Chapter 7
Non-imaging Method: 3D Scanning

Clinton O. Njoku, Arthur D. Stewart, Patria A. Hume, and Stephven Kolose

Abstract Three-dimensional body scanning is used to determine surface anthropometry characteristics such as body volume, segment lengths and girths. Three-dimensional scanning systems use laser, light or infrared technologies to acquire shape and software to allow manual or automatically extracted measures. Body posture during scanning is important to ensure accurate measures can be made from the images. The images vary depending on the configuration, resolution and accuracy of the scanner.

Keywords Three dimensional • Body scanning • Body volume • Segment lengths Girths • Laser • Technologies • Shape • Body posture • Images • Configuration Resolution • Accuracy • Scanner

C.O. Njoku (✉)
Department of Anatomy, Faculty of Medicine–Preclinicals, Ebonyi State University, Abakaliki, Nigeria
e-mail: clinton.njoku@ebsu-edu.net

A.D. Stewart
School of Health Sciences, Robert Gordon University, Aberdeen AB10 7GJ, UK
e-mail: a.d.stewart@rgu.ac.uk

P.A. Hume
Sport Performance Research Institute New Zealand, Auckland University of Technology, Auckland, New Zealand
e-mail: patria.hume@aut.ac.nz

S. Kolose
Operations Analysis and Human Systems Group, Defence Technology Agency, New Zealand Defence Force, Auckland, New Zealand
e-mail: S.Kolose@dta.mil.nz

7.1   Why Measure Physique Using 3D Scanning?

The availability of reliable three-dimensional (3D) whole-body scanners and software-hardware suites capable of rapid measurement, data extraction and analysis has the potential to revolutionise surface anthropometry. The main driver behind 3D scanning has been the apparel industry, envisaging the possibility of garments on demand, tailored to fit each individual perfectly. 3D scanning has parallel applications in human factors, where humanoid manikins can be rescaled using the extracted measurements and animated to interact with the built environment. These techniques are already being employed in military research and in the design of mass transportation and operator workspaces. There are currently only a few examples of 3D anthropometry scanning for applications to health and exercise science (Olds and Rogers 2004) for research purposes. For example, in a study of 85 male participants who completed duel X-ray absorptiometry, Bod Pod and 3D body scanning, the comparisons of body fat percentage showed significant differences between the three methods. Although the 3D body scanner shows promise as a method of evaluating body fat percentage, more refinement is needed before it can be used as a method of assessment (Ryder and Ball 2012). Such differences relate to the physical attribute of the body being measured, and as long as 3D scanning relies on establishing body volume accurately, its body fat prediction will be predicated on the two-compartment model which naïvely assumes a constant density for the fat-free mass and relies on lung volume determination.

7.2   What Is 3D Scanning?

7.2.1   Hardware

Fixed scanners can derive human body shape in several ways, the most common of which uses class 1 (eye-safe) lasers or structured light projected onto the body surface. Multiple digital cameras capture the position of the projected light, and software reconstructs the body contour of the acquired image via a mathematical algorithm which is based on triangulation. Most fixed scanner systems house the cameras in columns which are coordinated to scan the body from head to toe in a co-horizontal plane. In this configuration, three or four columns are enclosed within a booth which reduces ambient light and provides privacy.

A body scan from a fixed scanner typically consists of 500,000–700,000 xyz coordinates referred to as a "point cloud". Each point is joined to their near points to form polygonal meshes. The tiny facets formed by the polygonal mesh can be smoothed, producing a rendered body (the metaphor is that of a plasterer smoothing render over a wire frame). The resulting images vary depending on the accuracy of the scanner and its software and may be enriched with colour and texture data.

Portable scanners are either mounted on a tripod or bench or are hand-held and can be used in a variety of settings. These do not necessarily orient the 3D image in a standard way and thus must be positioned using post-processing tools—a procedure made much easier if a section of horizontal floor is also captured in the scan. Portable scanners generally use structured light, although more recently, depth sensor cameras have been increasingly used. Although their accuracy is improving, depth sensor cameras cannot yet compete with either portable or fixed scanners for accuracy.

7.2.2   Software

Early software approaches were very primitive by today's standards. Body segmentation was first developed using orthogonal only axes. While applications would purport to be able to generate segmental volumes and proportions, close scrutiny of anatomical regions reveals such junctions are invariably oblique rather than orthogonal. Torso-limb segment contact in overweight individuals critically distorts where true boundaries should fall, and extra caution is required for such individuals. Although some users may fail to appreciate these limitations and continue to use orthogonal segmentation, software developments in the last few years have advanced more rapidly than hardware, so more authentic segmentation is now possible using oblique planes. Software tools include basic processing (registration and fusion), mesh simplification, smoothing and even cloud-based storage systems available for the scans. This advancement has been driven by the inadequacy of conventional storage for the massive size of files. For example, a rich mesh acquired using the Artec-L will generate about 20 million data points (~500 MB of data).

7.2.3   Training in 3D Scanning

Unfortunately, there are gaps left by the somewhat haphazard development of the 3D scanning technology. At present, there are no universally recognised training systems for scanning humans, other than manufacturers' own specific guidelines. This process has not been helped by the increasing use of scanning in related fields including engineering, architecture, digital archiving and 3D printing and the cross-disciplinary use of more recent scanners. With such a blurring of boundaries between disciplines, it may be easy to forget that scanning fixed objects and infrastructure can be very different from a living human. In the absence of an agreed, standardised protocol, there is a pressing need for consensus regarding standard participant presentation (clothing), euhydration, fasting (in some cases), breathing cycle, posture and clothing. There are ISO standards which relate to scanning devices, but the nature of the development of the field is so rapid that these standards may date rather quickly. Such standards mostly relate to regulation designed to keep

participants and operators safe. Various laws govern the use of class 1 lasers, and structured light scanners can possibly cause photosensitive epilepsy which may occur in about 1 in 2000 adults.

7.3 How Do You Use 3D Scanning for Athletes?

7.3.1 Calibration

Within the scientific field of metrology, different devices scan solid objects of known volume, placed at different distances to provide an in vitro calibration. The specification sheet for each model of scanner should contain this information, but it is not always presented in a standardised manner.

7.3.2 Apparel for All Postures

The environment conditions for scanning include no eyeglasses, watches and jewellery, wearing light form-fitting apparel, tying long hair and wearing a bathing cap to cover the hair. The surface area of clothing and hair can have a direct impact on the measured volume, due to its potential for encapsulating trapped air. As a result, men should wear swimming trunks or single-layer form-fitting shorts without padding. Women should wear a single-layer sports top and form-fitting shorts.

For those using laser scanning, researchers should be aware that the wavelength of the source may restrict the use of dark clothing colours, and so lighter colours are recommended. The burgeoning market in compression sports clothing might appear to fit these requirements; however, if valid measurements of body shape are to be made, clothing should conform to the body contour without compressing it. This may be difficult to achieve in practice, and care must be taken to ensure the clothing surface is smooth and free from creases and also to avoid strong elastic waistbands from altering the uncompressed body shape.

7.3.3 Landmarks

In order to extract traditional anthropometric measurements, the 3D scanner software must be able to identify certain landmarks. There are three common landmarking systems used in 3D anthropometry: (1) automatic landmark recognition (ALR), where the software identifies landmarks from the scan without human intervention; (2) digital landmark placement (DLP), where landmarks are located on a digital image by identifying surface features; and (3) physical-digital landmark location (PDL), where landmarks are placed physically on the body and then located

digitally on the scanned image. ALR has proved to be unacceptably inaccurate, while DLP is often difficult on obese or very muscular participants, where underlying bony landmarks are hard to locate. Therefore, we rely heavily on PDL, which has the disadvantage of requiring more time and operator skill. There is no universally accepted protocol for 3D scanning; however, current protocols are being lodged with the J.E. Lindsay Carter Anthropometry Archive (Stewart and Hume 2014).

Physical-digital landmark location landmarking of the body can be undertaken before acquisition of the scan. Landmarks need to be identifiable as a three-dimensional (xyz) point from the rendered scan file and so may be affixed as small triangles, bespoke reflective stickers or some other physical marker such as cod liver oil capsules fixed to the body surface. Bony landmarks require physical palpation to identify and cannot be inferred directly from the scan. This process requires considerable time and technical skill. For example, the acromiale, trochanterion and iliac crest ISAK landmarks (Stewart et al. 2011) might be marked for direct length (or height) measurements or to assist defining the required plane for body segmentation. In addition, the use of scans to measure volumes requires the breathing cycle to be carefully regulated, and this may require extra landmarks. In this respect, the level of the third costal cartilages of the rib cage corresponds to the point of the highest mobility during breathing cycles, which is at the same level as the axilla in most individuals.

7.3.4 Protocols, for Example, Specific Landmarks

The T3 costal landmark is defined as the point on the skin surface corresponding to the midline of the sternum at the level of the third rib costal cartilage (*see* Fig. 7.1). Note that this is superior to the ISAK mesosternale landmark.
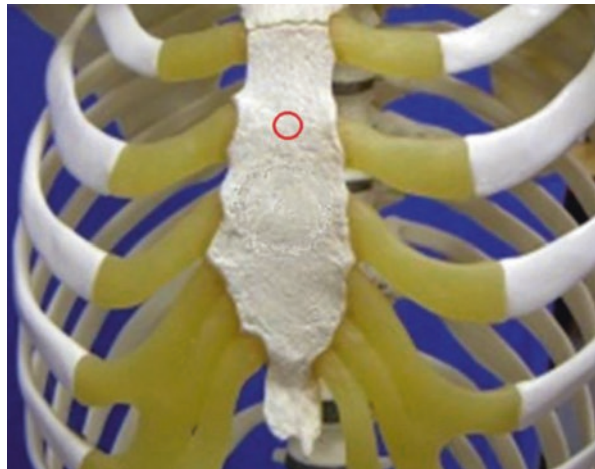

Fig. 7.1 Location of the T3 costal landmark

The T3 posterior landmark is on the dorsal side of the torso, which is defined as the point on the skin surface of posterior median furrow at the corresponding height of the T3 costal landmark.

The lateral deltoid landmarks are defined as the most lateral points on the skin surface overlying the deltoid muscles as observed from the front when the participant is standing erect with feet together and arms against the sides and hands in the mid-prone position (i.e., thumbs pointing forwards) resting on the lateral thighs. These landmarks are described in Stewart and Hume (2014) and are required for bi-deltoid breadth measurement.

7.3.5   Scan Postures

Body posture during scanning is important to ensure accurate measures can be made from the images. Inside the 3D scanning booth, participants are positioned into standard scanning poses (*see* Fig. 7.2) and instructed to hold their breath (at end tidal expiration) for the duration of each scan (~10–12 s).

Generally, the scan position is with arms and legs abducted to permit body segmentation, so enabling calculation of limb segment parameters such as girths, volumes and areas. However, in practice, this posture is not strictly defined in terms of the specifics of positioning, and there is a lack of consensus in terms of arm abduction angle, forearm or elbow angle and hand position and orientation. In addition, a

Fig. 7.2 Example scanning pose for 3D scanning and initial 3D image

range of other position definitions may be required to enable standardisation of the breathing cycle and to facilitate range of measurements that compare with conventional anthropometry. For fixed scanners, the acquisition time generally makes it feasible for participants to hold their breath, thereby eliminating the breathing artefact, but depending on the stage of the breathing cycle adopted, there are important consequences for girth and volume measurements.

For optimal results from 3D scanning, a particular posture must be maintained. For example, when scanning with fixed scanners such as the Hamamatsu, the following postures are used: egress position end tidal, egress position inspired, egress position expired and scanner position end tidal. Alternatively, with the portable Artec-L Scanner, scanner position end tidal is used, and participant stability is facilitated with a pair of orthopaedic walking poles.

For the egress position end tidal posture, the participant stands erect with the head facing forwards and the eyes maintained at the horizontal level. Arms are adducted to the lateral aspect of the torso, with forearms extended and in a mid-prone position. Thighs and legs are held together, with feet oriented forwards, to give the entire body an erect posture. The participant adopts shallow breathing to prevent noticeable movements of the thorax, and scanning takes ~8–10 s for the image to be acquired.

For the egress position inspired posture, the participant stands erect in the booth with both feet together in-between two pre-marked foot images on the floor of the scanner. The head is held erect and facing forward, with the eyes maintained at the horizontal level. Arms remain adducted and the forearm extended and in mid-prone position with the palms placed on the lateral aspect of thighs. The thighs and the legs are fully adducted with the feet oriented forward. When alerted by the operator, the participant breathes in maximally and holds the breath. Once again, scanning takes ~8–10 s, whereupon the participant can resume normal breathing. This breath-holding factor is important when quantifying the scan volume (which includes entrapped air within the lungs), which in turn affects body fat predictions using the two-compartment method.

Egress position expired is similar to the egress position inspired posture, except that when alerted by the operator, the participant breathes out maximally leaving the lungs with only the residual gas volume (RGV). In this posture, the rib cage depresses with concomitant reduction of the thoracic volume and increment of the abdominal volume. Care must be taken not to allow the participant to flex forwards out of a vertical position when maximal expiration is undertaken.

The scanner position end tidal posture fixes each of the feet onto the pre-marked foot symbols on the floor of the scanner, thereby causing each leg to be abducted from the midline. The head is oriented forwards with the eyes fixed at the horizontal level. Arms are abducted from the torso, and the forearms flexed at the elbow and in mid-prone position to align the palms parallel to the thighs. The participant maintains shallow breathing throughout the scan to avoid noticeable movements of the rib cage.

When using portable 3D scanners such as the Artec-L scanner, the scanner position end tidal is used. However, postural stability is aided by using a pair of adjust-

able orthopaedic walking poles since the time for scanning is ~45 s. The use of these poles helps reduce movement artefact caused by the longer scan duration compared to fixed scanners.

There are landmarks and volumetric differences according to breathing cycle in egress positions. In the egress position inspired, there is vertical mobility upwards of all the landmarks and thoracic expansion, and, consequently, there is increase in the body volume. The reverse occurs in the egress position expired where the landmarks undergo vertical mobility downwards, with consequent reduction of thoracic diameters and body volume. The differences in landmark mobility in the two egress positions have been measured up to 25 mm on the mesosternale, and bi-deltoid breadth and chest depth expansion measured up to 4 mm and 10 mm, respectively.

There are also body dimension differences between data extracted from egress position end tidal and scanner position end tidal 3D images (*see* Fig. 7.3). The waist and hip circumference measures vary in the two postures. A participant's waist circumference (812.1 mm) and hip circumference (991.5 mm) in egress position end tidal change to 817.1 mm and 1020.5 mm, respectively, in scanner position end tidal. Abdominal and waist circumferences acquired in the standing position show differences in level, size and shape compared with lying or sitting positions. 3D scan body volume will contain thoracic gas and, therefore, overestimate the true body volume value, which leads to a corresponding inflation of estimated fat content using the two-compartment model. Such breathing directives have led to variation in estimated %fat from 10.3% (expired) to 27.6% (inspired) in a sample of 116 adults (Njoku and Stewart 2016) which underscores the importance of standardising
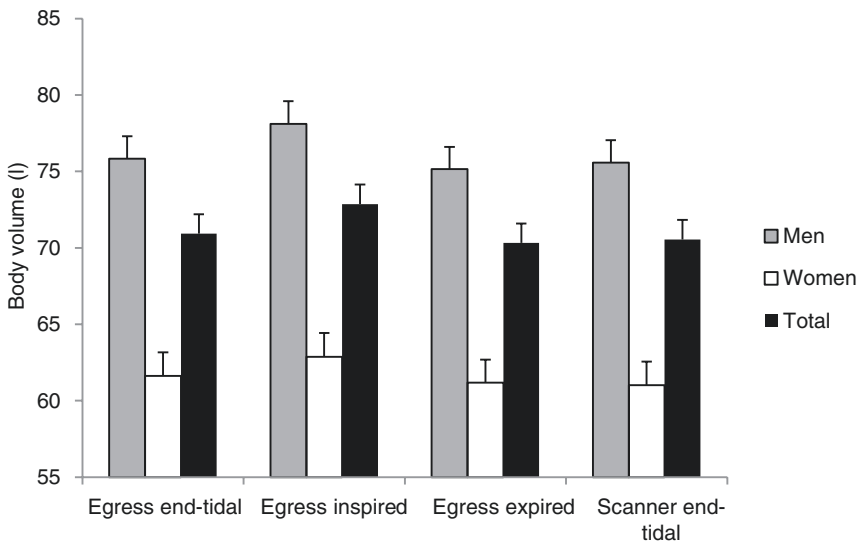

Fig. 7.3 Body volume in 74 male and 39 female healthy adults; all gender differences were significant after Bonferroni adjustment ($p < 0.001$)

breathing. While more in-depth respiratory research could usefully quantify this, such work has yet to be conducted. As a result, it is important that the expiratory reserve volume, plus half of the tidal volume, be subtracted from the scan volume to yield a body composition prediction, when this is required.

The level, shape and size of the abdomen change with different body positions. Waist girth, for example, will generally be largest when sitting, an intermediate value when standing and least when lying. Even within the standing posture, arm position makes a profound difference to the magnitude of the waist (Lennie et al. 2013). It is paradoxical that the health risk imposed by abdominal obesity is almost always predicted by standing anthropometry in field and clinical settings, yet verified by supine medical imaging, without consideration of the influence of positional difference on measurement value. With landmarks on the appropriate level to identify the waist or abdominal girth, the differences can be verified.

This is the background for the development of an "enriched abdominal waist model" by quantifying the waist area using abdominal transverse sections in both standing and lying positions and combining the 3D image of abdominal circumference in different positions with subcutaneous fat measured by ultrasound. Plotting the depth of subcutaneous fat with ultrasound on the abdominal circumference extracted from the standing posture could result in a cascade of errors in the prediction of waist shape, waist area, coronal diameter, sagittal diameter and subcutaneous tissue percentage within the abdominal circumference. However, this error can be corrected by designing a protocol for extracting the abdominal circumference from the 3D scan using a lying posture, since ultrasound measures are performed while the participant lies in prone or supine postures. This technique requires a different protocol and a hand-held scanner.

The supine scan for enriched abdominal waist model requires the alignment of two strong tables of similar height with a gap of 20 cm. Arms are folded across the shoulders in the same way as the ISAK standard waist protocol (Stewart et al. 2011), and the feet are together. The 20 cm gap should correspond with the waist-abdominal region and facilitate access to the torso in almost 360°. Participants should be scanned at the end tidal position, and if a breath is required, the scan should be suspended until the participant has returned to the end tidal position. In a sample of 18 adults, such postural difference between standing and supine has been shown to lead to a mean reduction of 4.9% in abdominal girth and 17.1% in abdominal cross-sectional area (Ng et al. 2016). This is one example of the contribution 3D scanning is making to increasing contemporary understanding of what anthropometric measurements actually mean.

7.4 What Is 3D Scanning Used to Measure?

For measurements to be extracted from traditional fixed scanners, the body scan is modelled by converting point-cloud surface representation to a polygon. Selected body landmarks, such as the vertex (superior aspect of the head), nape of neck, right

and left axilla, and crotch are generally required to be located before the scan can be converted into polygon.

When using a portable scanner software such as Artec Studio or similar products, the positioning tool is used to orient the scans in xyz coordinates. Standard practice is for the x axis to point towards the observer, y axis to the right and z axis vertical, when the scanned person is facing the observer. Once in this orientation, successive frames of a particular scan can be aligned together and then registered as a single frame. All the unwanted segments, including the pair of orthopaedic walking poles and the floor, are deleted using the eraser sub-menu. Orienting the scan in xyz space enables planar eraser function which makes a range of processing tasks much more straightforward. Other sub-menu tools include hole filling, applied to re-edit small areas of missing data, while the small object filter removes data sets which are distant from the scanned image. With the edges sub-menu, larger sections of missing data are filled. After this, a solid 3D model is produced using the fusion menu, and measurements can be extracted from it.

Three-dimensional analysis can be extended to calculate segmental and whole-body volumes and, hence, to estimate body fat percentage. If the mass of the participant is known and the volume estimated by 3D scanning, one can calculate the whole-body density. Then, with certain assumptions regarding tissue density made, one may estimate body fat percentage. However, studies examining the accuracy and precision of using 3D scans to predict whole-body density measured against a criterion standard such as dual X-ray absorptiometry or composite models which additionally include bod pod or hydrostatic weighing are needed.

Body changes due to growth, maturation, dietary and training interventions can also be assessed. 3D scanning can be used to visualise and better quantify size and shape changes that occur due to ageing or as a result of exercise or nutrition interventions. Somatotyping using 3D anthropometry has been conducted which moves beyond the traditional triple-view approach in a standard pose and enables interactivity with the image and viewing from any angle (Olds et al. 2013) in addition to other applications to health and exercise science (Olds and Rogers 2004).

7.4.1   Special Challenges for Some Populations

Capturing the body shape of athletes, as compared to the general population, offers some advantages but also some challenges. Firstly, athletes are commonly lean and healthy individuals with positive self-esteem and are generally receptive to being measured, while the population at large (most especially overweight individuals) might have considerable reluctance to be scanned in form-fitting clothing. By contrast, athletes generally are comfortable being scanned in minimum clothing and usually have the type of clothing required, thus avoiding the issue of wearing a size provided by the research lab which may not fit perfectly or indeed

alter body shape in a subtle way. Athletes are also used to routine physical measurements and are generally at ease in a laboratory environment, which is in contrast to members of the public who may be much less comfortable. However, athletes may present some difficulties by virtue of their unusual size or proportions; this has also been cited as an issue for other types of measurement (e.g., dual energy X-ray absorptiometry scanning). Extremely tall or large athletes may exceed the detectable scan volume of fixed scanners, either by being too tall (perhaps >195 cm) or too broad.

For 3D scanning, segmentation of the body requires the arms to be separated from the torso and the legs from one another. In stocky individuals, this may not be possible, and the orientation of the head and shoulder girdle in some individuals may be challenging for the default settings on scan software to detect properly, due to extreme development of neck musculature. This also causes a problem when it comes to identifying planes to use when dividing the arms from the torso. Well-developed latissimus dorsi musculature can add to the difficulty in identifying the required plane, underscoring the inadequacy of the default to orthogonal axes in sagittal and transverse planes for the "cut lines" with older scanners, meaning that inevitably some of the arm is included in the torso and vice versa.

7.5 How Do You Report 3D Scanning Data to Athletes and Coaches?

There are currently no standards for reporting 3D scanning to athletes given the recent use of 3D scanning with athletes. Reports are generated by each individual manufacturer's software. There are some company databases that can be used for comparison purposes, usually for a fee.

7.6 Example of a 3D Scanning Protocol for a Large-Scale Survey

The following example 3D scanning protocol was used for a large-scale survey in New Zealand. The survey used a Vitus XXL scanner. The scanner projects non-ionising laser light onto the body with the reflection captured by cameras as a series of points (generally between 700,000 and 1,000,000) with Cartesian coordinates, joined together to create the digital statue. It uses eye-safe class 1 visible red laser light (minimum levels of ionising radiation) and was manufactured and developed in compliance with the regulations of the US Food and Drug Administration (US Department of Health and Human Services) pertaining to laser safety.

7.6.1 Team Personnel

To ensure quality data are collected and participants complete the scanning requirements in as short a time as possible, a team of personnel with specific responsibilities is needed at each survey data collection session:

Team leader

- The survey protocol conduct
- Data sampling site logistics (e.g., liaison and coordination with data collection site manager)
- Overseeing transport, (un)packing, (dis)assembly and calibration of scanner and all equipment
- Recording any incidents on a Serious Events Register
- Timekeeping for workflow
- Ensuring that all data files are backed up regularly
- Assisting other team members when required

Participant receptionist

- Greeting and briefing participants
- Administering informed consent forms and demographic questionnaires
- Collecting and filing all hard copies of paperwork
- Assigning participants an ID number

Anthropometrists

- Locating and placing physical landmarks on participants
- Taking physical measurements
- Recording all measurements
- Observing other anthropometrists to minimise mistakes
- Escorting participants to the scanner technician

Scanner technicians

- Positioning participants in the correct postures for scanning
- Operating the scanner system
- Verifying the scanned images for correct posturing, landmark positioning and checking scan image quality
- Saving the scan

7.6.2 Survey Protocol

The survey protocol consists of five stages with approximately 60 min per participant.

Stage 1: Briefing and informed consent (10 min)

The receptionist greets the individual participants at reception. Prior to their visit, all participants will have been issued with an information sheet (i.e., about the study aims and methods, instructions on level of hydration and food intake, clothing, no prior exercise) and a consent form. At the session they will also be verbally informed of the measurement procedures and their rights as volunteers. After providing written informed consent, participants complete a short demographic questionnaire and are assigned a unique identification number using a four-digit coding convention. The consent form is the only document linking each participant's identification number to their names.

Stage 2: Change to form-fitting clothing (5 min)

Participants are then shown to the private changing area so they can change into light-coloured sports or undergarments (tight-fitting briefs for men and high-rise underpants and stretch midriff tops for women), remove all jewellery and, if necessary, tie their hair up. Participants are able to choose to wear their own underwear, provided it was deemed acceptable for scanning by an anthropometry team member. The apparel must be a light colour and a tight fit. These colours provide minimal reflection during the scanning process. Participants will not wear shoes or socks during the survey.

Participant's personal belongings are stored in a large plastic container for safekeeping (one container per participant).

Stage 3: Landmarking (8 min) and manual/physical measurements (20 min)

Manual measures from landmarking are required as they are either difficult or impossible to accurately derive automatically from the scan by the Vitus XXL system. Just prior to landmarking, all participants are reminded of the procedures via a poster of photos showing the landmarks and the three postures they are required to assume during landmarking, physical measurement and 3D scanning.

The required landmarks are marked on participants by their trained anthropometrist. Trained personnel must be either a qualified Level 2 anthropometrist or have received suitable training from a qualified Level 3 or 4 anthropometrist. The ideal situation is to have a landmarker and an observer (another anthropometrist from the team). This is to minimise mistakes. Instruction booklets on how to conduct the landmarking are provided for reference. These landmarks are necessary for obtaining measures to be derived post-scan.

To identify each skeletal reference point, each is physically located by palpation on the body surface, marked with a small pen-marked cross, and then raised double-sided adhesive sticker pointing at the landmark is placed on the cross (note: stickers are only placed on participants' bodies after the physical measures have been completed). Once landmarking is complete, anthropometrists check the placement of their landmarks and tick the corresponding box on the datasheet to signify that the landmarks have been located.

Once landmarking is complete, the anthropometric team conducts the manual measurements. This is so participants only get processed by the same two people, in order to protect their privacy. These measures are conducted using ISAK-approved anthropometric kits. Prior to use, the kit contents are calibrated and checked for damage.

An anthropometrist acts as a recorder. Each measure is repeated twice and entered by the recorder onto an Excel spreadsheet, which indicates whether a third measure is needed. Following completion of all of the physical measurements, a review of the datasheet is conducted. Measurements falling outside of normative bounds are rechecked by the anthropometrist, with a third measurement taken if the first and second measurements differed by more than 1.0%.

Stage 4: Scanning (15 min)

After manual measurements, participants proceed to the scanning area. The scanner technician tells participants of the three postures necessary to adopt and what to expect when the scan begins. The scanner technician instructs participants on where to stand, how to stand and when and how to breathe. Scanning will only commence once the operator is happy with how the participant is standing and positioned on the podium. Each scan will last 12 s and will produce a 3D image of the participant. After each scan, participants can relax while the operator visually inspects the image to check whether all the landmarks are clearly visible and that the posture is adopted correctly. The scanner technician takes two scans of each posture, which equals six scans in total. If the scan technician is not happy with the results of any of the scans, then the unacceptable scans are repeated.

Stage 5: Participants get changed back into their regular clothing (5 min)

Following completion of scans, participants are ushered back to the change area where they will change back into their clothes. The anthropometrist will then usher the participant back to reception and return the completed datasheet to either the team leader or the receptionist. The datasheet is checked to confirm whether all physical measurements fall within normative bounds (i.e., the 2.5th–97.5th percentile range). The participant is then released from the data collection process.

7.7 Summary

Three-dimensional body scanning is used to determine surface anthropometry characteristics such as body volume, segment lengths and girths. Body posture during scanning is important to ensure accurate measures can be made from the images. Training is required to ensure successful use of 3D scanning hardware and software.

References

Lennie S, Amofa-Diatuo T, Nevill AM, Stewart AD (2013) Protocol variations in arm position influence the magnitude of waist girth. J Sports Sci 31(12):1353–1358

Ng HY, Njoku CO, Stewart AD (2016) Waist shape, girth and area are affected by posture: insight from 3D scanning. In: Ferreyro Bravo F, Esparza Ros F, Marfell-Jones M (eds) Kinanthropometry XV proceedings of the 15th international society for the advancement of Kinanthropometry conference, Merida, Mexico, pp. 278–279

Njoku CO, Stewart AD (2016) 3D scanning: consequences of the breathing cycle for body composition. In: Ferreyro Bravo F, Esparza Ros F, Marfell-Jones M (eds) Kinanthropometry XV proceedings of the 15th international society for the advancement of Kinanthropometry conference, Merida, Mexico, pp. 267–268

Olds T, Daniell N, Petkov J, David Stewart A (2013) Somatotyping using 3D anthropometry: a cluster analysis. J Sports Sci 31(9):936–944

Olds T, Rogers M (2004) 3D anthropometry–applications to health and exercise science. Sport Health 22:21–23

Ryder JR, Ball SD (2012) Three-dimensional body scanning as a novel technique for body composition assessment: a preliminary investigation. J Exerc Physiol Online 15(1):1–14

Stewart AD, Hume PA (2014) Bideltoid breadth measurement. J.E. Lindsay Carter Kinanthropometry Archive 3D Scanning Protocols, 2. Retrieved from http://jelckca-bodycomp.com

Stewart AD, Marfell-Jones MJ, Olds T, de Ridder JH (2011) International standards for anthropometric assessment. ISAK, Lower Hutt, New Zealand