Contents

Multi-Compartment Model (MCM) and Body Composition Measurement Techniques

Learn more

The easiest scientific way to explain the difference in body composition measurement techniques is based on the work of Drs. Lohman and Going from the University of Arizona. First of all, there exists a hierarchy of assessment techniques that includes **direct** and **indirect** measurement. Although a direct measurement of body composition is the most accurate method, it is not an option, as it requires dissection of the body. Moving to the indirect measurement, there are many different techniques, but they are not all created equal. The closest researchers can get to a direct measurement of body composition as far as accuracy goes is by using the Multi–Compartment Model technique. In research, this indirect method is also commonly said to be the best "reference" technique.

Other indirect methods such as BOD POD and Underwater Weighing have a small individual error. These methods are considered indirect because the equations used to determine body fat from body density are only one step from the direct method. For instance, if a person's total body density is determined (mass / volume), their relative amounts of fat and fat free masses can be determined because the known, individual densities of each compartment have been measured directly in previous cadaver analysis.

DXA, Skinfold Calipers, and Bioimpedance are also indirect. They predict body fat by predicting density; however, some of these methods use other technique–specific regression equations that may or may not be published. Regression equations developed from one specific population group may not be valid for use in other population groups, leading to poor individual agreements between the investigated and the reference method.

Multi–Compartment Model (MCM) - Reference Technique

Principles

The Multi-Compartment Model used to measure body composition requires a combination of measurement methods. The following is a description:

- Determination of **Total Body Water (TBW)** by using deuterium or 180 labeled water dilution.
- **Body Mass.**
- **Body Volume** by air displacement (BOD POD) or Underwater (UWW) Weighing.
- **Bone Mineral Content** by Dual-Energy X-Ray Absorptiometry (DXA).

The reason a Multi-Compartment Model would be preferred over a Two-Compartment Model (although a Two-Compartment model is a fair and accurate determination), is that it provides additional nutritionally-important information, and a more accurate measurement for individuals whose bone mineral content and total body water are outliers of the predicted (or average) ranges.

Research/Literature

- *"While multi-compartment models require more equipment, time, and tester expertise, they represent the new gold standard for profiling, monitoring change, and serving as a criterion against which field methods can be validated." (1)*
- *"With multi-compartment models, the multiple compartments of the fat-free mass (mineral, bone, protein, and water) are actually measured, allowing for calculation of the density of fat-free mass, and the precision with which body composition can be estimated is increased. Because of these advantages, the 4C model has been recommended as the gold standard against which other techniques should be validated." (2, 3)*

COSMED Position

The closest science can get to cadaver analysis in accuracy is the Multi-Compartment Model. We consider this to be the best reference technique. It is likely different results will be obtained from techniques shown not to compare favorably with multi-compartment models.

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Methods comparable to MCM

Based on research, what methods are comparable to the Multi-Compartment Model?

Underwater Weighing (UWW)

Principles

- Underwater Weighing estimates body composition from body density: **D = Mass/Volume**
- **Mass** - Measured on a scale on land.
- **Volume** - Based on Archimedes' Principle that states when a body is immersed in a fluid, body volume is equal to the loss of weight in the water.
- **Computing D_b to %BF** - Established equations are used that incorporate measured densities of fat and fat-free mass, such as:

$$\text{density of fat} = 0.9007\ g * cm^{-3}$$

$$\text{density of fat-free} = 1.100\ g * cm^{-3}$$

- The more dense a body is, the lower the percentage of body fat; the less dense a body is, the higher the body fat.
- The subject must exhale all air as head is lowered under water.
- Residual Volume (RV) must be measured to obtain most accurate results (nitrogen, oxygen, or helium dilution or nitrogen washout technique).
- The most accurate method for measuring RV is to obtain the measurement **at the same time** the subject is submerged in the tank, while their body volume is being measured, as opposed to measuring RV when the subject is outside of the tank.
- Residual Volume is then subtracted from the Total Body Volume measurement.

Research/Literature

- *"Hydrodensitometry is an established reference method for measuring body density." (3)*
- *"Based on considerations of expense and the precision and accuracy of measurement, the underwater weighing technique continues to be the most widespread and useful method for estimating body volume leading to the assessment of body composition." (4)*
- *"Hydrodensitometry is considered to be the gold standard of the densitometric methods. This technique typically requires the subject to be completely submerged underwater while exhaling maximally to minimize the effect of buoyancy from lung air. The limitations associated with this method include time, labor intensity, subject discomfort and inaccessibility for many special populations such as the elderly, disabled, and chronically ill." (5-7)*
- *"In hydrostatic weightning, using predicted residual lung volume had no effect on the estimation of %BF for the group. However, individual estimates deviated quite substantially from that calculated by using measured residual lung volume, with over 50% of the subjects having deviations in density values ranging from ±0.003 to greater than ±0.0099 g/ml (%BF deviations ranging from 1 to 4%)." (8)*
- *"There is a wide range of equipment and protocols commonly used in laboratories measuring underwater weight (autopsy scale vs. load cells), subject position, calibration, and method for determining residual lung volume (simultaneous vs. separate, underwater vs. land, helium vs. oxygen dilution). Of these, differences in residual volume determination and trial selection criteria have been reported to contribute the largest sources of variation." (9)*

COSMED Position

Percent fat measurements using the Underwater Weighing technique are not statistically different than the Multi-Compartment Model **when proper protocol is followed** (i.e., measured Residual Volume).

Air Displacement Plethysmography (BOD POD)

Principles

- Estimates body composition from body density: **D = Mass/Volume**
- **Mass** – Measured on a scale on land
- **Volume** – Measured by air displacement plethysmography in the BOD POD chamber
- **Computing Density to %BF** – Established equations are used that incorporates measured densities of fat and fat-free mass. For example:

$$\text{density of fat} = 0.9007\ g * cm^{-3}$$

$$\text{density of fat-free} = 1.100\ g * cm^{-3}$$

- The more dense a body is, the lower the percentage of body fat; the less dense a body is, the higher the body fat.
- Subject can breathe normally during the test.
- Thoracic Gas Volume (TGV) is accounted for instead of RV.

Research/Literature

- Several studies have compared the BOD POD with Multi-compartment Models, and the average of the study means indicates that the BOD POD and Multi-Compartment Models agree within 2%BF. (10-14)
- ***"The mean bias between BOD POD and 4-compartment model was 0.5%. The regression between fat mass by the 4-compartment model and by BOD POD did not significantly deviated from the line of identity. BOD POD is the only technique that can accurately, precisely, and without bias estimate fat mass in 9- to 14-yr-old children." (14)***
- ***"The average of the study means indicates that the BOD POD and underwater weighing agree within 1%BF for adults and children." (10)***

COSMED Position

Percent fat results obtained form the BOD POD have not been shown to be statistically different than results from Multi-Compartment Models.

Summary

Because the BOD POD and Underwater Weighing compare favorably with Multi-Compartment Model results, they also compare favorably with each other when proper protocol is followed.

Methods NOT comparable to MCMC

Based on research, what methods are NOT as comparable to the Multi-Compartment Model?

Dual-Energy X-Ray Absorptiometry (DXA)

Principles

- Dual Energy X-Ray Absorptiometry or "DXA" (previously DEXA) is a means of measuring Bone Mineral Density (BMD).
- Two x-ray beams with differing energy levels are aimed at the patient's bones.
- When soft tissue absorption is subtracted out, the BMD can be determined from the absorption of each beam by bone.
- DXA is the most widely used and most thoroughly studied bone density measurement technology.
- The DXA technique involves a small amount of radiation, and is usually administered by a department qualified to use radiation for medical imaging.
- Subject thickness is assumed.

Research/Literature

- DXA can only estimate two compartments (14-17).
    - Bone compartment results are directly derived from actual measurements. On the other hand, soft tissue results are only in part derived from actual measurements.
    - In pixels containing only fat and non-bone fat free mass DXA can estimate both. In pixels containing bone, fat and non-bone fat free mass (50% of a DXA scan), DXA can estimate only bone and non-bone tissue. The amounts of fat and non-bone fat free mass are, therefore, "guesstimated" in these pixels.
    - **DXA is NOT a 3-compartment technology**. It estimates bone in every pixel and in 50% of pixels guesses the proportions of fat and non-bone fat free mass.
- ***"Body thickness may have a considerable influence on the estimates of soft tissue mass by DXA. The assessment of soft tissue in both thin and thick tissue regions appears to be subject to significant errors, leading to over- or under-estimates of 5%BF." (18-22)***
- ***"Contributing to the uncertainty regarding DXA validity is the variability among manufacturers of DXA instruments in the methods of calibration, data acquisition, and data analysis. Comparisons of whole-body soft tissue measurements between three commercial DXA systems showed that there were significant mean differences of %BF between DXA instruments of 3 – 6 %BF These findings indicate that DXA systems from different manufacturers are not interchangeable in measurements of individual subjects." (23, 24)***

- *"For each manufacturer, significant differences in the estimates of percent fat were found between DXA scan modes (i.e., pencil beam vs. fan beam) both cross-sectionally (25-29) and with weight changes." (30-32).*
- *"A larger fat mass (1.5 kg) and percent fat (2.0 %BF), and a lower lean mass (1.1 kg) was observed with DXA software version 3.6R compared with version 3.4, suggesting that significant differences exist in body composition measurements from different DXA software packages within the same manufacturer." (33)*
- *"Consistent discrepancies of 1.7 – 5.3 %BF in the estimates of %BF were shown between two identical DXA machines, indicating that even identical models of DXA from the same manufacturer may not provide comparable body composition estimates." (34, 35)*
- *"Even with standard cross-calibration procedure for soft tissue measurement by DXA, body composition results obtained from different DXA machines in multiple sites are not consistent and comparable, which may preclude the use of DXA for a reliable body composition assessment in multi-center studies." (36)*
- *"DXA has been suggested for the assessment of regional soft tissue composition. However, it accuracy has been questioned based on findings from several previous studies, suggesting significant underestimation of truncal fat." (37-40)*
- Any movement during DXA whole body scan will lead to invalid test results. This is particularly important for the use of DXA in infant population in which compliance with a test protocol cannot be expected. (16)
- *"There are limited studies that compared DXA estimates of body composition with other techniques in athletes practicing a variety of sports. Lunar DXA was found significantly underestimated %BF by ~ 4 %fat respect to other three different methods (UWW, TBW AND TBK) in a sample of 12 endurance athletes." (41)*
- *"In a recent study, the accuracy of DXA (Lunar Prodigy) was compared with 4-CM and found that the inconsistent bias of DXA varies according to sex, size, fatness and disease status, indicating that DXA is unreliable for patient case-control studies and for nutrition/health longitudinal studies." (42)*
- *"There was a poor agreement between %BF estimates from DXA and the criterion method of 4-compartment in infant population, with mean bias of 4.5 %BF. The study results did not support the use of DXA for body composition assessment in infants." (Ellis et al., unpublished data)*

COSMED Position

While DXA does a good job of measuring bone density, the measurement of body fat is not as well established according to the research. Percent fat readings measured by DXA have not been shown to agree favorably with the Multi-Compartment Model and, therefore, cannot be considered a gold standard.

Skinfold Calipers

Principles

- A small, hand-held device called Skinfold Calipers is used to measure the thickness of fat immediately below the skin's surface, which is also called subcutaneous fat.
- Usually 3 to 12 locations are chosen to measure. The most common sites are: suprailiac, anterior thigh, triceps, and subscapular.
- These 3 to 12 local fat measurements are used to predict the overall fat content of the entire body, however, significant errors can result from this approach, because people deposit fat in different areas, and a**bout half of the fat content of the body is internal, which skinfold calipers can't measure**.
- Once fatfolds are measured they are put into one of hundreds of different population-specific or generalized equations to determine BF% (see Appendix II).
- Because of this, the accuracy of skinfolds on an individual basis is not very high, with research studies indicating errors of up to ±8%. Example: If someone is really 20% fat, Skinfold Calipers could measure the person between 12 and 28% fat.
- The best application of Skinfold Calipers is to determine if subcutaneous fat is increasing or decreasing, but not for predicting total body fat.

Research/Literature

- *"The precision of the skinfold data has been shown to be highly variable and operator-dependent." (43)*
- *"The accuracy of skinfold method has been questioned for many years when assessing body fat mass of the individual. The error in body fat estimates from SF ranges from ± 3% to ± 11 %, and is influenced by sex, ethnicity, age and measurement sites." (44)*

- *"Significant errors can result from this approach, because people deposit fat in different areas, and about ½ of the fat content of the body is internal, which skinfold calipers can't measure. Because of this, the accuracy of skinfolds on an individual basis is not very high, and research studies indicate errors of as much as ±8%." (45)*
- *"It may be impossible to obtain skinfolds at the prescribed sites in overweight and obese subjects." (46)*
- *"Skinfold predictive equations should be applied only after they have been successfully cross-validated for a population similar to the one that will be studied. In their application, the anthropometric procedures and instruments must match those that were used when the equations were developed. The sites for the measurement of skinfolds must match those in the validation study and the same calipers must be used." (46-48)*
- *"It has been shown that it is not possible in infants to predict total body fatness from the measurement of skinfold thicknesses to an appropriate level of accuracy, and the equations derived for use in childhood and adolescents are extremely population specific." (49, 50)*

COSMED Position

With regards to overall body fat, body fat measured by Skinfold Calipers has consistently been shown to be inaccurate and unreliable. There is little research comparing Skinfold percent fat measurements and Multi-Compartment measurements because the principles and assumptions are completely different. For this reason, Skinfold measurements should also not be compared to methods such as Underwater Weighing and BOD POD.

Bioimpedance (BIA)

Principles

- There are a number of Bioimpedance devices that pass a small, alternating electric current through the body, and the resistance to that current indicates the amount of water in the body. This is, in turn, related to the amount of lean tissue in the body.
- The opposition of the flow is measured.
- Total body water is estimated.
- Fat-free mass is predicted from Total Body Water (TBW) estimates.
- To estimate TBW from the observed resistance-to-current flow, two assumptions are used.
- The whole body can be modeled as an isotropic cylindrical conductor, with its length proportional to the subject's height.
- The reactance term contributing to the body's impedance is small, such that resistance can be considered equivalent to impedance.
- Under these conditions, the impedance index (Height2/R) is assumed to be proportional to the volume of TBW.
- A large fat–free mass compartment = less resistance to current.
- A large fat compartment = more resistance to current.

Research/Literature

- In the past 10 years, many studies have been published in which the validity of the BIA method in assessing TBW or FFM was shown in specific population groups. However, many investigators found that the basic model failed; that is, the impedance index alone was not an accurate predictor and that additional anthropometric terms (i.e., weight, age, gender, race, shoulder width, girth waist-to-hip ratio, body mass index) were included in the prediction model to reduce the standard error of the estimate. No physiological justification for the added terms was provided.
- *"It has also been found, for reasons not known, that body position, posture, serum electrolytes, blood flow, skin temperature, fluid distribution, and vascular perfusion all can significantly change the observed resistance." (51-53)*
- *"The prediction equations for TBW or FFM were population-specific, which restricts the usefulness of these equations in other population groups who may differ from the original sample in which the equation was developed. Inaccurate results can be anticipated when, for example, BIA is applied in obese individuals and component prediction equations are used that were developed in normal weight individuals." (54, 55)*
- The major criticism on BIA technology at the National Institutes of Health (NIH) Technology Conference was that *"these BIA prediction equations tend to be applicable only for classifying a population, not necessarily individuals within that population" (56).* In a cross-sectional study of 117 adult subjects aged 19 -77 y, Piers et al. observed that an estimate of FFM from BIA could be up to 8.8 kg higher or 6.3 kg lower than the estimate obtained by the reference method of deuterium dilution. This could theoretically represent an estimated range of %BF of between 14 and

33% for an 80 kg man with a FFM of 60 kg. Clearly, *"such differences in estimates of body fat cannot be tolerated at the individual level." (57)*

- Several factors may limit the valid application of the BIA method in the obese state: increased relative amount of TBW, different body geometry, and increased relative extracellular water. *"All these factors have an effect on the validity of the method in the obese and severely obese state, for which the amount of body fat generally will be underestimated with use of prediction equations developed in normal-weight subjects."* (58)
- The validity of BIA in body composition assessment in the elderly remains uncertain. With age in fact, the changes in body composition; in particular the fluid balance, as well as the largest variability in FFM hydration, may interfere with the accuracy of BIA method. In a study of a sample of 24 healthy elderly subjects, the values of FFM derived by six BIA equations were compared with those measured by DXA, and found that five out of six equations underestimated the FFM significantly with a wide range error, from -22.8 to -1.7%. (59)

COSMED Position

Bioimpedance has not been shown to compare favorably with the Multi-Compartment Model; therefore, cannot be compared to methods such as Underwater Weighing and BOD POD. In addition, the summarized literature review indicates *"at the individual level, BIA estimate of body composition (including FFM and %BF) can not be used with any degree of confidence" (57).*

Summary

DXA, Skinfolds, and Bioimpedance results have shown to be statistically different than Multi-Compartment Model results and should not be compared to other technologies using the principle of densitometry such as Underwater Weighing and BOD POD.

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