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ESTIMATION OF PERCENT BODY FAT BY HYDROSTATIC WEIGHING IN HIGH SCHOOLS

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Concerns with fitness have increased interest in body composition and ideal body weight. Although anthropometric (e.g. skinfold) measurements can quickly determine general body composition, hydrostatic weighings are more accurate. While most exercise physiology laboratories on university campuses have a specialized tank for performing hydrostatic weighings, adequate stations can be set up in any swimming pool for a minimal initial cost. Several scientific concepts can be demonstrated during this exercise: measurement of lung volumes, determination of body density and calculation of percent body fat.

Generally regarded as the most accurate method for body composition assessment, the hydrostatic weighing procedure is based on Archimedes' Principle. In essence, this principle states that a mass less dense than water will float, while a mass more dense than water will sink. The hydrostatic weighing procedure divides the body into a fat component and a fat-free component. Because body fat is less dense than water, it increases a body's buoyancy, while the fat-free mass, which is more dense than water, makes a body sink. For example, think of two individuals who both weigh 60 kg (132 lb). One person is very lean and muscular and has little body fat while the other has much more body fat and less muscle. Due to reduced body fat, the leaner mass of the first person will be more dense than the second individual when each is weighed underwater. After determining body density from a hydrostatic weighing, percent body fat can be calculated.

Two essential steps are involved in determining percent body fat from hydrostatic weighing. The underwater weight of a submerged subject is taken after a forced maximum respiratory expiration. The necessity for the second step results from the fact that, even after a maximum expiration, some air still remains in the lungs, making the subject more buoyant. Correction for residual volume (RV), must be included in the calculation of body density. While high school laboratories are not equipped to measure RV, it can be estimated as a fraction of the vital capacity (VC), the volume of air that can be expired after a maximum inspiration (Wilmore

1969). The vital capacity should be estimated first so that the subject will not become chilled after the weighing.

Estimating Vital Capacity

Precise methods of measuring vital capacity are available, but most require expensive equipment. Instructors who are conducting an in-depth study of this topic may wish to have their classes visit a local hospital to observe direct RV measurements, but the following procedure allows teachers and students who wish to devote less time to develop a reasonably accurate estimate.

Needed to measure VC are a seven-liter (seven quart) container with a small opening, a 1- or 2-L graduated cylinder, and a 1-m (3-ft) flexible hose with an inside diameter of approximately 2.5 cm (1 in). The exact volume of the container must be determined. Fill the container completely with water, cover the opening, invert it and place it into a sink or water basin partially filled with water. While keeping the container inverted, place one end of the hose just inside the opening of the container and hold the other end out of the water. Instruct the subject to sit nearby and pinch her/his nose closed with one hand while holding the free end of the hose with the other. After making a maximum inspiration, the subject should place the hose in his/her mouth and make a rapid and maximum expiration. The amount of water remaining in the container subtracted from the total volume equals the VC. The largest value obtained from two or three trials should be used for the estimation.

Assembling the Weighing Apparatus

To assemble the apparatus for the hydrostatic weighing, suspend a hanging scale (accurate to $\pm$ 0.1 kg and capable of weighing at least 10 kg) over water at least 1.25 m (4 ft) deep (Figure 1). This may be done by bolting or clamping a piece of lumber to the lifeguard station so that it extends over the water.

Hang a depth-adjustable seating platform from the scale using an S-hook connection and a light-weight chain. A plastic swing seat or a snow saucer will serve adequately as a seat, but you might prefer one constructed from PVC pipe. Attaching several kilograms of weight to the seating platform will help steady the scale during weighings.

Conducting the Hydrostatic Weighing

To perform the hydrostatic weighing, adjust the depth of the chair in the water so that the subject's mouth is no more than 10 cm (4 in) above the water line. Instruct the subject to make a rapid and maximum expiration, slowly bend forward so that the entire body is submerged, and remain motionless. After the scale has steadied and a reading has been taken, signal the subject to surface.

Be sure to subtract the weight of the unloaded apparatus as well as the dry weight of the swimming suit from each subject's reading to obtain the subject's net weight. Eight to ten trials should be performed and the two heaviest corresponding readings used as the underwater weight. When instructing the subject, emphasize the need to make a maximum expiration and to remain motionless underwater.
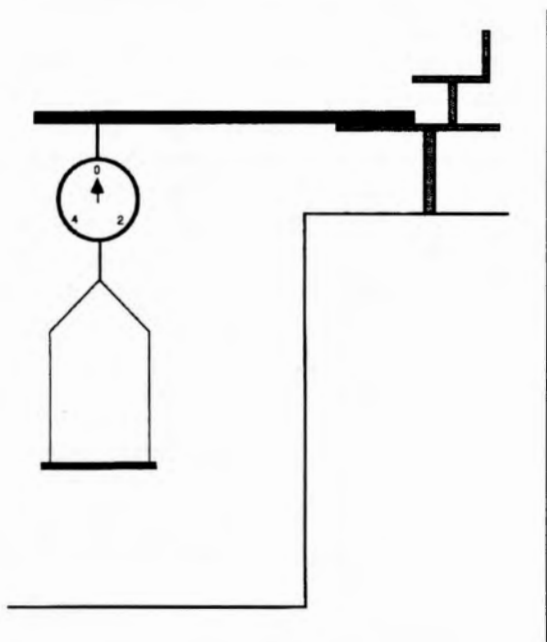

Figure 1. Set-up for hydrostatic weighing from a life guard stand in a swimming pool.

Performing the Calculations

The RV is easily and quickly estimated as a percentage of the VC according to the subject's sex (Wilmore 1969). The following approximations may be used:

females: RV (L) = VC (L) x 0.28,
males: RV (L) = VC (L) x 0.24.

Use the following formula to calculate body density (BD) from the hydrostatic weighing:

$$BD = \frac{\text{weight in air (kg)}}{\frac{\text{weight in air (kg) - weight in water (kg)}}{\text{water density}} - RV(L) - .01(L)}$$

Two of the values in this equation must be adjusted. Since water density is a function of its temperature (T_w), correction of water density for T_w should be made. However, the addition of chemicals such as chlorine to the pool water leaves the actual water density in doubt without further analysis. Water density can be estimated by:

$$\text{water density} = 1.005932 - (0.0003394 \times T_w \, (°C)).$$

The subtraction of 0.1 L in the denominator for the calculation of BD is another correction factor that assumes 0.1 L of gas present in the GI tract.

Several equations are available for calculating percent body fat from body density. The Siri formula (1956), one of the most commonly used, is as follows:

$$\% \, fat = \frac{495}{BD} - 450.$$

From the subject's weight and percent fat, three other variables can be determined. For these computations, convert the percent body fat into its fraction form.

fat weight = fraction of % fat x body weight

fat-free weight = body weight - fat weight

Although the literature reports various recommended maximum percent body fat values, commonly used values are 15 percent for males and

25 percent for females. Thus, a desirable body weight can be determined for those individuals exceeding a desired percent body fat. This is computed as follows:

$$\text{desired body weight} = \frac{\text{lean body weight}}{1.00 - \text{fraction of desired \% fat}}$$

If one is trying to calculate how much weight to lose in order to achieve desired body weight, this equation assumes that 100 percent of the weight loss is from fat. In most instances, however, weight loss is a combination of both fat and protein loss.

Interpreting the Results

Two assumptions made in the hydrostatic weighing procedure increase the potential for error. First, the densities of the fat and fat-free components are assumed to be 0.900 g/cc and 1.100 g/cc respectively (Behnke, Feen, & Welham, 1942). While the density of fat appears not to vary much between individuals, deviation in density of the fat-free component exists due to variation of water content and bone density which is influenced by sex, race, age and environmental setting such as altitude.

Second, the assumption that RV is a fixed percent of the VC may not be entirely valid and is thought to be the largest source of error for this protocol (Ross & Jackson, 1990). The necessity to estimate RV rather than measure it directly reduces the accuracy of the hydrostatic weighing procedure.

Several subject guidelines should be followed to enhance the accuracy of the test. Strenuous exercise should be avoided within 24 hours of the hydrostatic weighing as this may cause dehydration. For 12 hours before the test, subjects should refrain from eating, particularly those foods that produce gas in the GI tract (i.e. beans, cabbage, onions, cauliflower, corn, and certain high-irritant foods such as vinegar.)

Conclusions

Methods for determining body composition vary in the time, expense and expertise required to perform them and in the accuracy of the results obtained. Most of the formulae are based on constants estimated from a generalized population. Individual deviations from the norm cause accuracy to vary from person to person. For these reasons, even the best procedures currently in use for body composition assessment have a standard error of three to four percent. Consequently, one should view these methods as estimates rather than precise measurements.

References

Behnke, A.R., B.G. Feen, and W.C. Welham. 1942. Specific gravity of healthy men. Journal of American Medical Association,118:495-498.

Ross, R.M. and A.S. Jackson 1990. Valuation of body composition. In: Exercise Concepts, Calculations, & Computer Applications, Carmel, IN: Benchmark Press: 183-212.

Siri, W.B. 1956. The gross composition of the body. In: Advances in Biological and Medical Physics, vol. IV, J.H. Laurence and C.A. Tobias, eds. New York, NY: Academic Press, pp. 239-280.

Wilmore, J.H. 1969. The use of actual predicted and constant residual volumes in the assessment of body composition by underwater weighing. Medicine and Science in Sports 1(1):87-90.