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PROCEEDINGS OF THE NUTRITION SOCIETY

A Workshop of the Macronutrient Metabolism Group of the Nutrition Society was held at The Moller Centre, Churchill College, Cambridge on 1 November 1994

Workshop on 'Body composition methodology'

Review of Macronutrient Metabolism Group Workshop

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INTRODUCTION

Dr Marinos Elia (Cambridge) described the theoretical basis of compartmental analysis of body composition. Classically the body has been considered to be composed of fat and fat-free tissue. Fat is a relatively homogeneous compartment but fat-free mass (FFM) includes water, protein, bone, glycogen and small amounts of other constituents. He described how increasingly sophisticated methods of body composition analysis attempted to make measurements of each of these compartments of the body in order to re-assemble the components of body weight, without making assumptions about the relationship of one constituent to another, as required in traditional two-compartment models (Elia, 1992).

He also described how some of the methods employed in body composition analysis were increasingly finding use outside this narrow field. In particular, he referred to work on bioimpedance tomography (Brown *et al.* 1994). This can be used to produce images of specific regions of the body, including heart, lungs and brain throughout cycles of activity, and to pinpoint specific abnormalities in these tissues.

He suggested that further breakthroughs in both the measurement of body composition and scanning techniques, such as bioimpedance tomography, are most likely to come from physicists, but that input from nutritionists and clinicians would be essential in order to ensure that the greatest progress was made in producing answers to biologically-relevant issues.

DENSITOMETRY

Dr Susan Jebb (Cambridge) described the classical principle of densitometry to measure body composition, in which the body is divided into fat and FFM and also how measurements of body density may be combined with other techniques in a multi-compartment model. Specific reference was made to a four-compartment model in which total body water is measured by an isotope-dilution technique and bone mineral by dual-energy X-ray absorptiometry (DXA) (Fuller *et al.* 1992). The methodological precision of body density measurements was quoted as ±0·0023 kg/l, although it was observed that this precision may be impaired in subjects who are anxious or unaccus-

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tomed to the procedure. Within a four-compartment model the propagated measurement precision is of the order of ±0·75 kg fat.

Compared with sophisticated multi-compartment models for the measurement of body fat the agreement for densitometry is as good as, or better than, that for other reference methods, with a mean bias of less than 1 kg (Fuller *et al.* 1992). Furthermore, for populations of healthy subjects the evidence suggests that reference values used for the hydration and density of FFM are probably appropriate (Fuller *et al.* 1992). However, for individual subjects there may be substantial deviations leading to errors in the absolute measurement of fat mass when densitometry is employed as a single measure (Jebb & Elia, 1995). Data on the composition of FFM in the elderly and for sick or injured patients is scarce.

A variety of techniques to measure body density were presented including volometers, plethysmographs, and underwater-weighing devices. The importance of subject acceptability of the device to ensure compliance was highlighted and it was suggested that the procedure may be suitable for a wider range of subjects than commonly perceived, including pregnant women (van Raaij *et al.* 1988), children (Reilly *et al.* 1995) and patients with non-acute conditions.

In the discussion Dr Peter Tothill (Edinburgh) showed data which suggested that the measurement of bone mineral by DXA may be inaccurate since machines from different manufacturers give significantly different results for bone mineral mass (Tothill *et al.* 1994). This will clearly give rise to errors in the absolute accuracy of multi-compartment models. However, since bone mineral represents in general only about 3% of body weight the potential for error in estimating fat from a multi-compartment model is small. The possibility of developing other methods to measure body volume without the need for water submergence was also discussed. Currently systems of acoustic plethysmography, dilution of inert gases, and photographic methods are under development.

DUAL-ENERGY X-RAY ABSORPTIOMETRY

Dr Paola Manzoni (Milan, Italy) outlined the principle of DXA in which the fractional composition of a multi-component body can be determined from the attenuation of transmitted photons at two different energies (Mazess *et al.* 1970, 1990). Solving two simultaneous algebraic equations allows the calculation of bone mineral in the remaining soft tissue mass, with a quoted CV of 3% for bone, 2% for fat and 0·6% for lean tissue. In addition, DXA is able to make measurements of specific regions of interest, although it is not able to distinguish between subcutaneous and visceral depots.

Dr Manzoni then described a large study in which this method has been used to quantify differences in body composition between healthy children and those with a variety of disorders, including obesity, Prader-Willi syndrome, coeliac disease and growth-hormone deficiency. The results demonstrate specific differences between groups in terms of both gross body composition and the regional distribution of tissue expressed as the leg:trunk ratio.

The limitations of the DXA system were seen to be the failure to provide information on the water compartment of the body (although this problem may be overcome by simultaneous measurements of total body water (TBW) by isotope dilution), the absence of reference data for young subjects (and validity of data in older groups), and the effects on measured composition of patient size and geometry.

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The discussion of the present paper focused on the methodological issues encountered by others in the audience. Dr Tothill (Edinburgh), pointed out inter-machine differences in the measured soft tissue composition, and the unpredictable effect of changes in composition in one compartment on the measured composition in another (Tothill *et al.* 1994). Dr Jebb (Cambridge) referred to work in which significant differences in the measured composition with depth in experimental models were observed using a Hologic machine. Dr Jebb also referred to studies using samples of pork meat in which the measured fat mass by DXA was approximately 30% less than that measured by direct analysis (Jebb *et al.* 1995). General concern was expressed at the lack of validation of this method, particularly in view of the increasing availability of this technique in hospitals, throughout the country, where investigators may have little or no previous experience of body composition methodology. However, since there is little doubt about the precision of DXA measurements, they may be useful in the measurement of changes in body composition in individual subjects, but research of this type has not yet been published.

BIOELECTRICAL IMPEDANCE

Dr Leigh Ward (Brisbane, Australia) explained how the principles of bioelectrical impedance can be used to measure body composition. The impedance (or opposition) to the flow of an electric current is low through body fluids, but is high in fat tissue. In practice a small constant current, typically 800 μA at 50 kHz is passed between electrodes spanning the body and the voltage drop is measured. Prediction equations, previously generated by correlating impedance measured against an independent estimate of TBW, may be used to subsequently convert a measured impedance to a corresponding estimate of TBW. Lean body mass is then calculated from this estimate using an assumed hydration fraction for lean tissue. Fat mass is calculated as the difference between body weight and lean body mass.

The electronic accuracy of the equipment is good and differences between machines are more likely to be a consequence of inadequate calibration than electronic instability. With due care to ensure good electrode contact and careful positioning, measurements can be very precise, with quoted CV ranging from 0·3 to 3%. The precision and accuracy of the final estimates of fat or FFM depend on the prediction equation, which is inevitably population specific. Typically standard errors of estimates (SEE) for the prediction of TBW are 3–10%, and slightly higher for FFM.

Multi-frequency bioimpedance (MFBIA) allows the division of TBW into intra- and extracellular components. Body fluids provide the resistive component of the body impedance whereas the cell membranes, which act as imperfect capacitors, contribute a frequency-dependent reactive component. Impedance measurements made at low frequencies do not penetrate cell membranes and, hence, measure the extracellular component, whereas those measured at high frequencies (up to 1 MHz) will measure TBW.

Dr Wootton (Southampton) and others, expressed a healthy scepticism as to whether impedance measurements actually contributed more to the estimation of body composition than could be obtained from simple anthropometry. The concensus was that in many situations, particularly for healthy individuals there may be little advantage, but there are likely to be substantial benefits, particularly using MFBIA in patients with distorted water balance.

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VELOCITY OF ULTRASOUND

Mr Alan Fisher (Bristol) described how this method represents a development from the traditional methods of pulse-echo imaging and the need for subjective interpretation. The method is based on the differential speed of ultrasound in muscle *v.* fat tissue (Miles & Fursey, 1977). Since the difference is only about 10%, the system depends on high precision of the measurement of time of flight and distance. Likely errors yield a maximum deviation of ±0·5% of fat in a fat–lean mixture. The accuracy of the technique depends on the relationship between the composition of the small core of material measured during the experimental procedure and the composition of the whole body. This problem may be exacerbated in animal carcasses by the fact that intramuscular fat is deposited in irregular masses which may vary widely even within a localized area.

Early work on this type of system for use in the assessment of carcass composition of livestock has been sufficiently successful to warrant the production of a prototype commercial system at a cost of about £10 500. However, as yet the possibilities of this approach have not been tested outside the farm-animal or meat-carcass environment (Miles *et al.* 1984; Fisher, 1992).

Dr Campbell (Manchester) described some experience of ultrasound measurements in humans in which the pressure exerted appeared to have a major influence on the measured tissue thickness. The specific effect of exerted pressure has not been studied with velocity ultrasound, but since the reproducibility of the system in experienced hands can be very good it seems that this potential problem has been subconsciously overcome. The most significant factor in the reproducibility of the equipment was considered to be temperature. Mrs Munday (Melton Mowbray) suggested that the velocity of ultrasound may be affected by the specific characteristics of different fatty acids, in particular the degree of saturation. Members of the audience were impressed by the clear advantage of this system over other types of ultrasound, including those used in human studies, in terms of the quantitative rather than qualitative nature of the measurements.

FIELD AND BEDSIDE METHODS

Dr Nick Norgan (Loughborough) provided a guide to evaluating body-composition techniques which are widely used in the field or in the clinical environment, where their simplicity and portability are of prime importance. Actual anthropometric measurements such as height, weight, circumferences, diameters and skinfolds can be precisely and accurately measured. Other methods in which a physical or chemical property of the body is estimated from its density, electrical conductivity or water content etc., must be transformed to yield estimates of body composition; a process which may introduce errors. With this type of measurement the precision and accuracy depends on who is being measured, who is doing the measuring, the conditions at the time of the measurement and the quality of any prediction equation employed.

A series of points which should be considered when developing estimation equations were proposed (Katch & Katch, 1980; Roche & Guo, 1993). The sample size should be large, at least fifty subjects, the reference method should be stated and both the correlation coefficient and SEE of the prediction given. Preferably the variables should be selected using a hierarchical, best-subset design and not stepwise regression. Equations should be validated on an independent sample, and a consideration made of inter-laboratory variability.

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Prediction equations may be inaccurate for a number of reasons (Norgan & Ferro-Luzzi, 1985). The reference methods are not 100% accurate; particularly for two-compartment methods. There may be methodological errors including both variation in the technique employed and statistical errors of the type described in developing prediction equations. Finally, there are biological differences between subjects; in the case of skinfolds these include features such as variations in the proportion of fat situated subcutaneously, fat patterning and skinfold compressibility.

The discussion of this paper focused on the relative merits of the various techniques. It was clear that in many situations there is no need to derive an absolute estimate of fat mass and in such cases a variety of anthropometric measurements were seen to be extremely useful. In the case of skinfold thicknesses used to estimate body fat it was noted that the Durnin & Womersley (1974) equations consistently performed well, in comparison to other skinfold prediction equations and other estimation methods.

The validity of near infra-red interactance was widely questioned. Concerns were expressed in relation to its poor performance relative to other estimation methods in comparison with reference methods. The use of a single measurement at the biceps was considered unlikely to represent total body fat stores, but in practice this may be of little consequence since the contribution of the measured optical density at the measurement site is small, whilst other variables in the prediction equation, including weight and height, are much more dominant contributors to the final estimate of fat.

MEASUREMENT OF BODY COMPOSITION IN PAEDIATRICS

Dr Peter Davies (Cambridge) explained that since the measurement of body composition in paediatrics is confounded by ethical and practical difficulties which are not encountered in adult studies, each method must be reconsidered with reference to this particular population. Furthermore, as body composition changes so rapidly during growth and development the interpretation of data can be difficult (Fomon *et al.* 1982).

Underwater weighing is impractical except in older children. In infants it is not possible to predict total body fatness from skinfold thicknesses with an appropriate degree of accuracy and the equations for older children are often extremely population specific (Parizkova, 1961; Frerichs *et al.* 1979). The measurement of TBW, most usually using $^{2}H_2O$ is common, with a 3% allowance for the exchange of isotope with non-aqueous H. The prediction of TBW using bioelectrical-impedance analysis has also been widely used in children and it was suggested that the equations may be less population specific than in adults. However, Dr Elia (Cambridge) suggested that this may be due at least in part to the wide range in the size of subjects studied, frequently from babies through to adolescents and young adults (Davies & Gregory, 1991; Mayfield *et al.* 1991; Danforth *et al.* 1992; Novak *et al.* 1992). Dr Davies responded that while a wide range of size may certainly influence the correlation coefficient there is no reason to suggest that the regression coefficient and intercept will be similarly affected. With both isotope dilution and bioimpedance there is the outstanding problem of converting TBW measurements to estimates of FFM which requires assumptions about the hydration fraction of FFM. Dr Norgan (Loughborough) pointed out that this is essential, since in many situations, particularly for healthy children, the variable of interest is fat or FFM and not TBW itself.

DXA was considered as a potentially exciting advance in paediatric body composition,

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which additionally allows the quantification of bone mineral (Davies, 1993). Many of the issues described earlier in adults are also of concern in children and may be exacerbated in this group in view of the wide variations in size and shape of children from neonates to adolescents. A further problem is the lack of consistency between software packages which produce apparent changes in body composition when children are moved onto adult software for data analysis.

Currently most body composition analysis is limited to two-compartment models, but it is likely that the future, as for adult research, will lead towards multi-compartment models combining a number of different methods of body composition analysis.

PANEL DISCUSSION

The meeting concluded with an invitation to the audience to present their difficulties in selecting body composition techniques appropriate to particular studies. A good example was given by Dr Paton (London) where a group of human-immunodeficiency-virus-positive men were to receive a growth-hormone supplement in a randomized clinical trial. Growth hormone has been previously shown to enhance lean tissue mass, although with a possible exceptional increase in body water.

Clearly in this situation there is a need to measure TBW, either by isotope dilution or bioelectrical impedance. Since this will involve a limited number of patients and costly growth-hormone supplementation it was felt strongly that the former should be used in spite of the additional cost and complexity of the analysis, since it is at least a direct analysis of one of the variables of interest. Professor Thomas (Brisbane, Australia) suggested *in vivo* neutron-activation analysis (IVNAA) as a direct measurement of N accretion. Underwater weighing, also, was considered if the clinical situation of the patients was such that this was possible. Certainly, in combination with TBW measurements and possibly bone mineral by DXA, this would yield theoretically one of the most sophisticated measurements of body composition possible. DXA as a single method is extremely precise and may provide a useful measure of the change in body composition, but in view of concerns over its absolute accuracy was recommended only as a supplement to other methods. A number of anthropometric measurements were suggested to offer useful information, particularly relating to the distribution of body composition change, such as circumferences of limbs, waist and hip. Professor Macdonald (Nottingham) pointed out the need for functional measurements. The panel agreed that this was essential since increases in FFM were presumed to be acting as a proxy for changes in functional capacity. Techniques such as hand-grip strength and muscle-stimulation tests were suggested.

Overall it was clear that in this example, as for all others discussed, there is as yet no perfect method to measure body composition. Whilst it was recognized that not all possible methods had been considered within the Workshop the panel agreed that no single method was ideal in all circumstances. However, some methods did offer unique opportunities, e.g. IVNAA for elemental analysis, magnetic resonance imaging for imaging without ionizing radiation and especially for examining specific organs and tissues.

All speakers emphasized the importance of the independent effects of precision and accuracy when considering the merits of different methods. In summary, when selecting a body-composition method the key questions to address are: is it accurate, is it precise and, most importantly, is it valid for the specific purpose for which it is required?

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REFERENCES

Brown, B. H., Karatzas, T., Nakielny, R. & Clarke, R. G. (1994). Impedance tomography. *Physiological Measurement* **2A**, Suppl., A1–A224.

Danforth, L. C., Schoeller, D. A. & Kushner, R. F. (1992). Comparison of two bioelectrical impedance analysis models for total body water measurements in children. *Annals of Human Biology* **19,** 603–607.

Davies, P. S. W. (1993). Body composition assessment in children. *Archives of Disease in Childhood* **69,** 337–338.

Davies, P. S. W. & Gregory, J. W. (1991). Body water measurements in growth disorders. *Archives of Disease in Childhood* **66,** 1–46.

Durnin, J. V. G. A. & Womersley, J. (1974). Body fat assessed from total body density and its estimation from skinfold thicknesses: measurements on 481 men and women aged from 16 to 72 years. *British Journal of Nutrition* **72,** 77–97.

Elia, M. (1992). Body composition analysis: an evaluation of 2 component models, multicompartment models and bedside techniques. *Clinical Nutrition* **11,** 114–127.

Fisher, A. V. (1992). Estimation of body composition using the velocity of ultrasound. *Pig News and Information* **13,** 149N–154N.

Fomon, S. J., Haschke, F., Ziegler, E. E. & Nelson, S. E. (1982). Body composition of reference children from birth to age 10 years. *American Journal of Clinical Nutrition* **35,** 1169–1175.

Frerichs, R. R., Horsha, D. W. & Berensen, G. S. (1979). Equations for estimating percentage body fat in children 10–14 years old. *Pediatric Research* **13,** 170–174.

Fuller, N. J., Jebb, S. A., Laskey, M. A., Coward, W. A. & Elia, M. (1992). Four compartment model for the assessment of body composition in humans: comparison with alternative methods and evaluation of the density and hydration fraction of fat-free mass. *Clinical Science* **82,** 687–693.

Jebb, S. A. & Elia, M. (1995). Multicompartment models for the assessment of body composition in health and disease. In *Body Composition Techniques and Assessment in Health and Disease* [P. S. W. Davies and T. J. Cole, editors]. Cambridge: Cambridge University Press.

Jebb, S. A., Goldberg, G. R., Jennings, G. & Elia, M. (1995). Dual energy X-ray absorptiometry measurements of body composition: effects of depth and tissue thickness, including comparisons with direct analysis. *Clinical Science* (In the Press).

Katch, F. I. & Katch, V. L. (1980). Measurement and prediction errors in body composition assessment and the search for the perfect prediction equation. *Research Quarterly in Exercise and Sports Science* **51,** 249–260.

Mayfield, S. R., Vavy, R. & Waldelich, D. (1991). Body composition of low-birth weight infants determined by using bioelectrical resistance and reactance. *American Journal of Clinical Nutrition* **54,** 296–303.

Mazess, R. B., Barden, H. S., Bisek, J. P. & Hanson, J. (1990). Dual energy X-ray absorptiometry for total-body and regional bone-mineral and soft-tissue composition. *American Journal of Clinical Nutrition* **51,** 1106–1112.

Mazess, R. B., Cameron, R. C. & Sorensen, J. A. (1970). Determining body composition by radiation absorption spectrometry. *Nature* **228,** 771–772.

Miles, C. A. & Fursey, G. A. J. (1977). Measurement of the fat content of meat using ultrasonic waves. *Food Chemistry* **2,** 107–118.

Miles, C. A., Fursey, G. A. J. & York, R. W. (1984). New equipment for measuring the speed of ultrasound and its application in the estimation of body composition of farm livestock. In In vivo *Measurement of Body Composition in Meat Animals* [D. Lister, editor]. London: Elsevier Applied Science Publishers.

Norgan, N. G. & Ferro-Luzzi, A. (1985). The estimation of body density in men: are general equations general? *Annals of Human Biology* **12,** 1–15.

Novak, I., Davies, P. S. W. & Elliott, M. J. (1992). Non-invasive estimations of total body water in critically ill children after cardiac operations. *Journal of Thoracic and Cardiovascular Surgery* **104,** 585–589.

Parizkova, J. (1961). Total body fat and skinfold thickness in children. *Metabolism* **10,** 794–807.

Reilly, J. J., Wilson, J. & Durnin, J. V. G. A. (1995). Estimation of body composition in children using skinfold thickness: a cross validation. *Proceedings of the Nutrition Society* (In the Press).

Roche, A. F. & Guo, S. (1993). Development, testing and use of predictive equations for body composition measures. In *Recent Developments in Body Composition Analysis: Methods and Applications* [J. G. Kral and T. B. van Itallie, editors]. London: Smith Gordon.

Tothill, P., Avenell, A., Love, J. & Reid, D. M. (1994). Comparisons between Hologic, Lunar and Norland dual energy X-ray absorptiometers and other techniques used for whole-body soft tissue measurements. *European Journal of Clinical Nutrition* **48,** 781–794.

https://doi.org/10.1079/PNS19950025 Published online by Cambridge University Press

van Raaij, J. M. A., Peek, M. E. M., Vermaat-Miedema, S. H., Schonk, C. M. & Hautvast, J. G. A. J. (1988). New equations for estimating body fat mass in pregnancy from body density or total body water. *American Journal of Clinical Nutrition* **48,** 24–29.

FURTHER READING

Brunton, J. A., Bayley, H. S. & Atkinson, S. A. (1993). Validation and application of dual energy X-ray absorptiometry to measure bone mass and body composition in small infants. *American Journal of Clinical Nutrition* **58,** 839–845.

Coward, W. A., Parkinson, S. A. & Murgatroyd, P. R. (1988). Body composition measurements for nutrition research. *Nutrition Research Reviews* **1,** 115–124.

Heymsfield, S. B., Wang, J., Heshka, S., Kehayias, J. J. & Pierson, R. N. (1989). Dual photon absorptiometry: comparison of bone mineral and soft tissue mass measurements in vivo with established methods. *American Journal of Clinical Nutrition* **49,** 1283–1289.

Ivings, W. E., Gibb, M. J., Dhanoa, M. S. & Fisher, A. V. (1993). Relationships between velocity of ultrasound in live lactating dairy cows and post-slaughter measurements of body composition. *Animal Production* **56,** 9–16.

Jebb, S. A. & Elia, M. (1993). Techniques for the measurement of body composition: a practical guide. *International Journal of Obesity* **17,** 611–621.

Kushner, R. F. (1992). Bioelectrical impedance analysis: A review of principles and applications. *Journal of the American College of Nutrition* **11,** 199–209.

Lohman, T. G. (1992). *Advances in Body Composition Assessment.* Champaign, IL: Human Kinetics Publishers.

Miles, C. A., Fursey, G. A. J., Fisher, A. V. & Page, S. J. (1991). Estimation of lamb carcass composition from measurements of the speed of ultrasound in the soft tissues of live animals and carcasses. *Meat Science* **30,** 245–256.

Norgan, N. G. (1995). The assessment of the body composition of populations. In *Body Composition Techniques and Assessment in Health and Disease* [P. S. W. Davies and T. J. Cole, editors]. Cambridge: Cambridge University Press (In the Press).

Porter, S. J., Owen, M. G., Page, S. J. & Fisher, A. V. (1990). Comparison of seven ultrasonic techniques for *in vivo* estimation of beef carcass composition with special reference to performance testing. *Animal Production* **51,** 489–495.

Shepherd, R. J. (1991). *Body Composition in Biological Anthropology.* Cambridge: Cambridge University Press.

Thomas, B. J., Cornish, B. H. & Ward, L. C. (1992). Bioelectrical impedance analysis for measurement of body fluid volumes. A review. *Journal of Clinical Engineering* **17,** 505.

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