The Ins and Outs of Body Composition Research

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Why assess body composition?

• Identify health risks associated with excessively low or high body fat values

• Educate clients and athletes about the risks of low or high body fat values

• Monitor changes in body composition

• Estimate healthy body weight goals

• Formulate dietary and exercise recommendations

• Monitor growth, development, and age-related changes
We will discuss

• Understanding the science behind the facts
  – Assumptions (that lead to the misinterpretation of data)

• Different methods and the benefits of each
  – Underwater weighing, BODPOD, DXA
  – MRI, CT
  – Fields methods, BIA, Skinfolds, etc.

• Publishing tips if body composition is a main DV
We will also discuss

• Is an individual change a “real” change?
  – Biological/Physiological Variability
    • The person/client is never the same
  – Methodological Variability
    • Is your method without error
  – External variables
    • Are there other factors influencing your results?
What are we (Mostly) made of?
These models are not dependent on age, sex, ethnicity, fitness level, or fatness level and are considered the BEST reference methods!
Neutron activation example

Neutrons interact with common table salt (sodium chloride)

Calcium, Sodium, Potassium, Chlorine, Nitrogen

Volunteer in position to enter the neutron irradiator

https://www.bcm.edu/bodycomplab/ivnamainpage.htm
As the ‘true’ value of total body fat is unmeasurable, a reference with high accuracy is necessary to evaluate other less accurate methods. The reference should avoid major assumptions and have maximal precision.

These methods form a core with the six-compartment criterion model.

...all share in common their derivation from multi-compartment body composition models and a requirement for TBW estimates.

In Body Composition Measurements a combination of both Accuracy and Precision is required for a method to be considered VALID.
What can we measure?

Reference Methods

• Models that are not dependent on age, sex, ethnicity, fitness level, or fatness level are considered the BEST reference methods!

• Multiple-compartment models used to validate laboratory and field methods
  – Six-compartment (6C) – Atomic level
  – Five-compartment (5C) – Molecular level
  – Four-compartment (4C) – Molecular level
  – Three-compartment (3C) – Water molecular level

  NOT IDEAL or BEST
  – Three-compartment (3C) – Mineral molecular level*
  – Three-compartment (3C) – Tissue level (DXA model)*

• Advanced imaging techniques
  – MRI, CT, Ultrasound – Tissue level

• Depending on the model, the following components can be used to calculate %fat
  • Nitrogen, Calcium, Sodium, Potassium, Chloride, Mineral, Protein, Water, Soft tissue mineral
Siri 1961 (53 years ago)

- About 2C densitometry (HW & BodPod)
  - “…if there were no error whatsoever in measuring density, the uncertainty in fat estimate would still remain +/- 3.8% body weight primarily because of normal variability in body constituents...”

- “…significant differences from the average in any of the gross constituents other than fat introduce a comparable indeterminate error in fat estimate. The method is obviously invalid, for example in the presence of abnormal hydration.”

- “…the nature of tissue gained or lost during weight change cannot be deduced from densitometry alone if other tissue in addition to adipose tissue are involved. It is conceivable, for example, that the apparent density of tissue lost could be less than that of pure fat, i.e., 0.9 gm/cc, if there occurred a gain in muscle mass concurrently with a loss of adipose tissue.”
Problems with DXA for a single assessment of body composition (including bone)

- "let it be clear that the World Health Organization T score criteria were proposed for use in epidemiological studies, for comparison between populations ... They were not intended for diagnosis or treatment decisions in individual cases."
  - Regarding the utilization of DXA for classifying osteoporosis.
  - Dequeker et al. 2001

- “In diabetes mellitus, a method to measure blood glucose level with a comparatively high inaccuracy would be dangerous.”
  - Peter Schneider 2009
  - FUTREX?

- Heyward (1996): “Given that hydrodensitometry, hydrometry and DEXA are subject to measurement error and violation of basic assumptions underlying their use none of these should be considered as a gold standard method for in vivo BC assessment” (p. 151).

- “The combination of all findings of this study suggests therefore insufficient confidence in the ability of DEXA to accurately measure the variables it claims to measure.” Provyn, S et al. 2008

- “This study equally confirms the lack of accuracy of DEXA in the capacity of measuring total mass, Fat mass/AT mass, lean and LeanBMC/ATFM, Fat/AT%, and BMC/Ashed Bone Mass. This study also gives reason to believe that the amount of water in lean mass influences the estimated amount of AT and suggests equally that the variable water content of AT may influence ATFM.” Provyn, S et al. 2008
%Fat... as we know it
%Fat and FFM

• FFM is EVERYTHING!!! Except (ALL) the fat!
  – 100% Fat Free 😊 not Lean Body Mass (+ Essential Fat)
Adipose Tissue (AT)

“Adipose tissue, being the morphological dimension, can be defined anatomically as the paniculus adiposus (e.g. subcutaneous, intramuscular, and visceral) including connective tissue and microscopic blood supply and nerves.” (Provyn, 2008)

Total Body Fat (%Fat)

- Adipose Tissue (AT) ≈ 80%
- Other Lipids/Fats ≈ 20%

Water 83.8%

Adipose Tissue (BIG Fat Cells)

Lipids/Fat, Connective Tissue, etc. 16.2%

Water 83.2%

Adipose Tissue (SMALL Fat Cells)

Lipids/Fat, Connective Tissue, etc. 16.8%
Individual Variability (within)
Individual Variability (Between)

- Ask yourself if you think the %Fat scale you purchased for $80 is considering how much water is in your adipose tissue. What about your DXA and/or BODPOD

- Do you think this is constant even from day-to-day?
Muscle Mass (MM)

*NOT Fat-Free Mass (FFM)
*FFSMM = Fat-Free Skeletal Muscle Mass

Skeletal Muscle

FFM of Skeletal Muscle
Endurance/More Slow Twitch

- Water: 80.40%
- Protein: 19.60%

FFM of Skeletal Muscle (FFSMM)
Strength/More Fast Twitch

- Water: 67.50%
- Protein: 32.50%
Individual Variability (within)
Ask yourself if you think the scale you use that gives you a muscle mass and FFM readout that you purchased for $80 is considering how much water is in your muscle tissue. What about DXA and/or BODPOD?

Do you think this is constant even from day-to-day? What about with training? What about age?
Corey & Chris Wheir
Natural Bodybuilding
5' 10" 205 lbs; 6' 0" 203 lbs.

Shane Hamman
Weightlifting
5' 9" 370 lbs.

King Kamali
Bodybuilding
5' 10" 248 lbs.

Oscar Chaplin III
Weightlifting
5' 9" 169.5 lbs.
**Total Body Mass**

*(Lean: 10%Fat)*

- Fat-Free (No Lipids/Fat): 86.0%
- Pure Fat/Lipids (%Fat): 10.0%
- Bone: 4.0%

**Total Body Mass**

*(Overweight: 35%Fat)*

- Pure Fat/Lipids (%Fat): 35.0%
- Fat-Free (No Lipids/Fat): 61.0%
- Bone: 4.0%
Total Body Water is Contained in...

- **Skeletal Muscle**: 54.0%
- **Blood**: 10.9%
- **Other**: 29.4%
- **Adipose Tissue (AT)**: 5.7%

*Muscle Mass contains nearly 5 times more water than any other organ or tissue.*
**Total Body Variability?**

**TABLE 1**
Fat-free body mass (FFM) hydration (TBW:FFM) evaluated in 9 adult human cadavers

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age</th>
<th>Body mass</th>
<th>TBW</th>
<th>FFM</th>
<th>TBW:FFM</th>
<th>Cause of death</th>
<th>Reference and year</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>46</td>
<td>53.8</td>
<td>29.7</td>
<td>43.3</td>
<td>0.686</td>
<td>Skull fracture</td>
<td>Forbes et al (4), 1953</td>
</tr>
<tr>
<td>M</td>
<td>60</td>
<td>73.5</td>
<td>37.2</td>
<td>53.0</td>
<td>0.702</td>
<td>Heart attack</td>
<td>Forbes and Lewis (5), 1956</td>
</tr>
<tr>
<td>M</td>
<td>25</td>
<td>71.8</td>
<td>44.4</td>
<td>61.1</td>
<td>0.726</td>
<td>Uremia</td>
<td>Widdowson et al (6), 1951</td>
</tr>
<tr>
<td>M</td>
<td>63</td>
<td>58.6</td>
<td>35.0</td>
<td>48.0</td>
<td>0.729</td>
<td>Esophageal cancer</td>
<td>Knight et al (7), 1986</td>
</tr>
<tr>
<td>F</td>
<td>59</td>
<td>25.9</td>
<td>13.3</td>
<td>18.2</td>
<td>0.731</td>
<td>Extreme cachexia</td>
<td>Knight et al (7), 1986</td>
</tr>
<tr>
<td>F</td>
<td>42</td>
<td>45.1</td>
<td>25.3</td>
<td>34.5</td>
<td>0.733</td>
<td>Drowning</td>
<td>Widdowson et al (6), 1951</td>
</tr>
<tr>
<td>M</td>
<td>48</td>
<td>62.0</td>
<td>43.9</td>
<td>59.3</td>
<td>0.740</td>
<td>Infectious endocarditis</td>
<td>Forbes and Lewis (5), 1956</td>
</tr>
<tr>
<td>M</td>
<td>35</td>
<td>70.6</td>
<td>47.9</td>
<td>61.7</td>
<td>0.776</td>
<td>Mitral insufficiency</td>
<td>Mitchell et al (8), 1945</td>
</tr>
<tr>
<td>F</td>
<td>67</td>
<td>43.4</td>
<td>32.0</td>
<td>39.6</td>
<td>0.808</td>
<td>Advanced malignancy</td>
<td>Moore (9), 1946</td>
</tr>
</tbody>
</table>

$\overline{y} \pm SD$ 49 ± 14 50.1 ± 15.8 34.3 ± 10.8 46.6 ± 14.5 0.737 ± 0.036

$^{1}$TBW, total body water.

**TBW:FFM ranges from 68 to 81%**


*Obesity Research Center, St. Luke’s-Roosevelt Hospital, Columbia University*
So what devices/methods are valid?

- Only devices that have been researched (compared to reference methods) and proven accurate can be considered valid and reliable. What population?

- **What has been researched?**
About 6,090 results (0.46 seconds)

Body Weight Scales → Body Analysis

Most popular

#1

Weight Watchers Scale, Glass, Body Analysis

$30 from 20+ stores - 17 nearby stores

Conair - Floor - Digital - Body Analysis - Glass Platform

9 reviews

Add to Shortlist
How large are the errors?

• Valid body composition methods all have larger individual errors compared to group errors.
  – NIR, BIA, Skinfolds, BOD POD®, underwater weighing, and DXA
    • Group Total/Pure Error – 1.8 to 10.4%fat
    • Individual errors ranging from around ±2%fat to ±12%fat

• Let’s see what these errors look like

<table>
<thead>
<tr>
<th>PRE</th>
<th>(x +/- SD)</th>
<th>Slope</th>
<th>Intercept</th>
<th>r</th>
<th>SEE</th>
<th>TE</th>
<th>CE / Bias +/- 2SD</th>
<th>Upper Limits</th>
<th>Lower Limits</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>4C</td>
<td>33.41 +/- 6.14</td>
<td>0.84</td>
<td>7.58**</td>
<td>0.68</td>
<td>4.56</td>
<td>5.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tanita</td>
<td>30.50 +/- 7.80</td>
<td>0.67**</td>
<td>13.05**</td>
<td>0.85</td>
<td>3.30</td>
<td>5.06</td>
<td>2.91 +/- 8.18</td>
<td>11.09</td>
<td>-5.27</td>
<td>-0.26**</td>
</tr>
<tr>
<td>Escali</td>
<td>24.37 +/- 8.24</td>
<td>0.52**</td>
<td>20.76**</td>
<td>0.70</td>
<td>4.46</td>
<td>10.70</td>
<td>9.04 +/- 11.64</td>
<td>20.67</td>
<td>-2.60</td>
<td>-0.34**</td>
</tr>
<tr>
<td>WW</td>
<td>30.74 +/- 4.96</td>
<td>0.79**</td>
<td>11.90**</td>
<td>0.84</td>
<td>3.40</td>
<td>7.02</td>
<td>2.67 +/- 9.01</td>
<td>11.68</td>
<td>-6.33</td>
<td>0.26**</td>
</tr>
<tr>
<td>Omron 306</td>
<td>27.40 +/- 6.56</td>
<td>0.79**</td>
<td>11.90**</td>
<td>0.84</td>
<td>3.40</td>
<td>7.02</td>
<td>6.01 +/- 7.15</td>
<td>13.17</td>
<td>-1.14</td>
<td>-0.07</td>
</tr>
<tr>
<td>Omron 500</td>
<td>34.83 +/- 7.73</td>
<td>0.71**</td>
<td>8.69**</td>
<td>0.89</td>
<td>2.80</td>
<td>3.82</td>
<td>-1.42 +/- 7.00</td>
<td>5.58</td>
<td>-8.42</td>
<td>-0.24**</td>
</tr>
</tbody>
</table>

Table 5 - PRE training validation of BIA devices for predicting percent body fat compared to a 4C model (men and women), TE = Total error, * p < 0.01, ** p < 0.05, n = 60.
Tracking Changes With Home Scales

Figure 1 - Individual differences between BIA devices and the 4C model for the exercise group delta %fat values.
Laboratory Methods
• BOD POD – 16.2%
• Underwater weighing – 15.8%
• DXA – 20.1%

Field Methods
• Futrex 6100 – 19.5%
• SFB7 (BIS) – 19.9%
• DF50 (BIA) – 27.6%
• Skinfold (3-site) – 10.6%
• Skinfold (7-site) – 14.5%
Laboratory Methods
• BOD POD – 29.5% (1.4%)
• Underwater weighing - 27.3% (0.8%)
• DXA – 31.2% (3.1%)

Field Methods
• Futrex 6100 – 27.1% (1.0%)
• SFB7 (BIS) – 31.8% (3.7%)
• DF50 (BIA) – 34.1% (6.0%)
• Skinfold (3-site) – 23.2% (4.9%)
• Skinfold (7-site) – 23.3% (4.8%)

Reference
5C model
28.1%
Group vs. Individual

Table 3: Validation of all methods for predicting % body fat compared to the Wang 5C

<table>
<thead>
<tr>
<th>Method</th>
<th>(X ± SD)</th>
<th>Slope</th>
<th>Intercept</th>
<th>r</th>
<th>SEE</th>
<th>TE</th>
<th>Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CE/Bias ± (1.96 × SD)</td>
<td>Upper Limits</td>
<td>Lower Limits</td>
<td>Trend</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wang-4C</td>
<td>24.98 ± 4.63</td>
<td>1.000</td>
<td>-0.06</td>
<td>&gt;0.99</td>
<td>0.01</td>
<td>0.05</td>
<td>-0.05 ± 0.02</td>
</tr>
<tr>
<td>Siri-3C</td>
<td>25.00 ± 4.50</td>
<td>1.027</td>
<td>-0.74</td>
<td>&gt;0.99</td>
<td>0.38</td>
<td>0.39</td>
<td>-0.07 ± 0.77</td>
</tr>
<tr>
<td>Lohman-3C</td>
<td>25.65 ± 5.85</td>
<td>0.724</td>
<td>6.35</td>
<td>0.91</td>
<td>1.91</td>
<td>2.54</td>
<td>-0.72 ± 4.86</td>
</tr>
<tr>
<td>HW-Brozek</td>
<td>24.31 ± 5.03</td>
<td>0.832</td>
<td>4.71</td>
<td>0.90</td>
<td>2.04</td>
<td>2.22</td>
<td>0.62 ± 4.26</td>
</tr>
<tr>
<td>HW-Siri</td>
<td>24.97 ± 5.44</td>
<td>0.767</td>
<td>5.76</td>
<td>0.90</td>
<td>2.04</td>
<td>2.33</td>
<td>-0.04 ± 4.64</td>
</tr>
<tr>
<td>ADP-Brozek</td>
<td>25.02 ± 5.73</td>
<td>0.716</td>
<td>7.01</td>
<td>0.89</td>
<td>2.19</td>
<td>2.65</td>
<td>-0.09 ± 5.29</td>
</tr>
<tr>
<td>ADP-Siri</td>
<td>25.74 ± 6.21</td>
<td>0.661</td>
<td>7.91</td>
<td>0.89</td>
<td>2.19</td>
<td>3.07</td>
<td>-0.81 ± 5.90</td>
</tr>
<tr>
<td>DXA</td>
<td>28.63 ± 7.05</td>
<td>0.609</td>
<td>7.49</td>
<td>0.93</td>
<td>1.78</td>
<td>4.90</td>
<td>-3.71* ± 6.39</td>
</tr>
<tr>
<td>5C</td>
<td>24.93 ± 4.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Represents significance at (P ≤ 0.00625), **represents significance at (P ≤ 0.05), HW hydrostatic weighing, ADP air displacement plethysmography via the BOD POD®, DXA dual-energy X-ray absorptiometry, CE/Bias constant (mean) error, TE total error, SEE standard error of estimate, r = Pearson product-moment correlation coefficient, Limits 95% limits of agreement [CE ± 1.96 SD of residual scores (predicted-actual)], Trend relationship between the difference of the criterion and laboratory method and the mean of both methods.

CE/Bias is the Mean difference between measurements
Bland and Altman analysis of Individual errors

What methods have the largest errors compared to reference models?

- **BOD POD®**
  - ±4.4%fat
- **Underwater weighing**
  - ±3.8%fat
- **NIR (Futrex 6100)**
  - ±5.2%fat
- **BIA (General equation)**
  - ±3.8%fat
- **Skinfold 3-site (Jackson and Pollock)**
  - ±5.5%fat

- At BEST, both laboratory and field methods produce about a ±4.0%fat individual error.
- Any single measurement will have a range between 8% of the ACTUAL %fat value!
- Group errors at best for methods that don’t measure TBW are around a ±2% or half that of the best Individual errors.


**Figure 1** – All subjects’ mean %fat change values after intervention comparing all models to the 4C model.

**Figure 2** – Men’s mean %fat change values after intervention comparing all models to the 4C model; • = p > 0.05.

**Figure 3** – Women’s mean %fat change values after intervention comparing all models to the 4C model; • = p > 0.05.
Figure 4 – Individual %fat results of both 3C models compared to the 4C model.

Figure 5 – Individual %fat results of both 2C models and DXA compared to the 4C model.
TrackingChanges in FFM

**4C (Mean)**

<table>
<thead>
<tr>
<th>Women Control</th>
<th>Women Exercise</th>
<th>Men Control</th>
<th>Men Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10 kg*</td>
<td>0.83 kg*</td>
<td>-0.44 kg*</td>
<td>0.32 kg*</td>
</tr>
<tr>
<td>DXA (Mean)</td>
<td>0.09 kg*</td>
<td>0.84 kg*</td>
<td>-0.29 kg*</td>
</tr>
</tbody>
</table>

* Significantly different between control and exercise group

"The current data in combination with the reliability errors for both BIA and DXA FFM estimations suggest that results should be interpreted with caution if individual FFM changes are <5 kg; however, the magnitude of the change in FFM estimated by BIA and DXA may not be accurate. Nevertheless, DXA and BIA can be used interchangeably for tracking changes in FFM in small groups (15–22) of healthy older adults."

* Significantly different from pre to post testing

<table>
<thead>
<tr>
<th></th>
<th>Women Control</th>
<th>Women Exercise</th>
<th>Men Control</th>
<th>Men Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>4C (Mean)</td>
<td>0.10 kg*</td>
<td>0.83 kg*</td>
<td>-0.44 kg*</td>
<td>0.32 kg*</td>
</tr>
<tr>
<td>BIA Eq5 (Mean)</td>
<td>0.20 kg*</td>
<td>0.82 kg*</td>
<td>-0.01 kg</td>
<td>0.26 kg</td>
</tr>
</tbody>
</table>

A simple way to track changes

- Measuring skinfold thickness (or ultrasound SAT) and circumference can be more beneficial than body fat estimations!
  - ~75% of muscle is in the arms and legs
  - ~33% of fat is in Subcutaneous Adipose Tissue
  - Use skinfold calipers to measure the skinfold thickness of the biceps, triceps, forearm, thigh, and calf.
    - Use ultrasound to measure SAT at the same locations
  - Use a measuring tape to measure the circumference of the biceps, triceps, forearm, thigh, and calf.
    - If the circumference measurements get bigger while the skinfold measurements get smaller than they are most likely gaining muscle and losing fat
    - If the circumference measurements get bigger and the skinfolds stay the same, than they are most likely gaining muscle and not losing fat
    - You get the idea!
Calculating Muscle Circumference

- Muscle Circumference (MC)
- Limb circumference (LC)
- Skinfold Thickness (ST)

**MC = LC − π x ST**

- Because the ST is a double thickness measurement you don’t need to multiple ST by 2 in order to get the full diameter of fat and skin.
  - If it was Ultrasound you would need to multiple SAT by 2

**Example**

- Arm circumference of 44 cm (440 mm) skinfold thickness 15 mm
- MC = 440 - 3.14 x 15
- MC = 393 mm (39.3 cm)
Improving tracking accuracy

• NUMBER ONE
  – If the changes (in a group or individual) are too small, every body composition variable (fat mass, %fat, lean mass, etc.) may result in inaccurate estimations.
    • Small changes can ONLY be evaluated ACCURATELY with a multiple-compartment models that estimate TBW.

• If less accurate methods are used, there will need to be a much greater change in body composition to determine actual change, both at the group and individual level.

• However, in the end, the accuracy of many methods is determined by the protocol and technique.
Reducing body composition assessment errors

• When using anthropometric methods the largest errors can be attributed to the investigator/trainer/coach.
  – Practice Practice Practice!
    • 3 - 9% variability can be attributed to differences between investigators/trainers (Lohman et al. 1984, Morrow et al. 1986)
    • Jackson and Pollock (1978) suggest practicing on at least 50-100 subjects/clients and take minimum of 2 measurements per site.
    • Wet and skin with lotion can alter skinfold values

  – Use estimation equations to calculate body composition values that were developed using the same population you are testing.
    • The Jackson and Pollock sum of 3 and 7 skinfold equations have been validated in both athletic and nonathletic populations with success.
Reducing body composition assessment errors

• Consistency is KEY
  – Measure at the same time, each time
    • 12hr prior, fast and no exercise is ideal
  – For women, measure at the same point in the menstrual cycle.
    • Preferably when they are not in peak body mass periods, which can occur at different times for all women (Bunt et al. 1989).
  – Use the same device for all measurements used to track changes; do not assume all devices can be used interchangeably.
  – The most used skinfold calipers are the Lange and Harpenden, which both apply consistent pressure (7-8g/mm²) throughout the range of measurement (0-60mm).
Calculating your own MD is KEY!

• To be sure your clients’ skinfold thicknesses and circumferences are reducing/increasing, you need to calculate your “minimal difference” statistic.

  – WHY USE SKINFOLD THICKNESS AND CIRCUMFERENCES?
    • They are simple measurements, like height and weight and are not dependent on age, sex, ethnicity, or fitness level.

• What you need
  – Preferably 10 people per sex
  – Measure each site around 24 hours apart
  – A way to calculate your MD Statistic
How to Calculate MD

• The Hard Way
  • http://musclepharm.com/data/Reliability_Calculator.xlsx

• Calculate the ICC: \[ \frac{MS_S - MS_E}{MS_S + (k - 1)MS_E} \]

• Calculate the SEM: \[ SEM = SD\sqrt{1 - ICC} \]

• Calculate the MD: \[ MD = SEM \times 1.96 \times \sqrt{2} \]

The Easy Way (Mathematically Identical)

\[ =(\text{Select Time 2 Cell})- (\text{Select Time 1 cell}) \]

\[ =(\text{Time 2 - Time 1})/(\text{Time 1}) \]

<table>
<thead>
<tr>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 2 - Time 1</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
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<td>-1</td>
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</tr>
<tr>
<td>7</td>
<td>7</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>1</td>
<td>16.67%</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>-1</td>
<td>-14.29%</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
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<td>2</td>
<td>28.57%</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>-4</td>
<td>-44.44%</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>1</td>
<td>12.50%</td>
</tr>
</tbody>
</table>

\[ \text{SD} = 1.62 \]

\[ 1.96 \times \text{SD} = 3.174 \]

\[ \text{STDEV}(\text{select the Time 2 – Time 1 data}) = (\text{Select the STDEV cell}) \times 1.96 \]
This is just 2 standard deviations of the differences between Time 1 and Time 2.

We round 95.45% to 96%
1.96 in the equation is equal to 96% of the data

Thus, we are 96% confident that a change that exceeds this number is BEYOND the error associated with the method and biological/physiological variability which is why we call it the Minimal Difference (MD) needed to be considered “Real”
## Expert Values (to aim for or better)

<table>
<thead>
<tr>
<th></th>
<th>Weight (lbs)</th>
<th>Chest</th>
<th>Mid Chest</th>
<th>Waist</th>
<th>Waist (Navel)</th>
<th>Hip</th>
<th>Proximal Thigh</th>
<th>Mid Thigh</th>
<th>Upper Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MD</strong></td>
<td>3.13</td>
<td>4.23</td>
<td>6.99</td>
<td>3.18</td>
<td>3.60</td>
<td>3.42</td>
<td>2.58</td>
<td>2.05</td>
<td>1.58</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Tri</th>
<th>Adb</th>
<th>Chest</th>
<th>Thigh</th>
<th>Supra</th>
<th>Sub</th>
<th>Axilla</th>
<th>Sum7</th>
<th>Sum3</th>
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</thead>
<tbody>
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<td><strong>MD</strong></td>
<td>4.24</td>
<td>4.26</td>
<td>2.81</td>
<td>7.03</td>
<td>5.08</td>
<td>3.51</td>
<td>5.08</td>
<td>14.78</td>
<td>6.79</td>
</tr>
</tbody>
</table>
MD Values For Other Methods And Measures

**Single Method Body Composition Reliability % Fat**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>MD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underwater Weighing % Fat</td>
<td>2.05</td>
</tr>
<tr>
<td>BODPOD % Fat</td>
<td>1.33</td>
</tr>
<tr>
<td>Tester 1 SF % Fat</td>
<td>1.45</td>
</tr>
<tr>
<td>Tester 2 SF % Fat</td>
<td>1.35</td>
</tr>
<tr>
<td>BIS % Fat</td>
<td>1.81</td>
</tr>
<tr>
<td>BIA Bodygram % Fat</td>
<td>1.89</td>
</tr>
<tr>
<td>Futrex 6100 % Fat</td>
<td>2.04</td>
</tr>
<tr>
<td>DEXA % Fat</td>
<td>2.07</td>
</tr>
</tbody>
</table>

**Body Composition Reliability Muscle Mass (kg)**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>MD</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEXA Muscle Mass (kg)</td>
<td>0.11</td>
</tr>
<tr>
<td>BIS Muscle Mass (kg)</td>
<td>1.32</td>
</tr>
<tr>
<td>BIA Muscle Mass (kg)</td>
<td>1.26</td>
</tr>
</tbody>
</table>

**Body Composition Reliability Other Variables**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>MD</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEXA Lean mass (kg)</td>
<td>1.91</td>
</tr>
<tr>
<td>BIS ICF (liters)</td>
<td>1.24</td>
</tr>
<tr>
<td>BIS ECF (liters)</td>
<td>0.97</td>
</tr>
</tbody>
</table>

- **BUT WAIT! The MD statistic is not enough for %Fat because there are other assumptions and more variability in the prediction...**

- **Remember, %Fat is a prediction while circumferences, weight and skinfold thicknesses are true “measurements”**.
Examples

- **Best case (+/- 4%)**
  - 190 lb
  - 28%Fat
    - 190 x 0.28 = 53.2 lb Fat
    - 190 - 53.2 = 136.8 lb Lean
  - Need to exceed the 4%
  - 53.2 x 0.24 (24%) / 0.28 (28%) = 45.6 lbs
  - 53.2 - 45.6 = 7.6 lbs
  - 1-2 lb’s per week loss will take 4-8 weeks (1-2 months) before you can be 95% sure a change in %Fat is taking place AT BEST!

- **Reality (+/- 8%)**
  - 190 lb
  - 28%Fat
    - 190 x 0.28 = 53.2 lb Fat
    - 190 - 53.2 = 136.8 lb Lean
  - Need to exceed the 8%
  - 53.2 x 0.20 (20%) / 0.28 (28%) = 38 lbs
  - 53.2 - 38 = 15.2 lbs
  - 1-2 lb’s per week will take 8-15 weeks (2-4 months) before you can be 95% sure a change in %Fat is taking place AT BEST!
Table 4. Comparison of methods for predicting FFM compared to 4C model in women

<table>
<thead>
<tr>
<th>Group, method, equation no.</th>
<th>Mean</th>
<th>s.d.</th>
<th>r</th>
<th>SEE</th>
<th>TE</th>
<th>CE</th>
<th>LOA</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercise and control (n = 114)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>4C</td>
<td>36.77</td>
<td>3.30</td>
<td>0.87</td>
<td>1.64</td>
<td>2.04</td>
<td>-1.12</td>
<td>3.35</td>
<td>-0.03</td>
</tr>
<tr>
<td>DXA</td>
<td>37.90</td>
<td>3.64</td>
<td>0.87</td>
<td>1.66</td>
<td>2.65</td>
<td>-1.92</td>
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<td>-0.11</td>
</tr>
<tr>
<td>1</td>
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<td>3.70</td>
<td>0.82</td>
<td>1.90</td>
<td>2.54</td>
<td>1.38</td>
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</tr>
<tr>
<td>2</td>
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<td>0.81</td>
<td>1.95</td>
<td>2.89</td>
<td>2.01</td>
<td>4.09</td>
<td>-0.04</td>
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<tr>
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<tr>
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<td>40.80</td>
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<td>0.86</td>
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<td>4.36</td>
<td>4.03</td>
<td>3.29</td>
<td>0.09</td>
</tr>
<tr>
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<td>1.76</td>
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<td>0.78</td>
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<td>-0.01</td>
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<td>0.52</td>
</tr>
<tr>
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</tr>
<tr>
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</tr>
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<td>0.23</td>
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<td>0.41</td>
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<td>0.53</td>
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<td>0.37</td>
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<td>0.39</td>
<td>1.01</td>
<td>0.47</td>
<td>1.18</td>
<td>1.29</td>
<td>0.43</td>
<td>2.41</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Abbreviations: 4C, four-compartment model; CE, constant error/mean difference; DXA, Dual-energy X-ray absorptiometry; FFM, fat-free mass; LOA, limits of agreement; r, Pearson’s product moment correlation coefficient; SEE, standard error of estimate; TE, total error. *Significantly different from 4C (P < 0.005). †Significant slope (P < 0.05). ‡Significant interaction (P < 0.05). §Significantly different from pre to mid between groups (P < 0.05). ¶Significantly different from mid to post between groups (P < 0.05). ‖Delta significantly different from pre to post between groups (P < 0.05).
### Table 3. Comparison of methods for predicting FFM compared to 4C model in men

<table>
<thead>
<tr>
<th>Group, method, equation no.</th>
<th>Mean</th>
<th>s.d.</th>
<th>r</th>
<th>SEE</th>
<th>TE</th>
<th>CE</th>
<th>LOA</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exercise and control (n=102)</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>0.95</td>
<td>1.83</td>
<td>2.53</td>
<td>-1.75°</td>
<td>3.60</td>
<td>0.015</td>
</tr>
<tr>
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<td>5.57</td>
<td>0.89</td>
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<td>2.68</td>
<td>-0.35</td>
<td>5.24</td>
<td>0.015</td>
</tr>
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</tr>
<tr>
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<td>54.20</td>
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<td>2.02</td>
<td>2.66</td>
<td>4.61°</td>
<td>5.22</td>
<td>0.19°</td>
</tr>
<tr>
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<td>4.71</td>
<td>0.88</td>
<td>3.24</td>
<td>3.91</td>
<td>2.60°</td>
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</tr>
<tr>
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<td>54.37</td>
<td>4.63</td>
<td>0.82</td>
<td>3.07</td>
<td>3.41</td>
<td>-1.53°</td>
<td>6.01</td>
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<td>5.14</td>
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<td>58.95</td>
<td>4.26</td>
<td>0.87</td>
<td>3.50</td>
<td>3.50</td>
<td>-1.97°</td>
<td>5.68</td>
<td>0.30°</td>
</tr>
<tr>
<td>8</td>
<td>53.03</td>
<td>4.58</td>
<td>0.91</td>
<td>2.39</td>
<td>4.63</td>
<td>3.95°</td>
<td>4.78</td>
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</tr>
<tr>
<td>9</td>
<td>56.03</td>
<td>4.09</td>
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<td>2.98</td>
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</tr>
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<td>0.41</td>
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<td>1.22</td>
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<td><strong>Exercise delta (n=45)</strong></td>
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<td>0.51</td>
<td>1.17</td>
<td>1.36</td>
<td>0.49</td>
<td>2.52</td>
<td>0.09</td>
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Abbreviations: 4C, four-compartment model; CE, constant error/mean difference; DXA, dual-energy X-ray absorptiometry; FFM, fat-free mass; LOA, limits of agreement; r, Pearson's product moment correlation coefficient; SEE, standard error of estimate; TE, total error; *Significantly different from 4C (P<0.005). 
°Significant slope (P<0.05). 
+Significant interaction (P<0.05). 
**Significantly different from pre to mid between groups (P<0.05). 
Delta significantly different from mid to post between groups (P<0.05). 
ΔDelta significantly different from pre to post between groups (P<0.05).

Ideal Protocol to Track Changes

• Pre-Testing (Body Composition)
  – Use BodPod, Underwater Weighing, or DXA
    • Advanced BIA is also acceptable but not as good
      – Fasted 8-12 hours (water is fine)
      – Have them go to the bathroom before testing (Empty everything)
        » Anything not actually part of their body will throw off results
      – Make sure you measure urine color and verify they are hydrated
      – No heavy exercise 24 hours prior
      – Same time of day preferably in the morning
      – Record menstrual cycle time
        » These all need to be followed otherwise weight measurements are not valid
    • Record Fat, FFM, and %Fat, (and arms and legs if you have DXA)
  – Measure Skinfold thickness via Calipers or ultrasound along with circumferences at the standard 7-sites or more depending on where you want to see changes. Do two measurements per site and take the average.
    • ALWAYS MEASURE AT THE SAME LOCATION
    • Record Skinfold thickness average along with circumference (calculate Muscle Circumference equation in earlier slide) if you like.
  – Measure weight

• Weekly tests (Body Composition)
  – Follow Skinfold guideline measurements (Calipers or Ultrasound) discussed earlier
  – Measure Weight, skinfolds, and circumferences
    – Ideally same as above
Ideal Protocol to Track Changes

• Pre-Testing (Performance)
  – Use a valid and reliable method
    • Same food the day before or at least 8-12 hours before
    • Have them go to the bathroom before testing (Empty everything)
    • Make sure you measure urine color and verify they are hydrated
    • No heavy exercise 24 hours prior
    • Same time of day preferably in the morning
    • Record menstrual cycle time
    • Use both the average of the tests as well as the best score

• How often (Performance)
  – Depends on
    • Training and training goals
    • Measurement
    • Most important: The Individual!
## Ideal Protocol to Track Changes

- Measurement frequency (AT MOST)
- Depending on rate of weight loss
  - Example for about 2lb lost per week
    - 190lbs
    - 28%Fat
    - 8%Fat loss requirement
      - 20%Fat Goal
      - 16lb fat loss to reach 8%

<table>
<thead>
<tr>
<th>Week</th>
<th>Weight</th>
<th>Amount lost (lbs)</th>
<th>Skinfold Thickness (Calipers/Ultrasound)</th>
<th>Circumference</th>
<th>BP/HW/DXA/BIA</th>
<th>Confidence in change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>190</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td>28%</td>
</tr>
<tr>
<td>1</td>
<td>188</td>
<td>-2</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>187</td>
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<td>x</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>185</td>
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<td>x</td>
<td>x</td>
<td></td>
<td>27% 50%</td>
</tr>
<tr>
<td>4</td>
<td>182</td>
<td>-8</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>180</td>
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<td>x</td>
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<td></td>
</tr>
<tr>
<td>6</td>
<td>178</td>
<td>-12</td>
<td>x</td>
<td>x</td>
<td></td>
<td>24% 65%</td>
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<tr>
<td>7</td>
<td>176</td>
<td>-14</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
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<tr>
<td>8</td>
<td>175</td>
<td>-15</td>
<td>x</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>174</td>
<td>-16</td>
<td>x</td>
<td>x</td>
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<td>20% 95%</td>
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## Alternative (minimal)

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<th>Amount lost (lbs)</th>
<th>Skinfold Thickness (Calipers/Ultrasound)</th>
<th>Circumference</th>
<th>BP/HW/DXA/BIA</th>
<th>Confidence in change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>190</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td>28%</td>
</tr>
<tr>
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<td>x</td>
<td>x</td>
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<tr>
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<td>6</td>
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<td>x</td>
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<td>x</td>
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<tr>
<td>Post</td>
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<td>-16</td>
<td>x</td>
<td>x</td>
<td></td>
<td>20%</td>
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</table>
You can track on a graph ANY site you measure to see what is changing.

The more times you measure the better the tracking will look, but remember that the BP/HW/DXA/BIA may not be valuable or true until about an 8% change is observed.

Tracking “Measurements” like skinfold thicknesses, girth, circumferences, and weight will be more sensitive than your %Fat “predictions” so you can do those more often.
Measuring a group is better!

- Even if you have small changes as long as the group all changes you will see a difference.
- Example:

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<th>Change</th>
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<td>14</td>
<td>-2</td>
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<td>19</td>
<td>-1</td>
</tr>
<tr>
<td>8</td>
<td>24</td>
<td>23</td>
<td>-1</td>
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<td>18</td>
<td>17</td>
<td>-1</td>
</tr>
<tr>
<td>10</td>
<td>17</td>
<td>15</td>
<td>-2</td>
</tr>
<tr>
<td>11</td>
<td>19</td>
<td>17</td>
<td>-2</td>
</tr>
<tr>
<td>12</td>
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</tr>
<tr>
<td>Mean</td>
<td>17.67</td>
<td>16.25</td>
<td>-1.42</td>
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</tbody>
</table>

P = 0.002
Indicating a significant change from pre to post

But what if we looked at just individuals?

But what if we looked at just individuals?

As long as the group is all changing in the same direction you can be confident there is a change really occurring, even if there are some that don’t change.
MRI/CT

• True 3-dimentional image
• Total body is very difficult and not practical, but these methods are the “TRUE GOLD STANDARDS” for segmental/tissue analysis.

• Maden-Wilkinson et al. J Musculoskelet Neuronal Interact 2013 (MRI compared to DXA)
  – “The total thigh volume was estimated by summation of the cross-sectional area of each head of the individual quadriiceps muscles and other muscles in each slice multiplied by the distance between slices, as previously described$^{17,18}$. To aid comparison between the two measures, MRI volumes were converted to mass by multiplying by 1.04 g.cm$^{-3}$ (the density of muscle tissue)$^{19}$.”
  • Accepted method
Recent Invited Review Paper

• Fosbol and Zerahan, Contemporary methods of body composition measurement, Clin Physiol Funct Imaging, 2014.
  — MUST READ FOR ANYONE DOING BODY COMPOSITION TESTING

• Imaging methods, such as computed tomography (CT) and magnetic resonance imaging (MRI), are considered the most accurate methods for in vivo quantification of body composition on the tissue level. Measures obtained using CT or MRI may be classified as total adipose tissue (TAT), subcutaneous adipose tissue (SAT), visceral adipose tissue (VAT) and interstitial adipose tissue (IAT). Skeletal muscle can be compartmentalized into individual muscles or muscle groups. This level of specificity in tissue composition is only possible with CT or MRI (Ross & Janssen, 2005).
Recent Studies

• Silva et al. Int J Sport Med 2014
  – ICW (Sodium bromide) was the best predictor of performance change over DXA variables and ECW and TBW (D2O)

• Maden-Wilkinson et al. J Musculoskelet Neuronal Interact 2013
  – DXA underestimates the age-related loss of thigh muscle mass in comparison to MRI. The quadriceps muscles were more susceptible to age-related atrophy compared with other thigh muscles.

  – Skinfolds and DXA can both track significant changes in SMM.
• Dengel et al. JSCR 2014
• GE DXA in NFL Athletes
• Averages ALL OVER 10%Fat
Publishing tips

• Always calculate your labs ICC and SEM and MD for ALL DV’s for ALL body composition methods and report this data in your methods
  – 8-12 men and women measured 24-48 hours apart is all you need.
• Always follow “best practices” for all methods.
  – Even if the GE says you can scan someone who has eaten recently and you don’t know their hydration status that doesn’t mean you shouldn't control for these variables.
• Use ONLY methods that have been validated in your population
• Have a control group
• INTERPRET ALL DATA WITH CAUTION!!!!!!
  – Know what you are REALLY measuring
Conclusions

• The ‘true’ value of total body fat is unmeasurable in living humans/mammals
• Measure groups if possible
  – Larger groups can detect smaller changes
    • Assumptions are met with more people/athletes
• When measuring individual body composition compartments (%Fat, FFM) remember AT BEST both Lab and Field methods have an error range of around 8% fat (+/- 4%), but if you use an invalid method or if done incorrectly these can be double to triple that or more!
  – Plan on a range of AT LEAST +/- 6-10% Fat with your techniques regardless of a single measurement or tracking changes.
    • Use a true measurement like skinfold/Ultrasound thicknesses or circumferences
    • Use CT or MRI if possible as these are true gold standards for measuring tissue volumes.
      – Diagnostic ultrasound is good, but is not 3-dimensional, so you only get a thickness
• To be confident in an individual change in either performance or body composition you need to know the device/method and testers MD along with understanding how to reduce external variables (using standard protocols).
• Consider your available methods and use as many as possible because you never know what your intervention will alter regarding body composition (TBW, ICW, ECW, AT, MM, etc.)
• The 95% agreement for changes in estimated body composition variables will ALWAYS exceed their MD, which means REGARDLESS of the reliability of the method, the values may not represent a “true” change unless they are large.
Recommended equations for all

- **Skinfoold Equations**
  - **Men**
    - \( BD = 1.10938 - 0.0008267(SUM3) + 0.0000016(SUM3)^2 - 0.0002574(AGE) \)
    - \( BD = 1.112 - 0.00043499(SUM7) + 0.00000055(SUM7)^2 - 0.00028826(AGE) \)
    - \( SUM3 = \text{Chest, abdomen, thigh} \)
    - \( SUM7 = \text{Chest, subscapular, axilla, anterior suprailiac, abdomen, thigh, triceps} \)
  
  - **Women**
    - \( BD = 1.099421 - 0.0009929(SUM3) + 0.0000023(SUM3)^2 - 0.0001392(AGE) \)
    - \( BD = 1.097 - 0.00046971(SUM7) + 0.00000056(SUM7)^2 - 0.00012828(AGE) \)
    - \( SUM3 = \text{anterior suprailiac, thigh, triceps} \)
    - \( SUM7 = \text{Chest, subscapular, axilla, anterior suprailiac, abdomen, thigh, triceps} \)

- **BD = Body Density**
- **%fat from BD = \([(4.57 / BD) - 4.142] \times 100**

  - **THESE EQUATIONS ONLY USE AGE AND SKINFOOLD THICKNESS**
  - **WILL SHOW THE SAME CHANGE IN %FAT AS THE RAW SKINFOOLD MEASUREMENTS IN mm.**
Thank you

Please feel free to contact me with any questions
jordan@musclepharm.com
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jordan@musclepharm.com

Thank you