible algorithm updates may occur between uses, thereby impacting comparison and anthropometric surveying.

All system manufacturers reported a minimum user age, ranging from 2 to 18 years, demonstrating that commercially available 3D surface imaging systems that estimate the body composition of children and young persons are available. This is advantageous as there is an increasing volume of research recommending the use of 3D surface imaging systems on children [13,14,16,34,35]. The potential usefulness of this technology for regular use with children and young persons is exacerbated by the unsuitability of existing body composition estimation methods for children—such as DEXA, due to its cost and use of ionizing radiation, as discussed by Simoni et al. [36]. However, to the researcher's knowledge, no system manufacturers provided child specific guidance, packages, or evidence of the accuracy of body composition estimations when measuring children or young persons. This is of concern as it is suggested that the potential usefulness of this technology with children and young persons is reliant upon child specific guidance and predictive algorithms [16,37].

4.2. System Details

Although all commercially available 3D surface imaging systems reviewed in this paper were based upon structured light they demonstrated a variety of system details. The systems demonstrated capture durations of 7 to 90 s. Whilst this is quicker than manual measurement, it is still possible for movement artefacts to influence the accuracy of the data collected. In addition, the systems were reported to cost between $799 to $10,000, thereby evidence systems are available at a variety of costs, and thus accessible for those with a variety of budgets. Although reported within Daanen & Haar's review of 3D surface imaging systems [21], no system manufacturer reported capture volume. It is possible that this information is reflected in the distribution of the maximum user height and weight. However, as users could present the same height and weight but different body girths, such information would have been valuable to confirm the suitability of the systems for different body sizes.

Accuracy of the Humanoid Mesh, the Anthropometrics Extracted, and the Predictive Algorithms

Due to instrument imprecision and human inconsistencies, error is inevitable, and complete 100% accuracy is unachievable [38], thus all systems will present degrees of error. However, of the commercially available 3D surface imaging systems reviewed, only four of the six manufacturers reported accuracy for one field; humanoid mesh, anthropometrics, or body composition estimates, of which none reported accuracy for all fields. For those that did report accuracy for body composition estimates, it ranged between 2.5—5%. This is comparable to the reported accuracy values within published literature. For example, Tinsley et al. [19] reported RMS-%CV of 2.3–4.3% for body fat percentage, 2.5–4.3% for fat mass, and 0.7–1.4% for fat-free mass in an assessment of 4 systems, when compared with 4C model of air displacement plethysmography, DEXA, total body water and bioimpedance spectroscopy of 139 participants. Ng et al. [8] reported the predictive body composition algorithm of a Fit3D Proscanner to demonstrate a root mean square error of 2.4 kg for fat mass and 2.2 kg for fat-free mass, when compared to DEXA, when measuring 39 participants.

Transparency regarding how accuracy is established is essential to ensure informed judgment of the systems outputs and their suitability for use within different contexts [39]. However, only two system manufacturers provided details regarding the process through which accuracy was established. Typically, this was because the accuracy had been established in an external research project. However, it is worthwhile to note that reported accuracy is only valid for the hardware and software versions, population samples, and predictive algorithms used at the time of data collection. Thus, any alterations to these would render reported accuracy invalid. It is unknown why 3D surface imaging system manufacturers are not reporting their systems' accuracy for one or all fields. With the countless potential applications of 3D surface imaging devices, there are potential applications for systems with different degrees of accuracy. By not reporting 3D surface imaging systems accuracy, we risk the incorrect use and misinterpretation of outputs, thereby damaging the reputation and potential usefulness of this technology.

Although not sought within this review, it was noted by the researchers that no 3D surface imaging system manufacturer publicly reported the fidelity of the 3D humanoid mesh created through their system; the degree to which the humanoid is comprised of true data and systematic data, the type and amount of smoothing, filtering and repair the humanoid undergoes during post processing. Such information is important for the appropriate selection, use, and interpretation of outputs. This is likely to become increasingly important as the prevalence of app-based technologies, specifically those using passive stereo of front and side profile images in which such techniques are more prevalent, increases.

4.3. Availability of Information

Within this review, no 3D surface imaging system manufacturer publicly presented all sought user and system details. Furthermore, several companies were unable or refused to provide the requested details about their systems when contacted directly. The details requested were not sensitive intellectual property, they were not niche pieces of information—they were fundamental user and systems details that would be necessary for any system to be used and its outputs interpreted correctly. The justification for why much of this information was not, and remains, publicly unavailable is not known. It is possible that such information does not exist, might be provided within a user manual or anecdotally upon purchase, or is perceived as intellectually sensitive. Regardless, it is essential that such information is available prior to use to ensure the acquisition of the most suitable system. Although international guidance exists for the validation of 3D surface imaging systems and anthropometry extraction through the International Standard Organisation (ISO) 20685:2018 [40], no standardisation or guidance exists for the estimation of body composition components.

4.4. Limitations of Body Composition through 3D Surface Imaging

It is essential we remain realistic regarding the capabilities of 3D surfacing imaging in estimating body composition. Using 3D surface imaging to estimate body composition is a doubly indirect method, predicting body composition through the use of a predictive regressions algorithm of the relationship between anthropometrics and direct or indirect methods. Consequently, actions such as using the term 'measurement' or suggesting differential abilities between internal and visceral fat are fundamentally incorrect. By overselling the capabilities of 3D surfacing imaging to estimate body composition we risk the inappropriate selection and interpretation of outputs, alongside damaging the reputation and potential usefulness of this technology. In addition, at present, the differing hardware, software, calibration techniques, anthropometric definitions, and data collection procedures used by each system, makes the comparison of body composition estimates unsuitable. Thereby limiting its suitability for use in research and practice. A further critical review of 3D surfacing imaging as a method of estimating body composition is presented by Heymsfield et al. [9].

4.5. Study Limitations & Future Research

This study focuses solely on commercially available whole body surface imaging systems, however, body composition estimations are available from app-based 3D surface imaging systems. With the increasing prevalence of mobile based systems, it is essential that future research also encompasses app-based systems. In addition, the study only explores the publicly available user and system details of systems, making note of the published research exploring the validity of the systems. Consequently, further research may seek to summarise the results of these studies. Furthermore, further research is required to explore the validity of body composition estimations from 3D surface imaging systems across sex, size, shape, age, ethnicity groups, atypical populations groups, and inter system agreement.

4.6. Recommendations

To ensure the correct selection of the system, appropriate use and interpretation of outputs detailed user and systems details are required. At present, for the majority of 3D surface imaging systems, this information is not publicly available. Consequently, manufacturers of 3D surface imaging systems should seek to present more detailed user and system details, descriptions of their target audience, the populations from which their body composition estimations are based upon and cohort specific guidance. International standards group and training associations should seek to encourage inter system agreement in body composition estimation using 3D surface imaging devices. This could be achieved by providing common landmark definitions and predictive algorithms, alongside the incorporation of 3D surface imaging systems into their battery of measurement methods—particularly with the increasing prevalence of app-based 3D surface imaging systems and thus increasing accessibility of this technology. Practitioners and researchers need to ensure they approach the use of 3D surface imaging systems critically; request additional details where necessary and validate their system prior to use. End users should be cautious about the interpretation of outcome data if uncertain of the manufactures user and system details.

5. Conclusions

Several 3D surface imaging systems that extract body composition are commercially available, each presenting different user and system details. Although this information is necessary to ensure the correct selection of system, appropriate use, and interpretation of outputs, it is not consistently publicly available. Consequently, it is recommended that manufacturers should strive to present, as well as researchers and practitioners seeking to identify this information. As this information is necessary to ensure the correct selection of system, appropriate use and interpretation of outputs, international standards groups and training associations should encourage standardisation of information provided by manufacturers. Practitioners and researchers should request additional details where necessary and validate their system prior to use, and end users should cautiously interpret outputs without the availability of comprehensive user and system details.

Author Contributions: Conceptualization, A.M.B.; methodology, A.M.B.; Data curation, A.M.B. and R.G.; writing—original draft preparation, A.M.B.; writing—review and editing, A.M.B., S.C., M.T. and R.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by Sheffield Hallam University (Ethic Review ID: ER43903722, May 2022).

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Thank you to Loretta Reiss from the IEEE 3DBP for their help, support and guidance, and 3D surface manufacturers for their cooperation.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Campa, F.; Toselli, S.; Mazzilli, M.; Gobbo, L.A.; Coratella, G. Assessment of body composition in athletes: A narrative review of available methods with special reference to quantitative and qualitative bioimpedance analysis. *Nutrients* **2021**, *13*, 1620. [CrossRef] [PubMed]
2. Santanasto, A.J.; Newman, A.B.; Strotmeyer, E.S.; Boudreau, R.M.; Goodpaster, B.H.; Glynn, N.W. Effects of changes in regional body composition on physical function in older adults: A pilot randomized controlled trial. *J. Nutr. Health Aging* **2015**, *19*, 913–921. [CrossRef] [PubMed]
3. Lukaski, H.; Raymond-Pope, C.J. New frontiers of body composition in sport. *Int. J. Sports Med.* **2021**, *42*, 588–601. [CrossRef] [PubMed]
4. Wang, Z.M.; Pierson, R.N., Jr.; Heymsfield, S.B. The five-level model: A new approach to organizing body-composition research. *Am. J. Clin. Nutr.* **1992**, *56*, 19–28. [CrossRef]
5. Deurenberg, P.; Schutz, Y. Body composition: Overview of methods and future directions of research. *Ann. Nutr. Metab.* **1995**, *39*, 325–333. [CrossRef]
6. Heymsfield, S.B.; Wang, Z.; Baumgartner, R.N.; Ross, R. Human body composition: Advances in models and methods. *Annu. Rev. Nutr.* **1997**, *17*, 527–558. [CrossRef]
7. Duren, D.L.; Sherwood, R.J.; Czerwinski, S.A.; Lee, M.; Choh, A.C.; Siervogel, R.M.; Chumlea, W.C. Body composition methods: Comparisons and interpretation. *J. Diabetes Sci. Technol.* **2008**, *2*, 1139–1146. [CrossRef]
8. Ng, B.K.; Hinton, B.J.; Fan, B.; Kanaya, A.M.; Shepherd, J.A. Clinical anthropometrics and body composition from 3D whole-body surface scans. *Eur. J. Clin. Nutr.* **2016**, *70*, 1265–1270. [CrossRef]
9. Pleuss, J.D.; Talty, K.; Morse, S.; Kuiper, P.; Scioletti, M.; Heymsfield, S.B.; Thomas, D.M. A machine learning approach relating 3D body scans to body composition in humans. *Eur. J. Clin. Nutr.* **2019**, *73*, 200–208. [CrossRef]
10. Heymsfield, S.B.; Bourgeois, B.; Ng, B.K.; Sommer, M.J.; Li, X.; Shepherd, J.A. Digital anthropometry: A critical review. *Eur. J. Clin. Nutr.* **2018**, *72*, 680–687. [CrossRef]
11. Milanese, C.; Giachetti, A.; Cavedon, V.; Piscitelli, F.; Zancanaro, C. Digital three-dimensional anthropometry detection of exercise-induced fat mass reduction in obese women. *Sport Sci. Health* **2015**, *11*, 67–71. [CrossRef]
12. Harbin, M.M.; Kasak, A.; Ostrem, J.D.; Dengel, D.R. Validation of a three-dimensional body scanner for body composition measures. *Eur. J. Clin. Nutr.* **2018**, *72*, 1191–1194. [CrossRef]
13. Wong, M.C.; Ng, B.K.; Kennedy, S.F.; Hwaung, P.; Liu, E.Y.; Kelly, N.N.; Pagano, I.S.; Garber, A.K.; Chow, D.C.; Heymsfield, S.B.; et al. Children and adolescents' anthropometrics body composition from 3-D optical surface scans. *Obesity* **2019**, *27*, 1738–1749. [CrossRef] [PubMed]
14. Ng, B.K.; Sommer, M.J.; Wong, M.C.; Pagano, I.; Nie, Y.; Fan, B.; Kennedy, S.; Bourgeois, B.; Kelly, N.; Liu, Y.E.; et al. Detailed 3-dimensional body shape features predict body composition, blood metabolites, and functional strength: The Shape Up! studies. *Am. J. Clin. Nutr.* **2019**, *110*, 1316–1326. [CrossRef] [PubMed]
15. Tinsley, G.M.; Moore, M.L.; Dellinger, J.R.; Adamson, B.T.; Benavides, M.L. Digital anthropometry via three-dimensional optical scanning: Evaluation of four commercially available systems. *Eur. J. Clin. Nutr.* **2020**, *74*, 1054–1064. [CrossRef] [PubMed]
16. Gallagher, D.; Andres, A.; Fields, D.A.; Evans, W.J.; Kuczmarski, R.; Lowe, W.L., Jr.; Lumeng, J.C.; Oken, E.; Shepherd, J.A.; Sun, S.; et al. Body composition measurements from birth through 5 years: Challenges, gaps, and existing & emerging technologies—A National Institutes of Health Workshop. *Obes. Rev.* **2020**, *21*, e13033. [CrossRef]

17. Bennett, J.P.; Liu, Y.E.; Quon, B.K.; Kelly, N.N.; Wong, M.C.; Kennedy, S.F.; Chow, D.C.; Garber, A.K.; Weiss, E.J.; Heymsfield, S.B.; et al. Assessment of clinical measures of total and regional body composition from a commercial 3-dimensional optical body scanner. *Clin. Nutr.* **2022**, *41*, 211–218. [CrossRef]
18. Kristijan, B.; Bojanić, D.; Petković, T.; Pribanić, T. A review of body measurement using 3D scanning. *IEEE Access* **2021**, *9*, 67281–67301. [CrossRef]
19. Tinsley, G.M.; Moore, M.L.; Benavides, M.L.; Dellinger, J.R.; Adamson, B.T. 3-Dimensional optical scanning for body composition assessment: A 4-component model comparison of four commercially available scanners. *Clin. Nutr.* **2020**, *39*, 3160–3167. [CrossRef]
20. Allied Market Research: 3D Scanning Market Outlook–2030. Available online: https://www.alliedmarketresearch.com/3D-scanning-market (accessed on 1 June 2022).
21. Daanen, H.A.; Ter Haar, F.B. 3D whole body scanners revisited. *Displays* **2013**, *34*, 270–275. [CrossRef]
22. Friedl, K.E.; Westphal, K.A.; Marchitelli, L.J.; Patton, J.F.; Chumlea WCGuo, S.S. Evaluation of anthropometric equations to assess body-composition changes in young women. *Am. J. Clin. Nutr.* **2001**, *73*, 268–275. [CrossRef] [PubMed]
23. Fit3D-Mount Sinai Partnership & Accuracy: Partnership & New Body Fat Algorithm. Available online: https://fit3d.com/blog/2018/2/28/mount-sinai-fit3d-partnership (accessed on 1 June 2022).
24. Wagner, D.R.; Castañeda, F.; Bohman, B.; Sterr, W. Comparison of a 2D iPad application and 3D body scanner to air displacement plethysmography for measurement of body fat percentage. *J. Hum. Nutr. Diet.* **2019**, *32*, 781–788. [CrossRef]
25. Totosy de Zepetnek, J.O.; Lee, J.J.; Boateng, T.; Plastina, S.E.; Cleary, S.; Huang, L.; Kucab, M.; Paterakis, S.; Brett NRBellissimo, N. Test–retest reliability and validity of body composition methods in adults. *Clin. Physiol. Funct. Imaging* **2021**, *41*, 417–425. [CrossRef]
26. Tian, I.Y.; Ng, B.K.; Wong, M.C.; Kennedy, S.; Hwaung, P.; Kelly, N.; Liu, E.; Garber, A.K.; Curless, B.; Heymsfield, S.B.; et al. Predicting 3D body shape and body composition from conventional 2D photography. *Med. Phys.* **2020**, *47*, 6232–6245. [CrossRef]
27. Wong, M.C.; Ng, B.K.; Tian, I.; Sobhiyeh, S.; Pagano, I.; Dechenaud, M.; Kennedy, S.F.; Liu, Y.E.; Kelly, N.N.; Chow, D.; et al. A pose-independent method for accurate and precise body composition from 3D optical scans. *Obesity* **2021**, *29*, 1835–1847. [CrossRef] [PubMed]
28. Bourgeois, B.; Ng, B.K.; Latimer, D.; Stannard, C.R.; Romeo, L.; Li, X.; Shepherd JAHeymsfield, S.B. Clinically applicable optical imaging technology for body size and shape analysis: Comparison of systems differing in design. *Eur. J. Clin. Nutr.* **2017**, *71*, 1329–1335. [CrossRef] [PubMed]
29. Silver, B.; Wilson, P.B. Reliability and Minimal Detectable Change of the Styku 3D Body Scanner. *Meas. Phys. Educ. Exerc. Sci.* **2020**, *24*, 165–171. [CrossRef]
30. Johnson Stoklossa, C.A.; Forhan, M.; Padwal, R.S.; Gonzalez, M.C.; Prado, C.M. Practical considerations for body composition assessment of adults with class II/III obesity using bioelectrical impedance analysis or dual-energy X-ray absorptiometry. *Curr. Obes. Rep.* **2016**, *5*, 389–396. [CrossRef]
31. Hodgdon, J.A.; Beckett, M.B. *Prediction of Percent Body Fat for US Navy Women from Body Circumferences and Height*; Naval Health Research Center: San Diego, CA, USA, 1984.
32. Brownbill, R.A.; Ilich, J.Z. Measuring body composition in overweight individuals by dual energy X-ray absorptiometry. *BMC Med. Imaging* **2005**, *5*, 1. [CrossRef]
33. Wells, J.C.; Fewtrell, M.S. Measuring body composition. *Arch. Dis. Child.* **2006**, *91*, 612–617. [CrossRef]
34. Loeffler-Wirth, H.; Vogel, M.; Kirsten, T.; Glock, F.; Poulain, T.; Körner, A.; Loeffler, M.; Kiess, W.; Binder, H. Body typing of children and adolescents using 3D-body scanning. *PLoS ONE* **2017**, *12*, e0186881. [CrossRef]
35. Loeffler-Wirth, H.; Vogel, M.; Kirsten, T.; Glock, F.; Poulain, T.; Körner, A.; Loeffler, M.; Kiess, W.; Binder, H. Longitudinal anthropometry of children and adolescents using 3D-body scanning. *PLoS ONE* **2018**, *13*, e0203628. [CrossRef]
36. Simoni, P.; Guglielmi, R.; Gómez, M.P.A. Imaging of body composition in children. *Quant. Imaging Med. Surg.* **2020**, *10*, 1661–1671. [CrossRef] [PubMed]
37. Choi, K.; Kim, M.; Lee, K.; Nam, O.; Lee, H.S.; Choi, S.; Kim, K. Accuracy and Precision of Three-dimensional Imaging System of Children's Facial Soft Tissue. *J. Korean Acad. Pedtatric Dent.* **2020**, *47*, 17–24. [CrossRef]
38. Harris, E.F.; Smith, R.N. Accounting for measurement error: A critical but often overlooked process. *Arch. Oral Biol.* **2009**, *54*, S107–S117. [CrossRef] [PubMed]
39. Kallet, R.H. How to write the methods section of a research paper. *Respir. Care* **2004**, *49*, 1229–1232.
40. International Standard Organisation. *3-D Scanning Methodologies for Internationally Compatible Anthropometric Databases—Part 1: Evaluation Protocol for Body Dimensions Extracted from 3-D Body Scans (ISO) 20685:2018*; International Standard Organisation: Geneva, Switzerland, 2018.