

Body composition at the bedside

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Objective: To evaluate the use of an inexpensive *hand-held* bioelectric impedance analysis machine which measures lean body mass, by technical comparisons against standard instruments and techniques (an *in-house* bioelectric impedance machine and dual energy X-ray absorptiometry), and by performing body composition analyses in groups of potentially malnourished patients.

Design: Prospective simultaneous comparison of measurements made by the *hand-held* and *in-house* bioelectric analysis machines and dual energy x-ray absorptiometry.

Setting: Medical Physics Department and Gastrointestinal Unit in a university teaching hospital.

Subjects/methods: One hundred and sixty subjects were recruited into the study. Data from 58 adolescent and 14 adult volunteers and from 42 adult patients were used for technical comparisons ($n=114$). Body composition information was evaluated ($n=102$) for 60 adult volunteers and 42 patients (17 with eating disorders, 7 with chronic alcoholic pancreatitis and 18 with inflammatory bowel disease).

Outcome measures: Estimation of bias, limits of agreement and correlations on data from the three machines. Relationships between percentage body mass as lean, absolute weights and body mass index, in the adult subjects.

Results: Both resistance and calculated impedance measured by the *hand-held* machine significantly correlated with the impedance measured by the *in-house* machine ($r=0.996$; $P<0.0001$). An estimation of the level of agreement in percentage lean measurement between dual energy x-ray absorptiometry and *hand-held* bioelectrical impedance analysis machine by the Bland and Altman method showed a bias of -0.07% and satisfactory limits of agreement from -7.97% to 7.76% . Body mass index was similar in the groups of healthy men and women, but proportion of weight as lean was significantly higher in men than women. In underweight patients with eating disorders, the ratio of lean to fat varied widely; in inflammatory bowel disease patients, proportions of lean and fat were similar to controls; however patients with alcoholic pancreatitis had values for body mass index similar to controls, but had significantly lower proportion of their body weight as lean ($P<0.05$).

Conclusion: In non-obese and thin adults, an accurate two-compartment (lean, fat) measurement of body composition can be made in 10 min by using an inexpensive, hand-held, bioelectric impedance analysis machine.

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Introduction

Appraisal of nutritional status is still a frequently neglected component of clinical examination [1]. In many situations it should be mandatory to measure body weight accurately, or, alternatively, to calculate the body mass index (BMI), which takes account of appropriateness of weight for height, and allows patients and healthy individuals to be categorized as underweight, normal (in the range $20-25 \text{ kg/m}^2$) or overweight [2].

For any more sophisticated analysis of body composition, it is necessary to differentiate in some way between body fat and fat-free (so-called 'lean') body mass (LBM). This two-compartment model, although invaluable conceptually, is still a highly over-simplified statement of the clinically relevant body constituents in states of under-nutrition. The 'fat' compartment includes brain, and the non-fat, 'lean' mass includes body water, muscle and bone mass. In stable conditions, total body water is remarkably constant at 73.2% of lean [3], and this principle underlies

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the use of total body water by isotope dilution techniques, in studies of body composition. However, this also means that data on so-called 'lean' will be misleading in the presence of oedema, dehydration, ascites, cardiac failure, and in conditions with rapid fluid shifts such as the immediate postoperative period.

Several different methods of body composition analysis have been developed for research purposes, including neutron activation analysis, ^{40}K counting and dual energy x-ray absorptiometry (DEXA). All give broadly comparable results, despite their very different theoretical bases [4], and at present, there is no *a priori* reason for choosing any one technique as the gold standard [3]. In our institution, DEXA has proved to be a precise and reproducible method of measuring lean body mass [5].

Recently, medical physicists have exploited the fact that electrical conductivity is much greater in lean tissues than in fat, and have built machines which measure bioelectrical impedance of the body, and from which information on the lean:fat ratio can be derived. User-friendly versions of these machines have found a place in sports medicine and nutrition/slimming clinics but have rarely been used in clinical practice or clinical research. We have now evaluated the accuracy and ease of use of a small, hand-held, menu driven, bioelectrical impedance analysis machine, and illustrate its use with data on body composition of patients with gastrointestinal or nutritional diseases.

Subjects and methods

Subjects

For technical comparisons of body composition measurement methods

One hundred and fourteen subjects were recruited for a technical comparison of various body composition measurement methods. There were 58 healthy adolescents (2 male; 56 female, aged 11–13 years) and 56 adults: 14 healthy volunteers (hospital staff) (5 male, 9 female; median age 32 years, range 20–43 years); 17 patients with eating disorders (all female; median age 26 years, range 16–44 years; one obese and 16 underweight); 7 patients with chronic alcoholic pancreatitis (6 male, 1 female; median age 47 years, range 33–58 years); and 18 patients with inflammatory bowel disease (IBD) (9 male, 9 female; 14 Crohn's disease and 4 ulcerative colitis; median age 34 years, range 21–64 years). The preponderance of females in the healthy adolescent group was a consequence of recruitment as a control group for females with eating disorders [6].

All measurements described below were carried out on the same day in the Medical Physics Department. Subjects were not specifically asked to fast. In female patients no standardization was made for menstrual cycle.

For comparison of body composition data and BMI

We analysed both BMI and body composition data from the hand-held, bioelectrical impedance analysis instrument for the 56 adults described above; a further 46 healthy adults (24 male, 22 female, median age 35 years, range 20–56 years) were only measured using the hand-held bioelectrical impedance analysis equipment. Hence a total

of 102 subjects were studied, 60 healthy adults and 42 adult patients.

BMI

All subjects had height measured without shoes in centimetres as previously described [7] and weight measured, wearing indoor light clothes on the same, accurately calibrated machine in kilograms. In adult subjects, BMI was calculated by the formula:

$$\text{BMI} = \text{weight (kg)} / \text{height (m)}^2$$

Bioelectrical impedance analysis

Bioelectrical impedance was measured using two machines.

1. A standard four-terminal bioelectrical impedance plethysmograph (RJL Systems Inc., model 101, Detroit, MI, USA), housed in and operated by staff of the Medical Physics Department. The machine gives a value for measured resistance, which is then used to calculate lean body mass on a personal computer, using a formula and software supplied by the manufacturer. This is hereafter referred to as the *in-house* machine.
2. Hand-held bioelectrical impedance machine (Bodystat-1500, Bodystat Ltd, Isle of Man, UK) body composition unit. This is a single frequency, light-weight, menu-driven bioelectrical impedance analyser that can store and recall data from 100 consecutive measurements. Results may be read out directly from the machine's display. The machine needs input of age, sex, height and weight, and directly displays lean body mass (as a percentage of total body weight and in kilograms), fat mass (as a percentage of total body weight and in kilograms), total body water (as a percentage of total body weight and in litres), estimated basal metabolic rate and impedance in ohms. This is hereafter referred to as the *hand-held* machine.

Impedance was measured between the right wrist and right ankle using a tetrapolar electrode method. The subjects were lightly clothed but without shoes or socks, and lay supine with arms separated from the body and legs not touching each other. Adhesive aluminium foil electrodes were positioned in the middle of the dorsal surface of the hands and feet proximal to the metacarpophalangeal and metatarsophalangeal joints; a second electrode was positioned more proximal between the distal prominence of the radius and the ulnar styloid and between the medial and lateral malleoli at the ankle. An excitation current of 800 μA at 50 kHz was applied to the distal electrodes and the voltage drop was detected by proximal electrodes.

Calculation of lean body mass from impedance value

The *in-house* machine had software supplied by the manufacturer for calculation of lean body mass. The hand-held machine was programmed to run on the manufacturer's prediction equation. The exact prediction equations used were not disclosed by the manufacturers. For patients with eating disorders, a prediction equation based on the readings from the *in-house* impedance machine compared with DEXA data had been previously derived in our institution by multiple stepwise regression [6]: lean body mass (kg) =

$0.344W + 0.328(H/R) + 0.576SW - 9.63$, where W is body weight (kg), H is height (cm), R is resistance (ohm) and SW is shoulder width (cm).

In the group of patients with eating disorders, we used the value for impedance measured by the *hand-held machine* in this equation, and compared the result with that of the lean body mass derived automatically and displayed in the machine.

In IBD patients, the prediction equation derived by Jeejeebhoy's group [8] was used in addition to the manufacturer's equation. This is as follows:

$$\text{Lean body mass} = \frac{0.25H/R + 0.29W + 3.63}{0.733}$$

Dual energy x-ray absorptiometry

DEXA measurements were performed using a Hologic QDR-1000W scanner (Hologic Inc., Waltham, MA, USA) operated in the total body mode. Analysis was performed using the software version 5.51 P. The effective radiation dose was $6\mu\text{Sv}$. Lean body mass was determined from the sum of bone and lean tissue components. The DEXA equipment was housed in a dedicated room with standard radiation protection measures.

Statistical analysis

Agreement between measurements by different methods was estimated by the Bland and Altman method [9], which plots the paired difference between a measurement by the two methods against the mean of these two readings. The mean difference (d) provides an estimate of the bias, and the limits of agreement is given by the interval $d - 2s$ to $d + 2s$, where s is the standard deviation of d [9]. Correlation between the measurements by different methods was carried out by using Pearson's correlation coefficient.

Results

Table 1 summarizes features of the three devices used for measuring body composition in this study. Trained medical physics personnel are required to operate the DEXA and the *in-house* bioelectrical impedance machine (R.J.L systems), and to calculate the results. With DEXA, imaging time was typically 12 min and analysis time 14

Table 1. Characteristics of the different methods of body composition measurement.

Feature	In-house BIA	Hand-held BIA	DEXA
Portable	Yes	Yes	No
Direct output of result	No	Yes	No
Radiation	No	No	Yes
Input height and weight	Yes	Yes	Yes
Cost	£2200	£400	£80000
Weight	3.5 kg	420 g	1200 kg
Trained operator	Yes	No	Yes

BIA, bioelectrical impedance analysis.

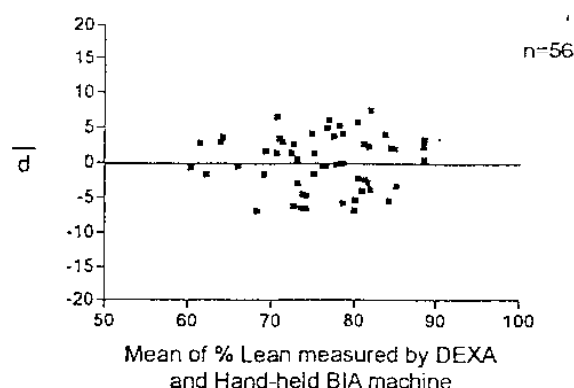


Fig. 1. Percentage lean measured by DEXA and by *hand-held* bioelectrical impedance analysis machine ($n=56$). Scatter diagram of difference between the two methods (d) plotted against mean of both measurements.

min. Bioelectrical impedance analysis using the *in-house* machine typically took about 10 min to perform and 10 min to analyse.

Doctors learned to use the *hand-held, menu-driven machine* after about 30 min reading of the instruction manual. The machine was easily operated by nursing staff after 10 min of verbal instruction and demonstration. It typically took 8 min to make the measurements; the machine displays the results immediately. The coefficient of variation for repeated measurements of electrical impedance was 0.4% when measured by the *in-house* bioelectric impedance analyser and 0.7% when measured by the *hand-held* machine.

Technical comparisons

In the entire series of 114 subjects, impedance measured by the *hand-held machine* correlated very closely with results from the *in-house* machine, both directly measured resistance ($r=0.996$; $P<0.0001$), and calculated impedance ($r=0.996$; $P<0.0001$). Agreement between the two methods was estimated by the Bland and Altman method as described above. The bias in measurement of impedance and resistance between the two methods was 26.40 and the limits of agreement were 2.14 to 50.66.

Fig. 1 shows the scatter diagram of the differences between percentage lean measured by DEXA and by the *hand-held* machine plotted against the mean of percentage lean measured by both methods in the 56 adult subjects. It can be seen that there is no obvious relation between the difference and the mean. The bias was -0.07% and the limits of agreement were -7.97% to 7.76% .

In the patients with eating disorders, the prediction equation previously described was also used to calculate the lean body mass directly from the impedance values – this gave an r value of 0.959 against DEXA measurements ($r=0.974$ using the manufacturer's equation). In IBD patients, the prediction equation derived by Jeejeebhoy's group was also used to calculate the lean body mass from impedance values – this gave an r value of 0.904 against DEXA measurements ($r=0.937$ using the manufacturer's equation).

Table 2. Lean body mass measured by the hand-held bioelectrical impedance machine in different diagnostic groups.

Subject group (n)	Lean body mass, kg (SD, range)	% Lean body mass (SD, range)	Body mass index, kg/m ² (SD, range)	Body weight, kg (SD, range)
Healthy adult subjects				
Men (n=29)	64.8 (8.3) (54.4–73.6)	83.6 (4.7) (74.9–91.1)	25.7 (2.0) (21.9–31.1)	79.9 (7.1) (67.0–92.0)
Women (n=31)	43.2 (5.9) (31.0–70.2)	71.1 (4.6) (62.1–82.3)	24.1 (3.9) (18.5–32.0)	62.9 (14.6) (43.7–100)
Women with eating disorders				
Undernourished (n=16)	37.2 (8.1) (17.0–46.0)	76.5 (7.0) (58.6–88.8)	17.6 (2.9) (11.0–21.5)	48.3 (8.5) (29–59)
Overweight (n=1)	49.3	62.9	30.3	78.4
Chronic pancreatitis				
Men (6)	57.2 (10.8) (43.7–72.5)	74.0 (3.5)* (70.7–80)	25.5 (5.4) (19.1–32.7)	77.5 (15.6) (57.8–101.3)
Woman (1)	38.1	65.8	21.5	57.9
IBD				
Men (n=9)	55.4 (5.3) (45.1–63.7)	84.6 (6.7) (78.9–90.3)	22.7 (3.6) (17.9–27.4)	66.6 (8.3) (54.0–78.8)
Women (n=9)	43.0 (3.6) (36.5–47.9)	73.8 (9.7) (60.0–90.9)	21.7 (3.9) (17.6–29.2)	59.3 (10.4) (48.2–77.5)

* $P < 0.05$ vs. healthy males.**Information obtained from consideration of proportions of fat and lean, in relation to BMI**

We investigated the relationship between BMI and lean:fat composition by using results obtained in the 102 adults. The key data (body weight, lean body mass, percentage lean and BMI) are summarized in Table 2 and in Figs 2 (males) and 3 (females). By plotting percentage lean against BMI, it becomes evident that groups of patients with similar values for BMI may be strikingly different with respect to body composition. Values for BMI were similar in healthy men and women, but in the men, a mean of 83.6% of total body mass was lean, whereas in the healthy women the lean compartment was significantly lower at 71.1% ($P < 0.01$).

In men with alcoholic pancreatitis or IBD, body composition was affected differently in the two groups; for both, the ranges of BMI were lower (although not significantly) than in the healthy men; the percentage of body weight as lean was significantly lower than controls in the alcoholic pancreatitis patients, but not in the IBD group.

Four of the nine women with IBD were underweight (BMI < 20), but their proportion of body weight as lean was within the range of healthy adults. This, with the similar data for men, indicates that underweight IBD patients in this small series (none of whom was acutely ill) were depleted of fat rather than lean. The percentage fat in the 13 underweight women with eating disorders had a much wider spread (11.2–41.3), indicating that some had lost both fat and lean tissue.

Discussion

The ideal instrument for assessment of body composition in patients should yield accurate and reproducible results, be

inexpensive, portable, easy to operate and to interpret the readings, safe for the patient, ideally should not involve irradiation, and repeated measurements should be possible. None of the available methods fulfil all, or even most, of these criteria and clearly this explains the limited use of body composition data in clinical practice. Furthermore, there are no accurate reference data for the general population on the lean:fat ratio, analogous to the regularly updated information which is collected on height, weight and BMI, related to age, sex, UK region and social class.

The lightweight, portable hand-held bioelectrical impedance analyser used in the present study proved to be a satisfactory instrument for measuring body composition. The estimation of bias between measurement of percentage lean by DEXA and the hand-held bioelectrical impedance analyser was small, and the limits of agreement were satisfactory. There was a small bias in measurement of impedance between the hand-held machine and the in-house machine and the limits of agreement were clinically acceptable. If the two electrical impedance measurements differed by 50 ohm, the widest limit of agreement, this would lead to an approximate difference of 1 kg in lean body weight measurement in a 60 kg person, 170 cm tall. Reproducibility between repeated measurements was also consistently less than 1%. Non-medical staff could be taught to use the machine in a few minutes, the program is driven by a simple menu and the results could be directly read out and stored without the need for additional software or access to a computer. If further studies in larger clinical groups support our current findings, this type of instrument is likely to have wide applications in medical practice and could also be used to collect reference population data. Since the patient has to be weighed in order to calculate lean body mass, some degree of mobility is necessary.

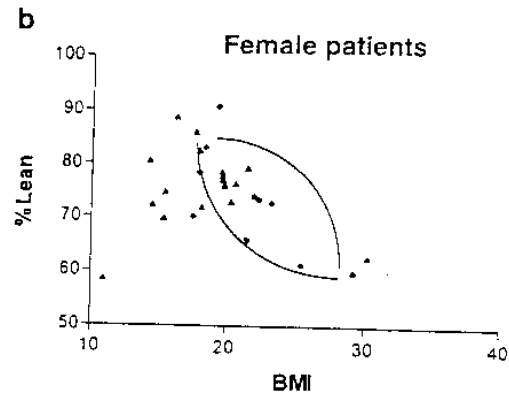
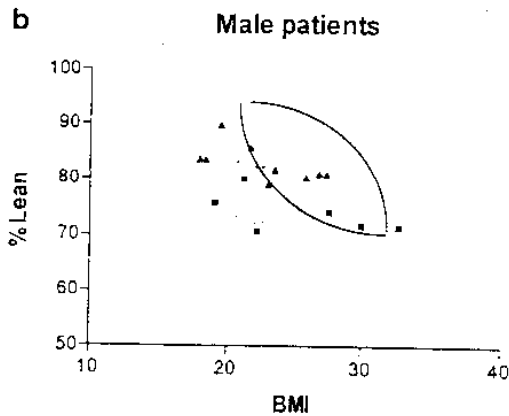
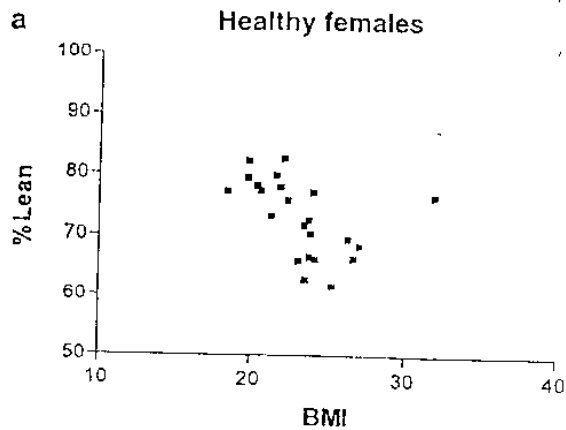
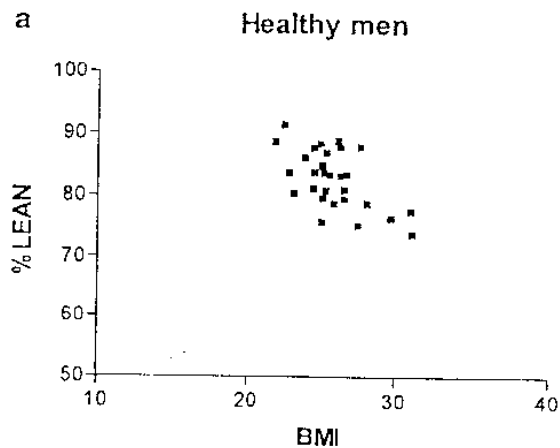


Fig. 2. Percentage lean in different groups of adult males ($n = 44$) plotted against their BMI in (a) healthy subjects and (b) patients (normal results from (a) outlined for reference). In Fig. 2b: ■, pancreatitis; ▲, IBD.

Fig. 3. Percentage lean in different groups of adult females ($n = 58$) plotted against their BMI in (a) healthy subjects and (b) patients (normal results from (a) outlined for reference). ■, Healthy; ▲, eating disorder; ▼, pancreatitis; ◆, IBD.

Apart from direct chemical analysis of postmortem tissue, every technique for measuring body composition has theoretical problems and will be unsuitable for certain groups of patients. In studies of obesity, quite different criteria are used to select an appropriate method than will be used for research in starvation, malabsorption or inflammatory bowel disease. Studies in our institution which involved comparisons with prompt neutron activation analysis (PNAA) and total body water (TBW) determination using tritiated water have shown that DEXA is a reproducible and accurate method of estimating lean body mass [5]. We now report that lean body mass, derived from impedance measurements made with a hand-held instrument (costing £400) agreed satisfactorily with that measured by DEXA (using a machine that cost £80000, 6 years ago), in both healthy and diseased subjects. Use of prediction equations derived for specific disease groups (i.e. eating disorder, IBD), instead of the manufacturer's built-in equation for the hand-held machine, did not improve the correlation with values obtained by DEXA.

The limitations of BMI in respect of the proportions of lean and fat are well recorded [10-12], but this is not widely appreciated by clinicians. BMI is an index of over- or underweight, and does not measure whether patients are over- or undernourished. Though decrease or increase in both lean and fat occur with weight loss or weight gain, the relationship between the two compartments may change. A good example of this is the increase in percentage of body mass as lean associated with the use of anabolic steroids. Our data illustrate that undernourished patients segregate into different groups predominantly depleted either of fat, of lean, or of both. More widespread use of two-compartment body composition analysis as well as body mass index in these situations should provide valuable information on the complex interplay between low nutrient intake, inflammation, nutrient loss and the effects of physical inactivity and drugs.

The two-compartment model, although invaluable conceptually, is still a highly over-simplified statement of the clinically relevant body constituents in states of under-

nutrition. Data on so-called 'lean' will be misleading in the presence of oedema, dehydration, ascites, cardiac failure, and in conditions with rapid fluid shifts such as the immediate postoperative period. Young children, in particular, may need completely different equations as the total body water compartment in children is substantially different from that in adults. One of the problems of the *hand-held* machine is the pre-programmed equation which cannot be altered. It will be useful if customized equations can be used with this machine for different groups of patients, thus maintaining the user-friendliness of instant results with the possibility of using a range of equations for different patient groups. Currently, it will be difficult to use the machine for studying kwashiorkor or beriberi in children from underdeveloped countries. The electrical impedance measurements were not done in any particular part of the menstrual cycle, but all body composition assessments were done on the same day. It is not possible in this study to determine the effect of menstrual cycle on the normal values for percentage lean or fat in healthy females.

Our primary purpose in carrying out the work described was to evaluate a technique which could be used in day-to-day practice as well as research, and would improve our clinical assessment of patients with gastrointestinal and nutritional diseases. It is increasingly important that medical and nursing staff understand and use the simple principles of anthropometry, including the two-compartment model of body composition. Our experience shows that a portable bioelectrical impedance analysis machine can be introduced easily into clinical practice. At present there are no standard population-based tables on the percentage lean when related to age, sex, stature or

body frame, but with a simple machine such as the one we have used, these data could and should be collected in future population studies.

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