

Body Composition

Body Composition

- Percent of body weight that is body fat
- Two classifications of body fat
 - Essential – necessary for optimal health
 - Fat in bone marrow
 - Cell membranes
 - Nonessential or storage
 - Subcutaneous adipose tissue
 - Visceral fat

Essential Fat

- Males – 2-3%
- Females – 5-12% (varies)

Percent Body Fat Standards

	Men	Women
At risk+	≤ 5%	≤ 8%
Below average	6-14%	9-22%
Average	15%	23%
Above average (ow)	16-24%	24-31%
At risk* (obesity)	≥25%	≥32%

+ diseases/disorders associated with malnutrition

* Diseases associated with obesity

Hydrostatic Weighing

- Two compartment model
 - Fat mass (FM) – all extractable lipids
 - Fat free mass (FFM) – water, muscle, bone, connective tissue, and organs

Fat Free Mass vs Lean Body Mass

- Lean body mass = FFM + essential fat

Hydrostatic Weighing

- Calculate body density
 - Density = mass/volume
 - Mass – weigh on land
 - Volume – Archimedes Principle of Displacement

Archimedes Principle of Displacement

- A partially or fully submerged object experiences an upward buoyant force equal to the weight of the volume of the fluid displaced by the object
- Loss of weight under water is directly proportional to the body volume

Density

- g/cm³
- Fat = 0.901 g/cm³
- FFM = 1.10 g/cm³
- Range of body density in population
 - 0.93 – 1.10 g/cm³

Body Density

$$\frac{\text{Weight in air}}{[(\text{Wt in air} - \text{Wt in water}) / \text{Density of water}] + (\text{Residual Volume} \times .1)}$$

1 L of displaced water has a buoyant force exerted that is equivalent to 1 kg at 4 degrees C

Potential Sources of Error

- Assumption of density of FFM is not same for all individuals
 - FFM is not constant – varies with growth, maturation, age, gender and ethnicity (± 2% variation in FFM within a homogenous group)
- Residual volume should be measured – estimation can produce errors of 2.8 – 3.7% in % body fat
- Subject cooperation – anxiety, clothing, and cooperation
- Air in intestines

A note – load cell vs autopsy scale

Factors Affecting FFM

- Bone density
- Body water
- Age
- Race
- Gender

Examples of Variations

- African Americans – higher bone density
 - FFM women = 1.106 g/cm³
 - FFM men = 1.113 g/cm³
 - Underestimate % body fat with 2 compartment models
- Children and elderly - lower bone density
 - Children FFM = 1.084 g/cm³
 - Elderly FFM = 1.096 g/cm³
 - Overestimate % body fat with 2 compartment model

Anthropometry

- Study and technique of human body measurement, includes height, weight, girth, bone diameters and skinfold measurements

Height/weight Charts

- Metropolitan Life Insurance Co. Charts
- 1959 Blood and Blood Pressure Build Study
- 26 life insurance companies
- 5 million insured people for up to 20 years
 - Purchased nongroup insurance (25-59 years of age)
 - Heart disease, cancer or diabetes excluded
 - Smokers included
 - Self-reported weights (some)
- Shoes and indoor clothing
- Method for determining frame size not given
- Desirable weights based on lowest mortality

Height/weight Charts

- 1973 – recalculated to express heights without shoes and weights without clothes
 - Fogarty Intl Center Conference on Obesity
- 1983 – Metropolitan Life Ins Co issued new ht/wt charts
 - Frame size based on NHANES
 - Weight ranges 2-3% higher than 1959 tables
 - Tables based on specific populations
 - No consideration for smoking (skewed ideal weights upward)
 - Not based on lowest mortality
 - Initial data collection only
 - Muscle differences
- *1959 better except for elderly

Example

- Male
 - Height - 70 in. (stadiometer)
 - Weight - 180 pounds
 - Elbow breadth 2.75 in.

Table 5.3 1983 Metropolitan Height-Weight Tables
(in Pounds by Height and Frame in Inches, Clothing,
Men—3 lbs, 1-inch Head; Women—3 lbs, 1-inch Head)

Height (inches)	Men			Women		
	small	medium	large	small	medium	large
62	128-134	133-143	140-150	98	102-111	109-111
63	130-136	133-143	140-150	99	103-113	111-123
64	130-136	135-145	140-150	100	104-115	113-126
65	134-140	137-146	144-160	101	106-118	113-129
66	136-143	139-151	146-164	102	108-121	116-132
67	138-145	142-154	149-168	103	111-124	121-139
68	140-148	145-157	151-172	104	114-127	124-138
69	142-151	148-160	155-176	105	117-130	127-143
70	144-154	151-163	158-180	106	120-133	130-144
71	146-157	154-166	161-184	107	123-136	133-147
72	148-160	157-170	164-188	108	126-139	136-150
73	150-164	160-174	168-192	109	129-142	139-153
74	153-168	164-178	172-197	110	132-145	142-156
75	156-172	167-182	176-202	111	135-148	145-159
76	160-176	171-187	181-207	112	138-151	148-162

Source: Reprinted with permission from the Metropolitan Life Insurance Company, New York.

Table 5.4 Height and Elbow Breadth

Height (inches, no shoes)	Elbow Breadth (in inches)		
	Small Frame	Medium Frame	Large Frame
63-65	<2.7/8	2.7/8 - 2.7/8	>2.7/8
63-66	<2.7/8	2.7/8 - 2.7/8	>2.7/8
67-70	<2.7/8	2.7/8 - 2.7/8	>2.7/8
71-74	<2.7/8	2.7/8 - 2.7/8	>2.7/8
75	<2.7/8	2.7/8 - 2.7/8	>2.7/8
77-78	<2.7/8	2.7/8 - 2.7/8	>2.7/8
79-82	<2.7/8	2.7/8 - 2.7/8	>2.7/8
83-86	<2.7/8	2.7/8 - 2.7/8	>2.7/8
87-90	<2.7/8	2.7/8 - 2.7/8	>2.7/8
91	<2.7/8	2.7/8 - 2.7/8	>2.7/8

Source: Reprinted with permission from Metropolitan Life Insurance Company, New York.

Note: Tables adapted to represent height without shoes.
Note: To measure the elbow breadth, extend the arm, and then bend the forearm upwards at a 90-degree angle. Fingers straight up, palm facing up. Measure with a sliding caliper the width between the two prominent bones on either side of the elbow (measure the widest point). (See Figure 2.3.) Make sure that the arm is positioned evenly and that the upper arm is parallel to the ground. The elbow breadth frame gauge (EB) is available from Metropolitan Life Insurance Company, Health and Safety Education Division, One Madison Avenue, New York, N.Y. 10010.

Example

- Select frame size
 - Medium
- Select midpoint of recommended weight range
 - 151 – 163 pounds
 - 157 pounds
- Body wt/recommended wt = % \pm weight
 - $180/157 = 1.14 = 114\%$ of ideal body weight
- 14% above ideal weight

Standards for Relative Weight

< 90%	underweight
90-110%	desirable
111-119%	overweight
120-139%	mild obesity
140-199%	moderate obesity
$\geq 200\%$	severe obesity

Body Mass Index

- Used in large population studies
- Measure of obesity
- Index of weight relative to height
 - Quetelet index (kg/m^2)
- Overweight – 25.0 – 25.9 kg/m^2
 - obesity-related health problems increase beyond a BMI of 25 kg/m^2
- Obesity - $\geq 30 \text{ kg}/\text{m}^2$

Body Mass Index

- $r = 0.70$ compared to hydrostatic weighing
- Low cost
- Easy to measure
- Difficult to interpret to patients – wt loss
- Not useful in athletic, muscled individuals
- Not a sensitive indicator of changes in body composition
 - Increase FFM = increase in wt = increase BMI

Estimating Ideal Body Wt Based on Height - Dietitians

Women: 100# for 5 ft + 5# for each in. above 5 ft

Men: 106 # for 5 ft + 6# for each in. above 5 ft

Waist/Hip Ratio

- Regional fat distribution
- Type of obesity
 - Android obesity (upper body obesity) – apple
 - Gynoid obesity (lower body obesity) – pear
- Males vs Females
- Menopause
- Pattern of fat distribution – good predictor of health risks of obesity

Waist/Hip Ratio

- HTN, NIIDDM, Hyperlipidemia, CAD and premature death compared to individuals with equal fat but lower ratios
- Not give idea of ideal body weight
- Good tool for assessing disease risk
- Easy to measure
- Low cost

Waist/Hip Ratio

- Increased Risk of Disease
- | | | |
|-----------|---------|-------|
| < 60 yrs | Males | >0.95 |
| | Females | >0.82 |
| 60-69 yrs | Males | >1.03 |
| | Females | >0.90 |
- Focus shifting to waist circumference alone or waist circumference and BMI

TABLE 4-2. Classification of Disease Risk Based on Body Mass Index (BMI) and Waist Circumference*

	BMI, kg/m ²	Disease Risk [†] Relative to Normal Weight and Waist Circumference [‡]	
		Men, ≤102 cm; Women, ≤88 cm	Men, >102 cm; Women, >88 cm
Underweight	<18.5
Normal [§]	18.5–24.9
Overweight	25.0–29.9	Increased	High
Obesity, class			
I	30.0–34.9	High	Very high
II	35.0–39.9	Very high	Very high
III	≥40	Extremely high	Extremely high

*Modified from Expert Panel. Executive summary of the clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults. Arch Intern Med 1998;158:1855–1867.

[†]Disease risk for type 2 diabetes, hypertension, and cardiovascular disease. Ellipses indicate that no additional risk at these levels of BMI was assigned.

[‡]A gender neutral value for waist circumference (>100 cm) has also been suggested as an index of obesity (see Table 2-1).

[§]Increased waist circumference can also be a marker for increased risk even in persons of normal weight.

Diameters

- Used as indices of body frame
- Somatotyping
 - Endomorph – round, soft
 - Mesomorph – muscular
 - Ectomorph – lean, fragile, linearity
- Alone – no relationship between skeletal size and amount of body fat
- Can be utilized in conjunction with other measures

Circumferences

- Error in predicting body fat - 2.5-4.0%
- Requires little equipment
- Useful in obese – skinfolds a problem
- Assume as increase circumference, increase body fat
- Not useful for predicting body fat in very thin, very fat or athletic
- Not good to assess changes in fat free mass over time
- Low cost
- Little skill

Skinfold Measurements

- Most accurate predictor of body density compared to other anthropometric measures correlated to hydrostatic weighing
- Constant pressure of 10 g/mm²
- Cost \$300-500
- Fast enough for mass testing
- Little space required

Skinfold Measurements

- Skill required
- Ideal – same technician for retests (intertester reliability)
- Not after exercise/sweating
- Accuracy \pm 3-5%

Skinfold Measurements

- Assumption
 - Total subcutaneous adipose tissue mass is represented by the selected skinfold sites
 - Subcutaneous tissue has a known relationship with total body fat
 - 1/3 total fat (varies)
 - Increasing age – less fat stored subcutaneously
 - Important to use equations that...
 - Age-adjusted
 - Population-specific for athletic groups

Error

- Largest source – improper location of site
- Practice – 50-100 people for skill
- Same technician for pre and post

TABLE 2. Intertester error in selected skinfold sites using experienced investigators (45).

Condition	Differences in Skinfold Fat			
	Suprailiac	Abdomen	Triceps	Fat
No Practice	5.9 mm	2.7	1.7	2.9%**
Practice*	1.8 mm	0.9	1.0	0.5%

*Denotes 30-minute practice session to review exact site selection.

**Percent fat was estimated from all three skinfold measures.

- Why use sum of skinfolds rather than individual values?

TABLE 3. Intertester error for testers of varied experience but who practiced together (28).

Variable	Tester 1*	Tester 2	Tester 3	F-ratio
	Mean	Mean	Mean	
Skinfolds (mm)				
Chest	18.0	19.4	17.2	S
Axilla	18.5	17.9	18.1	NS
Triceps	15.9	16.7	15.8	NS
Subscapula	19.8	20.4	22.8	S
Abdomen	31.3	30.9	32.2	NS
Suprailium	19.9	20.6	19.1	S
Thigh	21.6	20.9	19.1	S
Sum of Seven	144.9	146.7	148.3	NS
Sum of Three	70.9	71.1	72.6	NS
Percent Fat Estimates				
Σ of 7	20.0	20.0	20.3	NS
Σ of 3	19.3	19.4	19.5	NS

*Tester 1 was most experienced and tester 3 was least experienced.

Body Composition Prediction Equations

- Population-specific – small homogenous sample with limited application
 - Assume a linear relationship between skinfolds and body density – large prediction errors at extremes
 - Overestimate body fat in lean
 - Underestimate body fat in fatter subjects

Body Composition Prediction Equations

- Generalized – large heterogeneous samples which vary greatly in body fatness
 - Assumes a quadratic relationship between skinfolds and body density – no loss of prediction accuracy at extremes
 - One equation replaces several without loss of accuracy
 - Valid for adults varying greatly in age and body

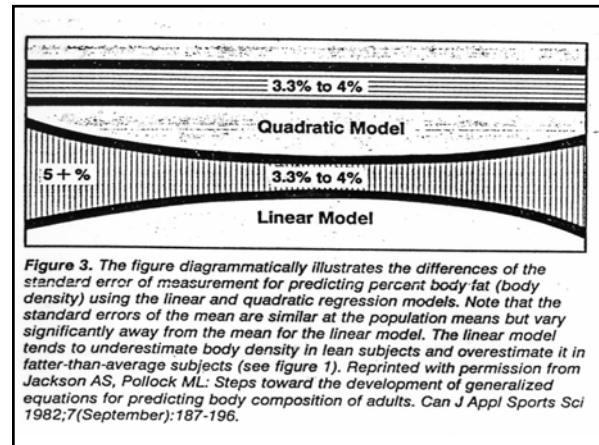
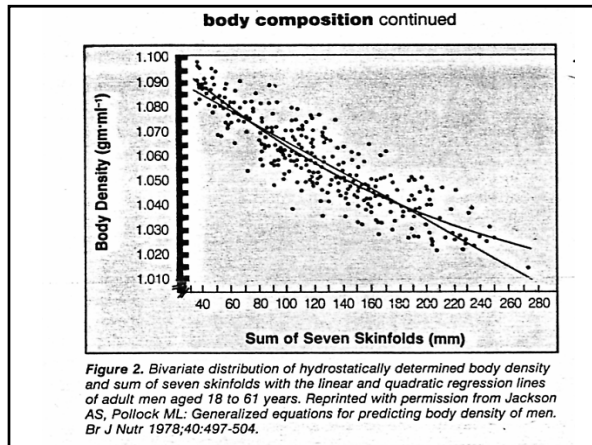


TABLE 1. Correlation between hydrostatically determined body density (BD) and anthropometric variables.*

Anthropometric Variable	Female Sample (N=248)			Male Sample (N=308)		
	r	SEE(BD)	SEE(%fat)	r	SEE(BD)	SEE(%fat)
Age	-0.35	0.015	6.7	-0.38	0.017	7.4
Height	-0.08	0.016	7.2	-0.11	0.018	8.0
Weight	-0.63	0.012	5.6	-0.62	0.014	6.3
Body Mass Index**	-0.70	0.011	5.1	-0.69	0.013	5.8
Sum of Seven Skinfolds	-0.85	0.008	3.8	-0.88	0.009	3.8
Sum of Three ††	-0.84	0.009	3.9	-0.89	0.008	3.6
Sum of Three †‡	-0.83	0.009	4.0	-0.86	0.009	4.1

*Table from Pollock, Schmitt, and Jackson (59). Reprinted with permission.

**Body Mass Index = W/H^2 , where weight is in kilograms and height in meters.

†Sum of three skinfold fat measures: Females: triceps, suprailium, and thigh; Males: chest, abdomen, and thigh.

‡Sum of three skinfold fat measures: Females: triceps, abdomen, and suprailium; Males: chest, triceps, and subscapula.

Selecting a equation

- Sum of 7 skinfolds – highest correlation with hydro
- Sum of 3 can also be used with minimal loss of accuracy – feasibility
- Recommendation –
 - Sum of 3 men – chest, abdomen, thigh
 - Sum of 3 women – tricep, suprailium, and thigh
- Consider removal of clothing
- Look up charts – Phys and Sp Med – vol 13, no. 5, 1985

body composition continued

Table 8. Percent Fat Estimate for Women: Sum of Triceps, Abdomen, and Suprailium Skinfolds

Age to Last Year

Sum of Skinfolds (mm)	18-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	Over 57
8-12	8.8	9.0	9.2	9.4	9.5	9.7	9.9	10.1	10.3
13-17	10.8	10.9	11.1	11.3	11.5	11.7	11.8	12.0	12.2
18-22	12.6	12.8	13.0	13.2	13.4	13.5	13.7	13.9	14.1
23-27	14.5	14.6	14.8	15.0	15.2	15.4	15.6	15.7	15.9
28-32	16.2	16.4	16.6	16.8	16.9	17.0	17.1	17.3	17.5
33-37	17.9	18.1	18.3	18.5	18.7	18.9	19.0	19.2	19.4
38-42	19.6	19.8	20.0	20.2	20.3	20.5	20.7	20.9	21.1
43-47	21.3	21.4	21.6	21.8	21.9	22.1	22.3	22.5	22.7
48-52	22.8	22.9	23.1	23.3	23.5	23.7	23.8	24.0	24.2
53-57	24.2	24.4	24.6	24.8	25.0	25.2	25.3	25.5	25.7
58-62	25.7	25.9	26.0	26.2	26.4	26.6	26.8	27.0	27.2
63-67	27.1	27.2	27.4	27.6	27.8	28.0	28.2	28.3	28.5
68-72	28.4	28.6	28.7	28.9	29.1	29.3	29.5	29.7	29.8
73-77	29.6	29.8	30.0	30.2	30.4	30.6	30.7	30.9	31.1
78-82	30.8	31.0	31.2	31.4	31.6	31.8	31.9	32.1	32.3
83-87	32.0	32.2	32.4	32.6	32.7	32.9	33.1	33.3	33.5
88-92	33.1	33.3	33.5	33.7	33.8	34.0	34.2	34.4	34.6
93-97	34.1	34.3	34.5	34.7	34.8	35.1	35.2	35.4	35.6
98-102	35.1	35.3	35.5	35.7	35.9	36.0	36.2	36.4	36.6
103-107	36.1	36.2	36.4	36.6	36.8	37.0	37.2	37.3	37.5
108-112	36.9	37.1	37.3	37.5	37.7	37.9	38.0	38.2	38.4
113-117	37.8	37.9	38.1	38.3	38.5	38.6	38.8	38.9	39.2
118-122	38.5	38.7	38.9	39.1	39.4	39.6	39.8	40.0	40.0
123-127	39.2	39.4	39.6	39.8	40.0	40.1	40.3	40.5	40.7
128-132	39.9	40.1	40.2	40.4	40.6	40.8	41.0	41.2	41.3
133-137	40.6	40.7	40.8	41.0	41.2	41.4	41.6	41.7	41.9
138-142	41.0	41.2	41.4	41.6	41.7	41.9	42.1	42.3	42.5
143-147	41.5	41.7	41.9	42.0	42.2	42.4	42.6	42.8	43.0
148-152	41.9	42.1	42.3	42.5	42.6	42.8	43.0	43.2	43.4
153-157	42.3	42.5	42.6	42.8	43.0	43.2	43.4	43.6	43.7
158-162	42.6	42.8	43.0	43.1	43.3	43.5	43.7	43.9	44.1
163-167	42.9	43.0	43.2	43.4	43.6	43.8	44.0	44.1	44.3
168-172	43.1	43.2	43.4	43.6	43.8	44.0	44.2	44.3	44.5
173-177	43.2	43.4	43.6	43.8	43.9	44.1	44.3	44.5	44.7
178-182	43.3	43.5	43.7	43.8	44.0	44.2	44.4	44.6	44.8

Statistical Techniques

- Multiple regression – identify an equation that used the best combination of measured variables for predicting body composition sum of SF and age
- Good prediction equation yields a high multiple correlation coefficient
- Standard Error of Estimate (SEE) – individual's predicted score relative to the individual's reference
- Regression line – line of best fit – scatter plot

Statistical Techniques

- Cross-validation
 - Validate the equation developed on a validation sample to determine if the regression weights are stable

Consideration in Choosing a Method

1. Reliability – extent to which a test yields the same results on successive trials
 - Intertester – difference between individuals – t-test
 - Where site is located
 - Most variability in abdomen and thigh, least in tricep and subscapular
 - Clothes

Considerations

- Reliability
 - Intratester reliability – successive trials by same technician on same subject
 - Experts – 0.85 – 0.90 (50-100 subjects)
 - 2-5 trials
- 2. Validity – ability to assess the variable to be measured
 - A. Validity coefficient $\geq 0.80 R_{mc}$
 - 64% of variation in reference measure accounted for by predictors in equation

Considerations

- Validity – t-test
 - B. >0.05 (not significantly from the reference value)
 - Must have both A and B under validity
- 3. What is the reference method?
 - hydro or DEXA
- 4. Sample size used to develop prediction equation
 - 10-20 subjects/predictor variable
 - Larger N produces more stable regression weights for the predictor variables

Considerations

5. SEE – degree of deviation of the individual points about the line of regression $\pm 3.5\%$
6. To whom is the equation applicable?
7. How were the variables measured by the researchers?
8. Was it cross-validated?

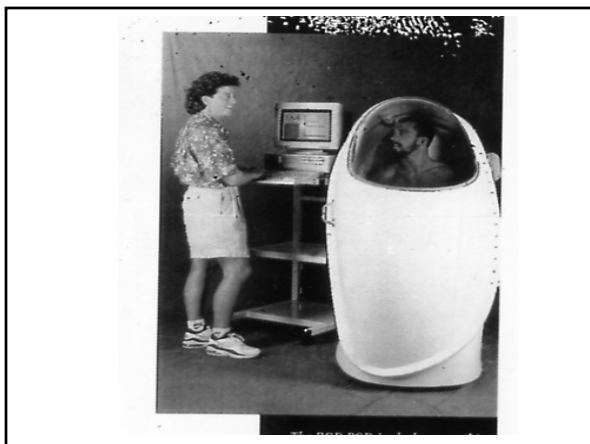
Bod Pod

- Air displacement plethysmography
- Measures variations in volume via air displacement
- Two-component model
- 3-5 minutes
- Special populations – obese, elderly, and disabled



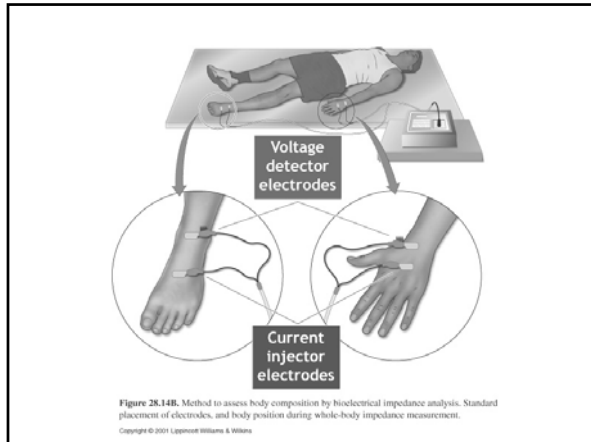
Bod Pod

- Mobile
- Minimal training
- Reliable ($r > 0.90$)
- Valid $\pm 0.3\%$ of hydrostatic weighing ($r = 0.96$)
- Needs further validation on athletes, children, homogenous groups with average levels of body fat



Bioelectrical Impedance Analysis

- A small electrical current is passed through the body
- Actually measures total body water (TBW)
- Measure impedance (resistance to flow)
- FFM – good conductor, low impedance
- FM – poor conductor, high impedance
- Requires little technician skill
- Follow strict procedures



Procedures for BIA

- Abstain from eating or drinking within 4 hours of assessment
- Avoid moderate or vigorous exercise within 12 hours of assessment
- No alcohol within 48 hours
- No diuretic agents – caffeine, etc. unless prescribed by physician
- Urinate within 30 minutes
- Not test during menstrual cycle if retaining water
- Consistent ambient temperature

BIA

- Accuracy depends on normal hydration
 - Hydration effect controversial – probably depends on whether the electrolyte compartment changes proportionally to water
- Accuracy depends on regression equation
 - must be population specific
- Equation must be specific to equipment – arm to leg, leg to leg, and arm to arm
- Less research on scales and hand-held devices than electrodes
- If correct equation, accuracy shown to equal skinfolds

BIA

- Biggest limitation – lack of sensitivity to small changes in body composition

Dual Energy X-ray Absorptiometry

- 3 compartment model- fat, bone and lean soft tissue
- Measures differences in absorption of 2 different low X-ray energies
- Small dose of radiation
- Expensive - > \$30,000
- ~ 10-20 minutes
- Little subject cooperation required
- Error is <2% compared to densitometry

Near-Infrared Interactance

- Based on light absorption and reflection
- Developed by USDA to assess body composition of livestock
- Futurex-5000 - portable
- Uses probe that emits two frequencies of low-energy beam near-infrared light over biceps
- Body fat absorbs the light and FM reflects the light
- Detector in probe measures intensity of the reflected light (OD)
- Accuracy is questionable
- Uses bicep image only – no disrobing

NIR

- Must clean wand after each test
- Change activity level, changes % body fat
- Little training required
- Not affected by menstrual cycle
- Unacceptable prediction errors (3.7-6.3%)
- More research needed – not accurately predict body fat across across a broad range of body fat levels
- Overestimates body fat in lean and underestimates in fatter
- Not accurately assess body composition changes from resistance training