PART I – AN OVERVIEW OF KINANTHROPOMETRY STANDARDS AND PROTOCOLS

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Preface

Traditionally, anthropometric data are captured physically by trained anthropometrists, using various tools and in strict accordance with defined protocols. This Part (I) briefly reviews the literature on the key concepts of kinanthropometry and anthropometry. It also describes different physical measurement protocols and the advantages and disadvantages of traditional anthropometry. An understanding of these concepts is vital for large-scale anthropometric survey planning, especially since most surveys to date have relied largely on traditional anthropometric measurement.

Overview

There is no universally accepted protocol for three-dimensional (3D) human body scanning. This book has been produced as a call for international standards in 3D body scanning. Initial 3D body scanning protocols were lodged with the J.E. Lindsay Carter Anthropometry Archive in 2014 [1].

Throughout this book, 3D body scanning is discussed as a tool that captures, measures, or records anthropometric data. Three-dimensional body scanning uses laser, light or infra-red technologies 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 scan images. The images vary depending on the configuration, resolution, and accuracy of the scanner.

Scanning technology is expensive given the hardware and software required, and only provides surface anthropometry characteristics. For physique assessment including estimates of body composition, body size, and shape, the International Society for the Advancement of Kinanthropometry (ISAK) protocols should be followed. The advantages of the ISAK surface anthropometry methods are that assessments take approximately 10 minutes for a restricted profile, up to 40 minutes for a full profile, and the equipment is readily available, less expensive, and easily calibrated. The ISAK methods are valid and reliable if ISAK training is undertaken to ensure correct landmarking is performed.

Keywords

Kinanthropometry; Anthropometry; Measurements; Protocols; Three-dimensional; Body scanning; Body volume; Segment lengths; Girths; Laser; Technologies; Shape; Body posture; Images; Configuration; Resolution; Accuracy; Scanner; Physique; Equipment; Caliper; Landmarking; Skinfolds; Girths, Breadths, Circumference; Profile; International standard.

Introduction

What is Kinanthropometry and Anthropometry?

Kinanthropometry is the study of human size, shape, proportion, composition, maturation, and gross function. The term is named from the Greek root words kinein (to move), anthropos (human) and *metrikos* (the act of measuring) [2]. Anthropometry is part of the field known as kinanthropometry, which can be defined as: "The academic discipline which involves the use of anthropometric measures in relation to other scientific parameters and/or thematic areas such as human movement, physiology or applied health sciences" [3].

A pioneer of anthropometry, Quitelet in 1870 attempted to obtain measurements of the 'average' man to provide better-fitting uniforms for Napoleon's army. In the 1950's anthropometrics became a recognized scientific discipline. Today a more contemporary definition of anthropometry is: "*The scientific procedures and processes of acquiring surface anatomical dimensional measurements such as lengths, breadths, girths and skinfolds of the human body by means of specialist equipment*" [3].

Anthropometry is associated with measurements of body size, shape, strength, mobility, flexibility, working capacity [4] and the study of body dimensions (e.g. lengths, breadths, girths skinfolds) that utilize surface landmarks for reference [5]. Anthropometry is used in the design of vehicles, work sites, equipment, aircraft cockpits, clothing [6], sports science and ergonomics [7]. Anthropometric data provide designers with the physical and functional characteristics of potential end-users which can be applied to many design solutions. Poor quality, or a lack of anthropometric data, can result in failure to accommodate individuals in the workplace , customer dissatisfaction, and may lead to discomfort, accidents and injury [8].

Measurements

Anthropometric data comes in many forms that include one-, two- and three-dimensional data (Figure 1). One-dimensional (1D) data is identified easily as there is only one number (e.g., body height = 1670 mm) [8]. One-dimensional data are often captured using traditional anthropometry or 'direct' measurements obtained by a skilled anthropometrist. The measurements are captured using tools such as tapes, callipers, or a stadiometer. Two-dimensional (2D) anthropometry data have two dimensions (i.e. x and y) which can be extracted from a two-dimensional source such as a photograph. Digital photogrammetry is a method of measuring limb segment dimensions from photos [9]. Three-dimensional (3D) anthropometric data have three dimensions (i.e. x, y, z) which can be extracted from a 3D body scanner [10].

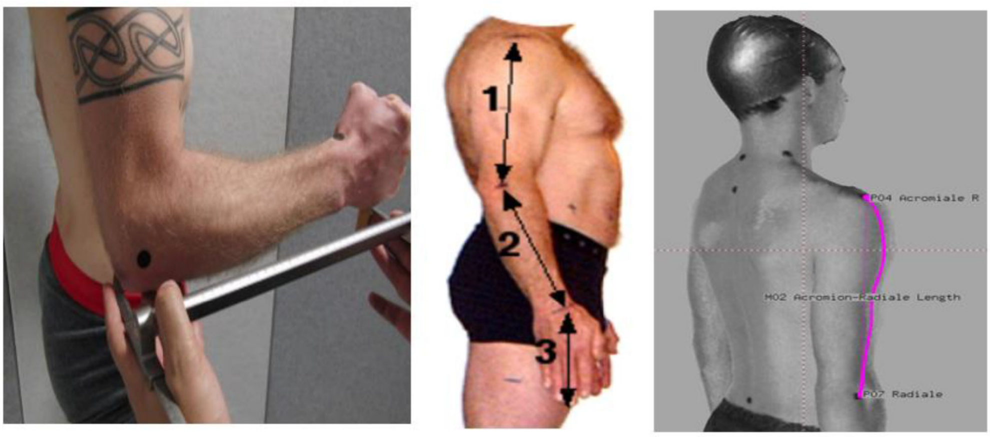

Figure 1. [Left to right] Examples of length measurements using 1D (Radiale-stylion length), 2D or photograph-based anthropometry (Acromiale-radiale length, radiale-stylion length and hand length) and 3D (acromiale-radiale length) data collection methods. Centre photo courtesy of Mellow, Hume [9].

The three types of anthropometric data rely on several important factors. The measures are acquired by skilled anthropometrists who are trained to use specialised equipment. All participants must be minimally clothed or wear tight fitting garments. Most measurements require the location and placement of bone landmarks (especially for segment lengths). Measurements are generally conducted on one side of the body because fat patterning is largely symmetrical within measurement precision, however, muscle development can show marked asymmetry, especially in the upper limb. The survey purpose may require both, left, right, preferred, or non-preferred limb sides to be measured.

Measurement protocol

An anthropometric protocol or measurement profile (also referred to as a landmark profile) refers to instructions or guidelines on how to conduct anthropometric measurements. There are many anthropometric protocols in use today, each having bony landmark sites and measurement definitions [5]. The most well-known civilian and military protocols are:

- Military Handbook: Anthropometry of the U.S. Military Personnel [11]
- International Society for the Advancement of Kinanthropometry (ISAK) [12]
- Civilian American and European Surface Anthropometry Resource (CAESAR) [13]
- National Health and Nutrition Examination Survey (NHANES) [14]
- ISO 7250 standard [15]
- US Army Anthropometry Survey (ANSUR) [16].

We describe military anthropometry protocols and measurements later in this book. Despite the number of protocols there is no 'universal anthropometric' protocol. Such a title would be difficult as many existing protocols differ with respect to measurement and landmark terminology, definition, and implementation. For example, measurements such as height are also known as stature, sitting height can also be called seated height, and weight is also referred to as body mass. Stature can be 'stretched', via upward traction of the mandible by the measurer, which minimises diurnal height loss, or not stretched. Chest girth (or circumference) is defined by some protocols as the circumference around the scye or armpit (CAESAR) or at the level of the thelion or nipple (for males) (ANSUR and ISO 7250) (Figure 2). Chest circumference measurements can vary with the ISAK protocol – chest girth is recorded at end-tidal (fully exhaled breath) while other protocols [12] take the maximum circumference value.

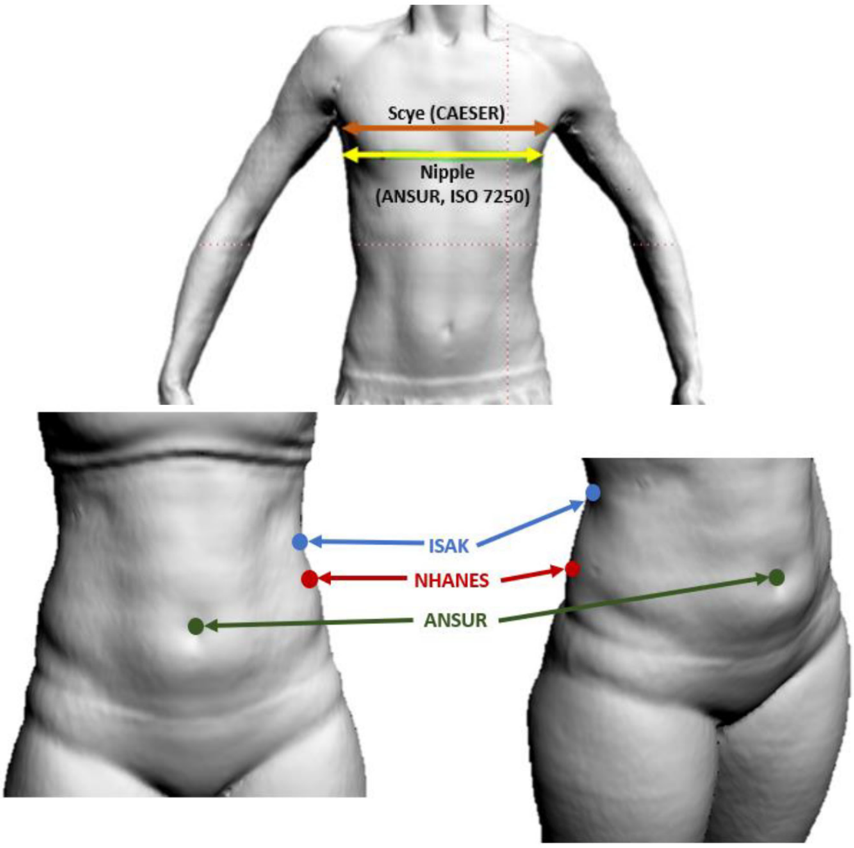

Figure 2. Differences in chest circumference (top) definitions when taken at the level of the scye (CAESAR) or nipple (ANSUR and ISO 7250). Waist girth (bottom) is taken at the level of the narrowest point of the waist between the lower costal (10th rib) border and the iliac crest in ISAK [12], at the point of the uppermost lateral border of the right ilium (in line with the midaxillary plane) in NHANES [14] and the level of the Omphallion (navel) in ANSUR [17].

Protocols such as ISAK and ISO 7250 are examples of internationally recognised, stand-alone anthropometric standards. However, a large proportion of the ISAK and ISO 7250 measurements (based on the civilian population) do not feature in various military anthropometry survey protocols such as ANSUR and vice-versa. The same can be said for measurements between ISAK (with origins in the field of human biology sport and exercise science) and ISO 7250 (an ergonomics-orientated protocol). For example, ISAK does not include ISO 7250 measurements such as popliteal height and elbow height which are critical to ergonomics workstation design [18]. Furthermore, the same issue of ambiguity of measurement names, landmarks and definitions persist. The differences between various protocols measurement terminology or definitions are likely discipline related.

Literature comparing existing anthropometric measurement protocols and standards is limited. Researchers have provided commentary on how future anthropometric protocols should be theorised, written, implemented and shared. The book chapter "Towards a generalised anthropometric language" [19] provides a Generalised Anthropometric Language (GAL) mechanism by which future protocols should be designed. It was recommended that the GAL would entail landmarks being defined by using a description of anatomical terms and sites, and a combination of dimensions would make up an anthropometric protocol. It was envisaged that the GAL would help establish links between protocols and therefore between studies. A well-defined GAL with syntactic rules would help instruct researchers to refine and explicitly record their techniques. It would also decrease the incompatibility and confusion that exists between researchers using different anthropometric protocols. We support this approach and have therefore produced this book as a call for international standards in 3D body scanning.

Traditional anthropometry standards and protocols

This next section discusses the most widely used traditional anthropometric measurement and landmarking protocols and standards for measuring civilians (i.e. military anthropometric protocols are covered in a later section).

The International Society for the Advancement of Kinanthropometry (ISAK)

The International Society for the Advancement of Kinanthropometry was formed in 1986 by experts in the fields of sport, exercise science and human biology seeking methods to standardise practice. This was a collective effort to limit vague and ill-defined definitions of previous protocols which did not allow for exact landmark location, delineation and a systematic approach to quality control [20].

The ISAK scheme became highly popular due to (at the time) several innovative features. For example, ISAK was one of the first schemes to introduce a teaching and practice structure based on a 4-level hierarchy of practitioner licensing, based on competency as assessed by a practical exam. As part of this process all measurers were required to pass error control targets in terms of reproducibility in a standardised setting [20]. While other schemes focus on the reproducibility of measurers within a single lab setting, the ISAK's inter-measurer and intra-measurer reliability protocols enabled comparisons of measurers across different lab settings. The ISAK scheme has a strict focus on identifying landmarks consistently and accurately to enable accurate measurements. ISAK was one of the first schemes to utilise raw data scores (as opposed to conversion into % fat values) as a result of strict protocol definitions and quality assurance of individual measures [20]. Compared to other anthropometric protocols, ISAK is very descriptive and is specific with regards to measurer, client and equipment positioning and recording. The accreditation or license period is 4 years plus an additional 6 months aside for levels 2 to 4 to complete their 20 practical profiles. The extension period is only 4 months for level 1 students to complete their profiles (as their profiles contain less measurements).

There are some disadvantages with the ISAK system. For example, measurers with little to no background in human biology may struggle with the anatomical terminology and the identification of landmark sites. The teaching structure in level 1 (beginner level) provides theory and practical sessions to ensure adequate understanding of anatomical bony locations and performance of measurements based on the landmarks. Success during the course comes down to practical experience and a firm grasp of terminology and fundamental skills.

Courses can be perceived as costly given the need for the limited number of ISAK level 3 or 4 instructors to travel for delivering courses. There is a substantial cost associated with purchasing anthropometry equipment for a full profile set of measurements. The standard anthropometry kit consists of small and large bone callipers, small and large sliding callipers, a segmometer, skin fold callipers and a metal girth tape (Figure 3). Weight scales, anthropometry box and stadiometers are purchased at additional cost to the standard anthropometry kit.

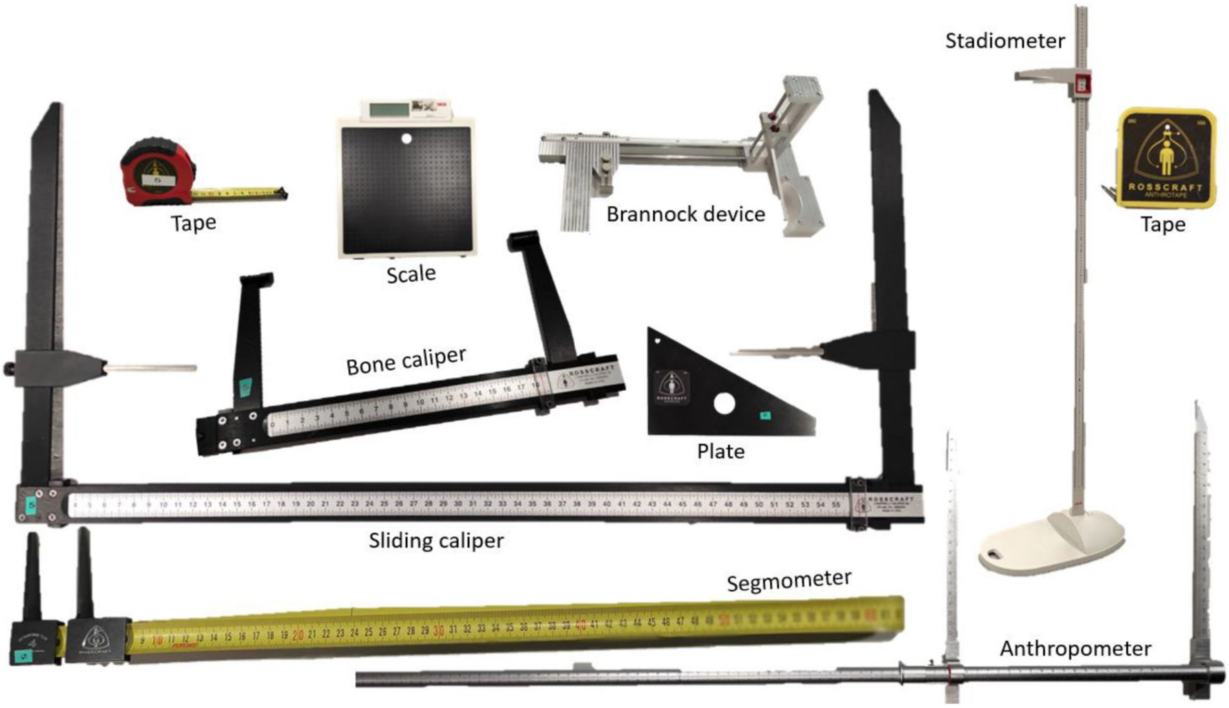

Figure 3. Common traditional anthropometry measurement tools.

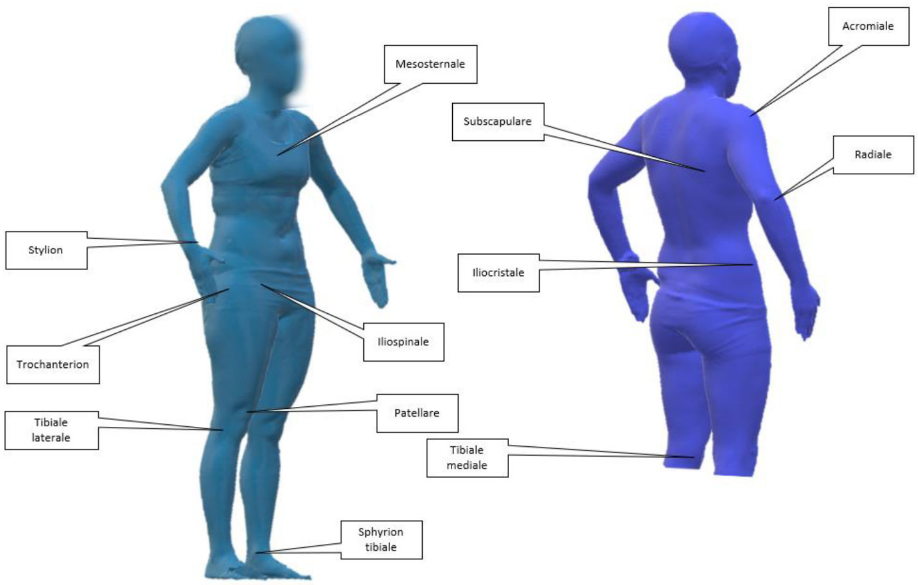

Figure 4. Boney landmarks used to help identify measurements in the full ISAK level 2, 3 and 4 profile.

The ISAK protocol consists of restricted (18 measurements taught in the level 1 course) and full (43 measurements taught in the level 2 course) profiles [21]. Both profiles consist of basic (mass, stature and sitting height, arm span), skinfolds (triceps, subscapular, bicep, iliac crest, supraspinale, abdominal, front thigh and medial calf), girths (arm flexed and tensed; waist gluteal and calf), and breadths (humerus and femur). The additional measures in the full profile include girths (head, neck, forearm, wrist, chest, thigh-gluteal, mid-thigh, ankle), breadths (biacromial, biiliocristal, bi-styloid, transverse chest, anterior-posterior chest, anterior-posterior abdominal), lengths (acromiale-radiale, radiale-stylion, midstylion-dactylion, trochanterion-tibiale laterale, tibiale mediale-sphyrion tibiale, foot) and heights (iliospinale, trochanterion, tibiale laterale). The ISAK full profile consists of 12 bony landmarks that are used to assist the measurement process (Figure 4).

Currently there is no publicly available database from ISAK that is accessible for comparison of body composition data.

Civilian American and European Surface Anthropometry Resource (CAESAR)

CAESAR was the first 3D whole-body surface anthropometry survey [22] of three civilian populations (United States of America, the Netherlands and Italy) conducted by the U.S. Air Force, Syntronics Inc, the Netherlands Organization for Applied Scientific Research (TNO) and a consortium of companies under the Society of Automotive Engineers (SAE) [23].

The CAESAR database consists of approximately 12,000 body scan images taken between 1998 and 2000 of over 4,000 men and women, aged 18–65, covering various weights, ethnic groups, geographic regions, and socio-economic status.

World Anthropometry Engineering Report (WEAR)

The WEAR web-portal was set up by experts in engineering anthropology to unify 145 anthropometric databases across 10 countries and six continents [24]. The web-based database of 3D size, shape, fit and performance data is maintained by members of the WEAR organisation [25].

The WEAR database includes 250,000 participants (men, women, and children, from civilian and military populations) with approximately 50 traditional anthropometric dimensions collected on each individual making over 12 million individual datum. Datasets date from the 1950s, with most post-1970, and more than 20 large datasets collected post-1990 [24].

The WEAR portal contains checklists for measurement validity (sampling, subject population, and secular change), comparability (definition of measurements), and accuracy (before, during, and after measurement capture), lessons learned, fit and accommodation maps, human size and shape information, 3D visualisation, statistical analysis tools and fit prediction models.

International Standards Organization (ISO)

The International Standards Organization describe anthropometric measurements, instruments, standard postures, clothing, and measurer training. ISO guidelines enable practitioners (especially ergonomists) to apply their knowledge to the geometric design of workplaces, tools, apparel and to enable comparison of anthropometric data from different international populations [26]. Example ISO standards with respect to anthropometry include:

- "ISO 15535: 2012 General requirements for establishing anthropometric databases" describes the general requirements for establishing anthropometric databases, their associated reports and measurements taken in accordance with ISO 7250-1. It provides information such as characteristics of the user population, sampling methods, measurement items and statistics, to make international comparison possible across various populations.
- "ISO 7250-1: 2017 Basic human body measurements for technological design - Part 1: Body measurement definitions and landmarks" serves as a basis for extracting one- and two-dimensional measurements from three-dimensional scans (specified in ISO 20685). It provides guidance on how to take anthropometric measurements and gives information to the ergonomist and designer on the anatomical and anthropometrical bases and principles of measurement, which are applied to design tasks. The standard is intended to be used in conjunction with national or international regulations or agreements to ensure coherence in defining population groups and to allow comparison of anthropometric data among member samples.

Advantages and disadvantages of traditional anthropometry

The advantage of traditional anthropometric protocols such as ISAK, ISO and CAESAR are that they have been developed by experts in the field. The protocols have been refined over time to increase accuracy and establish competency and efficiency when taking and recording measurements (for instance the technical error of measurement).

Traditional methods use measurement equipment that is easy to transport. Although the equipment can vary in design and build quality, accurate measurements can be obtained if the equipment is routinely maintained and calibrated, and the measurer is skilled and experienced in its use.

Traditional measurements require only enough space (e.g. a small office) to enable the participant and measurement technician to complete the anthropometric profile. The traditional anthropometrist is trained to utilise various structural features of a room to make measurements efficient. For example, utilizing the corners of a room as a 'zero' point for arm span measurements. Seated leg length measurements (e.g. buttock to heel) can be made with the participant sitting against a wall. The room ceiling can be used to conduct standing arm reach measurements. These room 'features' such as the location of windows or doors can influence how the anthropometrist sets up the equipment, or the order in which to take body measurements and landmarking. Whatever the environment, it is important that measurements can be made consistently with minimal changes between settings. Although the precise protocols are robust the timing is flexible.

With international accreditations like ISAK, accredited anthropometrists are trained to identify, implement, and record measurements consistently. This ensures that measurements are acquired in the same way with confidence.

There are, however, disadvantages of traditional anthropometry. Measurements can be subjective [27] and susceptible to human error. The experience, expectations, training, and accuracy of the measurer can influence the results [28]. Traditional measurements are subject to observer error in landmark location, participant positioning and instrument applications [29].

Traditional measurement surveys are also expensive to plan and conduct [5]. Costs include equipment hire or purchase, booking of the testing location, accommodation facilities and travel. Costs will vary depending on the sample size required, the number of landmarks and measurements required, and the availability and locality of participants and measurement personnel.

Despite the precision of a skilled anthropometrist, the use of traditional measurement tools to obtain measurements is time consuming (e.g. 40 minutes for a full profile) and at times, invasive for the participant [30]. Equipment has varying levels of precision with Harpenden skinfold callipers (Figure 5) enabling readings to 0.1 mm versus 0.5 mm for SlimGuide skinfold callipers. Tools such as the tape-based segmometer (Figure 5) can be fragile and bend or break after prolonged use. Tool-related maintenance tasks are required such as checking springs (coil properties may change with time or be affected by contaminants, including rust), lubrication of joints, bolt, or screw tightness.

Figure 5. Differences in Harpenden and Slim guide skinfold callipers and an example of a broken segmometer.

The high variability in intra and inter-observer traditional measurements [31] is increased for atypical body types [32, 33]. For example, in a study of intra-abdominal bleeding [34] there was a 6 cm difference in patient waist girth measurements across 10 measurers. Inter-observer variability using traditional measurements of thigh girth has been reported as 8.27% (4 cm difference) [35]. This contrasted with errors of 0.2–0.5 cm reported for the same measurement [28, 36, 37]. To minimise these errors, protocols such as ISAK suggest using multiple measurements with calculation of the mean or median. The differences between measurements must lie within an acceptable measurement limit depending on the type of measurement performed. In ISAK, these limits are <5% for skinfolds and <1% for all other measurements (e.g. breadths, girths, and lengths). Furthermore, the real virtue in tight error control is to become capable of detecting small changes in measurements which are real. The main disadvantage of taking multiple measurements is that it is time consuming [28, 38-40].

Traditional anthropometric protocols, while providing good accuracy for linear and circumference measurements, provides limited information for volume, area, body size and shape [28, 30, 41]. The use of anthropometry has stagnated [42] with static or one-dimensional measures. While the Whole-Body Surface Area (WBSA) equation [43] was based on one dimensional measurements, the three-dimensions of the body should be measured using techniques that provide three-dimensional outputs [30].

Summary

Kinanthropometry is a scientific field that is traditionally associated with physical or 'hands on' measurements conducted by experienced anthropometrists. No universal anthropometric protocol exists as many disciplines such as ergonomics, sports science, clothing design, and manufacturing have developed their own set of standards targeted to their own industry. Traditional methods have been tested, validated, and quantified to a point where measurement skills are taught internationally to practitioners. Despite their historical success in many larger-scale surveys, traditional anthropometric measures do possess shortcomings, many of which can be addressed with modern day technology. Part II of this book outlines the advantages and disadvantages of 3D body scanning and the implications for kinanthropometry.