測定身體組成的適當技術

Appropriate technology in body composition: a brief review

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This paper attempts to link the particular method to be used for body composition measurements to the objectives of the study. There is often inadequate attention paid to the real requirement for different degrees of precision, and excessive amounts of time and labour are spent on quite unnecessary minutiae of technology. Special attention is paid to bio-electrical impedance, skinfold thicknesses, stable isotope techniques, and methods for assessing fat distribution.

Introduction

This is not intended to be a dull reiteration of the several excellent reviews giving detailed descriptions of the various techniques[1–3]. This is a selective and abbreviated review which intends no disrespect to unquoted distinguished research workers but reflects simply my own prejudices.

What I should like to be the outcome of this somewhat cursory analysis of the 'appropriate technology in body composition' studies, would be a more critical and, perhaps, sceptical attitude to the interpretation of our measurements. I want to deal briefly with such basic concepts as the constancy of the fat-free mass (FFM) and 'active cell mass'. And I want to encourage a continued appraisal of the validity and precision of the measurements we make. And finally, I should like to suggest that for most purposes concerned with field work or in most clinical situations, a very simple methodology is appropriate.

Fundamental naïvetés

There are now many different methods available for making some assessment of the several aspects of body composition. They vary in accuracy and validity, in ease of operation, and in cost. They also inform us about different parameters which, in themselves, may be interpreted or extrapolated in various ways. For example, bioelectrical impedance is an indirect method of measuring total body water (TBW). The method involves an assessment of TBW from the resultant resistance across electrodes placed on hands and feet. From an equation, the validity of which is accepted more or less on trust, TBW and thus FFM are calculated and fat mass and fat percentage (the fat mass relative to total body mass) are derived. The final calculation often pays little regard to the likely influence of considerable *inter*-individual variabiltiy in the water content of the FFM, and even the *intra*-individual variability in the total water content of the body which can show a difference of up to 1–2 kg from day to day, even in individuals living a quiet existence in a thermo-neutral environment[4,5]. That is, intra-individual variability may account for a difference, from day to day, of about 2–5% in the estimation of TBW even if the method could measure this with 100% accuracy. When we take into account the impossibility of confidence in the consistency of the water content of the FFM in different individuals, though the method may be easy to use, though it may be convenient for the subject or patient, any high degree of relationship to other indirect methods, all of them with their own errors and built in problematical assumptions, must be more or less accidental. This is also the general conclusion of Deurenberg et al.[6] in their assessment of impedance measurements in field studies. To my mind, the plethora of published papers showing what an admirably reliable and satisfactory method electrical impedance is, mainly reflects the lack of attraction, either to scientists or to editors, of publishing negative results, so that we never learn (except at first-hand) of all the careful investigators who find very large and inconsistent differences between impedance results and those from other methods.

However, the desirability or otherwise of using electrical impedance, or indeed other techniques, depends upon what questions are being asked. If we want to measure accurately comparatively small alterations in body fatness in individuals during relatively short periods of time, bio-electrical impedance will not provide the requisite data. If, on the other hand, we want to make a generalized assessment in a large number of bed-ridden elderly patients, bio-electrical impedance may give us some general information, though it may well be difficult or even rash to draw specific conclusions.

We should therefore carefully appraise exactly what aspect of body composition we wish to assess in order to choose the best method in the circumstances – nuclear magnetic resonance imaging (NMRI) may be what we really need for our particular investigation but lack of money or an instrument may compel us to make do with anthropometric measures.

Brief description of information from different techniques

A brief critique of some of the current techniques for estimating body composition now follows.

The commonly used techniques measure:

- Skinfold thickness
- Other anthropometric variables, including height and weight only (to calculate the body mass index-BMI).
- Bio-electrical impedance

- Electrical conductivity
- Total body water (TBW)
- Total body potassium (TBK)
- Densitometry
- Dual-energy X-ray absorptiometry (DEXA)
- Computerised axial tomography (CAT scan)
- Nuclear magnetic resonance imaging (NMRI)
- In vivo neutron activation analysis

Measurements thus obtained may be used for a variety of purposes. These may be of a physiological nature – perhaps describing in quantitative terms, the fat or the FFM of individuals or groups of individuals, not only as *absolute values* but also with regard to how the fat is *distributed* in the body. *Age,* may be the topic of interest with measurements on infants, children, adolescents, adults, and elderly people, not only of fat and FFM but also total body water or calcium; the differing distribution of fat in various ethnic groups may be the purpose of the investigations: another very common use may be as one of the relevant factors in assessing *nutritional status* and the relationship of the body composition to *diet, to the way of life in general,* and perhaps specifically to *physical activity.*

Body composition measurements have also a clear relevance in many *clinical* situations - general medicine; in anaesthetics and therapeutics, where some quantitative information has always seemed to me to be to be desirable because of the high fat solubility of many anaesthetics and other drugs; in surgery, the degree of obesity or of wasting may be important to assess, perhaps in a longitudinal fashion to monitor progress; in obstetrics where it may be worthwhile to assess fat gain during pregnancy as an indication of the possible long-term disadvantages for the mother of adding too much adipose tissue to her body; in epidemiology with particular relevance to cardiovascular disease, and in other medical conditions.

The measurement of fatness is probably the commonest reason for using one or other of the techniques in studies of body composition. However, even if we are prepared to accept as valid, values for fatness when these are obtained by a variety of techniques, there is yet a considerable problem in the definition of 'Obesity', which, lamentably in my opinion, is still usually based on some arbitrary cut-off value of BMI. The papers presented at a recent symposium where there was a considerable emphasis on the importance of the degree of fatness and obesity, demonstrate clearly the problems resulting from the absence of an agreed definition[7].

Fat mass, FFM and 'active cell mass'

Before attempting to define the criteria which affect the particular aspect of body composition which it is desired to measure, together with the most appropriate technique for the measurement, I should like to discuss briefly some of the parameters which are relevant. *Fat mass* is relatively straightforward to deal with. In many situations, a quantitive assessment of the absolute or relative mass of fat in the human body is useful. However, we need to remember that what is being measured, directly or indirectly, is the total mass of chemical lipid, and that the structures which incorporate this lipid – ie the adipocyte membrane, the fibrous or connective tissue, together with the water content of the tissue – are all part of the FFM. The FFM is a real factual description: by most techniques which measure it, it is the mass of the body, free of fat. Imprecise terms, (obviously unless they are defined) such as 'lean body mass', have rarely any justification for their existence. Distinguishing between fat mass and adipose tissue is particularly important in energy balance studies where the energy equivalent of 'fat', or chemical lipid, is quite different from that of adipose tissue, and where the energy equivalent of weight gain and weight loss can also have different values. Because most of the techniques which allow us to calculate fat mass do so indirectly, and are really measuring the FFM (only skinfold thicknesses, CAT and NMRI, attempt to make a direct assessment), additional errors are incurred in the extrapolation from an indirect measure of the FFM – for example, if TBW or TBK is measured, an assumption has to be made about the water or the potassium content of the FFM, which is itself subject to appreciable variability and error. It is at least theoretically possible by skinfolds, CAT scan and NMRI to make a direct calculation of the actual total fat mass either subcutaneously only or else in the whole body. I find it interesting and perhaps a little astonishing that Deurenberg feels that calculation of the FFM or fat from skinfolds is, as he puts it, 'doubly indirect'.

FFM and 'active cell mass' are terms which seem to me to be used frequently in a misconceived fashion. 'Active cell mass' is particularly favoured by clinicians but both terms are used as standards of reference for many variables such as basal metabolic rate (BMR), blood volume, cardiac output, VO_2 max, and others. This surely gives a distorted impression of how the body actually works. Cells are active or not depending on the circumstances. Most skeletal muscular cells are relatively inactive most of the time. We may think of bone as being metabolically inactive but sometimes bone marrow cells are extremely active. In the resting fasting state, much of the available capacity of the blood vessels in the muscles, the gut, the liver, the skin, and other organs is shut down. Since the fasting state is one in which, by definition, no food has recently been taken into the body, the adipocytes are quite likely to be receiving at least a moderate supply of blood to enable them to provide energy to the body, and to suggest that we should ignore adipose tissue activity, by referring many variables to the FFM, seems lacking in physiological logic. During exercise, blood flow to the gastro-intestinal tract and the liver, the skin, and the kidneys is reduced in order to allow maximal flow to the muscles. Suggesting that the FFM is the mass which is 'active' in some sort of uniform way is erroneous. The use of FFM as a reference when the activity of selective components of the FFM is so variable demonstrates a confusing over-simplification of the real life situation.It is always tempting to search for simplified approaches to complex problems but the temptation should be resisted unless it is clearly a tenable proposition. In general, it is my impression that in biology any simple explanation of a highly variable problem is always wrong: few things are simple in biological science.

I am perhaps over-emphasising this point but in my opinion FFM as a general reference is used too often in a manner which seems to betray an uncritical approach. In adults who vary from having a relatively low mass of body fat to those who are moderately obese — for example, men who differ in their body fat proportion from about 10% up to 25% – 30%, or women with a range of from 15–20% up to 30–35% — there is little persuasive evidence, of a statistically acceptable nature, that there is any difference in using either *gross body weight,* or *FFM* as the reference for metabolic activity. And surely this is what would be expected from physiological and anatomical evidence Adipose tissue is not a metabolically inactive tissue. It has a relatively profuse blood supply and its 'resting' metabolism is of the same order as that of resting skeletal muscle. Also, as I have mentioned earlier, in the resting fasting state it would be expected that its metabolism would be markedly increased. In *gross* obesity we have a very different situation, but gross obesity is seldom defined and too of ten individuals are classified as 'obese' with no clear indication that the state of obesity which is being analysed is one which might range from the physiological to the obviously pathological. The energy metabolism in *gross obesity,* either in the resting state or in physical activity, reflects a complex situation where neither gross body weight nor FFM would be anticipated to be a particularly simple or useful standard of reference.

Types of information wanted: the simplest sub-division of body composition is into two components, the fat mass, and the FFM. This may be desired for a variety of purposes, often not so much concerned with the FFM but to determine the level of fatness of an individual, or of a group of individuals or of a whole population. Fatness was, for instance one of the factors being investigated in an epidemiological context, perhaps related to cardiovascular disease.

The measurement of fatness might also be used to assess the *thinness* of an individual, for example in the investigation or treatment of anorexia, or in situations supposedly common in the developing world where loss of weight and consequent thinness might be a factor affecting physical work capacity: poor people might have a food supply, especially at certain seasons of the year, inadequate to sustain energy balance in an environment where moderately hard physical activity was required, and the resultant weight loss could have a deleterious effect on the ability to work at the required or desirable levels.

Simple measurement of fatness might also assess and partially reflect the consequences of certain dietary habits. For example, Fabry et al.[8] many years ago suggested the possible influence on the efficiency of energy conversion resulting from the number of meals consumed in the day, thus having an effect on body fatness and on the development of obesity. People eating three or less meals/d, were more likely to become obese than those eating five times or more. Whether or not this dietary factory really did have an influence could be conjectured by actual measurements of fatness, ideally in a longitudinal study. An extensive properly controlled study has not, to my knowledge, been described.

Another situation where a simple measurement of fatness of the individual is needed, is as a description of one of the basic physical characteristics of nutritional status.

Validity and precision of measurements

The desirable level of validity and precision of measurements of fatness differs depending on the circumstances. In an epidemiological context, where large population groups are being compared or contrasted, neither the validity nor the precision of the measurements are necessarily of great importance. In other words, as long as we can reply on the actual measurements having been carried out with reasonable care, their exact assessment of fatness is of limited importance. Indeed, it may be that height and weight alone are sufficient. These are not values which necessarily relate very highly to actual fatness in the individual[9–11] – indeed, as Durnin et al.[12] have shown – individuals with the same BMI can have fat ratios varying from 10–30% of the body mass, presumably because of variable proportions of skeleton and muscle in the same body mass – but for groups of people, the BMI is usually closely enough linked to fatness to provide a satisfactory variable, for example, in deriving some conclusions about relationships between BMI and hypertension in populations.

Weight, height and skinfolds

However, certain facts must be borne in mind with regard to these simple physical measurements of height and weight. Firstly, *height* is not always an easy and reproducible measurement to make, especially in young children and in elderly and old people. And secondly, it is rather pointless to consider body mass as having a very precise value which has any particular meaning – eg 64.57 kg. It has already been mentioned that body mass may fluctuate by as much as 1–2 kg from one day to the next even when individuals are physically inactive, in fluid balance, and not sweating. Accuracy and the correct use of techniques are always desirable but an excessive emphasis on unnecessary precision often betrays a lack of knowledge and understanding of the basic circumstances.

In many situations where a simple estimate of fatness is required, for example, in assessing the relationship between fatness and physical activity, or in interpreting how an inadequate dietary intake affects loss of body fat, or as a simple description in studies of nutritional status,the use of *skinfold thicknesses* is often reasonably satisfactory. There is probably little argument that skinfold thicknesses give a direct manifestation of fatness; and theoretically by taking multiple skinfolds all over the body surface, a calculation of the total subcutaneous fat mass would be possible. Since a considerable proportion of the total fat mass in the body is in the subcutaneous tissues, some estimation of increasing or decreasing fatness can be obtained from measuring skinfold thicknesses. Indeed for many purposes, it is strictly unnecessary, and only a matter of numerical convenience, to translate values for skinfold thicknesses into some equivalent figure for body fatness. Satisfactory comparisons can be made within and between individuals from the gross values of certain skinfold thicknesses. We know that increasing or decreasing fatness is at least partly reflected by the amount of adipose tissue in the subcutaneous layers, and therefore by the size of the skinfolds. What these values are equivalent to in percentages of body fat, although often helpful in allowing us to obtain a clearer picture of the situation, may not be critically important. Also, in certain population groups such as infants and elderly people, we have at present no acceptable method of translating skinfolds into fatness because of our inadequate experimental data, but we can still make useful deductions from the gross skinfold data. This approach has been used in the study of Hoey and Cox[13] on Irish children. They were able to make instructive population comparisons between different socio-economic groups, and also between Irish and UK children, using only skinfold thicknesses.

An area of possible disagreement concerns the specific sites at which skinfold thicknesses should be measured and the possibility that there may be individual and ethnic differences in the proportion of the total subcutaneous fat at these different sites. This difficulty would obviously affect the equations which should be used to convert skinfolds into overall relative fatness or FFM. At the present time, it seems to me that these problems can be resolved only from an extensive investigation using NMRI and skinfolds. Only CAT scans and NMRI have the real possibility of allowing a direct estimation to be made of the total fat mass and of its distribution, and CAT scans are probably unethical because of the repetitions that would be necessary. Therefore, we are probably limited to investigations using NMRI, and considering the laborious nature of the task of making enough 'slices' through enough bodies to cater for diversity due to individual differences in degrees of fatness, varying fat distribution, age, ethnicity and gender, it is unlikely that we shall obtain a more definitive picture for many years.

However, as long as the data are used sensibly, there have probably been sufficient comparison s of equations using differing combinations of skinfolds, and related to other techniques of assessing fatness (such as by densitometry, TBW, TBK, etc) to allow us to be reasonably confident that the equations produced by Durnin and Womersley[14] or Jackson et al.[15,16] are sufficiently valid for most studies on adults up to about 60 yrs of age and children down to about 10 yrs of age. More data on these two extremes of this age range are needed, but the situation at present for the great majority of purposes is reasonably acceptable. Some of the published comparisons of FFM and fat derived from skinfolds and from other techniques, such as in the papers by McNeill et al.[17] and Fuller et al.[18] appear to demonstrate little, if any, advantage in the use of more elaborate or expensive techniques. Even in lactating women (perhaps surprisingly in the light of possible complications due to varying total body fluid), Wong, Butte and their colleagues[19] found 'no significant differences in body fat and FFM' calculated from using skinfolds or deuterium-dilution.

However, the above arguments would not necessarily be pertinent in some clinical conditions where body composition might differ very much from the physiological or near physiological state.

Spuriously valid assumptions

It seems to me that there is often a great deal of unnecessary emphasis on what are really spurious degrees of precision in relation to the quantification of the FFM or the fat mass. This affects not only the use of skinfold thicknesses but also the more complex assumptions on which the relationships between skinfolds and fatness are indirectly based – the density of the FFM, for example. Densitometry is still often considered as the 'gold standard' in the measurement of FFM. The 'gold standard' it may still be, but this is surely a sad reflection of the lack of good validated information on body composition. When we consider the potential for error with regard to the relative mass and density of the various tissues and organs of the human body, the variability between individuals (and even within individuals as a result of changing nutritional state or of physical activity or inactivity), ethnic differences in the components of the FFM[20], the error in the measurement of the density of the body when weighed underwater, with the influence on this of the dimensions of the tank and the stability of the water in the tank as it affects the recording of the body's weight, the errors inherent in the simultaneous and necessary measurement of the volume of air in the lungs, it is probable that we are dealing with composite errors which could account for at least plus or minus about 5% in the calculated value for FFM[21].

The assumptions entailed in using TBW or TBK are probably likely to lead to even larger errors, because of variations in the water content or the potassium content of the FFM and the methodological errors of these measurements also. In the light of this, obtaining an estimate for FFM and then deriving a value for the fat mass or fat ratio can only sensibly be regarded as an approximation and should never be considered as giving the impression of great precision; we ought always to remember that with a measurement where the FFM is apparently perhaps 62 kg, the probability is that the true value would be lie somewhere between 59 and 65 kg, and a fat percentage of 16% could mean a true value somewhere between 13 and 20%.

Body composition and energy metabolism: the two component (FFM and fat) analysis is often used to compare the energy metabolism of different individuals measured either as the BMR or in standard sub-maximal exercise, or as VO_2 max. How does one compare the VO_2 max in individuals of markedly different body composition? This is frequently done on the basis of ml O_2/kg/FFM. Statisticians throw up their hands in horror at the very idea of such an analysis; normalizing for different body masses in this way in fact does not succeed in removing the weight factor. However, if we are to indulge in such unacceptable procedures, we should at least realize that there is little point in trying to measure FFM by an elaborate and precise technique (if one existed), because of the other uncertainties. For comparative purposes in energy metabolism studies, skinfold thicknesses again seem to be to be adequate for the purpose.

Multiple methods: there are special circumstances when several different techniques of measuring body composition may need to be used on the same individuals, perhaps because it can be anticipated that none of the usual basic assumptions are valid. This would be the case in some clinical situations. It also applied in a recent study we undertook on pregnant women where we were trying to measure the changes in FFM and in total body fat throughout and after pregnancy. Because of the alterations taking place in the body due to the growth of the fetus, placenta, uterus, the increase in body fluids, the likely alteration in TBK, changes in the subcutaneous and perhaps intra-abdominal body fat, measurements by densitometry, skinfold thicknesses, TBW and TBK would all have even greater potential error than is normally the case, since the basic assumptions no longer pertained. It was therefore decided to make measurements simultaneously by all four techniques in the expectation that a composite analysis would allow us to make some deductions about the relative effects of these factors.

Measurements of fat distribution: some forms of cardiovascular disease have been linked with certain types of fat distribution between the subcutaneous and abdominal depots, but the attempt to derive this information by comparing limb and trunk skinfolds seems to me to be too naive to be likely. However, there is some evidence, eg from Despres et al.[22], which seems to show a remarkable ability of waist circumference, waist-to-hip ratio, age, and sagittal diameter, incorporated into different equations, to predict deep abdominal adipose tissue; CAT scans or NMRI may *not* be the only techniques with a reasonable hope of obtaining the requisite information on fat distribution, although I have to confess I am sceptical (as are others[23,24]).

Investigations of body composition by DEXA which are specifically related to bone have become popular. A reduction in bone mineralization with ageing seems to be an accepted phenomenon and studies using DEXA have proliferated in many laboratories round the world to investigate this problem. This appears to me exemplary, and of considerable potential use. However, I see very little purpose in using the technique to assess the FFM, other than in providing us with more data on bone density which could improve our theoretical estimate of the density of the FFM.

Neutron activation analysis is capable of measuring total body protein, minerals and total body calcium. It thus has a place in the investigation of some clinical problems, particularly related to bone disease. However, it has the considerable disadvantage of requiring complex and expensive equipment.

The last technique to be mentioned is the 'Total Body Electrical Conductivity' method, developed by Dr van Itallie and his colleagues. While this is undoubtedly an ingenious method to measure 'lean body mass' [sic], in the light of the basic uncertainties involved in trying to measure FFM it is difficult to find justification for the use of such elaborate and expensive equipment.

Conclusion

If we are to measure body composition, in the two sub-divisions of fat and FFM, careful consideration needs to be paid to the basic purpose of the study. For many population investigations, we need to justify the use of other than simple techniques in the light of the uncertainty attached to the validity and precision of the measurement. For most purposes concerned with field studies or clinical situations, simple skinfolds are adequate.

Obviously, if the objective of the study is to compare several techniques, then the approach has to be wide-ranging, but just because the mean results of two or three methods agree does not necessarily mean that they are equally valid. A proper statistical and biological analysis is required before we can happily come to reasonable conclusions. For my part, I am not too enamoured of studies done on six or 10, or some equally small number of individuals, when we know well that the within and between individual variability is considerable.

A final word needs to be said about the fact that almost all the techniques which have been considered measure a static anatomical parameter and have little relevance by themselves to function. Body composition studies could benefit by being much more oriented towards functional capacity, particularly in a longitudinal context.

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