INTERNATIONAL STANDARD

ISO 20685

Second edition
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3-D scanning methodologies for internationally compatible anthropometric databases

Méthodologies d'exploration tridimensionnelles pour les bases de données anthropométriques compatibles au plan international

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 20685 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 3, *Anthropometry and biomechanics*.

This second edition cancels and replaces the first edition (ISO 20685:2005), of which it constitutes a minor revision.

Introduction

Anthropometric measures are key to many International Standards. These measures can be gathered using a variety of instruments. An instrument with relatively new application to anthropometry is a three-dimensional (3-D) scanner. 3-D scanners generate a 3-D point cloud of the outside of the human body that can be used for clothing and automotive design, engineering and medical applications. There are currently no standardized methods for using 3-D point clouds in the design process. As a result, many users extract one-dimensional (1-D) data from 3-D point clouds. This International Standard concerns the application of 3-D scanners to the collection of one-dimensional anthropometric data for use in design.

There are a number of different fundamental technologies that underlie commercially available systems. These include stereophotogrammetry, ultrasound and light (laser light, white light and infrared). Further, the software that is available to process data from the scan varies in its methods. Additionally, software to extract dimensions similar to traditional dimensions varies markedly in features and capabilities.

As a result of differences in fundamental technology, hardware and software, extracted measurements from several different systems can be markedly different for the same individual. Since 3-D scanning can be used to gather measurements, such as lengths and circumferences, it was important to develop an International Standard that allows users of such systems to judge whether the 3-D system is adequate for these needs.

The intent of ISO 20685 is to ensure comparability of body measurements as specified by ISO 7250-1 but measured with the aid of 3-D body scanners rather than with traditional anthropometric instruments such as tape measures and callipers. It is further intended that by conformance with this International Standard any data extracted from scans will be suitable for inclusion in international databases such as those described in ISO 15535.

3-D scanning methodologies for internationally compatible anthropometric databases

1 Scope

This International Standard addresses protocols for the use of 3-D surface-scanning systems in the acquisition of human body shape data and measurements defined in ISO 7250-1 that can be extracted from 3-D scans. It does not apply to instruments that measure the location and/or motion of individual landmarks.

While mainly concerned with whole-body scanners, it is also applicable to body-segment scanners (head scanners, hand scanners, foot scanners).

The intended audience is those who use 3-D scanners to create 1-D anthropometric databases and the users of 1-D anthropometric data from 3-D scanners. Although not necessarily aimed at the designers and manufacturers of those systems, scanner designers and manufacturers will find it useful in meeting the needs of clients who build and use 1-D anthropometric databases.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7250-1:2008, *Basic human body measurements for technological design — Part 1: Body measurement definitions and landmarks*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

NOTE In the case of definitions of terms for skeletal landmarks, when there is a separate term for the skin overlying the landmark and another for the landmark itself, the skin landmark term is used. Where there is no separate term, the skeletal term is used and assumed to refer to the skin overlying the landmark.

3.1
three-dimensional
3-D
pertaining to the use of three orthogonal scales on which the three coordinates, x, y and z, can be measured to give the precise position of any relevant anatomical point in the considered space

NOTE Many anthropometric distances can be calculated from the coordinates of anatomical landmarks. Some additional points may be necessary to obtain circumferences.

3.2
3-D body scanner
hardware and software system that creates digital data representing a human form, or parts thereof, in three dimensions

3.3
3-D processing software
operating system, user interface, programs, algorithms and instructions associated with a 3-D scanning system

3.4
3-D scanner hardware
physical components of a 3-D scanner and any associated computer(s)

3.5
accuracy
extent to which the measured value approximates a true value

NOTE Since it is difficult to trace the accuracy of complex hardware and software systems to recognized ISO sources, for the purposes of this International Standard *true value* is taken to mean the measured value obtained by a skilled anthropometrist using traditional instruments such as tape and calliper.

3.6
acromion
most lateral point of the lateral edge of the spine (acromial process) of the scapula

[ISO 7250-1:2008, 2.2.1]

3.7
anatomical landmark
clearly defined point on the body that can be used for defining anthropometric measurements

3.8
anterior superior iliac spine
most downward-directed point of the iliac crest

3.9
anthropometric database
collection of individual body measurements (anthropometric data) and background information (demographic data) recorded on a group of people (the sample)

[ISO 15535:2006, 3.8]

3.10
cervicale
tip of the prominent bone at the base of the back of the neck (spinous process of the seventh cervical vertebra)

NOTE Adapted from ISO 7250-1:2008, definition 2.2.5.

3.11
crotch level
distal part of the inferior ramus of the pubic bone on a standing subject

NOTE It is typically marked using the top of a horizontal straightedge.

3.12
Frankfurt plane
standard horizontal plane at the level of the left tragion and left infraorbitale when the midsagittal plane of the head is held vertically

NOTE Adapted from ISO 7250-1:2008, definition 2.2.8.

3.13
glabella
most anterior point of the forehead between the browridges in the midsagittal plane

[ISO 7250-1:2008, 2.2.9]

3.14
iliocristale
most lateral palpable point of the iliac crest of the pelvis

3.15
infraorbitale
lowest point on the anterior border of the bony eye socket

3.16
lateral malleolus
most lateral point of the right lateral malleolus (outside ankle bone)

3.17
lowest rib
inferior point of the bottom of the rib cage

3.18
menton
lowest point of the tip of the chin in the midsagittal plane

[ISO 7250-1:2008, 2.2.16]

3.19
mesosternale
point on the union of the third and fourth sternebrae

[ISO 7250-1:2008, 2.2.17]

3.20
opisthocranion
most distant point from glabella in the midsagittal plane

3.21
point cloud
collection of 3-D points in space referenced by their coordinate values

NOTE A point cloud constitutes the raw data from a 3-D scanner and needs to be translated to a human axis system.

3.22
radial styloid
protuberance of the radius at the wrist

NOTE Adapted from ISO 7250-1:2008, definition 2.2.26.

3.23
repeatability
extent to which the values of a variable measured twice on the same subject are the same

3.24
sellion
point of greatest indentation of the nasal root depression

3.25
stylion
distal point of the radial styloid

NOTE Adapted from ISO 7250-1:2008, definition 2.2.26.

3.26
suprapatella
superior point of the patella (kneecap)

3.27
thelion
centre of the nipple

3.28
thyroid cartilage
prominent cartilage on the anterior surface of the neck

[ISO 7250-1:2008, 2.2.28]

3.29
tibiale
point at the upper inside (medial) edge of the proximal end of the tibial bone of the lower leg

[ISO 7250-1:2008, 2.2.29]

3.30
top of head
highest point of the head with the head oriented in the Frankfurt plane

3.31
tragion
notch just above the tragus

NOTE Adapted from ISO 7250-1:2008, definition 2.2.30.

3.32
tragus
small cartilaginous flap in front of the ear hole

NOTE Adapted from ISO 7250-1:2008, definition 2.2.30.

3.33
ulnar stylion
most distal point on the ulnar styloid

NOTE Adapted from ISO 7250-1:2008, definition 2.2.26.

3.34
ulnar styloid
protuberance of the ulna at the wrist

NOTE Adapted from ISO 7250-1:2008, definition 2.2.26.

3.35
vertical plane
geometric plane tangent to a point on the body and orthogonal to the mid-sagittal plane

3.36
x, *y*, *z* **coordinate system**
axis system
system for measuring the body with respect to the standing or sitting human where X refers to the fore-and-aft direction (the sagittal axis), Y refers to the side-to-side direction (the transverse axis) and Z refers to the top-to-bottom direction (the longitudinal axis)

See Figure 1.

NOTE Researchers establish their own origin for the axis system, convenient to their research, while keeping the direction of the axes as indicated and reporting the origin in the data base and any publications.

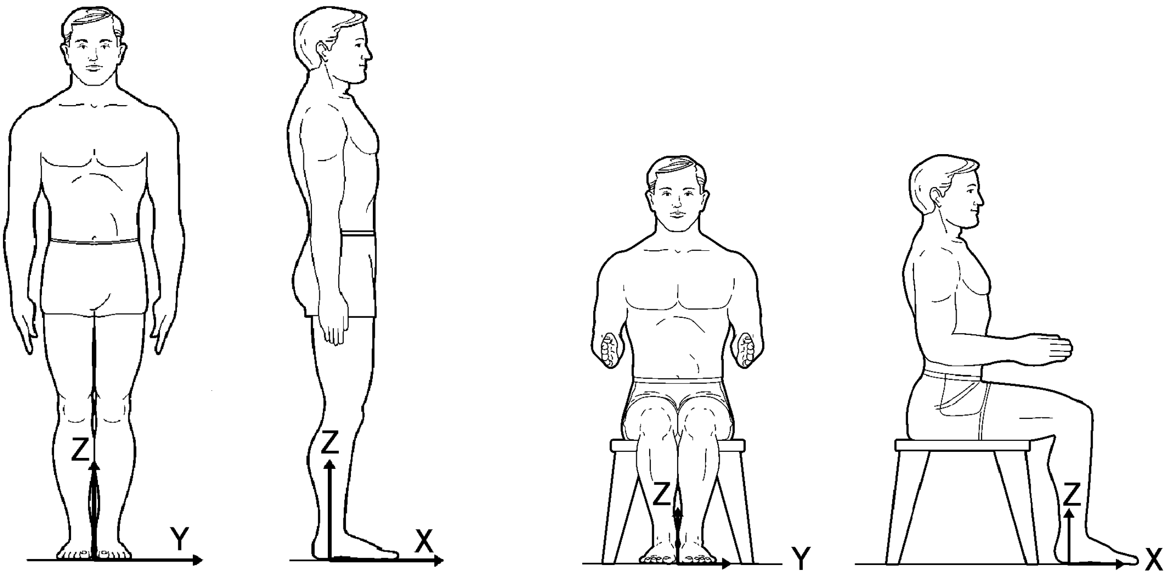


Figure 1 — *x*, *y*, *z* **coordinate system**

4 Accuracy of extracted measurements

4.1 Selection of extracted measurements

In order to use data from 3-D scanners in internationally compatible databases, dimensions should be drawn from ISO 7250-1. However, not all of those measurements are well suited to extraction from 3-D scanned images. In particular, the resolution from whole-body scanners might not be sufficient to allow accurate extraction of measurements from smaller body parts such as the hand. Tables 1 to 3 give measurements according to the type of scanner most likely to produce the best results. The numbers indicate the measurement number in ISO 7250-1.

Table 1 — ISO 7250-1 measurements by whole-body scanner

Dimension	ISO 7250-1:2008	Position
Stature	4.1.2	B
Eye height	4.1.3	B
Shoulder height	4.1.4	B
Elbow height	4.1.5	C
Iliac spine height, standing	4.1.6	B
Crotch height	4.1.7	B
Tibial height	4.1.8	B
Chest depth, standing	4.1.9	A, B
Body depth, standing	4.1.10	A, B
Chest breadth, standing	4.1.11	A
Hip breadth, standing	4.1.12	A
Sitting height (erect)	4.2.1	D
Eye height, sitting	4.2.2	D
Cervicale height, sitting	4.2.3	D
Shoulder height, sitting	4.2.4	D
Elbow height, sitting	4.2.5	D
Shoulder–elbow length	4.2.6	C
Elbow–wrist length	4.2.7	C
Shoulder (biacromial) breadth	4.2.8	A, B
Shoulder (bideltoid) breadth	4.2.9	A, B
Elbow-to-elbow breadth	4.2.10	D
Hip breadth, sitting	4.2.11	D
Lower leg length	4.2.12	D
Thigh clearance	4.2.13	D
Knee height	4.2.14	D
Abdominal depth, sitting	4.2.15	D
Thorax depth at the nipple	4.2.16	B
Buttock–abdomen depth, sitting	4.2.17	D
Forearm–fingertip length	4.4.5	C
Buttock–popliteal length	4.4.6	D
Buttock–knee length	4.4.7	D
Neck circumference	4.4.8	A, B
Chest circumference	4.4.9	A
Waist circumference	4.4.10	A
Wrist circumference	4.4.11	A
Thigh circumference	4.4.12	A
Calf circumference	4.4.13	A

NOTE For whole-body scanners, depending on the type of scanning system used, the positions according to A.2.4 could also be useful for extracting the indicated dimensions.

Table 2 — ISO 7250-1 measurements by head scanner

Dimension	ISO 7250-1:2008
Head length	4.3.9
Head breadth	4.3.10
Face length	4.3.11
Head circumference	4.3.12
Sagittal arc	4.3.13
Bitragion arc	4.3.14

Table 3 — ISO 7250-1 measurements by hand or foot scanner

Dimension	ISO 7250-1:2008
Hand length	4.3.1
Palm length perpendicular	4.3.2
Hand breadth at metacarpals	4.3.3
Index finger length	4.3.4
Index finger breadth, proximal	4.3.5
Index finger breadth, distal	4.3.6
Foot length	4.3.7
Foot breadth	4.3.8

4.2 Standard values

The human body is difficult to measure and does not lend itself to standards of accuracy that might be applied to machine tooling, for example. For the purposes of this International Standard, the standard for accuracy of a measurement extracted from a 3-D image is the corresponding traditional measurement, when measured by a skilled anthropometrist [3][4][5]. The difference between an extracted measurement and the corresponding traditional measurement on actual subjects should be derived using the test methods given in Clause 5. If the values are lower than those specified in Table 4, then the measurement may be included in ISO 15535 databases.

As any good scientific report documents the observer and measurer error, the accuracy of extracted measurements should be reported in any documentation that results from the use of these systems.

Table 4 — Maximum allowable error between extracted value and traditionally measured value

Measurement type	Maximum mean difference (see 5.4) mm
Segment lengths (e.g. buttock-popliteal length)	5
Body heights (e.g. shoulder height)	4
Large circumferences (e.g. chest circumference)	9
Small circumferences (e.g. neck circumference)	4
Body breadths (e.g. biacromial breadth)	4
Body depths (e.g. chest depth)	5
Head dimensions without hair	1
Head dimensions with hair	2
Hand dimensions	1
Foot dimensions	2

5 Research designs for establishing accuracy of body dimensions extracted from scanners

5.1 General

The purpose of this International Standard is to ensure that body measurements obtained from 3-D systems are sufficiently close to those produced by ISO 7250 traditional methods that they can be substituted for one another without compromising the validity of standards relying on the data. Annex A contains information that will be helpful in meeting this goal. In order to demonstrate that a 3-D system is in conformance with this International Standard, a validation study shall be conducted.

5.2 Validation study procedures

All ISO 7250 variables that are to be measured by 3-D methods shall be included in the validation study.

The 3-D scanning and data extraction system used shall be exactly the same hardware and software configuration that will be used in collecting the ISO 7250 data.

The traditional measurer shall be an expert, trained and experienced in ISO 7250 techniques. He or she shall have recently practiced the ISO 7250 protocols for the body measurements in the study. It is preferable that the same expert measure all test subjects. If landmarks are to be marked prior to scanning, the positioning of landmarks should be done by an expert trained and experienced in ISO 7250 techniques.

Each subject shall be scanned and measured traditionally at least once. The order of scan and measuring shall be counterbalanced to control for measurement order effects; however they shall occur sequentially on the same day in order to minimize error introduced by transient intra-individual fluctuations in body dimensions (see Annex A).

5.3 Sampling size and test subject selection

A power analysis such as that presented in Clause 6 shall be done in order to ensure that the validation study sample size is large enough to detect mean scan-measure differences of the magnitudes presented in Table 4 with 95 % confidence. A sample of at least 40 test subjects is recommended, since this will ensure 95 % confidence in the validation test results for large circumferences such as chest, waist, and hip, which are particularly difficult to measure for both traditional and 3-D measurement systems.

Validation test subjects shall reflect approximately the same range of body sizes and shape variations expected in the study population that is to be measured by the 3-D system. If both males and females are to be surveyed, then the validation sample shall include an equal number of each sex. The validation sample shall also include a variety of body types — not just people of average height and weight. If children are to be measured, it is particularly important that the validation sample cover the age range of the intended survey.

5.4 Analytical procedures

After data collection is complete, the difference, d, between the scan value and the measured value (d = scan minus measure) shall be computed for each variable and test subject, and the mean of these differences shall be calculated for each variable and reported with its associated standard deviation, sample size and 95 % confidence interval. If the 95 % confidence interval for the mean of scan-minus-measure differences is within the plus or minus interval defined by the values in Table 4, then the 3-D system can be said to give results sufficiently comparable to ISO 7250 methods such that the 3-D data may be used in standards relying on ISO 7250 protocols.

5.5 Validation study reporting

A report of the validation study shall be published and/or included in the anthropometric survey report associated with any 3-D database provided for use in standards relying on ISO 7250 protocols. This report shall include the following information:

— demography (age, sex) and anthropometry (height, weight) of the test subjects;

— protocols for measuring and scanning, including subject clothing, anthropometric landmarks, and body positions;

— name and pertinent details (or references) describing the 3-D system being validated, including hardware model number, and software version number;

— means, standard deviations, sample sizes for each body dimension as measured by scanning and as measured traditionally;

— means, standard deviations, sample sizes and 95 % confidence intervals for scan-minus-measure differences for each body dimension.

6 Method for estimating the number of subjects needed

6.1 In order for scanner–measurer comparisons to be statistically valid, it is important that test samples be large enough to detect mean differences of the magnitude specified in Table 4 at least 95 % of the time, at the level of 0,05 or better.

6.2 Assuming that the differences observed between extracted values and measured values are normally distributed, the minimum sample size required for a one-sample test of differences can be estimated using the following power equation [5]:

$$n = \frac{s^2}{\delta^2} \times (1{,}96 + 1{,}65)^2$$

where

s is the standard deviation of extracted-minus-measured differences;

δ is the magnitude of the extracted-minus-measured difference that must be detected;

1,96 is the critical Z value for a two-sided 0,05 level test;

1,65 is the critical Z value for 95 % confidence.

6.3 In practice, the true standard deviation of extracted-minus-measured differences for a particular system is usually unknown, so it is estimated from previous studies of similar systems. A pilot study could be necessary. The magnitude of difference to be detected, δ, is obtained from Table 4, and varies among different classes of body dimensions.

6.4 Because the variance of extracted-minus-measured differences is different for each body dimension, and because the magnitude of extracted-minus-measured differences to be detected also varies among dimension classes, the investigator usually makes several sample-size estimates for different body dimensions, and chooses the largest result to establish the minimum sample size required. When this approach is taken, the calculated sample size will be sufficient for 95 % confidence in 0,05 level tests in the worst case, and it will be more than sufficient for all the other body dimensions.

EXAMPLE Suppose an investigator wishes to establish the validity of using scan-extracted circumferences in place of directly measured circumferences. Previous studies resulted in extracted-minus-measured differences with standard deviations as follows: chest circumference 16 mm, waist circumference 14 mm and buttock circumference 12 mm, see [3] and [5] in the Bibliography. Using the above power equation and a required detectable difference of 9 mm for large circumferences reported as a mean difference (see Table 4), the investigator determines that 42 subjects are required to test chest circumference, 32 subjects are required for waist circumference, and 24 subjects are required for buttock circumference. Using 42 subjects will ensure 95 % confidence or better for all three circumferences to be tested.

Annex A
(informative)

Methods for reducing error in 3-D scanning

A.1 General

There are a number of sources of anthropometric error (here, the difference between a scanner-extracted measurement and a measurement obtained by a skilled anthropometrist). This annex outlines the main sources of error, and methods for documenting and reducing it.

A.2 Subjects

A.2.1 General

The best anthropometric data will be available from scans whose subjects have been properly prepared in advance of the scanning. This preparation includes marking some anatomical landmarks, selection of appropriate scanning attire, and positioning the subject in the scanning volume.

A.2.2 Anatomical landmarks

Landmarks should be marked on the skin, and then identified with dots or other techniques that can be seen on the displayed image, and distinguished using the available software. Bilateral landmarks should be marked on both sides of the body. If landmarks (see Clause 3) are to be marked before scanning, a minimal list would be the following:

a) acromion;

b) anterior superior iliac spine;

c) cervicale;

d) crotch level;

e) glabella;

f) iliocristale;

g) infraorbitale;

h) lateral malleolus;

i) lowest rib;

j) menton;

k) mesosternale;

l) nipple;

m) opisthocranion;

n) sellion;

o) stylion;

p) suprapatella;

q) thyroid cartilage;

r) tibiale;

s) top of head;

t) tragion;

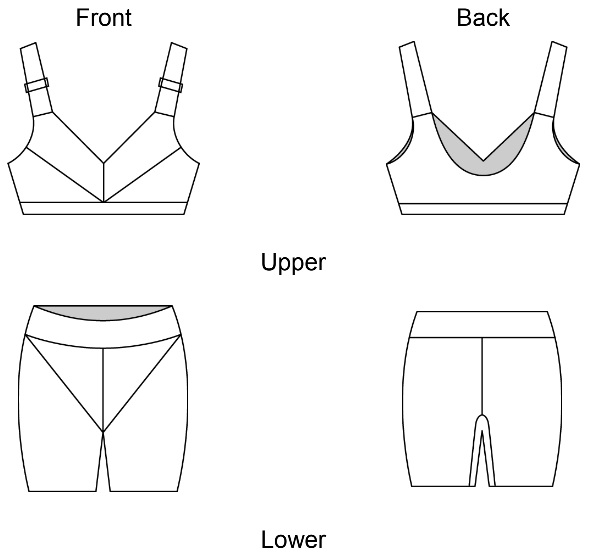
u) ulnar stylion.

A.2.3 Scanning attire

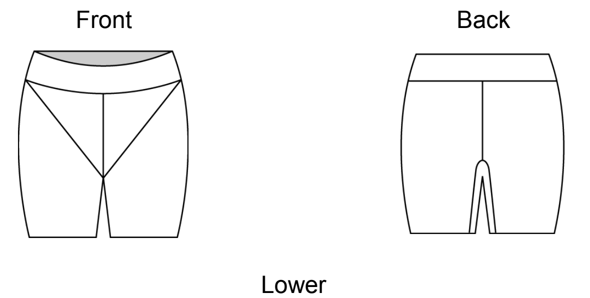
The scanning attire should be minimal, within the bounds of modesty (recognizing cultural differences). It should be form-fitting, so that there is no bagginess or folds. At the same time, however, it should not compress the flesh. The texture and colour should be such that it will be seen on the scanned image. Testing with each particular scanning system will be required to demonstrate the appropriateness of the fabric. The upper garment (women) should be constructed so the mesosternale point is clearly visible. The shoulder straps should not interfere with measurement points. The lower garment should expose the navel, and the inseam length should not interfere with measurement points of lower limbs. The pattern should be one that results in no side seam on the thigh.

A sample garment is shown in Figure A.1. Men need only wear the lower garment.

Surface scanners can capture the contour of the hair, rather than the head itself. Therefore, if measurements involving the head are contemplated, suitable arrangements should be made in respect of the hair so that accurate data on the head, neck and shoulder can be obtained. The use of flexible caps with holes in the centre is suggested for subjects with long or irregular hair styles (see Figure A.2). Alternatively, software in the scanning system may address the issue of hair contours in other ways.



a) Women



b) Men

Figure A.1 — Sample garments for scanning

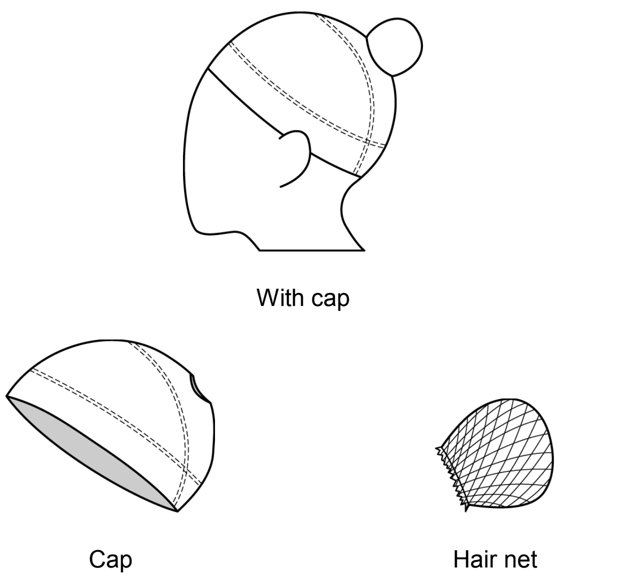


Figure A.2 — Suggested means for managing hair

A.2.4 Subject position

The position of the subject in the scanning volume is important for obtaining reliable data that can be used in an anthropometric database. However, because scanning systems vary, the optimal position can vary from system to system. When the optimal position is determined, it should be described precisely and used for all subjects. It is also important that the subject hold the posture during the entire scanning process. Depending on the optimal position(s), one or more support devices may be used. It should be noted that the scanning postures used may differ from those specified in ISO 7250-1, because ISO 7250-1 postures present difficulties for many scanning systems, for example, the masking of some body parts by other body parts. As a result, some corrections need to be made for certain measurements in order to meet the accuracy standards according to Clause 6. Corrections can be made by using multiple scan postures, or by mathematical transformations after the scan is complete. Examples of mathematical transformations include a regression prediction based on laboratory experimentation, and a geometric transformation based on the height of the hip and distance between the feet.

For all postures, quiet respiration (normal breathing) should be adopted. The shoulders should be straight without being stiff, and muscles should not be tense. Some postures are described below, illustrated in Figure A.3.

— **Standing position A**

  The head is in the Frankfurt plane; the long axes of the feet should be parallel to one another and 200 mm apart; the upper arms are abducted to form a 20° angle with the sides of the torso, and the elbows are straight; the palms face backward, and the subject is breathing quietly. This position may be used for obtaining circumferences of the upper and lower limbs.

— **Standing position B**

  The subject stands erect with the head in the Frankfurt plane. The heels are together, the upper limbs hang relaxed at the side, palms facing the body. The abdomen is relaxed and the subject is breathing quietly. To identify the crotch, a horizontal straightedge is placed between the lower limbs so that the uppermost edge is at the level of the crotch. This position may be used for obtaining heights from the floor.

— **Standing position C**

  The subject stands as for position B, but with one upper limb stretched forward horizontally and the palm facing inferiorly, while the other is bent 90° at the elbow with the palm facing medially.

— **Sitting position D**

  The subject sits erect with the head in the Frankfurt plane; the upper limbs hang down at the side, but the arms are bent 90° at the elbow, and the palms are flat, facing one another. The thighs are parallel to each other, and there is a 90° angle between the thigh and torso. The feet hang freely.

NOTE The act of sitting on the platform will compress body tissues, so that standing and sitting segments will not be comparable.

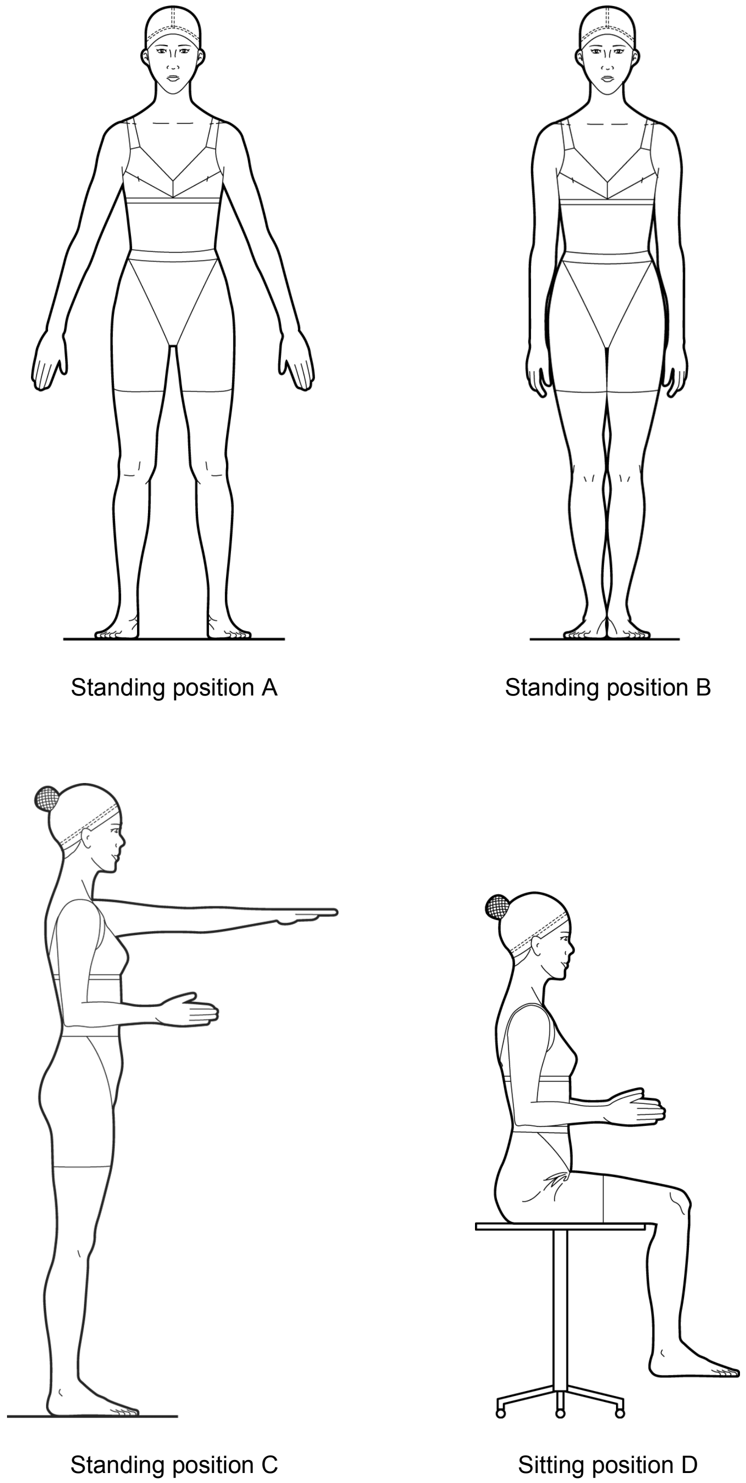


Figure A.3 — Standing and sitting positions

A.3 Hardware

A.3.1 General

The capabilities of scanner hardware are distinct from those of scanner software. While the hardware and software are often bundled together for sale as a single system, they are treated separately here. For both, the default unit of measurement is millimetres.

A.3.2 Resolution

The distance between points in scan data (resolution) should be defined separately for each of the three axes. Users should be aware that resolution could vary within the scanning volume and with the curvatures of the object being scanned. These variations in resolution, along with the size of the subject and the placement and curvature of body parts within the scanning volume, can affect the accuracy of certain measurements.

A.3.3 Test and calibration

A.3.3.1 Calibration

The scanner hardware should be calibrated when first delivered, and should be recalibrated periodically. The frequency of calibration should be related to the type of scanner and the frequency of use. Calibration should always be verified after moving the scanner.

Users should follow the calibration procedure recommended by the manufacturer before testing the hardware with the procedures given below.

A.3.3.2 Test object

The hardware should be tested with an object of known dimensions. While many different objects may be used, it will be helpful to use an object some of whose dimensions are similar to those found in humans. The test object can be useful in verifying the scanning volume.

As the test procedures recommended below involve placing the test object at various points within the scanning volume, it will be helpful to have a test rig that can place the object precisely and reliably.

A.3.3.3 Test measurements

The following test measurements should be made on the test object:

— point-to-point distance;

— arc length;

— cross-section circumference.

A.3.3.4 Accuracy

Usually, it will not be possible for the user to test machine accuracy. However, using a commercially available CAD package (not the scanner manufacturer's software) to verify the dimensions of the point cloud of the test object will identify serious error. The dimensions of the test object should be obtained using calibrated traditional instruments, such as callipers or tape.

a) Place the test object in the centre of the scanning volume on the floor or a platform.

b) Use the manufacturer's software to record the locations of all marked points.

c) Repeat the procedure at 500 mm, 1 000 mm, 1 500 mm and 2 000 mm off the floor/platform, above the first location.

d) Use the manufacturer's software to record the physical locations of all the marked points at each level.

e) Repeat the procedure at other locations near the edge of the scanning volume, as appropriate.

A.3.3.5 Repeatability

The locations of the points on the test object should be recorded from at least three scans, to assure repeatability of the hardware. This need not be done at each of the locations indicated in A.3.3.4, but should be done at least in the centre of the scanning volume.

A.3.3.6 Statistics

With only three replications, the analysis of the hardware repeatability data may be limited to an examination of the minima, the maxima and mean differences.

A.3.3.7 Multiple cameras

The camera should be tested to determine if it is operating, and to determine its field of view. If there are multiple cameras, the output of each camera should be tested individually, before the images are registered.

A.3.4 Scanning volume

The scanning volume should be large enough to accommodate considerable human variability. A volume of at least 2 100 mm in height (Z axis) and a width of 1 200 mm (Y axis) and depth of 1 000 mm (X axis) is recommended.

A.3.5 Scanning duration

To minimize movement artefacts, the scanning process should not take longer than 20 s.

A.3.6 Additional sources of error

Additional sources of error in hardware include colour perception, luminance perception and the shadowing of body parts by other body parts. Users need to be aware that these sources of error can affect extracted measurements.

A.4 Software

A.4.1 General

Early versions of scanning systems included various software tools bundled with the software required for operating the scanner. Nowadays, software is available from a number of developers and is not necessarily tied to any one scanner.

In order to successfully use 3-D scanning for anthropometric databases, it is useful to have certain software features available. Software can allow the user to manipulate the figure, identify various body landmarks and segment the body into its component parts. Finally, software can extract measurements that could be similar to those measured with traditional anthropometric instruments.

A.4.2 Features for human-figure manipulation

A.4.2.1 Zoom

The software may allow the user to move the figure closer — enough so that a single point can be identified — and farther away, so that the whole scanned image is visible.

A.4.2.2 Pan or translate

The software may allow the user to move the figure along each axis, throughout the scanning volume.

A.4.2.3 Rotate

The software may allow the user to rotate the human figure 360° in each axis.

A.4.2.4 Floating axis

At the user's option, the software may allow the XYZ axis indicator, as well as the origin of the axis system, to remain visible continuously.

A.4.3 Features of landmark identification

A.4.3.1 The software should allow landmarks to be identified either manually or automatically, and to be recognized as individual variables, with names or numbers.

A.4.3.2 The software should allow the user to assign names or numbers to identified landmarks, and allow the input or output of lists of landmark names, in ASCII code, according to ISO/IEC 8859-1[1].

A.4.3.3 The software should allow the user to create a file containing landmark names and their 3-D coordinates.

The file format should be

text, tab delimited (in ASCII code, according to ISO/IEC 8859-1).

The structure of the file should be

X [tab] Y [tab] Z [tab] Landmark Name [return]

A.4.3.4 The software should allow the user to visualize landmarks (with colour, or differential brightness) on the screen, with or without the figure. This feature should be available for all landmarks or a subset of landmarks.

A.4.4 Features of segmentation

A.4.4.1 The software may give the user the ability to separate body parts (upper limbs, lower limbs, torso, etc.) from the rest of the body — either automatically, using identified landmarks, or manually, using the cursor. If automatic segmentation is used, the user should verify that the segmentation points are appropriate for his or her purposes.

A.4.4.2 The software may give the user the ability to visualize one or more segments independent of the whole image.

A.4.4.3 The software may allow the user to pan, rotate and zoom segments.

A.4.4.4 The software may allow the user to pan, rotate and zoom the viewing field.

A.4.5 Features of measurement extraction

A.4.5.1 Manual measurements

From an identified point, the software should give the user the ability to

— extract the height from floor/platform,

— extract the distance from the vertical plane at the most posterior point on the body,

— extract the distance from the vertical plane at the most anterior point on the body,

— extract the distance from the vertical planes at the right or left most points on the body,

— calculate the horizontal or vertical circumference from an identified point, and

— calculate the circumference along a user-identified plane.

From two identified points, the software should give the user the ability to

— calculate the point-to-point distance in 3-D space between the points,

— calculate the vertical distance between the points,

— calculate the horizontal distance between the points,

— calculate the shortest surface distance between the points, and

— create and measure a cross-section for measuring along the surface, and as an outer hull.

A.4.5.2 Automatic measurements

The software may give the user the ability to define a measurement in terms of landmarks and procedures (e.g. a horizontal circumference or a point-to-point distance), and then extract that dimension automatically.

A.4.6 Data storage

Data should be stored in the raw format native to the system. The single exception is the case of a multiple-image system, where the images should be aligned and merged before storing. If the data are compacted before storage, the polygon reduction information should be retained. Outlying points should be eliminated before storage.

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