Chapter 2

Anthropometric and body composition measurement methods

1. Anthropometric measurement methods

Excluding body weight, anthropometric measurement is divided into three groups: (1) body length, span and height, (2) body circumferential measurement and (3) skin fold thickness. The most widely used anthropometric measurements of these are body stature (height or length) and body weight. These measurements can be made quickly and easily. Of these anthropometric parameters could be further categorized and calculated to anthropometric indices such as body mass index. The World Health Organization (WHO) has recommended some anthropometric indices for distinguishing abnormal growth in children such as stature for age and weight for stature.[1] Increasingly, body mass index (BMI) is used in epidemiological studies as the recommended indicator for defining overweight and obesity in adults. In hospitals, the anthropometric measurement of body size, circumferences and skin fold thickness are used to identify under- or overnutrition and obesity, and to monitor changes after a nutrition intervention as well as height and body weight prediction. The following discussion in this chapter will explain the standard measurement method of these three categories as well as combination of these raw parameters in anthropometric indices.

1.1 Height, length, span and weight measurements

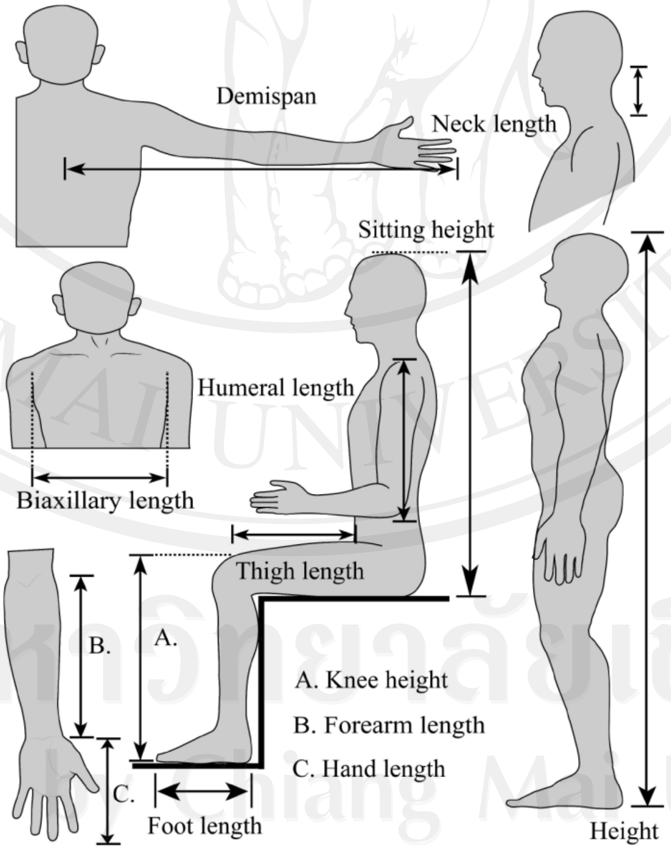

Figure 2.1 Measurement of height, length and span (From Chittawatanarat et al. Asia Pac J Clin Nutr 2012;21,347-354.with permission of the authors and of Hec Press publisher)

1.1.1 Body height

The measurement of height of adult and children greater than 85 cm should be measured in the standing position, if possible.[1] In the standard position, the subject has to look straight ahead horizontal plane (Frankfurt plane) with relaxed shoulders. Arms should be hanging loosely at the sides with palms facing the thigh. The legs position should be straight and with knees together and feet flat with the heels almost together. Shoulder blades, buttocks and heels must touch the scaling board during measurement (Figure 2.1). For younger subjects, it may be necessary to hold the heels to ensure they do not leave the ground.

Some investigators recommended applying gentle upward pressure to the mastoid processes to stretch the spine and minimize effects produced by diurnal variation.[2] The subjects are asked to take a deep breath and stand tall to aid the straightening of the spine. The shoulder should be relaxed. When a movable headboard or head gauge is available, it is then gently lowered until it touches the crown of the head. The height measurement is taken at maximum inspiration, with the examiner's eyes level with the headboard or gauge to avoid parallax errors. The height is recorded to the nearest millimeter, or even more precisely with more modern digital equipment.[3-4]

1.1.2 Knee height

The knee height is commonly recommended to use for stature estimation.[1,5-7] It is highly correlated with stature and could be used to estimate height in persons with severe spinal curvature or who are unable to stand. This measurement can be measured both in the sitting or supine position.

For the sitting position, the knee and ankle are each bent to a 90° angle. Kneeling at the side of the lower leg, the observer places the fixed blade of the caliper under the heel of the foot. The shaft of the caliper is positioned so that it passes over the lateral malleolus and just posterior to the head of the fibula. The movable blade is placed over the anterior surface of the thigh, above the condyles of the femur, about 4.0 cm proximal to the patella. The shaft of the caliper is held parallel to the shaft of the tibia and pressure is applied to compress the tissues (Figure 2.1).

The supine position is measured with the knee and ankle each bent to 90°. Standing to the side of the lower leg, the observer places the fixed blade of the caliper under the heel of the foot, and positions the shaft of the caliper so that it passes over the lateral malleolus and just posterior to the head of the fibula. The movable blade is placed over the anterior surface of the thigh, above the condyles of the femur, about 4.0 cm proximal to the patella. The shaft of the caliper is held parallel to the shaft of the tibia and pressure is applied to compress the tissues.

Several instruments are available for knee height measurement such as mini-knemometer for the sitting position of child,[8] knee height calipers for both sitting or supine position in adult. This equipment has a locking mechanism to retain the measurement after removing the caliper from the leg.[3]

1.1.3 Sitting height

The measurement of the sitting height requires a table and an anthropometer or measuring stick with a horizontal headboard. The individual sits on the table with the legs hanging unsupported over the edge and with the hands resting on the thighs. The posture is as erect as possible, and the line of vision parallel to the ground. It is useful for the person measuring to apply gentle pressure with the right hand over the lumbar area and the left hand, simultaneously, on the superior part of the sternum; this reinforces the erect position. Gentle upward pressure on the mastoid processes ensures the fully erect seated posture. The anthropometer is positioned vertically in the midline behind the subject so that it nearly touches the back. The measurer's left hand is placed under the subject's chin to assist in holding the proper position, and the right hand moves the blade of the anthropometer onto the vertex (the topmost point of the head). The subject is instructed to take a deep breath, and the measurement is made before he or she exhales and recorded to the nearest 0.1 cm (Figure 2.1). [5,9]

1.1.4 Arm span and demispan

Arm span, like knee height, is also highly correlated with stature and can be used as an alternative measurement when actual height cannot be used.[10] The arm span measurement is easier if carried out against a flat wall to which is attached a fixed marker board at the zero end of a horizontal scale. The equipment for arm span measurement used double arm board on the wall scale. One arm is fixed and on the zero ends and the other sliding arm is a vertical movable arm on the scale. The horizontal scale should be positioned so that it is just above the shoulders of the subject. Two examiners are suggested for measuring arm span. One is at the fixed end of the scale; the other positions the movable arm and takes the readings. For the measurement, the individual should stand with feet together, back against the wall, with the arms extended laterally in contact with the wall, and with the palms facing forward. The arms should be kept at shoulder height and outstretched maximally. The measurement is taken when the tip of the middle finger (excluding the fingernail) of the right hand is kept in contact with the fixed marker board, while the movable arm is set at the tip of the middle finger (excluding the finger nail) of the left hand. Two readings are taken for each measurement, which is recorded to the nearest 0.1 cm.[3-4] However, the arm span is difficult to measure in non ambulatory elderly persons and in individuals with significant chest and spinal deformities.

The modified method to measure the arm span is demispan measurement. It is a simpler method than arm span by using scaling tape or retractable metal tape.[11] The method can be measured both in the supine or standing position with the shoulders full extension laterally. At the ventral surface, the measurement starting point is from mid manubrium and then passed over the shoulder, elbow and wrist to the tip of middle finger.[5] This method is more suitable in non-ambulatory and elderly patients (Figure 2.1).

1.1.5 Other length measurements

Other anthropometric lengths are measured with other parts of subject's body such as biaxillary, neck, humerus, forearm, hand, thigh and foot length. The details of length measurements are summarized as following description.[5]

The biaxillary length (Figure 2.1) can be measured both in the supine or sitting position with arm adduction close to the body. At the ventral surface, measure side to side at the junction of deltopectoral groove and anterior axillary fold.

The neck length (Figure 2.1) can be measured in sitting with full neck extension. At the posterior, measurement is started at external occipital protuberance to tip of spinous process of 7th cervical spine (vertebral prominens at root of neck).

The humeral length (Figure 2.1) measured both in the supine or sitting position with a 90 degree elbow flexion. At the lateral aspect, the measurement starting point is at the tip of the acromioclavicular eminent to tip of olecranon of elbow of the non-dominant arm.

The forearm or ulnar length (Figure 2.1) is measured in the supine or sitting position with elbow extension. At the palmar surface, the measurement is started at the olecranon process of the elbow to the prominent bone of the wrist (styloid process) of the non-dominant arm.

The hand length (Figure 2.1) can be measured in both the supine and sitting position. At the palmar surface, the measurement is started at the last crease of wrist to tip of mid finger (3rd finger) of non-dominant hand.

The foot length can be measured both in the supine and sitting position. The measurement is started from the tip of the heel at the posterior to the tip of the first toe.

1.1.6 Body weight

Body weight is the sum of the protein, fat, water, and bone mass in the body. Alterations in body weight do not provide any information on the relative changes among each of these components. In normal adults, there is a tendency to increase fat deposition with age concomitant with a reduction in muscle protein. In conditions of acute or chronic illness, negative energy balance may occur as the body can use endogenous sources of energy as fuel for metabolic reactions. Therefore, the body weight declines. Of these, body weight is the most important parameter in clinical practice. In addition, weight changes using actual and usual weights of the subject give more the clinical information such as progression of nutritional status, and fluid balance. From these two measurements, the percentage of usual weight, percentage of weight loss and rate of change can be calculated. (Table 2.1)

Table 2.1 Calculation of weight change indicators

Weight change indicator	Calculation method
Percent usual weight (%)	(Actual weight/Usual weight) x 100%
Percent weight loss (%)	[(Usual weight – Actual weight)/Usual weight] x 100%
Rate of change	$(BW_p – Bw_i) / (Day_p – Day_i)$

Abbreviation: BW_p, Present body weight; Bw_i, initial body weight; Day_p, Present day; Day_i, intitial day.

In this measurement method, an individual who is able to stand without support is weighed using a level platform scale. The subject stands still in center of the platform, with the body weight evenly distributed between both feet. Light indoor clothing can be worn, but shoes, long trousers, and sweaters should be removed. The weight of the remaining clothing is not subtracted from the observed weight when the recommended reference data are used; however, if heavy clothing must be worn during weighing because of cultural constraints, adjustments should be made before weight measurements are interpreted. Weight is recorded to the nearest 100 gram. Individuals, other than infants, who cannot stand unsupported by reason of disability can be weighed using a beam chair scale or bed scale. If an adult weighs more than the upper limit on the beam, a compensating weight can be suspended from the left-hand end of the beam and the measurer must then determine how much weight must be placed on the platform for the scale to record zero. When the subject is reweighed, this compensatory weight is added to subject measured weight.[1,4]

1.2 Circumferential measurement (Figure 2.2)

The circumferential anthropometric measurement parameters play an important role in the growth record in child, weight estimation and fatness in adult.[3,12] The most common circumferential parameters used in clinical epidemiology are the waist and hip circumference and the indices of waist to hip ratio (WHR). The following discussion will summarize the method and landmarks of body circumference measurement in adult. Circumference results have diurnal variations especially in the torso regions. Therefore, subjects should be asked to fast overnight or at least 4-6 hours prior to measurement and wear little clothing to allow the tape to be correctly positioned (Figure 2.2).

1.2.1 Neck

For the neck measurement the subject lies supine, sits or stands. Measurement is performed at the level of the cricoid cartilage in the anterior and midpoint between the external occipital protuberance and the tip of the spinous process of 7th cervical spine (vertebral prominens at root of neck) in the posterior. The position of the tape measure is horizontal around this level. The measurement is recorded to the nearest 0.1 cm.[12]

1.2.2 Arm or mid upper arm circumference (MUAC)

For measurement of MUAC the subject stands erect, sitting or supine position with the arms hanging freely at the sides of the trunk, the palms towards the thighs. Loose clothing without sleeves is worn to allow total exposure of the arm and shoulder area. The circumference is measured at the midpoint of the arm. To locate the midpoint, the subject's elbow is flexed to 90^0 with the palm facing upward. The measurer locates the lateral tip of the acromion at the shoulder, and a small mark is made at the identified point. The most distal point on the olecranon process of the ulna (at the point of the elbow) is located and marked. A measuring tape placed over these two marks is used to find the midpoint between them, which is marked. With the subject's arm relaxed, the elbow extended and hanging just away from the side of the trunk, and the palm towards the thigh, the tape is placed around the arm and positioned perpendicular to the long axis of the arm at the marked midpoint. With the tape snug to the skin but not compressing soft tissues, the circumference is recorded to the nearest 0.1 cm.[1,4,12]

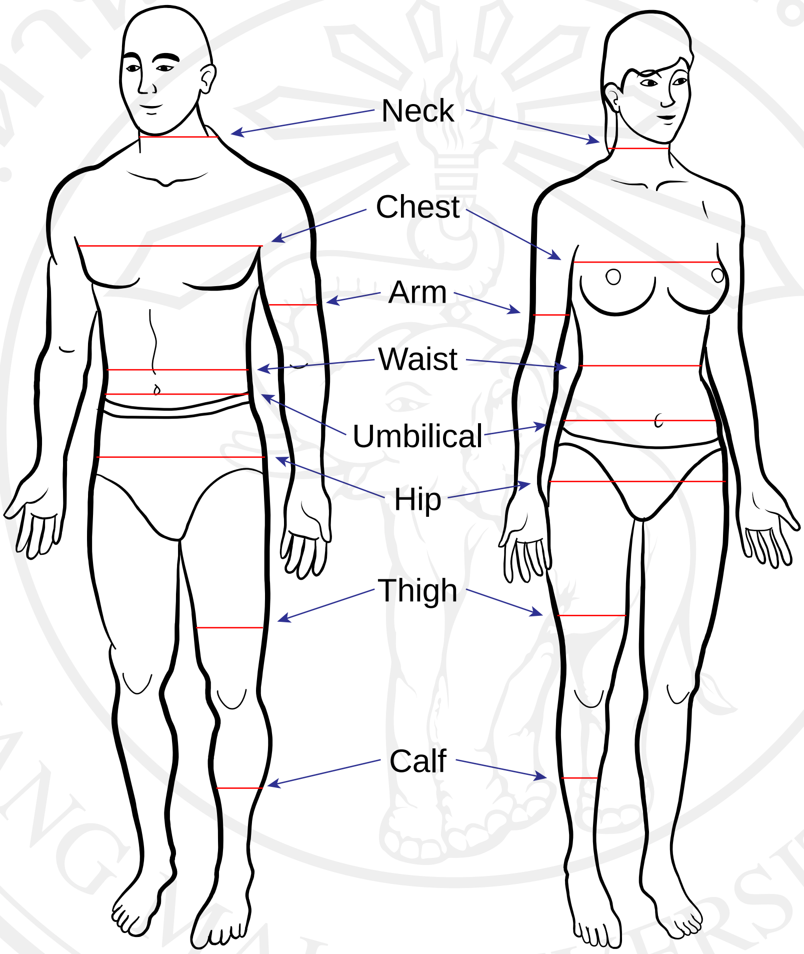

Figure 2.2 Level of circumferential anthropometric measurements

1.2.3 Chest

The chest should be bare. The arms are abducted slightly to permit passage of the tape around the chest. When the tape is snugly in place, the arms are lowered to their natural position at the sides of the trunk. The chest circumference is measured at the level of the fourth costosternal (rib) joint, counting the number of ribs from above. This level is usually located at the upper chest on the level of junction between the deltopectoral groove and the tip of anterior axillary fold.[12] The measurement is made in a horizontal plane to the nearest 0.1 cm at the end of a normal expiration.

1.2.4 Waist

Currently, no universally accepted procedure exists for defining the site for the measurement of waist circumference. Two sites are frequently used. The first, measurement is performed at the natural waist, i.e., mid way between the tenth rib (the lowest rib margin) and the iliac crest or measurement above umbilicus 1-1.5 inches in cases that the narrowest part could not be identified.[1,4,12] A second, measurement is performed at the umbilicus level.[13] The latter site is preferred for obese subjects because it is sometimes difficult to identify a waist narrowing.

1.2.5 Abdomen (Umbilical level)

The abdominal circumference is measured and recorded at the level of the umbilicus. This thesis separated the abdominal level from the waist circumference. This level is usually located about 1.5-2.0 inches above the superior posterior iliac spine at posterior.[12] Sometime this level is categorized as waist circumference.[13] This circumference is usually larger than waist circumference.

1.2.6 Hip

The hip measurement should be taken at the point yielding the maximum circumference over the buttocks, with the tape held in a horizontal plane, touching the skin but not indenting the soft tissue. This level is usually located at the level of the pubic symphysis at the anterior and ischeal tuberosity at the posterior. The measurement is taken to the nearest millimeter.[4,12,14]

1.2.7 Thigh

For the thigh measurement the subject lies supine or stands. The measurement is performed at the level of the midpoint between the inguinal point and upper border of the patella. The tape measure is positioned horizontally around this level. The measurement is recorded to the nearest 0.1 cm.[12]

1.2.8 Calf

The subject sits on a table so that the leg to be measured hangs freely; alternatively, the subject stands with the feet about 20 cm apart with the weight distributed equally on both feet. However, this measurement might be measured in the supine position with the knee flexed to 90°.[4,12] The tape measure is positioned horizontally around the calf and moved up and down to locate the maximum circumference in a plane perpendicular to the long axis of the calf. In Thai people, this level is usually located at the midpoint between the heel and upper most point of femoral condyles. (approximately 4 cm. proximal to the patella).The tape is in contact with the skin over the whole circumference but does not indent the skin. The measurement is recorded to the nearest 0.1 cm.

1.3 Thickness measurement

The skinfold thickness measurements provide an estimate of the size of the subcutaneous fat deposit which provides an estimate of the total body fat mass. Such estimations are based on two assumptions. First, the thickness of the subcutaneous adipose tissue reflects a constant proportion of the total body fat. Second, the skin fold sites selected for measurement, either single site or combination might represent the average thickness of the entire subcutaneous adipose tissue. However, neither of these is true. In fact, the relationship between subcutaneous and internal fat is nonlinear and varies with body weight and age. In addition, variations in the distribution of subcutaneous fat occur with sex, race or ethnicity and age.[15] The following sites of skinfold thickness measurements are commonly used.[3-4,16] Method of skin fold thickness measurement using caliper is demonstrated in Figure 2.3

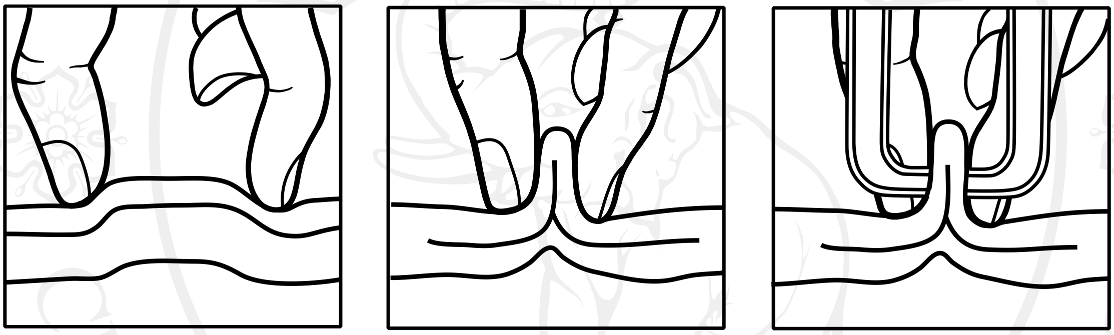

Figure 2.3 measurement of skinfold thickness by calipers

1.3.1 Triceps skinfold (Figure 2.4)

The triceps skinfold is measured in the midline of the posterior aspect of the arm, over the triceps muscle, at a level midway between the lateral projection of the acromion process at the shoulder and the olecranon process of the ulna (at the point of the elbow). With the elbow flexed to 90°, the midpoint is determined by measuring the distance between the two landmarks using a tape measure; it is marked on the lateral side of the arm. Except for infants and the handicapped, the subject should be measured standing, with the arm hanging loosely and comfortably at the side. The caliper is held in the measurer's right hand. A vertical fold of skin and subcutaneous tissue is picked up gently with the left thumb and index finger, approximately 1 cm proximal to the marked level, and the tips of the calipers are applied perpendicular to the skinfold at the marked level. Measurements are recorded to the nearest of smallest unit for the specific measuring instrument.

1.3.2 Subscapular skinfold (Figure 2.5)

The subscapular skinfold is picked up gently on a diagonal, inclined infero-laterally at approximately 45° to the horizontal plane in the natural cleavage lines of the skin. The site is just inferior to the inferior angle of the scapula. The subject stands comfortably erect, with the arms relaxed at the sides of the body. To locate the site, the measurer palpates the scapula, running the fingers inferiorly and laterally along its vertebral border until the inferior angle is identified. For some subjects, especially the obese, gently placing the arm behind the back will help identify the site.

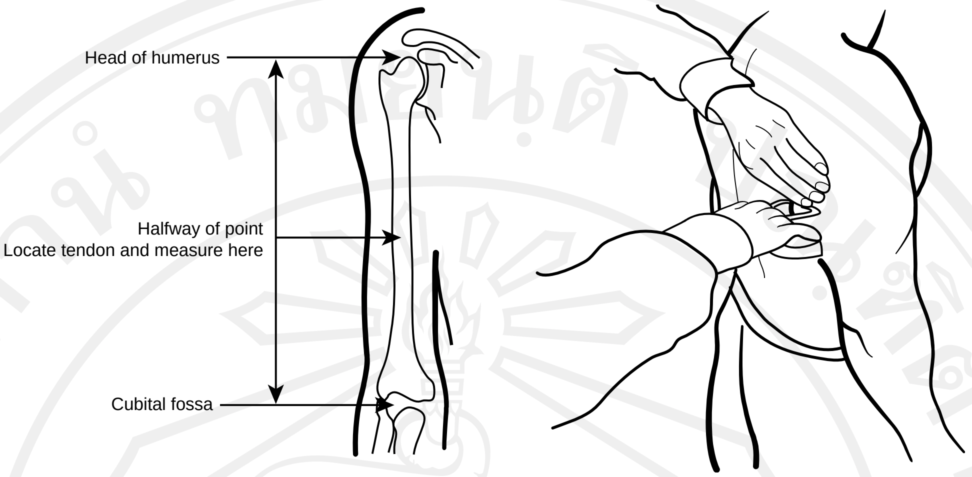

Figure 2.4 site and measurement of triceps skin fold

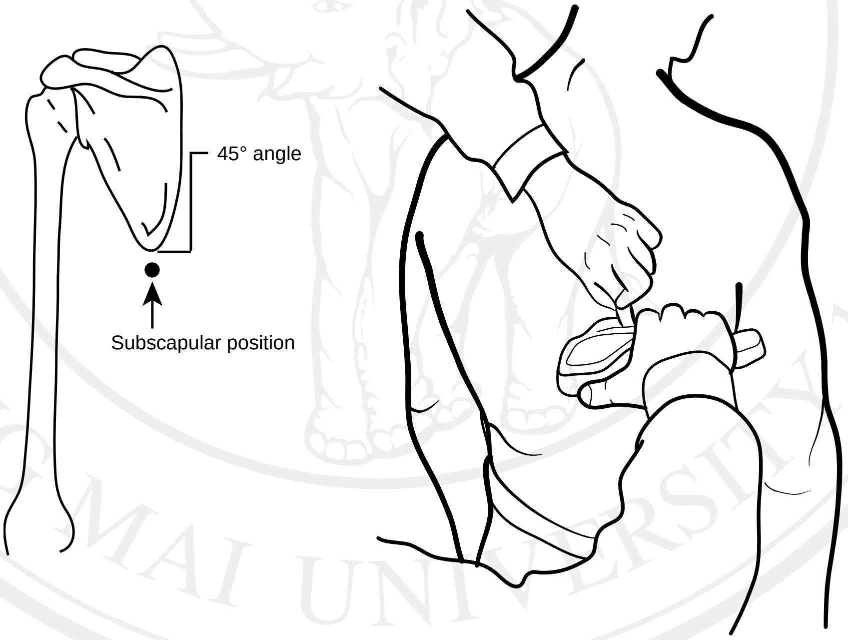

Figure 2.5 site and measurement of subscapular skinfold

1.3.3 Thigh skinfold (Figure 2.6)

The thigh skinfold site is located in the midline of the anterior aspect of the thigh, midway between the inguinal crease and the proximal border of the knee cap (patella). The subject flexes the hip to assist with the location of the inguinal crease. The thickness of the vertical fold is measured while the subject stands. The body weight is shifted to the other foot while the leg on the measurement side is relaxed with the knee slightly flexed and the foot flat on the floor.

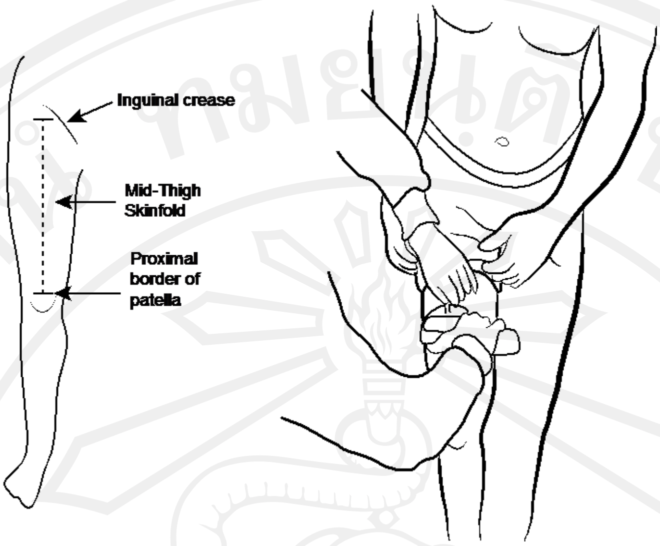

Figure 2.6 site and measurement of thigh skinfold

1.3.4 Supra-iliac skinfold (Figure 2.7)

The suprailiac skinfold is measured in the mid axillary line immediately superior to the iliac crest. The skinfold is picked up obliquely just posterior to the midaxillary line and parallel to the cleavage lines of the skin.

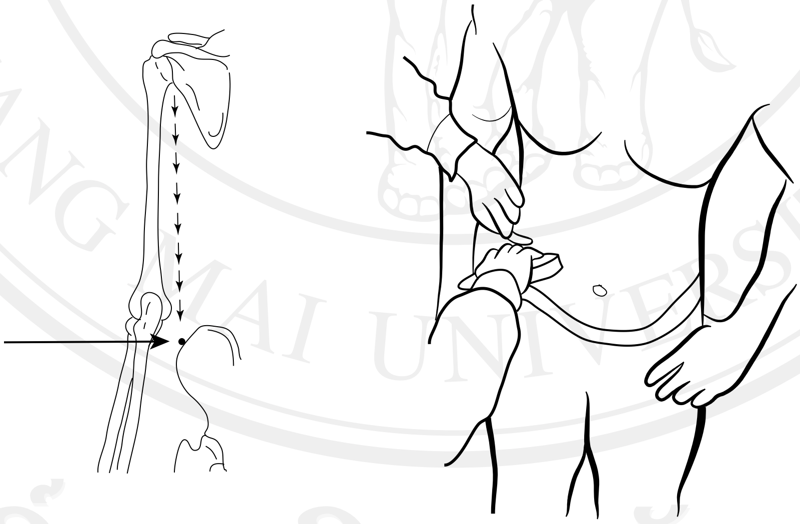

Figure 2.7 site and measurement of supra-iliac skinfold

1.3.5 Biceps skinfold (Figure 2.8)

The biceps skinfold is measured as the thickness of a vertical fold on the front of the upper arm, directly above the center of the center of the cubital fossa, at the same level as the triceps skinfold. The caliper jaws are applied about 1 cm distal to the fingers holding the fold, and the thickness of the fold is recorded to the nearest of smallest unit for each instrument.

Figure 2.8 site and measurement of biceps skinfold

1.3.6 Midaxillary skinfold (Figure 2.9)

The midaxillary skinfold is picked up horizontally on the midaxillary line. Measurement is performed at the level of the xiphoid process.

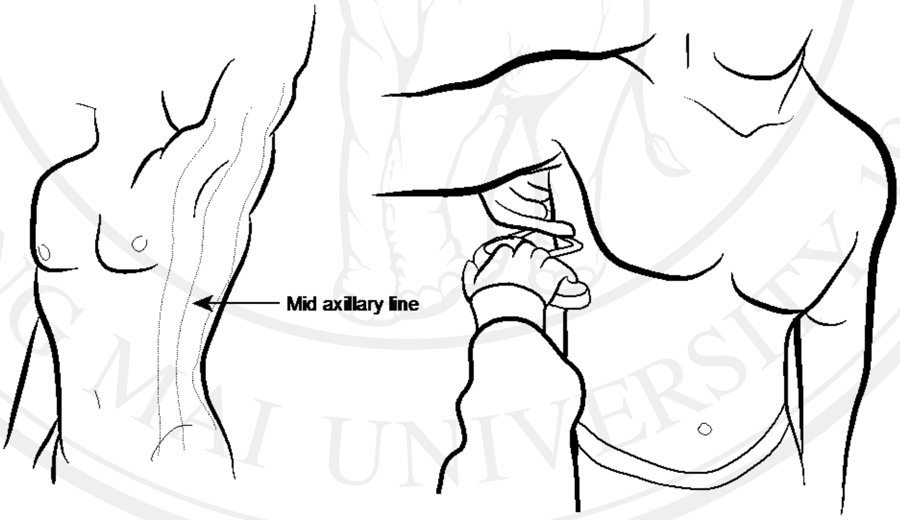

Figure 2.9 site and measurement of midaxillary skinfold

1.3.7 Abdominal skinfold (Figure 2.10)

The measurement of the abdominal skinfold is performed at 2 centimeters or 1 inch to right side of the umbilical level. The present technique suggests vertically picking up of the skinfold.

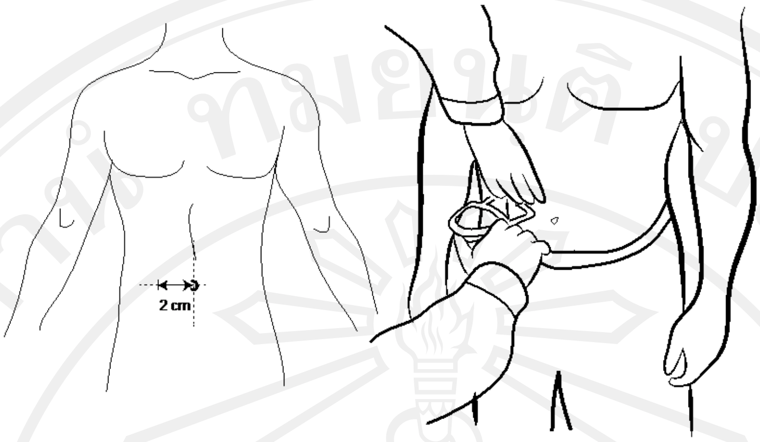

Figure 2.10 site and measurement of abdominal skinfold

1.3.8 Chest skinfold (Figure 2.11)

The measurement of the chest skinfold is performed utilizing different techniques between genders. For males, the location of the measurement is one half the distance between the anterior axillary line and nipple. For females, it is located one third the distance between them. The skin fold is picked up parallel to the pectoralis major border as the diagonal line.

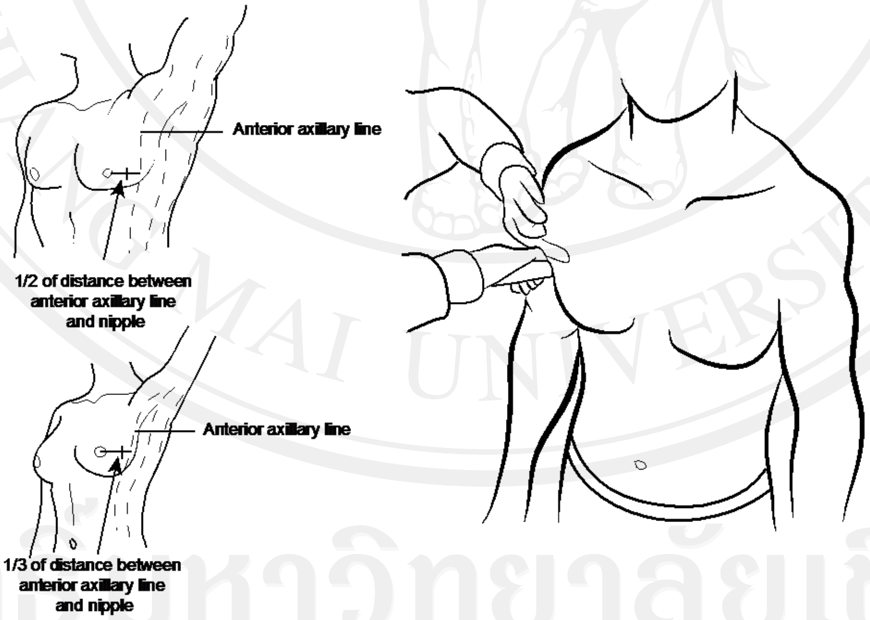

Figure 2.11 site and measurement of chest skinfold

Finally, there are some points of concern. The skinfold thickness measurements are best made using precision thickness calipers; these measure the compressed double fold of fat and skin. As a result of compression, these always underestimate the actual thickness of the subcutaneous fat.[3] The skinfold is always grasped at the marked site with the fingers on top, thumb below, and forefinger on the marked site. Presently, three types of precision calipers are available, Harpenden®, Lange® and Holtain®. Each instrument has own different smallest unit such as the nearest 0.5 mm for Lange® calipers and 0.2 mm for Holtain® calipers. Although low cost plastic calipers are also available but this equipment has reduced precision and accuracy.[3]

1.4 Combination anthropometric indices

Raw and single anthropometric measurement data, sometime, is difficult to generalize interpret and communicate to different populations including age, gender and race. Therefore, anthropometric data is modified to indicate the alteration of these parameters using a mathematical and statistical method to standardize them. These modified parameter call '*anthropometric indices*'. The most familiar anthropometric indices are body mass index, waist to hip ratio and others. The value of these indices could be applied in clinical setting both in individual and population level. For individuals, anthropometric indices are used in the early detection of abnormal changes in growth, and assessing the response of an individual therapy. In both cases, repeated measurements on each individual are needed.[1] For population or public health, indices are used in screening systems to identify individuals "at risk" for unfavorable outcomes such as malnutrition or overnutrition and those who may require intervention. The following substance will summarize adult anthropometric indices in clinical and epidemiological application.

1.4.1 Indices for weight relative to height

Weight to height ratios indicate body weight in relationship to height and are particularly useful for providing a measure of nutritional status in adult populations. At the present time, the ratio most commonly used in this way is the body mass index (BMI). This is also termed Quetelet's index. The BMI is used in preference to other indices including the weight/height ratio, the Ponderal index and Benn's index (Table 2.2).[3,17] In addition, it is now used extensively internationally to classify overweight and obesity in adults. The BMI is relatively unbiased by height and appears to correlate reasonably well with laboratory-based measures of adiposity.[18-19] However, it is difficult to calculate at the bedside or in the field and it could not be applied for individual use especially for low educated people in developing countries. In addition, to obtain an accurate result requires a means such as a calculator or a nomogram. Because of these limitations, the simple method of height weight difference index using the difference of height (cm) and body weight (kg) was proposed. This index had a high correlation and acceptable agreement to BMI and nutritional status classified by BMI.[20]

Table 2.2 Indices for weight relative to height

Index	Formula
Weight/height ratio	weight/height
Body mass index (Quetelet's index, BMI)	$\text{weight}/(\text{height})^2$
Ponderal index	$\text{height}/\sqrt[3]{\text{weight}}$
Benn's index	$\text{weight}/(\text{height})^p$
Height weight difference index (HWDI)	height – weight

Note: The power p in Benn's index is calculated to minimize the direct relationship with height[17]

Although the BMI is widely used but there are some inevitable limitations of using the BMI and should be of concern during BMI interpretation. First, the BMI does not distinguish between weight associated with muscle and weight associated with body fat. Hence, in some circumstances, an elevated BMI may result from excessive adiposity, muscularity or edema. Second, the BMI gives no indication about the distribution of body fat. Anomalies in the distribution of abdominal fat are now recognized to be as great a risk factor for disease as is excess body fat per se. Therefore, it is often better to include a more direct measure of obesity, such as skinfold thickness measurements, with the BMI.[1,3]

1.4.2 Indices of waist relative to hip

The most commonly used measurement is the waist to hip ratio (waist circumference divided by hip circumference; WHR). This is a simple method for distinguishing between the fat composition in the lower trunk (hip and buttocks) and the fat composition in the upper trunk (waist and abdomen area). The subject who has an increased lower trunk fat composition is often referred to as “gynoid obesity”. This contrasts to the subject who has upper trunk or central fatness and is called “android obesity”. Nevertheless, both men and women can be classified into either group.[3] Use of the WHR has risen dramatically with the recognition that central obesity is a critical risk factor in the development of certain diseases, independent of overall obesity. Several prospective cohort studies have confirmed that for both men and women with an elevated WHR there is strong association with an increased risk of developing coronary heart disease, stroke, and type 2 diabetes mellitus.[21-22] The widely accepted international cut point criteria is WHR>1.0 for men and >0.85 for woman.[23]

1.5 Summary of anthropometric measurement

Besides body weight, adult single anthropometric measurements are divided into three groups. First are length, span and height. Second are circumferential parameters and third is skin fold thickness. The combinations of two anthropometric measurements are calculated into anthropometric indices. The method of measurement and equipment used for each parameter should be standardized for valid interpretation.

2. Body composition measurements methods

The human body is a complex unit which comprised of multiple compositions. At present, two or four compartment models are most commonly used. The two compartment model assumes that the total body mass is composed of two major molecular compartments including body fat and the fat free mass. The four compartment model divides the body into four molecular fractions comprised of minerals, water, protein and fat. However, the detailing of body composition have been formally proposed that the body can be divided not only on a four compartment molecular basis but also according to parallel elemental, cellular and functional frameworks as following table 2.3.[24-25] These compositions could be determined in vivo as the following table.

Table 2.3 Multi-compartment models of body composition based on each frameworks

Frameworks of body compartment	Compositions
Elemental level	Oxygen + Carbon + Hydrogen + Nitrogen + Others [a]
Molecular level	Water + Lipid + Protein + Minerals
Cellular level	Body cell mass + Fat + Extracellular solid + Extracellular water
Functional level	Adipose tissue + Skeleton + Muscle + Viscera [b]

Note: [a] including calcium, phosphorus, potassium, sodium and trace elements; [b] including all the visceral organs and residua

2.1 Neutron activation analysis (NAA)

The neutron activation analysis (NAA) is the direct estimation of the amount of a range of chemical elements in the living human body. The NAA analyzes nearly all of the major elements present in the body including hydrogen, oxygen, carbon, nitrogen, calcium, phosphorus, sodium and chlorine. These methods have been developed to measure in vivo some other specific elements that become concentrated in particular organs in the body. Examples include cadmium, mercury, and iodine. However, the technical difficulties associated with the determination of some of these elements are significant, and at present the method is most commonly used in clinical medicine for the determination of total body calcium and total body nitrogen. A major negative factor associated with NAA is that the subject is exposed to radiation.[3,26]

2.2 Densitometry

Body density was the first measures of body composition which was reported by Behnke et al in 1942.[27] It is relatively easy to measure and is widely used and it has been regarded as the reference standard method for body fat determination and simple calculations were performed by using the two compartment model. The assumption of this model was based on uniform density of both body fat and fat free mass which was imprecise. For these reason, densitometry is now often combined with other measures, such as isotope dilution or dual energy X ray absorptiometry. With this combination, three and four compartment models can then be used to make an assessment of body fat.[28] Underwater weighing or hydrostatic weighing was the initial densitiometric method. However, this is now being replaced by two plethysmographic methods, air and water displacement plethymograpy, that are more acceptable to subjects and in particular to children.[28]

When calculating the body fat from body density for normal persons, body fat is assumed to have a relatively constant density, as well as negligible water and potassium contents. Different authors use different values for the density of fat; the Siri equation assumes that the density of fat is about 0.90 kg/L at 37^{O}c [29] The percentage of body fat is often calculated from the whole body density using one of the empirical equations describing the relationship between fat content and body density.[29-30] The theoretical error in body fat using densitometric measurements was 3-4%. These attributed to variability in the water content of the fat free mass and in the bone mineral density.[31]

2.2.1 Underwater weighing (UWW) or hydrostatic weighting

UWW is the conventional method of directly measuring whole body density using Archimedes's principle to determine the volume of the subject. The subject is weighed first in air and then completely submerged in water in a large tank after fully expiring as much air as possible from the lungs. During this period, the hydrostatic weight is recorded at the end of the forced expiration. The body volume is calculated from the apparent loss of weight in water. Body density is calculated with the following formula (1)

Body density = body weight in air (kg)/ apparent loss in weight (kg) ……….(1)

Three factors might disturb the validity of measurement including water temperature, trapping air in lung and gastrointestinal tract. If the residual air volume is in error by 300-500 mL, there will be a corresponding uncertainty in the percentage of body fat from 3-5%.[3] UWW can give very reproducible results for body density, provided that the examiners and the subjects are well trained. Of these, literature reported a standard deviation of 0.008 kg/L for serial measurements on these patients.[32]

2.2.2 Water displacement plethysmography

The use of a plethysmography eliminates the necessity for totally immersing the subject in water which is a disadvantage of UWW. This equipment is comprised of a main filled water reference chamber and pressure transducer for alteration of pressure and volume changes in the chamber during measurement. For measurement, the subject is weighed, and a weight of water equal to the weight of subject is removed from reference chamber. The subject then stands with water up to the neck only, and the head is covered by a clear plastic dome. The volume of air surrounding the head of the subject is then determined by a transducer. This allows the total volume of the subject to be determined. The principle of measurement density is the same as the UWW but it has been used successfully to measure the body density of obese adults.[33]

2.2.3 Air displacement plethysmography

Instead of water, this new technology used an air displacement method to evaluate body volume. Plethysmography consists of main chamber which is subdivided into two sections: a rear reference chamber and a front test chamber containing the seated subject. Measurement both with and without seated subjects give information on the total body volume of the subjects.[34]

2.3 Total body electrical conductivity (TOBEC)

TOBEC is measured by observing the changes induced by placing the subject in an electromagnetic field.[35] The change depends on the overall electrical conductivity of the body which is a direct variation on the proportion of the lean body mass. Of these, measures of TOBEC can provide an estimate of the lean body mass and total body water. During the measurement process, the subject lies supine on a motorized bed that is passed in a series of steps progressively through a uniform solenoid coil. This measurement is simple, safe and fast and can be used on individuals who cannot be weighed underwater. The instrument, however, is expensive. In addition, disturbances in electrolyte balance such as edema and dehydration will influence the signal generated. Moreover, TOBEC is relatively insensitive to shifts of fluid or electrolyte between the intracellular and the extracellular compartments and to variations in bone mineralization. Careful consideration must be given to the positioning of the subject and corrections for body geometry and length applied.[3]

2.4 Bioelectrical impedance analysis (BIA)

The measurement of the BIA depends on the differences in electrical conductivity of fat free mass and fat. The technique measures the impedance of an electrical current passed between two electrodes (typically 800 µA; 50 kHz). For single frequency BIA, two electrodes are generally located on the right ankle and the right wrist of an individual. The impedance is related to volume of a conductor (the human body) and the square of the length of the conductor – a distance which is a function of the height of the subject. BIA analysis most closely estimates body water, from which fat free mass is then estimated, on the assumption that the latter contains about 73% water. Fat mass can then be derived as the difference between body weight and fat free mass.[36] Because SF-BIA is not valid under conditions of significantly altered hydration,[37] therefore, before BIA, all volunteers were prepared with the following pre-test guidelines. (1) no alcohol consumption within 24 hours. (2) no exercise, caffeine or food within four hours prior to taking the test, and (3) Drinking two to four glasses of water two hours before examination. During the examination, two pairs of sensor electro-cardiograph (ECG) pads were placed on the patient, one on the right wrist and hand and the other on the right foot and ankle. At least 75% of the electrode should be in contact with the patient's skin.[38]

In the new BIA method, multifrequency measurements have been developed. This method allows the estimation of both total and extracellular body fluid compartments. These estimations have advantages in certain disease conditions involving disturbances in water distribution such as congestive heart disease, renal disease and malnutrition.[39-40]

The errors of BIA including the measurement of height, weight, resistance (R), the criterion reference method used, and errors from the prediction equation which the performance depended on the selection and number of independent variables.[41] However, the great advantages of BIA are safe and convenience, and the equipment is portable and relatively inexpensive. In the future, impedance spectrum analysis derived from multifrequency BIA may be increasingly used to distinguish differences in body water, body composition among individuals as well as specific parts of the body such as muscle and adipose tissue mass in limbs.[42]

2.5 Computer tomography (CT scan)

CT is based on the relationship between the degree of attenuation of an X ray beam and the density of the tissues through which the beam has passed. From this relationship, a two dimensional radiographic image of the underlying anatomy of the scan area can be constructed.

The CT scanner is made up of two components: a collimated X ray source and detectors, and a computer that processes the scan data and produces an X ray image. The density or attenuation differences cause demarcations between tissues. These attenuations relate to that of the water component in tissue. These are defined by CT numbers or densities. The cross sectional area of each of the tissues can be determined using specialized computer programs. When no sharp boundaries exist between structures; the pixels can be plotted as histograms to help separate the fat free and fat tissues. As the volume of each pixel is known, the volume of the fat free and fat tissue can be calculated from the number of pixels forming each slice and the number of slices. This method has several uses. It can be used to assess changes in the visceral organ mass in undernutrition and obesity, to measure regional muscle mass, to assess the distribution of subcutaneous versus internal fat, and to establish bone density in osteopenia.[43-44] The standardized technique uses the measurement level of the crossectional section at the umbilical area or lumbar level 4th – 5th.[45] However, CT involves exposure to ionizing radiation and is not recommended for pregnant women or children. The method is also very expensive.

2.6 Magnetic resonance image (MRT)

Hydrogen protons behave slightly differently in adipose versus lean tissue. The differences are in the relaxation time that it takes for the nuclei to release the radio frequency induced energy and return to a random configuration. These differences can be used to map the distribution of adipose versus lean tissue in the body.[46] However, the equipment is expensive.

2.7 Dual energy X-ray absorptiometry (DEXA)

DEXA is now the primary technique for the assessment of the bone mineral content of the axial skeleton but it is also used for determining the relative proportions of the fat free mass, body fat and bone in subjects by whole body scanning. DEXA scanners us a dual energy X ray source that generates X rays at 40 KeV and 70-100 KeV; these pass through the subject. The relative absorption at these two energies is measured to give two estimates of body composition along the beam path using a two compartment model. In bone free regions of the body, the attenuation provides an estimate of the relative proportions of fat and lean tissues. In the other regions, the attenuation provides a measure of the proportions of bone and soft tissues. To provide estimates of the overall relative proportions of the three components – the fat free mass, body fat and bone – the assumption is made that the soft tissue overlaying bone has the same fat to muscle ratio as that in immediately adjacent non-bone regions.[3] However, the computing algorithms used to partition the soft tissue between the body fat and the fat free mass are critically important in assessing body composition and have been shown to vary significantly with the manufacturer of the equipment. Such algorithms should take into account the different fat distributions in males and females and also the differences generated by overall increases in adiposity. At present, Fan beam technologies, replacing earlier pencil beam techniques, are resulting in a much shorter scan time, lower X ray doses and improved geometrical resolution as well as have a high precision with accurate results.[47]

2.8 Dilution methods

These techniques using the difference element radioisotopes which were contained dissimilarity in each body compartment to define proportion of element in body. The example of element radioisotopes both of natural occurring or external administration are commonly used in laboratory researches such as ^{40}K (Potassium-40), ^{2}H (Deuterium), ^{3}H (Tritium) and ^{18}O (Oxygen-18). The following common dilution techniques using in body composition were summarized

2.8.1 Total body potassium

Potassium is located in almost all intracellular compartments and is the main cation of its compartment included in muscle and viscera. Negligible amounts occur in extracellular fluid, bone, and other non cellular sites. The measurement of total body potassium is therefore used as a marker for the body cell mass and also as an index of the fat free mass in healthy people which it is assumed a constant proportion of potassium. Of these assumptions, a simple two compartment model of fat mass and fat free mass could be calculated. However, because potassium is not only contained in the intracellular component but it is also located in extracellular compartment as well as disease factors might disturb element distribution. Therefore, fat free mass measurement with this method will always be overestimated.[3]

2.8.2 Total body water (TBW)

Body fat contains essentially no water; all the body water is present in the fat free mass. In healthy adults, the latter contains about 73% water.[48] TBW can be measured in both healthy and diseased persons using isotope dilution techniques such as deutrium (^{2}H), tritium (^{3}H) and the stable isotope of oxygen (^{18}O).[3] Standard preparation protocol is important. The subject needs to be nil by mouth and to empty their bladder after midnight. After administering the isotope, the patient continues to be nil by mouth until the dilution of isotope to equilibrium phase about 2-6 hours. Total body water is calculated using formula (2).[3]

$$\text{Total body water} = (V \times C) / (C_2 - C_1) \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where V=volume of dose, C=concentration of administration isotope, C1= base line concentration of isotope in serum/urine/breath, and C2= concentration of isotope in serum/urine/breath sample after equilibration. Fat free mass and total body fat could be calculated using TBW results using the following formula (3) and (4) respectively. However, the major limitation for estimating fat free mass are the assumptions that the fat free mass are the assumptions that the fat free mass of an adult contains a constant percentage of water and that the total body water is independent of the fat content of the body.[49]

Fat free mass (kg) = Total body water(kg) / 0.732……………… (3)

Total body fat (kg) = body weight (kg) – Total body water (kg)……………… (4)

2.8.3 Other isotope dilution

The isotope dilution principle as notes in the previous discussion can be used to estimate the volume of various other body fluid compartments for detailing of fat free mass containing in extracellular mass (ECM) and the body cell mass (BCM). This method were developed using ^{22}Na and tritiated water. TBW and FFM could be calculated with formula (2) and (3). These combination method results are used in calculated of exchangeable potassium (K_e), BCM and ECF as formulas (5) (6) and (7) respectively.[50] Although the subject is exposed to more total radiation with these dual isotope procedure but the advantage of these methods could be applied to patients with malnutrition and cancer to evaluate their response to nutritional therapy.[51]

K_e = TBW x R -Na_e ……………….. (5)

BCM(kg) = 0.00833 x K_e ………………(6)

ECM(kg) = FFM(kg) – BCM (kg) ……………(7)

Where R = the sum of the sodium and potassium content of a sample of whole blood, divided by its water content, Na_e = total exchangeable sodium.

2.9 Summary of body composition measurement.

Table 2.4 Summary of the body composition measurement methods including methods, procedures and limitations.

Table 2.4 Summary of body composition measurements

Method and procedure	Limitation and comments
Neutron activation analysis (NAA) Radioactive isotopes of N, P, Na, Cl, Ca are used as tracer elements. These elements are measured by whole body counter.	Subjects are exposed to radioactivity. Elements are not uniformly activated and sensitivity varies Method need special equipment and expensive.
Densitometry Three methods are underwater weighing (UWW) or hydrostatic weighting, water and air displacement plethysmography These methods measure body mass and body volume using water or air displacement principle.	Methods require correction of water temperature, volume of air trapped in gastro intestinal tract and residual lung. UWW needs a high degree of co-operation and are not suitable for young children, the elderly or sick patients. These methods are relatively expensive.
Total body electrical conductivity (TOBEC) Conductivity value of subject is measured by machine after induced by 5 MHz of solenoid coil. This value is proportional to body electrolyte content and reflects the amount of fat free mass	Subjects with edema, ascites, dehydration and electrolyte imbalance might alter conductivity and results interfere. Variation of body shape and size as well as bone mass might affect results. It is an expensive method.
Bioelectrical impedance analysis (BIA) Weak electrical current is passed through subjects. Impedance is measured and this related to the volume of conductor which could estimate total body water. Developed of multifrequency segmental BIA allows estimation of both total and extra cellular compartments and segmental composition.	Method needs strict preparation. Subject with edema, ascites and dehydration lead to results distortion especially in single frequency BIA. Multi frequency BIA allows assessment of body fluid compartment volume changes during clinical intervention and physical activity studies.
Computer tomography (CT scan) Method measures different attenuation of X-rays through each tissue types. An image is revealed as density distinction. Level of measurement is umbilical area at 4th – 5th lumbar level	Subject is exposed to radiation. It could not be performed in pregnancy and children. Expensive equipment is not readily available. The CT does not provide information on chemical composition.
Magnetic resonance image (MRT) Magnetic field induce ^{1}H proton containing in each tissue type and resonance to imaging in different tissue. Measurement method is similar to CT scan using crossectional abdominal fat distribution.	Unlike CT or DEXA, no ionizing radiation is involved. However, the equipment is bulky and expensive. This could be performed when metal is contained in subject's body.
Dual energy X-ray absorptiometry (DEXA) Primary technique for assessment of the bone mineral content of the axial skeleton. Also used for body fat measurements. Utilizes the attenuation of a dual energy X ray beam, often during whole body scanning. New fan beam technologies lead to lower X ray doses.	High precision method, but results are calibration dependent and differences between different equipment manufacturers can be significant. Cross calibration using densitometry and isotope dilution methods on specific subject groups may be helpful.
Dilution methods Radiation both of natural occurrence of ^{40}K or administration tracer with ^{3}H, ^{2}H or ^{18}O are counted by radio counter machine. In ^{40}K, FFM is derived from the assumption that the average potassium concentration of FFM is constant. ^{3}H, ^{2}H or ^{18}O are given to subject to estimated total body water.	Although the ^{40}K method uses natural occurrence of ^{40}K but its measurement require expensive equipment. Obese and elderly subjects have lower potassium and lead to over estimation of total body fat. In ^{3}H, ^{2}H or ^{18}O, subject is exposed to radioisotope. Some special subject such as obesity, pregnancy and malnutrition result in the underestimating of fat with this method.

References

1. WHO. Physical status: the use and interpretation of anthropometry. Report of a WHO Expert Committee. World Health Organ Tech Rep Ser 1995;854:1-452.
2. Tanner JM, Whitehouse RH, Takaishi M. Standards from birth to maturity for height, weight, height velocity, and weight velocity: British children, 1965. II. Arch Dis Child 1966;41:613-35.
3. Gibson RS. Priniples of nutrition assessment. 2nd ed. Oxford: Oxford University Press; 2005.
4. Slaughter MH, Lohman TG, Boileau RA, Horswill CA, Stillman RJ, Van Loan MD, Bemben DA. Skinfold equations for estimation of body fatness in children and youth. Hum Biol 1988;60:709-23.
5. Chittawatanarat K, Pruenglampoo S, Trakulhoon V, Ungpinitpong W, Patumanond J. Height prediction from anthropometric length parameters in Thai people. Asia Pac J Clin Nutr 2012;21:347-54.
6. Chumlea WC, Guo S. Equations for predicting stature in white and black elderly individuals. J Gerontol 1992;47:M197-203.
7. Prothro JW, Rosenbloom CA. Physical measurements in an elderly black population: knee height as the dominant indicator of stature. J Gerontol 1993;48:M15-8.
8. Hermanussen M. Knemometry, a new tool for the investigation of growth. A review. Eur J Pediatr 1988;147: 350-5.
9. Lohmann TG, Roche AF, Martorell R. Anthropometric standardization reference manual. Champaign, IL: Human Kinetics Books; 1988.
10. Jarzem PF, Gledhill RB. Predicting height from arm measurements. J Pediatr Orthop 1993;13:761-5.
11. Hirani V, Aresu M. Development of New Demi-Span Equations From a Nationally Representative Sample of Older People to Estimate Adult Height. J Am Geriatr Soc 2012.
12. Chittawatanarat K, Pruenglampoo S, Trakulhoon V, Ungpinitpong W, Patumanond J. Development of gender- and age group-specific equations for estimating body weight from anthropometric measurement in Thai adults. Int J Gen Med 2012;5:65-80.
13. van der Kooy K, Seidell JC. Techniques for the measurement of visceral fat: a practical guide. Int J Obes Relat Metab Disord 1993;17:187-96.
14. Jones PR, Hunt MJ, Brown TP, Norgan NG. Waist-hip circumference ratio and its relation to age and overweight in British men. Hum Nutr Clin Nutr 1986;40:239-47.
15. Wagner DR, Heyward VH. Measures of body composition in blacks and whites: a comparative review. Am J Clin Nutr 2000;71:1392-402.
16. Durnin JV, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. Br J Nutr 1974;32:77-97.
17. Benn RT. Some mathematical properties of weight-for-height indices used as measures of adiposity. Br J Prev Soc Med 1971;25:42-50.
18. Gallagher D, Visser M, Sepulveda D, Pierson RN, Harris T, Heymsfield SB. How useful is body mass index for comparison of body fatness across age, sex, and ethnic groups? Am J Epidemiol 1996;143:228-39.
19. Morabia A, Ross A, Curtin F, Pichard C, Slosman DO. Relation of BMI to a dual-energy X-ray absorptiometry measure of fatness. Br J Nutr 1999;82:49-55.
20. Pruenglampoo S, Pruenglampoo B, Kingkeow C, Mongkalabrug A. Simple index for screening overweight and obesity. Public Health Nutr 2003;6:225-6.
21. Lapidus L, Bengtsson C, Larsson B, Pennert K, Rybo E, Sjostrom L. Distribution of adipose tissue and risk of cardiovascular disease and death: a 12 year follow up of participants in the population study of women in Gothenburg, Sweden. Br Med J (Clin Res Ed) 1984;289:1257-61.
22. Larsson B, Svardsudd K, Welin L, Wilhelmsen L, Bjorntorp P, Tibblin G. Abdominal adipose tissue distribution, obesity, and risk of cardiovascular disease and death: 13 year follow up of participants in the study of men born in 1913. Br Med J (Clin Res Ed) 1984;288:1401-4.
23. WHO. International association for the obesity, International obesity task force. Sydney: Health communications Australia; 2000.
24. Wang ZM, Heshka S, Pierson RN, Jr., Heymsfield SB. Systematic organization of body-composition methodology: an overview with emphasis on component-based methods. Am J Clin Nutr 1995;61:457-65.
25. Wang ZM, Ma R, Pierson RN, Jr., Heymsfield SB. Five-level model: reconstruction of body weight at atomic, molecular, cellular, and tissue-system levels from neutron activation analysis. Basic Life Sci 1993;60:125-8.
26. Mattsson S, Thomas BJ. Development of methods for body composition studies. Phys Med Biol 2006;51: R203-28.
27. Behnke AR, Jr., Feen BG, Welham WC. The specific gravity of healthy men. Body weight divided by volume as an index of obesity. 1942. Obes Res 1995;3:295-300.
28. Fields DA, Goran MI. Body composition techniques and the four-compartment model in children. J Appl Physiol 2000;89:613-20.

29. Siri WE. Body composition from fluid spaces and density: analysis of methods. In: Brozek J, Hanschel A, eds. Techniques for measuring body composition Washington DC: National Academy of Sciences, National Research Council; 1961:223-44.
30. Brozek J, Grande F, Anderson JT, Keys A. Densitometric Analysis of Body Composition: Revision of Some Quantitative Assumptions. Ann N Y Acad Sci 1963;110:113-40.
31. Lohman TG. Skinfolds and body density and their relation to body fatness: a review. Hum Biol 1981;53:181-225.
32. Durnin JV, Rahaman MM. The assessment of the amount of fat in the human body from measurements of skinfold thickness. Br J Nutr 1967;21:681-9.
33. Garrow JS, Stalley S, Diethelm R, Pittet P, Hesp R, Halliday D. A new method for measuring the body density of obese adults. Br J Nutr 1979;42:173-83.
34. Dempster P, Aitkens S. A new air displacement method for the determination of human body composition. Med Sci Sports Exerc 1995;27:1692-7.
35. Baumgartner RN. Electrical impedance and total body electrical conductivity. In: Roche AF, Heymsfield SB, Lohman TG, eds. Human body composition and human kinetic. IL: Champaign 1996.
36. Chumlea WC, Guo SS. Bioelectrical impedance and body composition: present status and future directions. Nutr Rev 1994;52:123-31.
37. Gudivaka R, Schoeller DA, Kushner RF, Bolt MJ. Single- and multifrequency models for bioelectrical impedance analysis of body water compartments. J Appl Physiol 1999;87:1087-96.
38. Chittawatanarat K, Pruenglampoo S, Kongsawasdi S, Chuatrakoon B, Trakulhoon V, Ungpinitpong W, Patumanond J. The variations of body mass index and body fat in adult Thai people across the age spectrum measured by bioelectrical impedance analysis Clin Interv Aging 2011;6:285-94.
39. Cornish BH, Thomas BJ, Ward LC. Improved prediction of extracellular and total body water using impedance loci generated by multiple frequency bioelectrical impedance analysis. Phys Med Biol 1993;38:337-46.
40. Van Loan MD, Mayclin PL. Use of multi-frequency bioelectrical impedance analysis for the estimation of extracellular fluid. Eur J Clin Nutr 1992;46:117-24.
41. Brodie D, Moscrip V, Hutcheon R. Body composition measurement: a review of hydrodensitometry, anthropometry, and impedance methods. Nutrition 1998;14:296-310.
42. Elia M, Ward LC. New techniques in nutritional assessment: body composition methods. Proc Nutr Soc 1999;58:33-8.
43. Heymsfield SB, Rolandelli R, Casper K, Settle RG, Koruda M. Application of electromagnetic and sound waves in nutritional assessment. JPEN J Parenter Enteral Nutr 1987;11:64S-9S.
44. Mitsiopoulos N, Baumgartner RN, Heymsfield SB, Lyons W, Gallagher D, Ross R. Cadaver validation of skeletal muscle measurement by magnetic resonance imaging and computerized tomography. J Appl Physiol 1998;85:115-22.
45. Yoshizumi T, Nakamura T, Yamane M, Islam AH, Menju M, Yamasaki K, Arai T, Kotani K, Funahashi T, Yamashita S, Matsuzawa Y. Abdominal fat: standardized technique for measurement at CT. Radiology 1999;211:283-6.
46. Ross R. Magnetic resonance imaging provides new insights into the characterization of adipose and lean tissue distribution. Can J Physiol Pharmacol 1996;74:778-85.
47. Tothill P, Hannan WJ, Wilkinson S. Comparisons between a pencil beam and two fan beam dual energy X-ray absorptiometers used for measuring total body bone and soft tissue. Br J Radiol 2001;74:166-76.
48. Kotler DP, Thea DM, Heo M, Allison DB, Engelson ES, Wang J, Pierson RN, Jr., St Louis M, Keusch GT. Relative influences of sex, race, environment, and HIV infection on body composition in adults. Am J Clin Nutr 1999;69:432-9.
49. Sheng HP, Huggins RA. A review of body composition studies with emphasis on total body water and fat. Am J Clin Nutr 1979;32:630-47.
50. Shizgal HM, Spanier AH, Humes J, Wood CD. Indirect measurement of total exchangeable potassium. Am J Physiol 1977;233:F253-9.
51. Shizgal HM. Body composition of patients with malnutrition and cancer. Summary of methods of assessment. Cancer 1985;55:250-3.