METODI E TECNICHE PER LA VALUTAZIONE DELLA COMPOSIZIONE CORPOREA
Everyday experience shows us that human beings come in many different shapes and sizes. These differences are a result of different genetic background and realisation of this genetic potential, modified by nutritional and environmental influences, over the individual’s life course. Differences in gross body habitus are, in turn, a reflection of different individual body compositions: the masses of the individual tissues and organs that comprise the body. The term, body composition, is not, however, limited to describing the relative sizes of anatomically identifiable body components. It is also used more commonly to describe the body in terms of conceptual models that represent body constituents in terms of compartments that represent biologically functional entities such as lean mass or total fat mass.
The composition of the body, at any point in time, captures the outcome of all prior influences upon human physiology that have led to the accumulation of all these different constituents up to that point. Other than the underlying genetic milieu, principal among these influences are nutrition and illness. Body composition represents an historic record of life’s balance of energy and nutrient intake. When nutritional intake is mismatched to requirement change in body composition occurs. For example, it has long been recognised that inadequate nutrition may lead to altered body composition as seen in wasting and stunting, while, conversely, over-nutrition leads to obesity particularly in children in populations undergoing nutritional transition. Similarly, body composition may be adversely affected by ill-health, e.g., surgical trauma may lead to short-term loss of lean mass while long-term infection with tuberculosis is associated with wasting.

The composition of the body, as well as being a reflection of nutritional experience, is also a gauge of body function. Optimal bodily functioning and good health demand a body composition that provides the ideal masses of tissues and organs that support the physiological and biochemical processes that underpin a healthy life. These two factors are not independent; nutrition impacts upon body composition which in turn impacts on bodily function. Knowledge of body composition provides insights into both nutritional status and functional capacity of the human body.

Yesterday: what do we already know about human body composition? How do we measure body composition?

The analysis of body composition has a long and rich history. The first quantitative studies of the human body date to early cadaver analyses in the 1840s. The obvious drawback of cadaver analysis is that it can only be undertaken at time of death and can only provide retrospective information. Since the early part of the 20th century, few cadaver studies have been undertaken, with the notable exception of the work of Clarys and colleagues, and the focus has been on the development of technologies for the quantitative assessment of body composition in vivo. One of the first measurements, by Shaffer and Coleman in 1909, was the estimation of muscle mass from the measurement of the excretion rate of creatinine, but the real advance came with the availability of isotopes of atoms of nutritional interest.

The availability of the stable isotope of hydrogen, deuterium, in the form of deuterated water in the mid-1930s allowed the measurement of total body water (TBW) by von Hevesey and Hofer. TBW is under tight physiological control and in healthy humans the hydration of the non-fat compartment of the body, the fat-free mass (FFM), is relatively constant at 0.732 mL/g FFM. If FFM is known, by difference with body weight (BW-FFM), body fat may be determined. This simple two-compartment (2C) model of the human body has become the mainstay of body composition assessment in clinical nutrition. A little later, in 1940s and 1950s, the 2C model was approached from the other direction, first estimation of fat, the development of methods based on Archimedes principle and the different densities of fat and FFM, allowed quantification of body fat mass. While remaining a research technique in a few centres, densitometric methods based on under-water weighing largely languished in the 1970s through 1990s but were revitalised with the development of air-displacement plethysmography (ADP) in 1995. Commercially available ADP devices have now made densitometry a tool usable not only in nutrition research but also in clinical practice.
Many different techniques for body composition analysis have been explored; most have fallen by the wayside as it is recognised that disadvantages outweigh their usefulness. A core set of methods remain in wide-spread clinical use: anthropometry, tracer dilution, densitometry, dual-energy X-ray absorptiometry (DXA), and bioelectrical impedance analysis (BIA)—all predominantly devoted to characterising the human body in terms of a 2C model of FFM and fat mass. The methods vary in precision and accuracy.
Two technologies for body composition assessment deserve particular mention. BIA became popular from the mid-1980s when a simple to use impedance device became commercially available. BIA systems measure the opposition to the flow of an harmless electric current through the body and, since electricity is conducted through body water, can provide an estimate of TBW which may then be transformed to a prediction of FFM based on an assumed hydration constant as for the deuterium dilution technique. This same period has seen wide-spread application of DXA for body composition analysis. Originally developed for the measurement of bone mineral density and content (BMC), DXA systems are now widely used to measure not only BMC but also lean and fat. DXA systems thus straddle the line between a 3-compartment model and the 2C model (FFM = BMC + lean) of the body.
Finally, imaging techniques such as nuclear magnetic resonance imaging (MRI) and computed tomography (CT) are become powerful tools in the armamentarium of the clinician and nutritionist. Still primarily considered as research tools because of cost and complexity of use, they are the closest we can get to emulate cadaver analysis in vivo by visualising and quantifying tissues, organs, or constituents such as muscle and adipose tissue.
Current state-of-the-art

The body compartments/constituents that can now be routinely measured include FFM, fat mass, TBW, and its sub-compartments intracellular water and extracellular water and BMC. This information can be gained for the whole body and for some technologies, e.g., BIA and DXA for body regions. Both of these techniques may be used in both research and routine clinical practice. In a research setting, where MRI and CT are available, these can provide actual tissue volumes of, for example, adipose tissue or muscles. In a handful of centres around the world, whole body potassium counting is available that can measure the metabolically active body compartment, the body cell mass.
Pierson identified two recent “epochs” in the development of body composition methods: the first from 1963, the publication of Moore’s seminal text The Body Cell Mass and Its Supporting Environment, to 1986, a period marked by the search for precision in measurement, and, the second, from 1986, the year of the 1st International Symposium on In Vivo Body Composition Studies to the present, marked by the search for accuracy in measurement. The quest for accuracy and precision has proved worthwhile. Methods in current use typically vary in precision from 2 to 5% with similar degrees of accuracy depending upon technique and the body compartment being measured. Efforts continue to improve accuracy and precision of methods and the literature is replete with publications comparing different methods in attempt to determine which is the more accurate. Unfortunately, many of these do not compare a test method to an accepted reference method ideally a 4-compartment model. Equally, there is no universal consensus on what is a clinically acceptable degree of accuracy. Body composition analysis lags here compared to clinical chemistry for which reference methods, protocols, and quality control procedures exist specifying acceptable levels of precision and accuracy.
Where has body composition information proved useful?

Even a cursory survey of the literature finds a wide range of applications for body composition analysis in nutrition. These include describing growth and development from birth through to adulthood, understanding the developmental origins of health and disease, understanding nutrition in public health and the design of population level nutritional strategies, the physiology of aging, the impact of disease, and the monitoring of therapeutic interventions.
Today: what we are getting to know now?

The emphasis in body composition research is evolving from simple assessment of body compartment sizes to attempts to link body composition to function. Functional body composition aims to existing quantitative knowledge of body compartments with their functional roles within the body’s regulatory environment. The most notable advances in this area is the ability to link body composition to energy balance and regulation. Great strides are being made in the use of imaging techniques, notably MRI, for quantitative body composition analysis. We now have, for example, the ability to measure with great fidelity muscle volumes and infiltration of adipose tissue. Traditional anthropometry is receiving a new lease of life with the development of automated optical scanning systems. These can provide in a very short time many more body dimensions (lengths, breadths circumferences) than could be feasibly measured manually with a measuring tape. Early validation studies show that optical methods compare favourably with reference methods but further refinements of the methods are required.
Tomorrow: what do we still need to know about body composition?

For the last century body composition research has been driven by technologically driven with research striving for ever increasing accuracy and precision. In 2005, Heymsfield and colleagues in an editorial review provocatively titled “The end of body composition research?” argued that many of the now over 3000 publications in the field per year are largely due to application of current technologies to understanding physiological processes rather than new advances in techniques of measurement. In large part this is due to increased access to inexpensive and easy to use technologies. Body composition analysis was once the province of a relatively small number of research centres in universities and medical research institutions. The advent of portable technologies such as BIA and the expansion of DXA as a routine clinical tool have now made body composition analysis readily available to the wider clinical community. This will only continue.
Body composition analysis and the smartphone revolution

Where are advances likely to occur? The early 21st century has been marked by the ever increasing miniaturisation and spread of personal electronic devices exemplified by the ubiquitous smartphone. The possibilities offered by the sensor technologies in such devices have quickly been recognised for providing a platform for personalised health monitoring. Body composition analysis has not been immune to this possibility. Already smartphone-based BIA measurement systems are available and optical scanning of the whole body to provide body volume and anthropometric data using the smartphones camera is in the early stages of development. The use of consumer mobile technologies for body composition analysis opens up many possibilities. For the first time, body composition data can be readily obtained in real-life settings rather than in specialised laboratories. Different physiological processes (heart rate, blood pressure, oxygen saturation, activity level, energy expenditure) can be simultaneously monitored along body composition. This is likely to develop further as innovation continues in sensor technologies.

The tyranny of low sample size

We are now a data-connected society. Health data can be collected on an hitherto unforeseen scale [26]. No longer need body composition research be limited to studies with sample sizes of a few hundred at most. This provides opportunity to explore connections between physiological processes and body composition in ways that were not previously possible. Large data analytics are likely to become the mainstay of nutritional epidemiology.
Standardisation of methodology

There is currently no internationally accepted quality assurance framework for body composition assessment. Individual research laboratories develop their own standard operating procedures and quality control processes. Data are not always comparable between laboratories despite them ostensibly using identical methods leading to the need for inter-laboratory cross-validation. This problem is exacerbated where different methods purporting to measure the same body compartment produce different results. This issue is exemplified by the BIA technique where BIA devices from different manufacturers will rarely provide the same estimate of FFM and FM. This inconsistency undermines confidence in the technique. At least 30 factors have been identified that might influence BIA. This potential for variation demands standardisation of measurement to minimise error. It is to be hoped that bodies such as the International Society for Body Composition Research can take the lead in developing quality control procedures for body composition assessment.

Functional body composition—the missing link

There is still an overwhelming need to bridge the gap between knowing the size of body compartments and their function. Indeed, the current paradigm of using conceptual models, driven by what we currently have the ability to measure, constrains our ability to relate form with function. The overwhelming application, particularly in nutritional practice, of the simple 2C model of fat and FFM in reality bears weak relationship with function. In this model, “fat” is chemical fat not the metabolically active biological compartment of adipose tissue. FFM is composite compartment that includes everything bar fat; it provides us with little information on the relative metabolic and physiological function of its constituents including individual muscles and the visceral organs. Imaging techniques can provide tissue level composition information but are not routinely available. Wider use of these technologies is required but is impeded by their cost and relatively limited availability.

Despite the power of imaging and other technologies, they are still unable to provide us with a reliable measurement of the nutritionally important chemical compartment of body protein. Arguably, this is the single most important compartment not routinely measured. The ability to measure protein has been available since the late 1970s with the development of in vivo neutron activation analysis (IVNAA). Always limited to a few centres, IVNAA for protein determination has fallen into decline in recent years owing to lack of facilities and little inclination to introduce the technology due to concerns over the radiation hazard that the method presents. Recently, a method to estimate body protein from a combination of DXA measurements of body volume and bone mass with TBW measured by BIA has been proposed. Errors compared to IVNAA were small (1.22 kg) and this method holds great promise for the future.
Conclusions

Heymsfield and colleagues concerns that we are at the end of body composition methodology research seem unfounded. Undoubtedly, the quest for ever simpler, cheaper more accurate methods of body composition analysis will continue. The focus is likely to shift to finding methods that can be used in populations en masse, harnessing the ever-increasing power of electronic technologies, sensor development, and signal processing coupling body composition directly with function. Perhaps, with deference to Mark Twain, reports of the imminent death of body composition methodology are greatly exaggerated and it would be better to suggest that we are at the dawn of new body composition methodology research.
Tecniche e modelli per la valutazione della composizione corporea

- **Principali tecniche tradizionali:**
  BMI – Circonferenze - Plicometria
  Pesata subacquea
  Metodi di diluizione

- **Principali tecniche recenti:**
  RMN/ DXA/ BIA/ TAC/ NAA
  Pletismografia ad aria/
  Misurazione con vicino infrarosso

**Livelli**

- ATOMICO
- MOLECOLARE
- CELLULARE
- TESSUTALE
- CORPOREO
Livello atomico

Azoto (N)
Idrogeno (H)
Carbonio (C)
Ossigeno (O)
Sodio (Na)
Potassio (K)
Fosforo (P)
Calcio (Ca)
Magnesio (Mg)
Zolfo (S)
Livello molecolare

Minerali, CHO e altre molecole
Proteine
Lipidi
Acqua

(Massa corporea = Massa Grassa + Acqua Corporea Totale + Proteine Corporee Totali + Minerali Ossei + Minerali Tessuti Molli + Carboidrati)

(Massa Corporea = Massa Grassa + Massa Non Grassa)
Livello cellulare

Solidi extracellulari
Fluidi extracellulari
(Adipociti)
Cellule

(Massa Corporea = cellule + Fluidi extracellulari + solidi extracellulari)
(Massa Corporea = Massa Grassa + Massa Cellulare Corporea + Fluidi extracellulari + Solidi extracellulari)
Livello tessuto

Altri tessuti
Organi viscerali
Osso
Muscolo scheletrico
Tessuto adiposo
Livello di organismo

Testa
Tronco
Arti
MODELLI DI COMPOSIZIONE CORPOREA

<table>
<thead>
<tr>
<th>Chemical model</th>
<th>Anatomical model</th>
<th>Behnke 2-component model</th>
<th>2-component model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat</td>
<td>Adipose tissue</td>
<td>Fat</td>
<td>Fat mass</td>
</tr>
<tr>
<td>Protein</td>
<td>Muscle</td>
<td>Essential fat</td>
<td></td>
</tr>
<tr>
<td>CHO</td>
<td>Organs</td>
<td>Lean body mass</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>Bone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral</td>
<td>Other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Chemical model**
- Fat
- Protein
- CHO
- Water
- Mineral

**Anatomical model**
- Adipose tissue
- Muscle
- Organs
- Bone
- Other

**Behnke 2-component model**
- Fat
- Essential fat

**2-component model**
- Fat mass
- Fat-free mass
Reference Man / Woman

• Developed by Albert Behnke, MD
• A theoretical model based on an “average” person.
• Divides body into:
  – Lean Body Mass
    • Protein and Bone
  – Fat
    • Essential
    • Non-essential or storage
Reference body composition components for men and women

Figure 28.3B. Behnke's theoretical model for the body composition of the reference woman. Values in parenthesis indicate percentage of total body mass.

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Essential fat

• Fat stored in:
  – Bone marrow, heart, liver, lungs, spleen, kidneys, intestines, muscles, and CNS.

• REQUIRED for NORMAL physiological function.

• Women carry additional “gender specific” essential fat in mammary glands and in pelvic region, surrounding reproductive organs. (EF 3X’s greater in females)
Non-Essential / Storage Fat

• Fat accumulated in adipose tissue
• Serves as nutritional reserve
• Two compartments
  – Visceral
  – Subcutaneous
Lean Body Mass

$LBM = \text{Body mass} - \text{storage fat}$

- Includes essential fat (EF) / Fat free mass does not include EF
- Male : 3% of LBM is EF= lower limit of leanness for normal function.
- Female : 12-14% of LBM is EF= lower limit of leanness for normal female function.
Too Thin?

• Men: Less than 4% BF
  – Reduced exercise tolerance (especially LSD)
  – Increased dissipation of heat, Less work during weight bearing exercise

• Women: Less than 17% BF
  – Oligomenorrhea – irregular menstruation
  – Amenorrhea – Cessation of menstrual cycle
  – Bone mineral loss
  – Decreased risk of cancer? *
Conceptual models of body composition. Models comprising 1–4 compartments are in common use; for details of 5C model, see [35], and 6C model, see [36]. Individual compartments only approximately to scale. FFM fat-free mass, TBW total body water, MC mineral content, NEL non-essential lipid, EL essential lipid, RS residual, BM bone mineral, SM soft-tissue mineral, GLY glycogen.

TECNICHE PER LA PRODUZIONE DI MODELLI BICOMPARTIMENTALI
Body fat provides more buoyancy so a fatter person weighs less (on a relative basis) than a lean person.
Figure 6.38 Subject's body position while submerged during underwater weighing. The water should be kept as calm as possible to get a good reading on the scale. Note how the tester is steadying the scale with his hand. Once the scale is relatively steady, the tester should remove the hand and take the reading.
Procedures

• 1. Wear light clothing (swimsuit)
• 2. Use bathroom prior to weighing
• 3. Calibrate scale
• 4. Weight the chair or seat and equipment
• 5. Measure water temperature
• 6. Remove all air from clothing
Procedures

• 7. Sit in seat
• 8. Submerge
• 9. Blow all air out of lungs and remain still
• 10. 3-10 trials; average of the highest three
• 11. Subtract weight of apparatus from average UWW
Hydrostatic Weighing

- Based on Archimedes principle
  - An object submerged in water has a counter force acting upward on it equal to the weight of the volume of water it displaces (buoyancy).

Able to determine VOLUME
Hydrodensitometry

• Density = Body weight/Body volume
• How does one estimate body volume?
• Archimedes principles:
  – volume of submerged object = volume of water displaced
  – weight in air - weight underwater = weight of water displaced
Hydrodensitometry

Density (D) is related to relative amounts of two compartments

- \( D(\text{fat}) = 0.9007 \text{ g/ml} \)
- \( D(\text{lbm}) = 1.1000 \text{ g/ml} \)
- \( D(\text{water}) = 1.0000 \text{ g/ml} \)
Under water weight

15 kg

10% BF

50 kg

30% BF

50 kg

5 kg
Hydrodensitometry: Assumption

- Density of fat and lean are constant
  - bone density
  - muscle density
  - hydration status
- GI gas volume is constant
Hydrostatic (Underwater) Weighing

- determines body density
- SE = 2.5 - 3.0 %
- accuracy influenced by sex, age, race, muscle mass, respiratory volume determination
Hydrodensitometry

• Weight of water displaced = vol of water displaced
• Weight of water displaced = vol of body (BV)
  • Since weight of water displaced = weight in air - weight underwater
    – BV = BW - UBW
• To calculate body density
  – BD = BW / BV

• Calculate %BF from BD
### Hydrostatic Measurements

- Weight in air (Wa)
- Tare weight
- Average gross weight (average of best two trials)

#### Underwater weighing trials

1  2  3  4  5  
6  7  8  9  10

- Weight in water (Ww) (average gross weight—tare weight)
- Density of water (Dw)
- Residual volume (RV)

### Calculations

\[
\text{Density} = \frac{\text{Wa}}{\left(\frac{\text{Wa} - \text{Ww}}{\text{Dw}}\right) - (\text{RV} + 100 \text{ ml})}
\]

- Percent body fat = \(495 \div \text{density}\) - 450
- Fat weight (weight in the air x fat%)
- Lean body weight (weight in the air - fat weight)
- Classification

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**Figure 6.37** Body composition worksheet.
Hydrodensitometry Calculations

• DATA
  - BW(air) = 81.6 kg
  - BW(water) = UWW = 3.6 kg
  - RV = 1.30 L, est GI gas vol = 0.1 L
  - Density of water at 25°C = 0.997 kg/L

• CALCULATIONS
  - BV = (BW-UWW)/0.997 – (RV +0.1)
  - BV = (81.6-3.6)/0.997 – (1.3+0.1)
  - BV = 78.23 – 1.4 = 76.83 L
Hydrodensitometry Calculations

• BV = 76.83 L
• BD = BW / BV = 81.6/76.83 = 1.062 kg/L
• % BF = (495/BD) - 450 = (495/1.062)-450
  - %BF = 466.09-450 = 16.09% = 16%
• Fat mass = 16% x 81.6kg = 13.1 kg
• Lean mass = 81.6-13.1 = 68.5 kg
<table>
<thead>
<tr>
<th>Variable</th>
<th>Kolkhorst</th>
<th>Buono</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>188 cm (74 in.)</td>
<td>188 cm (74 in.)</td>
</tr>
<tr>
<td>Weight</td>
<td>93 kg (205 lb)</td>
<td>93 kg (205 lb)</td>
</tr>
<tr>
<td>Underwater weight</td>
<td>6.5 kg</td>
<td>5.0 kg</td>
</tr>
<tr>
<td>Volume</td>
<td>86.5 L</td>
<td>88.0 L</td>
</tr>
<tr>
<td>Density</td>
<td>1.075 g/ml</td>
<td>1.057 g/ml</td>
</tr>
<tr>
<td>Relative fat</td>
<td>10.5%</td>
<td>18.4%</td>
</tr>
<tr>
<td>Fat weight</td>
<td>9.7 kg (21.4 lb)</td>
<td>17.1 kg (37.7 lb)</td>
</tr>
<tr>
<td>Fat-free weight</td>
<td>83.3 kg (183.6 lb)</td>
<td>75.9 kg (167.3 lb)</td>
</tr>
<tr>
<td>Goal weight at 10% fat</td>
<td>92.6 kg (204.2 lb)</td>
<td>84.3 kg (185.9 lb)</td>
</tr>
<tr>
<td>Weight loss to achieve goal weight</td>
<td>0.4 kg (0.8 lb)</td>
<td>8.7 kg (19.1 lb)</td>
</tr>
</tbody>
</table>

Note. volume = weight – underwater weight  
density = weight + volume
Hydrodensitometry

Limitations I

- Measurement of residual lung volume
- Precision of underwater weight
- Cost
- Non-portable
- Limited types of subjects
Hydrodensitometry

Limitations II

• Constant used for density of fat and LBM
• Racial differences
• Active people > LBM = denser
Hydrodensitometry

• Used to be considered the most accurate (up for debate now that DXA is used)
• $\pm 2.5\%$ if done with experienced subjects
• Considered a lab technique (can’t carry your tank with you out into the field)
• Two-component Model
Whole Body Plethysmography

• Measures body volume by air displacement
  – actually measures pressure changes with injection of known volume of air into closed chamber

• Larger body volume displaces larger air volume in chamber
  – results in bigger increase in pressure with injection of known volume of air
Bod Pod

- The BOD POD uses **Air Displacement Technology** for determining percent fat and fat-free mass in adults and children. The simple, 5-minute test consists of measuring the subject's mass (weight) using a very accurate electronic scale, and volume, which is determined by sitting inside the BOD POD chamber. From these two measurements, the subject's body composition is calculated.
The BOD POD consists of two chambers. The front, or Test Chamber, is where the subject sits and is comprised of a seat that forms a common wall separating it from the rear, or Reference Chamber.

During the brief data collection period of the volume measurement, the chamber door is secured by a series of electromagnets and a gasket. A Diaphragm is mounted on the common wall, which oscillates during testing.
This causes small changes in volume inside the chamber, of which the pressure response to these small volume changes is measured. This is done by measuring the interior volume of the empty BOD POD chamber, then measuring it again when the subject is seated inside.

By subtraction, the subject's body volume is obtained. For example, if the interior air volume of the empty chamber is 400 liters, and the volume of the chamber is reduced to 350 liters with the subject inside, the body volume of the subject would be 50 liters. Once the subject's mass and volume are determined, body density is calculated and the relative proportions of fat and fat-free mass are determined.
Port for attaching breathing tube (lung volume test)

- Window
- Electromagnetic latches
- Measurement Chamber
Whole Body Pethysmography

• Advantages over hydrodensitometry
  – Subject acceptability, can be performed on a greater variety of populations
  – Less client and technician error
  – Easy to do
  – Faster then Hydrostatic Weighing
  – ~3% error
  – Residual lung volume not factor

• Limitations
  – Costs > $65K
  – Facilities are hard to find
  – Still assumes constant density of lean and fat
During the body volume measurement, the subject breathes normally, known as relaxed tidal breathing, unlike underwater weighing which typically requires maximal exhalation to residual volume. Thus, the relevant measurement of lung volume for the BOD POD is not residual volume, but the average lung volume during normal tidal breathing (average thoracic gas volume). This is a much easier measurement to obtain and no difficult maneuvers are required.
To achieve optimal accuracy, the volume of air in the lungs must be determined. This may be done either by directly measuring the average thoracic lung volume or by using an estimated value based on standard prediction equations. The effect of skin surface area is also estimated. This information is then used to make corrections to the body volume measurement for obtaining final body composition measurement results.
Skinfold measures

- Measures subcutaneous fat layer using a caliper. Skinfold thickness measured using specialized calipers that exert exactly 10 g/mm² pressure.
Research Quality
Skinfold Calipers

Harpenden Calipers

Lange Calipers
Figure 6.17 Examples of commercially available skinfold calipers. Back row, left to right: Lange, Slim Guide, Holtain. Front: Harpenden.

Source: Photo by M. Ware.
Skinfolds

• Measurement of subcutaneous adipose tissue at specific anatomical sites
• BD or %fat is obtained with the use of equations (either population specific or generalized)
Skinfold Measurements

• Based on the rational that subcutaneous fat represents a certain % of total body fat.
• Sum of thickness readings can be placed into formulas to estimate BF %
• +/- 3.7% error!
Skinfold Thickness

• **Assumptions:**
  • predicts (not measures) non-subcutaneous fat (>50% of fat is subcutaneous)
  • sites selected represent average thickness of all subcutaneous fat
  • compressibility of fat similar between subjects
  • thickness of skin negligible
Skinfold Thickness

• **Limitations**
  • Technician error
  • Skinfold thickness affected by factors other than amount of fat
    – exercise increases skin thickness
    – dehydration reduces skin thickness
    – edema increases skin thickness
    – dermatitis increases skin thickness
  • Poorly predicts visceral fat
Bone

Skin

Muscle

Fat

Double fold of skin and adipose tissue—no muscle

Sides of skinfold should be approximately parallel
Grasp a double fold of skin and subcutaneous adipose tissue with the thumb and index finger of the left hand.

Place the caliper tips on the site where the sides of the skinfold are approximately parallel and 1 cm distal to where the skinfold is grasped.

Position the caliper dial so that it can be read easily. Obtain the measurement about 4 sec after placing the caliper tips on the skinfold.
SF Procedures

- Take all measurements on the right side of the body
- Identify and mark site
- Grasp skin and fat between thumb and index finger 1cm above marked site
- Continue grasping at the site while taking the measurement
SF Procedures

• Place the jaws of the caliper perpendicular to the fold and slowly release the pressure
• Take the measurement 4 seconds after pressure is released
• Read the dial of the nearest 0.1mm (Harpenden or Holtain), 0.5mm (Lange), or 1mm (plastic)
SF Procedures

• Take at least 2 non-consecutive measurements - if values vary by ±10% take additional measurements
• No measurements directly after exercise
• Reliability should be 0.95 or greater
Sites

• Chest
• Subscapular
• Midaxillary
• Suprailiac
• Abdominal
• Triceps
• Biceps
• Thigh
• Calf
Single Site Measurements

• Tricep skinfold thickness
• Subscapular skinfold thickness
• not for estimating body fat determination
• for comparing against other reference data
  – NHANES II (1097-1980)
  – appendix O (p530-532) (TSF)
  – appendix P (p533-535) (SSF)
Two site measurements

• Tricep SF and Subscapular SF
• correlated with body fatness in children
• Tricep SF and calf SF
Multiple Site Measurements

- Many sites
- Many equations
- Jackson & Pollock
- Durnin & Womersley
- Body density
<table>
<thead>
<tr>
<th>Age Range (Years)</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Males</strong></td>
<td></td>
</tr>
<tr>
<td>17–19</td>
<td>Body density = 1.1620 - 0.0630 \times (log \Sigma)^*</td>
</tr>
<tr>
<td>20–29</td>
<td>Body density = 1.1631 - 0.0632 \times (log \Sigma)</td>
</tr>
<tr>
<td>30–39</td>
<td>Body density = 1.1422 - 0.0544 \times (log \Sigma)</td>
</tr>
<tr>
<td>40–49</td>
<td>Body density = 1.1620 - 0.0700 \times (log \Sigma)</td>
</tr>
<tr>
<td>50+</td>
<td>Body density = 1.1715 - 0.0779 \times (log \Sigma)</td>
</tr>
<tr>
<td><strong>Females</strong></td>
<td></td>
</tr>
<tr>
<td>17–19</td>
<td>Body density = 1.1549 - 0.0678 \times (log \Sigma)</td>
</tr>
<tr>
<td>20–29</td>
<td>Body density = 1.1599 - 0.0717 \times (log \Sigma)</td>
</tr>
<tr>
<td>30–39</td>
<td>Body density = 1.1423 - 0.0632 \times (log \Sigma)</td>
</tr>
<tr>
<td>40–49</td>
<td>Body density = 1.1333 - 0.0612 \times (log \Sigma)</td>
</tr>
<tr>
<td>50+</td>
<td>Body density = 1.1339 - 0.0645 \times (log \Sigma)</td>
</tr>
</tbody>
</table>


*Σ = sum of the triceps, subscapular, suprailliac, and biceps skinfolds.
Durnin & Womersley

- Overpredicts by 3 - 5% Fat
- British (left side)
- Age and gender specific equations
- Upper body sites
- Electronic Skinfold Caliper
### Table 6.9  Generalized Body Composition Equations for Male and Female Adults

#### Males

<table>
<thead>
<tr>
<th>Term</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body density</td>
<td>$1.11200000 - 0.00043499(X_1) + 0.00000055(X_2)^2 - 0.00028826(X_8)$</td>
</tr>
<tr>
<td>Percent body fat</td>
<td>$0.29288(X_2) - 0.00050(X_2)^2 + 0.15845(X_8) - 5.76377$</td>
</tr>
<tr>
<td>Body density</td>
<td>$1.1093800 - 0.0008267(X_3) + 0.0000016(X_3)^2 - 0.0002574(X_8)$</td>
</tr>
<tr>
<td>Body density</td>
<td>$1.1125025 - 0.0013125(X_4) + 0.00000055(X_4)^2 - 0.0002440(X_8)$</td>
</tr>
<tr>
<td>Percent body fat</td>
<td>$0.39287(X_5) - 0.00105(X_5)^2 + 0.15772(X_8) - 5.18845$</td>
</tr>
</tbody>
</table>

#### Females

<table>
<thead>
<tr>
<th>Term</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body density</td>
<td>$1.0970 - 0.00046971(X_1) + 0.00000056(X_2)^2 - 0.00012828(X_8)$</td>
</tr>
<tr>
<td>Percent body fat</td>
<td>$0.29699(X_2) - 0.00043(X_2)^2 + 0.02963(X_8) + 1.4072$</td>
</tr>
<tr>
<td>Percent body fat</td>
<td>$0.41563(X_5) - 0.00112(X_5)^2 + 0.03661(X_8) + 4.03653$</td>
</tr>
<tr>
<td>Body density</td>
<td>$1.0994921 - 0.0009929(X_7) + 0.0000023(X_7)^2 - 0.0001392(X_8)$</td>
</tr>
</tbody>
</table>


$X_1$ = sum of chest, midaxillary, triceps, subscapular, abdomen, suprailliac, and thigh skinfolds; $X_2$ = sum of abdomen, suprailliac, triceps, and thigh skinfolds; $X_3$ = sum of chest, abdomen, and subscapular skinfolds; $X_4$ = sum of chest, triceps, and subscapular skinfolds; $X_5$ = sum of abdomen, suprailliac, and triceps skinfolds; $X_6$ = sum of triceps, abdomen, and suprailliac skinfolds; $X_7$ = sum of triceps, suprailliac, and thigh skinfolds; $X_8$ = age in years.
Equations

• Jackson’s 3-site
  – Males - BD=1.10938-
    0.0008267(sum3)+0.0000016(sum3)²-
    0.0002574(age)
  – chest, abdomen, thigh
  – Females - BD=1.0994921-
    0.0009929(sum3)+0.0000023(sum3)²-
    0.0001392(age)
  – triceps, suprailiac, thigh
Figure 6.32 Body fat standards for persons 6 to 17 years old based on the sum of triceps and subscapular skinfold measurements.

Skinfold Thickness

- Measures double thickness of skin and subcutaneous fat

**Advantages:**
- inexpensive
- fast
- portable
- large database
- accurate if tech is skilled
- can be noninvasive
- >100 equations available from which to choose

**Disadvantages:**
- accuracy takes time to master
- only measures subcutaneous fat
- ~3% error
- not advisable for obese clients or even those who are very lean
- accuracy affected by extremes in age, % fat, race
Most body density estimations are drawn from a relatively small population of cadavers.
## Fat-Free Body Composition

<table>
<thead>
<tr>
<th>Component</th>
<th>Density (g/cm³)</th>
<th>Fat-free body (%)</th>
<th>Reference body (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.9937</td>
<td>73.8</td>
<td></td>
</tr>
<tr>
<td>Mineral</td>
<td>3.038</td>
<td>6.8</td>
<td></td>
</tr>
<tr>
<td>Protein</td>
<td>1.34</td>
<td>19.4</td>
<td></td>
</tr>
<tr>
<td>Fat-fre body</td>
<td>1.1</td>
<td>100</td>
<td>84.7</td>
</tr>
<tr>
<td>Fat</td>
<td>0.9007</td>
<td>15.3</td>
<td></td>
</tr>
<tr>
<td>Reference body</td>
<td>1.064</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>
Assumed Densities:

FAT MASS: 0.9 g/ml
NON-FAT (FAT FREE) MASS: 1.1 g/ml

Equation:

% Body Fat = \( \frac{4.95}{\text{Density}} - 4.5 \) x \( \frac{100}{100} \)

%body fat

Siri

% BF = \( \frac{495}{BD} \) – 450
• The 1963 Brozek model uses:

\[
\%BF = \left(\frac{4.57}{BD} - 4.142\right) \times 100
\]

Assumptions:

FAT MASS 0.9 gm/ml

LEAN BODY MASS 1.095 gm/ml

(some essential lipids in Lean Body Mass)
• The major difference between the models is:

- In the Brozek model, any variation in measured BD from the reference body density is assumed to be due to a difference in obesity (adipose tissue).

- In the Siri model, any variation in measured BD from the reference body is due to a difference in triglyceride content instead of adipose tissue.
• However, they both yield nearly identical %BF estimates (varying by only 0.5-1.0% BF) for densities ranging from 1.0300 to 1.0900 g/cm³.

• For individuals with more than 30% BF, the Siri equation gives relatively higher body fat estimates than the Brozek equation.
• Both rely on the following assumptions:
  – The densities of the fat and the fat-free body components (water, mineral, and protein) are additive and are the same for all individuals
  – The proportions of water, mineral, and protein in the LBM or reference body are constant within and between individuals
• The individual being measured differs from the reference body only in the amount of body fat (triglyceride) or obesity (adipose) tissue.
Body Density

- Density has traditionally been defined as 1.10 g/ml.
- In young African American males, some studies have shown it to be 1.113 gm/ml.
- 8-10 yr old ~ 1.085 gm/ml.
# Variability of Constants

## Table 21.5

Alternative equations to those of Siri and Brozek for estimating percentage of body fat

<table>
<thead>
<tr>
<th>AGE</th>
<th>GENDER</th>
<th>PERCENTAGE OF BODY FAT</th>
<th>( D_{FFB} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-16</td>
<td>M</td>
<td>((5.03/D_w) - 4.59) \times 100</td>
<td>1.096</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>((5.07/D_w) - 4.64) \times 100</td>
<td>1.094</td>
</tr>
<tr>
<td>17-19</td>
<td>M</td>
<td>((4.98/D_w) - 4.53) \times 100</td>
<td>1.0985</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>((5.05/D_w) - 4.62) \times 100</td>
<td>1.095</td>
</tr>
<tr>
<td>20-50</td>
<td>M</td>
<td>((4.95/D_w) - 4.50) \times 100</td>
<td>1.100</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>((5.03/D_w) - 4.59) \times 100</td>
<td>1.096</td>
</tr>
</tbody>
</table>

For African-Americans, subtract 1.9% (males) and 1% (females) from each percentage of body fat calculation. Modified from Lohman TG: Exer Sports Sci Rev 14:325-327, 1986.
• A three-component model was then developed with the added component being **total body water**.

  – Referred to as the 3-C water molecular level model.
• A problem with all of these models was that one had to make assumptions about bone mineral and protein stores in the body.
Models

• This has led to the **4-C molecular level model** being the desired model for research purposes
  – Fat
  – Mineral (Bone)
  – Protein (Muscle)
  – Water
Bioelectrical Impedance (BIA)
Bioelectrical Impedance (BIA)

- Measure of electrical impedance.
- The more fat you have, the slower the flow of the current.
PRINCIPLES OF BIA

The resistance (R) of an homogeneous material of uniform cross-sectional area is proportional to its length (L) and inversely proportional to its cross-sectional area (A).

The body offers two types of R to an electrical current: capacitative R (Reactance), and resistive R (simply called Resistance).

Reactance (Re or X): Capacitative R CELL MEMBRANES
Reactance (R): Extra and Intracellular FLUIDS
Impedance (Z): Relation between X and R
Phase Angle (PA): Lower phase angles: decreased cell integrity.

A basic assumption of BIA is that the sum of the arm, trunk and leg volumes can be modeled as a cylinder with uniform conductivity.
Electrical Impedance

Cell Membrane Capacitances (Cm)

Intracellular Resistances (Ri)

Extracellular Resistance (Re)
Assumptions

• Biological tissues act as conductors or insulators, and the flow will follow the path of least resistance

• Impedance is a function of resistance and reactance (opposition to flow caused by the capacitance of a cell membrane)
Assumptions

• Fat free mass has a constant proportion of water (about 73%)
  – Then calculate fat free mass from body water

• $BW = FFM + FM$
  – Then calculate fat mass and %body fat
BIA: basic theory

- The body can be considered to be a series of cylinders.
- Resistance is proportional to the length of the cylinder.
- Resistance is inversely proportional to the cross-sectional area.
BIA: basic theory

• Volume is equal to length of the cylinder times its area

• Therefore, knowing the resistance and the length, one can calculate volume.

• Assuming that the current flows thru the path of least resistance (water), then the volume determined is that of body water.
Bioelectrical Impedance Analysis

• BIA measures impedance by body tissues to the flow of a small (<1mA) alternating electrical current (50kHz)
TERMINOLOGY

• BIA: Bioelectrical Impedance Analysis
• SF-BIA: Single Frequency Bioelectrical Impedance Analysis
• MF-BIA: Multi Frequency Bioelectrical Impedance Analysis
• BIS: Bioelectrical Impedance Spectroscopy
• BIVA: Bioelectrical Impedance Vector Analysis
• W-BIA: Whole Body Bioelectrical Impedance Analysis
• S-BIA: Segmental Bioelectrical Impedance analysis
Bioelectrical Impedance

- Detecting electrode edge is placed on an imaginary line bisecting the ulnar head (bone on little finger side of wrist)
- Red clip
- Red leads
- Black clip
- Signal electrode is placed on the first joint of the middle finger

- Detecting electrode edge is placed on an imaginary line bisecting the medial malleolus (bone on big toe side of ankle)
- Red clip
- Black leads
- Black clip
- Signal electrode is placed on the base of the second toe
Electrical Impedance
BIA Protocol

• Very sensitive to changes in body water (less water = higher BF)
  – normal hydration
    • caffeine, dehydration, exercise, edema, fed/fasted, fluid intake, female menstrual cycle, alcohol

• Sensitive to body temperature [warm skin conducts electricity better (↓ BF)]
  - Fever
  - Avoid exercise

• Sensitive to placement of electrodes
  – conductor length vs. height
Major types of BIA analyzers
NHANES III
BIA Equations

• Males
  – \( \text{FFM} = -10.68 + 0.65\frac{H^2}{R} + 0.26W + 0.02R \)

• Females
  – \( \text{FFM} = -9.53 + 0.69\frac{H^2}{R} + 0.17W + 0.02R \)

• Where
  – \( \text{FFM} = \) fat free mass (kg)
  – \( H = \) height (cm)
  – \( W = \) body weight (kg)
  – \( R = \) resistance (ohms)

• \( \% \text{BF} = 100 \times \frac{(BW-\text{FFM})}{BW} \)
BIA Calculations

• DATA
  – R = 520 ohms; BW = 77.3 kg; H = 178 cm
• CALCULATIONS
  - FFM= -10.68+(0.65H^2/R)+0.26BW+0.02R
  - FFM= -10.68+(0.65x178^2/520)+0.26(77.3)+0.02(520)
  - FFM= -10.6 + 39.6 + 20.1 + 10.4 = 59.5 kg
  - FM= W – FFM = 77.3 – 59.5 = 17.8 kg
  - %BF= (17.8/77.3)x100 = 23%
Each machine has its own equation (developed by the manufacturer and is proprietary)
Electrical Impedance

- Newer instruments use multiple frequencies with increased accuracy and wider capabilities.
Theoretical Basis of Bioimpedance

- Theory:
  - Apply current at low frequency: ECW

Diagram:
- Extracellular Water (ECW)
- Cells
- ECF
- ICF

~5 kHz
Theoretical Basis of Bioimpedance

- Theory:
  - Apply current at low frequency: ECW
  - Apply current at higher frequencies: TBW

ECF

≥50 kHz

Total Body Water (TBW)

ICF

ECF

Cells
Multiple-Frequency Bioelectrical Impedance Analysis (BIA)

- Fixed low and high frequency
  - 1 or 5 kHz to measure ECW
  - 50, 100, 200, or 500 kHz to measure TBW
  (Thomasset, 1963; Deurenberg et al., 1995; Hannan et al., 1994, 1998)

\[ V = \rho \frac{L^2}{R} \]

Regression of \( \frac{Ht^2}{R} \) (or other) measured at low and high frequency against ECW and TBW measured by dilution methods
- Equations are population-specific
  Ex: TBW (L) = \( m \frac{Ht^2}{R_{200}} + c \)
  Ex: ECW (L) = \( m \frac{Ht^2}{R_5} + c \)
  EX: TBW – ECW = ICW

- Theoretically able to differentiate ECW vs. ICW, and to quantify BCM

Figure 1: Association between TBW (laboratory criterion method (L)) and impedance index (cm²/kg), closed squares represent validation group, closed circles represent cross-validation group.

## Bioimpedance Spectroscopy (BIS)

- **Range of frequencies** (~5 - 1000 kHz)
- **Biophysical modeling**
  - Impedance data over the spectrum is fit to the Cole model through nonlinear least squares curve fitting
  - Cole model terms can then be:
    - Regressed vs. dilution volumes to derive equations (Cole)
      - Once cross-validated these equations can be used to estimate volumes
    - Applied to equations based on Hanai mixture theory (Cole/Hanai)
- Theoretically able to differentiate ECF vs. ICF, and to quantify body cell mass (BCM)
  - ICF ~ BCM
Bioimpedance spectroscopy is a unique bioimpedance approach that differs in underlying basis from the more readily recognized single-frequency bioelectrical impedance analysis in that it does not require the use of statistically derived, population-specific prediction equations. It has the potential advantage of not only measuring total body water, but also offering the unique capacity to differentiate between ECW and ICW and, thus, to provide an estimate of BCM.
Bioelectrical Impedance Analysis

• **1994 NIH Technology Assessment Conference**

  • “BIA provides a reliable estimate of total body water under most conditions.”
  
  • “It can be a useful technique for body composition assessment in healthy individuals”
BIA: Advantages and Limitations

- Advantages
  - costs ($1,000-$15,000)
  - portable
  - non-invasive
  - fast
- Limitations
  - accuracy and precision
  - no better/worse than hydrodensitometry
BIA: Advantages and Limitations

• Best used for epidemiologic studies
• Choice of predictive equations important
• Influenced by fluid shifts
• Biggest drawback is the need for appropriately calibrated, cross-validated predictive equations (sme age, sex, ethnicity, and health)
BIA: Advantages and Limitations

• The accuracy has been questioned:
  – Skinfolds 2.4 % error
  – BIA 5% error
  – Visual 3.1% error

• Race cannot be entered into the machine
• Children distribute water differently than adults
Equations

• Each machine has its own equation (developed by the manufacturer and is proprietary)

• \%fat = \(\frac{4.57}{1.1411 - (\frac{(BW \times \text{Resistance})}{Ht^2})} - 4.142 \times 100\)
  
  – ht = length of the conductor
The use of the phase angle has become more popular over the last few years because of its high association with clinical results, time of hospitalization and mortality in various diseases. Based on the principles of BIA, which mainly works by measuring body resistance and reactance in order to alternate an electric current, the storage of this current is thought to be able to create a change in phase which is considered to be the ratio between resistance and reactance and which is expressed geometrically as phase angle, being directly calculated as: 

\[
\text{Phase angle} = \arctan\left(\frac{X_c}{R}\right) \times 180^\circ \div \pi.
\]
Graphic derivation diagram of the phase angle and its relation to resistance (R), reactance (Xc), impedance (Z) and frequency of the current applied.
Among all the direct measurements of BIA, the phase angle has proved to be a good predictor of prognosis and mortality regarding hemodialysis, cancer, human immunodeficiency syndrome (HIV), and liver and geriatric diseases. This measurement has attracted strong interest by being a noninvasive, objective and rapid (less than 2 minutes) tool for the determination of nutritional status and risk of patient morbidity, whereas other nutritional screening tools, although also noninvasive, require more time and / or are highly subjective.
Interpreting % Fat Values

• All methods of measuring % fat have a certain amount of inaccuracy! This inaccuracy is determined by the Standard Error of Estimate (SEE).

• The SEE tells you the amount of deviation from the true % fat you can expect from a particular method.
• There is a 67% probability that the true % fat is within + or - one SEE from the measured value.

• Example: Measure % fat = 20%; SEE = 3 % units of body fat

  There is a 67% probability that the true % fat is between + or - one SEE or 3 % units of fat or between 17 - 23 %.
• There is a 95% probability that the true % fat is within + or - two SEE from the measured value.

• Example: Measured %fat = 20%
  SEE = 3 %
  There is a 95% probability that the true %fat is within + or - two SEE or 6% of the measured value or 14 - 26 %.
SEE of Common Methods

• UWW – 1.5-2.5%
• Plethysmography – 2.2-3.7%
• Skinfolds – 3-4%
• Bioelectric Impedance
  – Whole Body – 3-4%
  – Segmental – 4-6%
Riassunto delle assunzioni fatte dai metodi bicompartimentali
Assumptions of Two-Component Models

• 1. The density of fat is 0.900 g/ml
• 2. The density of FFM is 1.100 g/ml
• 3. The densities of fat and FFM are the same for all individuals
Assumptions

4. The densities of the various components of FFM are constant within an individual

5. The individual being measured differs from a reference body (73.8% water, 19.4% protein, 6.8% mineral) only in the amount of fat
Dual-Energy X-ray Absorptiometry
Dual Energy X-Ray Absorptiometry (DXA)

• Uses x-rays to measure thickness, density and chemical composition of tissue.
Scanning arm
Detector array
Scanning bed
X-Ray generator
Bed moves sideways and vertically
Scanning arm motion
Arm can also rotate
DXA Technology

Detector *(detects 2 tissue types - bone and soft tissue)*

Collimator *(pinhole for pencil beam, slit for fan beam)*

Patient

X-ray Source *(produces 2 photon energies with different attenuation profiles)*

Very low radiation to patient.

Very little scatter radiation to technologist
VARIAZIONE DEL COEFFICIENTE LINEARE DI ATTENUAZIONE PER L’ OSSO, LA MASSA MAGRA E LA MASSA GRASSA
• Attenuation constant between individuals.

• Assesses total bone mineral content. Further, each extra-bone pixel contains information on % fat and % lean tissue. Area determinations that tell both the % fat and % lean mass in a single region of interest.

• Three component model
  – bone, fat, fat-free soft tissue mass
Dual-energyXA

• Underlying principle: X-rays are attenuated by body tissue, each to a different degree depending on frequency (energy). DXA uses two beams at different energies. Ratio can accurately measure attenuation of each component.
DXA

• Two different energy level X-rays
• Lean, fat, and bone mass each reduce (attenuate) the X-ray signal in unique ways
• Computer analyzes scan point by point to determine body composition
• Method
  – 20-30/7-10/4-5 minutes
  – Applicable to young and old
TECNICA DUALE DI EMISSIONE RAGGI X

I due diversi livelli di energia per discriminare il tessuto molle da quello osseo, si possono ottenere con due tecniche differenti:

• **Energia Pulsata**

• **Energia Filtrata**
TECNICHE DI EMISSIONE RAGGI X

ENERGIA PULSATA

Il tubo radiologico (ad anodo fisso) di questa generazione di strumenti viene alimentato con due voltaggi differenti che si alternano per produrre i due livelli di alta e bassa energia. Tensione tipica:, 100-140 kVp.

ENERGIA FILTRATA

Il tubo radiologico (ad anodo fisso o rotante) viene in questo caso alimentato con un solo voltaggio in cui si interpone sul fascio prodotto un filtro di terra rara per produrre i due livelli di diversa energia. Tensione tipica: 84 kVp.
TECNICHE DI EMISSIONE RAGGI X

ENERGIA PULSATA

ENERGIA FILTRATA

Intensità relativa

Energia pulsata

Kev

45 100

Intensità relativa

Energia filtrata

Kev

45 100
• Bone mineral density
  – Attenuation calibrated to phantoms of known calcium content
  – Precision approximately 1%
• Lean mass
  - Precision approximately 1-2%
• Fat mass
  - Precision approximately 2.5%
DXA

• Advantages
  – Scan the entire body (regions) for total % fat, % lean mass, and bone density
  – Relatively non-invasive, relatively inexpensive to manage, fast
  – Good for absolute measurement and following changes in an individual
  – Rapid
  – Minimal subject cooperation (just lay there)
Disadvantage

• Costly (when buying)
• Limited Access
NON SOLO DENSITOMETRIA OSSEA

COMPOSIZIONE CORPOREA

Valutazione della massa grassa, magra e ossea settoriale.

Campi di applicazione:
Medicina Sportiva, Dietologia, Riabilitazione Funzionale, Fisiotterapia.
DEXA BMD Caveats

• Assumed that there is no change in attenuation with thickness. This is not true over about 20 cm

• DEXA MEASURES PERCENT COMPOSITION NOT ABSOLUTE VALUES

• Despite labels, DXA does not measure true bone density. It is the attenuation in a particular surface, there is no depth to the measurement
Computed Tomography ("CT Scan" or "Cat Scan")

- The scanner device incorporates a moving table & a revolving X-ray tube
  - The table moves the patient back and forth through the revolving X-ray emissions
  - The X-ray emitter moves (revolves) in a 360° arc around the patient
- Instead of film, the CT scanner collects emitted X-rays via a collector
  - scintillator
- Collector transforms X-ray photons into a proportionally strong electric current
- The electric current is then converted into an image
  - Contrast dyes may be used for image enhancement
CT scan

X-ray collector bank rotates around patient

X-ray tube
Normal CT scan (abdominal slice)
CT

• Area of interest outlined on the slice \( (r = 0.94 \text{ with planimetry on cadavers}) \)

• Specific density for each tissue of interest derived from standards

• Allows true volume measurement and thus true density.
CT

• Excellent correlation between body fat mass and cross-sectional abdominal adipose tissue area
  – Men $r=0.92$
  – Women $r=0.97$
• Nine scans required
• Difficulty is radiation exposure and cost
Figure 8.2  Relation of total cross-sectional abdominal adipose tissue area measured by computed tomography to body fat mass assessed by hydrostatic weighing in a sample of 89 men.
**Figure 8.3** Relation of total cross-sectional abdominal adipose tissue area measured by computed tomography to body fat mass assessed by hydrostatic weighing in a sample of 75 premenopausal women.
Magnetic Resonance Imaging

- Nuclei paramagnetici sono presenti nel corpo (1H, 13C, 23Na, 31P, 17O, 19F)
  Il nucleo dell’idrogeno è prevalente perché presente nell’acqua e negli acidi grassi
- Il soggetto è posto in un campo magnetico statico
- I nuclei magnetizzati (1H nuclei) nel soggetto si allineano a questo campo
- Un impulso di radiofrequenza (RF) crea un campo magnetico oscillante perpendicolare a quello statico
- I nuclei magnetizzati assorbono l’energia dell’impulso RF ed entrano in uno stato eccitato
- Quando la RF è spenta i nuclei eccitati ritornano allo stato basale ed emettono energia in forma di RF
- Differenti elementi assorbono ed emettono differenti quantità di energia RF (differenti risonanza)
- L’energia RF emessa è rilevata da un’antenna e trasformata in immagini
<table>
<thead>
<tr>
<th>Tissue</th>
<th>Signal Intensity T1</th>
<th>Signal Intensity T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat</td>
<td>high (whitish)</td>
<td>intermediate</td>
</tr>
<tr>
<td>Muscle</td>
<td>intermediate (gray)</td>
<td>intermediate</td>
</tr>
<tr>
<td>Hyaline Cartilage</td>
<td>intermediate</td>
<td>intermediate - low (dull gray)</td>
</tr>
<tr>
<td>Ligaments &amp; Tendons</td>
<td>low (dark gray)</td>
<td>low</td>
</tr>
<tr>
<td>Cortical Bone</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Granulation Tissue</td>
<td>intermediate</td>
<td>high</td>
</tr>
<tr>
<td>Fibrous Tissue</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Hemorrhage / Edema</td>
<td>high - intermediate</td>
<td>high</td>
</tr>
<tr>
<td>Immature Scar</td>
<td>intermediate - low</td>
<td>low to high</td>
</tr>
<tr>
<td>Mature Scar</td>
<td>low</td>
<td>low</td>
</tr>
</tbody>
</table>
MRI

- Same principle as CT
- May need as few as 1 to 4 slices at the L4-L5 level (questionable benefit)
- Major drawback is cost
- Considered by some to be reference techniques for body composition
MRI

![Graph showing Adipose Tissue Area (cm²) vs. L4-L5 (#21) with Total and Visceral markers.](image)
Near Infrared Red Spectroscopy (NIRS)

- Based on the premise that the degree of infrared light absorption is related to the composition of the substance through which light passes
- Fat and Fat-Free Mass absorb and reflect light differently
NIR

• Emit infrared light at wavelengths of 940-950 nm into a body part (ie., biceps) and measures the intensity of the re-emitted light

• More specific equations/machines are necessary
Advantages

- Non-invasive
- Safe
- Easy to administer
- Field technique
Disadvantages

• Cost? Is it worth it?
• Few Age/Gender Specific Equations
• Accurate?
  – Futrex 5000 3.1-4.2%
  – Futrex 5000A 6.3%
  – Futrex 1000 4.8-6.3%
  – Sum 3 2.4-3.6
Total Body Water

• Water in two compartments: body cells and extracellular fluids

• Dilution of known tracer – typically stable isotopes of water (tritium, deuterium, oxygen-18)

• Grams of tracer administered will be diluted and volume calculated
Total Body Water

Body water = w * f * \( C_{\text{dose}} / C_{\text{body water}} \)

W = moles of water in original sample
F = fractionation compared to water
\( C_{\text{dose}} \) = enrichment or concentration of dose
\( C_{\text{body water}} \) = enrichment or conc in body sample
Total Body Water

• Assumptions

  – Tracer only in body water – the labeled atoms can undergo exchange with other organics. 2-5 % error for all isotopes
  – Equal distribution of tracer to all compartments – not usually a problem
  – Fast rate of equilibrium – IV takes 2-3 hours. Oral up to 6 or more
  – No tracer metabolism – constant excretion and dilution. Plateau method with several determinations after ingestion
Total Body Water

• Fat will not take up water
• Use a hydration constant to determine fat free mass
• Problems encountered: must assume the hydration of fat free mass equal in different individuals and disease states, measurement error, instrumentation required
Total Body Water – fat free mass

- Fat will not take up water
- Use a hydration constant (.73) to determine fat free mass
- Problems encountered: must assume the hydration of fat free mass equal in different individuals and disease states, measurement error, instrumentation required
TOTAL BODY WATER

• Determined by introducing a marker fluid that moves freely in body water and is not metabolized. (isotope dilution)
• Deuterium Oxide, tritiated water
• % FAT PREDICTED FROM TOTAL BODY WATER
  – Assume 73.8% Water in Fat Free Mass
  – Even if no technical error in Body Water, there would still be S.E.E. = 3.6% Fat associated with biological variability
Whole-Body Counting

• Scintillation detectors were developed in the early 1950’s.
• They measure the body’s natural potassium as well as other radioactivity in the body.
Whole-Body Counting

• In 1958, Kulwich, Feinstein, and Anderson correlated natural potassium concentration with fat free mass.
• No longer in use
Whole-Body Counting

• There are an estimated 75 counters in the US.
• There are more than 180 whole-body counters worldwide.
• Two-thirds of these perform body potassium measurements in humans.
Whole-Body Counting

- Potassium is naturally distributed in three isotopic states.
- The isotope $^{40}$K is radioactive.
Whole-Body Counting

• Gamma rays from 40K are high-energy gammas, many of which exit the body and can be easily detected by external counting.

• The smaller the subject, the lower the 40K content and thus the weaker gamma signal.
Whole-Body Counting

- Factors such as age, fitness, or restricted mobility due to surgery or illness do not tend to affect the precision of total body potassium measurements.
- The 40K signal is natural and continuous, therefore the measurement can be interrupted as necessary, until counting is completed.
Whole-Body Counting

The three requirements for 40K whole body-counting include:

• Efficient gamma-ray detectors that can be placed close to the subject.

• Shielding for these detectors to reduce the natural background radiation levels
Whole-Body Counting

• Computer-based instruments that enable identification of the unique gamma rays.
Whole-Body Counting

Precision:

• For whole-body counters, precision is in the range of 2-5% for adults.

• In infants and very young children, precision is only 8-12% for 40 minute sample times.
Whole-Body Counting

• Total cost for an adult whole-body counter is $10,000-15,000.

• Cost of a special shielded room starts at $80,000.

• Start-up costs.

• Still in use for total body protein, body cell mass, skeletal mass mass
Neutron Activation Analysis

• IVNAA measures 11 elements from nuclear reactions.

• Protein, mineral, and fat can be estimated from these elements:
  – Carbon = Lipid
  – Nitrogen = Protein
  – Calcium = Bone
Neutron Activation Analysis

- IVNNA uses a whole-body counter.
  - It delivers a moderate beam of fast neutrons to the subject.
  - Atoms of target elements capture these neutrons.
  - This creates an unstable isotope.
Neutron Activation Analysis

• Unstable isotopes produce gamma rays when returning to a stable state.

• Gamma rays are measured:
  – energy level identifies the element
  – the activity indicates its abundance.
Prompt-Gamma Activation Analysis

• Isotope gets very excited with the added neurons.
  – Lasts only a fraction of a nanosecond before it returns to a stable state.
  – Measured simultaneously as the neutrons are exposed to the isotope.
Neutron Activation Analysis

Disadvantages:
• Radiation exposure.
• Must be performed by medical personnel
• Cost $30,000 - $300,000.
Neutron activation analysis determination of body composition.
Kehayias, Joseph; Valtuena, Silvia
Current Opinion in Clinical Nutrition & Metabolic Care.

Figure 7. C/O and C/H ratios for four chemical compartments. Carbon-to-hydrogen (C/H) and carbon-to-oxygen (C/O) ratios for four chemical compartments of the body. C/H is a measure of 'dryness', whereas C/O is an index of 'fatness'. Measurement errors are reduced when neutron activation is used for the simultaneous measurement of ratios of elements.
Equation 17

\[
\text{Skeletal muscle} = (0.188 \times \text{TBK}) + (0.00183 \times \text{TBN})
\]
Figure 8. The elemental partition analysis (EPA) method applied to the assessment of skeletal muscle. Selection of element for skeletal muscle assessment by elemental partition analysis (EPA). Total body potassium (TBK) will require a large number of corrections for non-muscle potassium, whereas phosphorus (TBP) requires high precision measurements of TBP and bone.

Neutron activation analysis determination of body composition.
Kehayias, Joseph; Valtuena, Silvia
Figure 9. Irradiation set-up for muscle and protein assessment. Subject irradiation set-up for the fast neutron activation analysis of phosphorus and nitrogen. The height, $h$, of the stepping stool is adjusted so the head is shielded. A whole-body detector is used for subsequent gamma ray counting.
Metodi antropometrici associati alla composizione corporea
Height – Weight Tables

• Developed in 1940’s by INSURANCE companies.
• Based solely on mortality statistics.
  – Fatter people = increased risk of death
• Do not take into account body composition!!!
Body Mass Index

• $\text{BMI} = \frac{\text{Weight (kg)}}{\text{Height (m)}^2}$

• Desirable
  – Men: 21.9 – 22.4
  – Women: 21.3 – 22.1
  – Over weight: 25 - 30
  – Obese: >30
Body Mass Index

• BMI’s above 27 associated with ↑ incidence of hypertension, diabetes, & CHD.

• Still used frequently by doctors and researchers.

• Does not take body composition into account either!
Body Mass Index

- Height: 5’10” = 1.77 m
- Weight: 221 lbs = 100.45 kg
- BMI = 32.09
- THIS GUY IS OBESE !!!!!
Waist to Hip Ratio

• Indication of the pattern of body fat distribution

• Indicator of the health risks of obesity
  – excess trunk fat - increased risk of hypertension, type 2 diabetes, high cholesterol, CAD, premature death
Waist to Hip Ratio

- Risks increase with increasing ratios
  - very high risk >0.94 young men and 0.82 young women
  - very high risk >1.03 older (60-69 years) men and 0.90 for older women
### Ratings of % Fat (ages 20-29 yr)

<table>
<thead>
<tr>
<th>Rating</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>6-9</td>
<td>10-17</td>
</tr>
<tr>
<td>Good</td>
<td>10-14</td>
<td>17-21</td>
</tr>
<tr>
<td>Acceptable</td>
<td>15-19</td>
<td>21-25</td>
</tr>
<tr>
<td>Too Fat</td>
<td>20-22</td>
<td>27-32</td>
</tr>
<tr>
<td>Obese</td>
<td>&gt;22</td>
<td>&gt;32</td>
</tr>
</tbody>
</table>
Potential Uses on Methods
Found in Literature

• Bod Pod
  – FFM & FM
    • Adults
    • Infant model – tested

• DXA
  – BMC, BMD, FFM, and FM
  – Tissue Distribution

• CT and MRI
  – Site specific tissue analysis
Potential Uses on Methods
Found in Literature

• BIA
  – FFM & FM
    • Adult and Pediatric
  – Dialysis
  – Survival
    • Cancer, peritoneal dialysis, malnutrition, obesity
  – Congestive Heart failure

• MFBIA or BIS
  – FFM, FM, TBW, ECF
  – Pregnancy, HIV+ wasting
Which Method to Use?

• Depends on compartment of interest.
• Availability of techniques.
• Technical training of staff.
• Condition of patient.
• Location where assessment will be done:
  – Laboratory / clinic
  – Field / remote site
<table>
<thead>
<tr>
<th>Technique</th>
<th>Capital Cost</th>
<th>Analytical Cost</th>
<th>Radiation Hazard</th>
<th>In Vivo Use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Techniques little used today</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Under water weighing</td>
<td>Low High capital</td>
<td>None</td>
<td>Low to medium</td>
<td>Medium to high</td>
</tr>
<tr>
<td>Whole body 40K counting</td>
<td>Low High capital</td>
<td>None</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Total body electrical conductivity</td>
<td>Low High capital</td>
<td>None</td>
<td>Medium</td>
<td>Medium to high</td>
</tr>
<tr>
<td>In vivo neutron activation analysis (INAA)</td>
<td>Low High capital</td>
<td>None</td>
<td>Medium to high</td>
<td>High radiation hazard</td>
</tr>
<tr>
<td><strong>Techniques in current use but not widely</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infra-red</td>
<td>Low Low to medium</td>
<td>High</td>
<td>Very low</td>
<td>High</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>Low Low to medium</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>EchoMRI</td>
<td>Low High capital</td>
<td>None</td>
<td>Low</td>
<td>Medium to high</td>
</tr>
<tr>
<td><strong>Techniques in current use mainly for research</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnetic resonance imaging (MRI)</td>
<td>Very high Very high</td>
<td>None</td>
<td>Medium to high</td>
<td>High</td>
</tr>
<tr>
<td>Computed tomography (CT)</td>
<td>Very high Very high</td>
<td>None</td>
<td>Medium to high</td>
<td>Low radiation hazard</td>
</tr>
<tr>
<td>3D photonic scanning</td>
<td>Low High capital</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Techniques in common use today for both research and clinical practice</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anthropometry (including skin-folds, weight, height, girths)</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Impedance</td>
<td>Low Low to medium</td>
<td>High</td>
<td>Very low</td>
<td>High</td>
</tr>
<tr>
<td>Dual-energy X-ray absorptiometry (DXA)</td>
<td>Low High capital</td>
<td>None to medium</td>
<td>High</td>
<td>Medium Low radiation hazard</td>
</tr>
<tr>
<td>Tracer dilution (deuterium, NaBr, 18O)</td>
<td>Medium Analytical costs may be high</td>
<td>High</td>
<td>High</td>
<td>Low to medium (analytical laboratory skills required)</td>
</tr>
<tr>
<td>Air displacement densitometry (ADP)</td>
<td>Low High capital</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Techniques in development</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2D smartphone scanning</td>
<td>Low</td>
<td>Very high</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>