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The Measurement of Body Composition: Techniques and Implications

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INTRODUCTION

Physiological approaches to body composition have introduced *in vivo* measurements of different compartments of the body, with the additional possibility of assigning a functional significance to these measurements. The body composition determines the risk for diseases associated with ageing and other chronic diseases[1], as well as for mortality[2]. It is also important in determining metabolic adaptations in acute[3] and chronic[4] alterations in nutritional status. Body composition in terms of fat mass is usually inferred from simple anthropometric measurements such as weight and height. However, these simple measures are often not sufficient to fully explore relations between body fat and alterations in human health. This is also something that needs to be recognised in growing children, given the increase in the prevalence of childhood obesity[5]. This increases the demand for accurate methods for determining body fatness.

MEASUREMENT OF BODY FAT

There are several methods available for the measurement of body fat, ranging from those that actually measure body components, to those that predict them. In terms of primary measurements, the body can be divided into two compartments: fat and fat free mass (FFM), and the measured density (by hydro-densitometry) of the whole body is then used in the Archimedes Principle, that the relative proportions of a two component mixture (each of known density) can be estimated if the density of the mixture is known[6]:

$$\frac{1}{\text{density}^{body}} = \frac{\text{Proportion of fat}}{\text{density}^{fat}} + \frac{\text{Proportion of FFM}}{\text{density}^{FFM}}$$

The densities of fat and FFM are typically assumed to be 0.9 kg/l and 1.1 kg/l, respectively[7]. These assumptions may or may not be true, since the density of the FFM varies with age[8] or composition. Although these variations are small, they can result in 5-10 per cent errors in the measurement of body fat.

To achieve a greater precision in the two-compartment model, the FFM compartment is subdivided into a water and water free compartment[1]. Thus, an independent estimate of the Total Body Water (TBW) can be used in conjunction with hydro-densitometry to arrive at a three-compartment model of the body consisting of water, fat and the anhydrous FFM. The same equation of proportions and densities is used to arrive at the proportion of body fat. TBW is measured by deuterium dilution, and typically, the total body water represents about 60 per cent of the body weight[9]. This measurement removes the uncertainty of assuming the hydration of the FFM, which influences the density of the FFM. The only assumption now made in this three-compartment model is of the combined density of the mineral and protein/nucleic acids/glycogen fraction.

Further precision can be achieved through the use of a four-compartment model. This model improves on the three-compartment model described above, by further dividing the anhydrous FFM into mineral, and mineral free compartments. Bone mineral content is measured by dual energy X-ray absortiometry (DEXA), and converted to total body mineral mass by a constant[10]. This allows the body to be measured in four compartments: fat, water, mineral and the rest, which consists primarily of protein with some glycogen and nucleic acids. Since the density of body mineral is known with a greater certainty, this leaves only the assumption of the density of protein to be made. Table 1 on the next page summarises these approaches to body composition measurement.

Even with high levels of precision in each of the primary measurements, it is unlikely that a precision of greater than 0.5 kg fat mass would be

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TABLE 1
Measurements that Need to be Made in Different Body Composition Models

2-Compartment Model	3-Compartment Model	4-Compartment Model
1. Body Density by hydro-densitometry or by air displacement plethysmography (BOD POD)	1. Body Density + 2. Total Body Water (TBW) by deuterium dilution * Controls for variability in body water.	1. Body Density + 2. Total Body Water + 3. Bone mineral mass by dual X-ray energy absorptiometry (DEXA) * Controls for variability in body water and bone mineral mass.

Other prediction methods:
- Bioelectrical impedance
- Total Body Water Measurements

achieved. Errors in each of the primary measurements will propagate along the calculation, such that a four-compartment model would yield an error of about 4 per cent in a 60 kg man with 20 per cent fat. For a three-compartment model, the errors are likely to be marginally higher[11,12].

MEASURING BODY FAT

The compartment models for measuring body composition are difficult to apply in the field, because of the number, cost and difficulty of the primary measurements. Therefore, fat mass is usually measured by more simple predictive measures, such as skinfolds and bioimpedance (BIA) which offer a two-compartment measure of fat and FFM (Table 1).

The skinfold method relies on the measurement of skinfolds at truncal and appendicular sites, and the sum of these skinfolds is used in age and gender specific equations to predict body density. Body density is then used in the equation to determine body fat. The skinfolds that are typically measured are the biceps, triceps, supra-iliac and sub-scapular[13,14]. This method requires special skinfold callipers, and training to reduce inter- and intra-observer variability.

BIA is also a field method to measure body composition. This method theoretically estimates body water, but is also used to predict the FFM directly (reviewed in[15]). It is also possible to use BIA to predict specific body components, such as muscle mass[16]. BIA is a deceptively simple technique; for reliable results several preconditions need to be met[17], and further, the prediction equation needs to be validated in the population being studied.

Both the methods referred to above need validation against a criterion method. Although the four-compartment model is the best criterion method, simpler two-compartment models, such as deuterium dilution to measure TBW are available. Values of TBW can be converted to FFM by a FFM hydration factor, which is usually stable[18], with an inter-individual variation of about 3 per cent[11,12]. However, it does vary with age[8,19], nutritional status[11], and clinical state[20,21]. Recently, accurate values of 73.2[22] and 73.8 per cent[8] have been reported for adults. Children have a higher degree of FFM hydration, at about 75 per cent[8,19].

The DEXA, which is also used for validation, was primarily designed for bone mineral mass measurement, and DEXA estimates of body fat vary from instrument to instrument, by about 3 to 13 per cent[23]. The DEXA extrapolates measurements of fat mass in bone image containing pixels: this is a significant problem considering that some 40 per cent of the body area may contain bone images. Overall, the DEXA is not a field method; it is quite expensive, there is some radiation exposure, and subjects need to be brought into a central facility.

BMI – BODY FAT RELATIONSHIP

The inappropriate accumulation of body fat is intrinsic to the pathophysiological framework for the development of chronic disease. The relationship between the amount of body fat and the BMI is steeper in Asians, particularly Indians[24,25], when compared to Caucasians. These data, coupled with observations that the risk of developing chronic disease increases at a BMI of 23 kg/m^2, have suggested that the cut-off for a healthy BMI in the South Asian or Indian population should be 23 kg/m^2 [(26)]. This approach seems perfectly reasonable to define the burden of risk of chronic disease in a population, but may not be ideal in terms of the long term prevention of disease.

If the aetiological framework of an increased slope of the BMI - body fat is correct, then the critical preventive measure would be one that reduced the slope of this line. This seems preferable to reducing the BMI cut-off with the attendant risks associated with weight loss. Recent evidence suggests that body fat is more closely linked to physical activity than energy intake[27], indicating that increasing physical activity, with the restoration of a physiologically favourable body composition balance, should be the focus of preventive measures in chronic disease. In this case the BMI cut-off becomes less relevant, but studies are required to assess if this surmise is correct.

SKELETAL MUSCLE MEASUREMENT

Insulin resistance and obesity, which are part of the metabolic syndrome, are among the important antecedents to the development of chronic diseases such as diabetes and coronary heart disease[28]. Measures of overall obesity and the location of body fat are strongly associated with insulin sensitivity in Indians[28,29]. Importantly however, Indian men with a normal BMI have been observed to have lower insulin sensitivity when compared to Caucasian men, independent of their body fat content or location[30].

Body compositional factors other than the total body fat, or its location, may predispose to the lowering of insulin sensitivity, particularly in populations with low levels of obesity. In a simple framework, a lower body muscle mass, which has an independent effect on insulin sensitivity and glucose disposal[31,32], could also determine the risk for developing insulin resistance. In India, a nutritional and lifestyle tran-

sition resulting in high fat intakes, with a low physical activity, would not only increase total body fat mass, but result in a relatively lower body muscle content, particularly if the muscle mass was low to begin with. This could also be termed sarcopenic obesity; however, sarcopenia is a term which defines the muscle loss associated with ageing, and is not entirely satisfactory for the low muscle mass in Indians, which is compounded by chronic undernutrition[33]. Accurate measurements of the total body skeletal mass can be made by measuring 24-hour urinary creatinine excretion, and more accurate measures can be made by MRI[34]. Prediction equations for muscle mass based on mid arm circumference are also available, based on Western populations[35].

In conclusion, the physiological distribution of body fat is an important determinant of health. More attention needs to be paid to methods of reducing adiposity beyond simply reducing the BMI, as well as to other body components such as muscle.

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References

1. WHO. Obesity: preventing and managing the global epidemic. Report of a WHO consultation. WHO Technical Report Series 894, Geneva, 2000.

2. Allison, D.B., Zannoulli, R., Faith, M.S., Pietrobelli, A., Van Itallie, T.B., Pi-Sunyer, F.X., and Heymsfield, S.B.: Weight loss increases and fat loss decreases all-cause mortality rate: results from two independent cohort studies. *Int J Obes* 1999, 23:603-611.

3. Hill, G.L.: Body composition research: Implications for the practice of clinical nutrition. *JPEN* 1992; 16:197-218.

4. Shetty, P.S.: Physiological mechanisms in the adaptive response of metabolic rates to energy restriction. *Nutr Res Rev* 1990; 3: 49-74.

5. Shetty, P.S.: Obesity in children in developing countries: indicator of economic progress or prelude to disaster? *Ind Pediatr* 1999;36:11-15.

6. Siri, W.E.: Body composition from fluid spaces and density: Analysis of methods. In: Brozek, J., Henschel, A. eds. *Techniques for measuring body composition*. Washington D.C: National Academy of Sciences, N.R.C 1961:223-44.

7. Siri, W.E.: The gross composition of the body. *Adv Biol Med Phys* 1956; 4: 239-80.

8. Well, J.C.K., Fuller, N.J., Dewitt, O., Fewtrell, Elia, M., and Cole,T.J.: Four-component model of body composition in children: density and hydration of fat free mass and comparison with simpler models. *Am J Clin Nutr* 1999; 69:904-912.

9. Borgonha, S., Petracchi, C., Ferro Luzzi, A., Shetty, P.S., and Kurpad, A.V.: Prediction of total body water in Indian men from anthropometry and bioelectrical impedance using deuterium dilution as reference. *Ann Hum Biol*. 1997 Jul-Aug; 24(4): 355-61.

10. Brozek, J., Grande, F., Anderson, J.T., and Keys, A.: Densitometric analysis of body composition: revision of some quantitative assumptions. *Ann N.Y. Acad Sci* 1963, 110: 113-40.

11. Kurpad, A.V., Borgonha, S., Shetty, P.S., and Ferro-Luzzi, A.: Body composition of chronically energy deficient human males by a 3 compartment model. *Indian J Med Res* 1999, 109:56-66.

12. Fuller, N.J., Jebb, S.A., Laskey, M.A., Coward, W.A., and Elia, M.: Four-compartment model for the assessment of body composition in humans: comparison with alternative methods, and evaluation of the density and hydration of fat free mass. *Clin Sci* 1992, 82: 687-93.

13. Durnin, J.V.G.A., and Womersley, J.: Body fat assessed from total body density and its estimation from skinfold thickness measurements on 481 men and women aged 16 to 72 years. *Br J Nutr* 1974, 32: 77-97.

14. Lohman, G.T., Roche, A.F., and Martorell, R.: Skinfold thicknesses and measurement technique. In: *Anthropometric Standardisation Reference Manual.* Champaign, Illinois: Human Kinetic Books, 1988; 55-70.

15. Houkooper, L.B., Lohman, T.G., Going, S.B., and Howell, W.H.: Why bioelectrical impedance analysis should be used for estimating adiposity. *Am J Clin Nutr* 1996; 64(suppl):436S-448S.

16. Janssen, I., and Heymsfield, S.B.: Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. *J Appl Physiol* 2000, 89:81-88.

17. National Institutes of Health. Bioelectrical impedance analysis in body composition measurement. Technology Assessment Conference Statement. US Department of health and human service, 1994.

18. Wang, Z., Deurenberg, P., Pietrobelli, A., Baumgartner, R.N., and Heymsfield, S.B.: Hydration of the fat free body mass: review and critique of a classic body-composition constant. *Am J Clin Nutr* 1999, 69:833-841.

19. Fomon, S.J., Haschke, F., Zeigler, E.E., Nelson, S.E.: Body composition of reference children from birth to age 10 years. *Am J Clin Nutr* 1982, 35:1169-1175.

20. Kerpel-Fronius, E., and Kovach, I.: The volume of extracellular body fluids in malnutrition. *Paediatrics* 1984, 2: 21-23.

21. Widdowson, E.M.: Responses to deficits of dietary energy. In: *Nutritional Adaptation in Man.* Blaxter, K.L., Waterlow, J.C., eds. John Libbey, London, 1985: 97-104.

22. Wang, Z., Deurenberg, P., Wang, W., Pietrobelli, A., Baumgartner, R.N., and Heymsfield, S.B.: Hydration of fat-free body mass: new physiological modeling approach. *Am J Physiol* 1999, 276:E995-E1003.

23. Economos, C.D., Nelson, M.E., Fistarone, M.A. *et al.:* A multi centre comparison of dual energy X-ray absorptiometers: *In vivo* and *in vitro* soft tissue measurements. *Eur J Clin Nutr* 1997, 51:312-317.

24. Deurenberg-Yap, M., Chew, S.K., and Deurenberg, P.: Elevated body fat percentage and cardiovascular risks at low body mass index levels among Singaporean Chinese, Malays and Indians. *Obes Rev* 2002, 3:209-15

25. Dudeja, V., Misra, A., Pandey, R.M., Devina, G., Kumar, G., and Vikram, N.K.: BMI does not accurately predict overweight in Asian Indians in northern India. *Br J Nutr* 2001, 86:105-112.

26. WHO/IASO/IOTF: Redefining obesity and its treatment. The Asia-Pacific perspective. 2000.

27. Yao, M., McCrory, M.A., Ma, G., Tucker, K.L., Gao, S., Fuss, P., and Roberts, S.B.: Relative influence of diet and physical activity on body composition in urban Chinese adults. *Am J Clin Nutr.* 2003, 77:1409-16.

28. Misra, A., and Vikram, N.: Insulin resistance syndrome (metabolic syndrome) and Asian Indians. *Curr Sci* 2002, 83:1483-1496.

29. Banerji, M.A., Faridi, N., Atluri, R., Chaiken, R.L., and Lebovitz, H.E.: Body composition, visceral fat, leptin, and insulin resistance in Asian Indian men. *J Clin Endocrinol Metab* 1999, 84:137-144.

30. Chandalia, M., Abate, N., Garg, A., Stray-Gunderson, J., and Grundy, S.M.: Relationship between generalised and upper body obesity to insulin resistance in Asian Indian men. *J Clin Endocrinol Metab* 1999, 84:2329-2335.

31. Poehlman, E.T., Dvorak, R.V., DeNino, W.F., Brochu, M., and Ades P.A.: Effects of resistance training and endurance training on insulin sensitivity in nonobese, young women: a controlled randomized trial. *J Clin Endocrinol Metab* 2000, 85:2463-2468.

32. Seidell, J.C., Perusse, L., Despres, J.P., and Bouchard, C.: Waist and hip circumferences have independent and opposite effects on cardiovascular disease risk factors: the Quebec Family Study. *Am J Clin Nutr* 2001, 74:315-321.

33. Kurpad, A.V., Regan, M.M., Raj, T. Vasudevan, J., Kuriyan, R., Gnanou, J., and Young, V.R.: Lysine requirement of chronically undernourished adult Indian subjects, measured by the 24h indicator amino acid oxidation and balance technique. *Am J Clin Nutr* 2003, 77: 101-108.

34. Lee, R.C., Wang, Z., Heo, M, Ross, R., Janssen, I., and Heymsfield, S.B.: Total body skeletal muscle mass: development and cross validation of anthropometric prediction models. *Am J Clin Nutr* 2000, 72:796-803.

35. Heymsfield, S.B., McManus, C., Smith, J., Stevens, V. and Nixon, D.W.: Anthropometric measurement of muscle mass: revised equations for calculating bone-free arm muscle area. *Am J Clin Nutr* 1982, 36: 680-90.