Bioelectrical impedance and body composition assessment

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ABSTRACT

Bioelectrical impedance (BIA) has become increasingly popular in recent years in the assessment of body composition and body fluid status. The level of interest in this technique is related to the following advantages: it is non-invasive, inexpensive, portable and requires minimal subject compliance. However, as with all indirect methods, the ability of BIA to accurately assess body composition is dependent upon a number of technical and biological assumptions. Most BIA research to date has utilised instrumentation capable of measurement at a single frequency, commonly 50kHz. More recently, significant improvements in the prediction of body water characteristics have been cited when multiple frequency bioelectrical impedance analyses (MFBIA) are employed. MFBIA may provide a more effective means of monitoring hydration levels in studies of nutrition and physical activity. This paper provides an overview of the strengths and weaknesses of the BIA method with specific reference to assessment protocols for experimental and clinical situations. A number of studies undertaken in the authors' laboratory have considered the influence of tester, machine, time and postural differences on the reliability of impedance measures. Results from one of these studies are discussed.

INTRODUCTION

In recent years bioelectrical impedance (BIA) has become an increasingly popular modality in the assessment of body composition. The acceptance of the technique has been related in part to the ease of use of the equipment. Unfortunately, as is commonplace with new technology, numerous assumptions have been made in the translation of impedance data to 'definitive' body composition values.

As for other body composition techniques, the raw data derived from by BIA instrumentation must be manipulated to estimate body composition characteristics. In the process, a number of assumptions have been made regarding the

composition of fat (FM) and fat-free mass (FFM) and a proliferation of equations developed. Unfortunately, assumptions regarding tissue inter-relationships are often based on a static environment which are not maintained in a biological system. There are numerous factors which may contribute to observed differences in BIA measurements (Baumgartner *et al*, 1990; Chumlea *et al,* 1994). Identification of the magnitude of these changes and the way in which these factors can be controlled is important for the protocol design.

BODY COMPOSITION ASSESSMENT

Interest in body composition assessment has been extensive in recent years and this has coincided with the development of new technology. A statement by Baumgartner *et al* (1990) illustrates some of the methodological concerns in the field, namely that the area is "full of naive usage of methodology and this has contributed to misconceptions regarding applicability and validity of particular techniques."

If the aim of a research project is to measure a change in body composition, there is a need to recognise the limitations of the chosen technique, and to determine both test-retest reliability and the minimum change that can be accurately measured by a given protocol. Therefore, in order for techniques employed for body composition assessment to have universal applicability, a number of important requirements must be met. The principal measurements must be accurate and precise; they must be repeatable across laboratories; and the subsequent prediction equations must be

based on a well-defined range of individuals representative of the population of interest (Pierson *et al*, 1993).

BIOELECTRICAL IMPEDANCE ANALYSIS (BIA)

The production of reliable BIA raw data is critical but this data must be manipulated to estimate the status of body composition compartments. It is this manipulation of the raw data (which itself may already have undergone some adjustment to fit an impedance plot - see Figure 1) which may markedly increase the error associated with body composition estimation. Whilst a prediction equation developed with a given population may be employed with an equivalent subject sample, the results are only comparable when the same assessment protocol has been employed. To determine what constitutes an optimal assessment
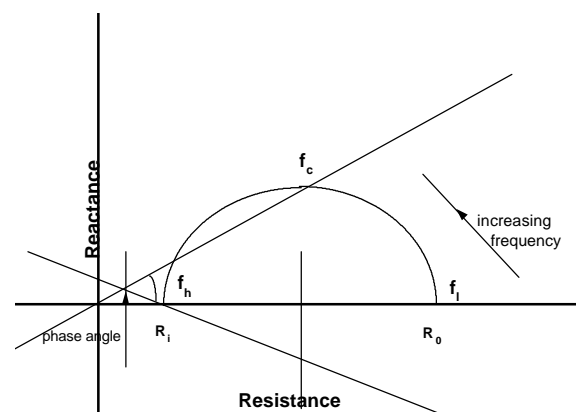

Figure 1. Impedance plot
            (Baumgartner et al, 1990)

protocol, an identification of what BIA is actually measuring, and what factors can influence this measurement, must be considered.

Impedance theory

Bioelectrical impedance analysis is based upon the greater electrolyte content and conductivity of fat-free mass, compared to adipose tissue, and on the geometrical relationship between impedance and the volume of the conductor. Impedance (Z) is the frequency-dependent opposition of a conductor to the flow of an alternating electric current, and is composed of two vectors, resistance (R) and reactance (Xc) (Baumgartner *et al,* 1988). The use of bioelectrical impedance to estimate body-fluid volumes is based on the assumption that the body can be represented by a biological circuit, with the extracellular and intracellular fluids acting as resistors in parallel, whilst the cell membrane behaves as a capacitor, and introduces a reactive and hence frequency dependent component to the total impedance (Stroud *et al*, 1995).

As displayed in Figure 1, the geometric relationship between impedance, resistance, reactance, and phase angle are frequency dependent. At low frequencies, the impedance of the cell membranes and tissue interfaces inhibit the current flow. Consequently the current is conducted through the extracellular volume only, and the measured impedance is totally resistive (R_0). At higher frequencies, the current is able to penetrate the cell membranes increasing the reactance vector, and causing the phase angle to open. The point at which the reactance and phase angle are maximum is representative of the characteristic frequency (f_c), a specific electrical trait of the conducting medium. At frequencies above this point, the reactance decreases as the capacitative ability of the biological circuit reduces, until at very high frequencies impedance is again totally reflective of the resistance vector (R_i).

Single versus multi-frequency BIA

To date, most studies of bioelectrical impedance have used machines operating at a single frequency, commonly 50kHz which is the characteristic frequency for skeletal muscle tissue. It is assumed that the total conductive volume of the body is equivalent to that of total body water (TBW), most of which is contained in muscle tissue, and that the hydration of adipose tissue is minimal. However, due to the large degree of heterogeneity in body composition of different populations, the use of this, or any single frequency may provide a significant limitation to use of this technology. Differences in body fluid distribution across body fluid compartments, variability in tissue hydration both within and among individuals, and differences in age, degree of physical fitness and adiposity can affect bioimpedance measures. Consequently, subsequent manipulation of baseline data to derive specific body composition information may be spurious.

Multifrequency bioelectrical impedance (MFBIA) has been effective in quantifying body fluid

compartments and levels of hydration among individuals (Cornish *et al*, 1993; Cornish *et al.,* 1994). Recent studies point to significant improvements in the prediction of ECW and TBW using MFBIA, as the swept multi-frequency facility is able to differentiate the proportions of intra- and extracellular fluid. At low fequencies (<50kHz) the bioelectric current is assumed to pass through the extracellular fluid. In contrast, at frequencies above 100kHz and up to 1,000kHz, the current passes through all body fluids and tissues. It has been suggested that because the water content of FFM and adipose tissue is not constant (Ryde *et al*, 1993), MFBIA may clarify the possible effects of different levels of hydration on estimates of FFM.

MFBIA Application

Bioelectrical impedance, like all non-invasive assessment techniques used to assess body composition, relies on various underlying assumptions that may have a greater or lesser degree of validity depending upon the individual being measured. As noted by Ryde *et al* (1993) more research is needed to evaluate the possible systematic errors inherent in methods such as BIA and, further, to question the validity of the various assumptions in individuals whose body composition departs from normal and to whom the greatest clinical interest may lie.

Factors which can potentially influence BIA measurements include level of hydration of the subject, posture, measurement protocol, environmental and/or skin temperature, age, gender, athletic status, body composition status and ethnic origin. Moreover, the use of BIA to assess changes in an individual over time must control for biological and environmental variables such as hydration status, timing and content of last ingested meal, skin temperature, and menstrual cycle.

Although MFBIA has improved the predictive capabilities of this technology, a consistent approach to its use must be employed if the results are to be meaningful across studies, and across measurement sessions. As outlined above, irrespective of the method employed, there is a need to recognise limitations of the chosen technique, and to determine both its reliability and precision. However, prior to this, a standard approach to the taking of measurements must be accepted. Currently no internationally accepted, standardised protocol exists for the assessment of body water compartments using BIA, including MFBIA. To enable comparison of data from different studies, and to ensure that multiple measurements in both laboratory and clinical settings can be reliably taken, a standardised protocol for whole-body bioelectrical impedance assessment needs to be devised.

While there are a number of requirements that must be met to ensure that reliable measurements are taken, these may differ depending on how the data is to be used. The requirements for experimental and clinical situations often differ as a function of restrictions in time and subject compliance.
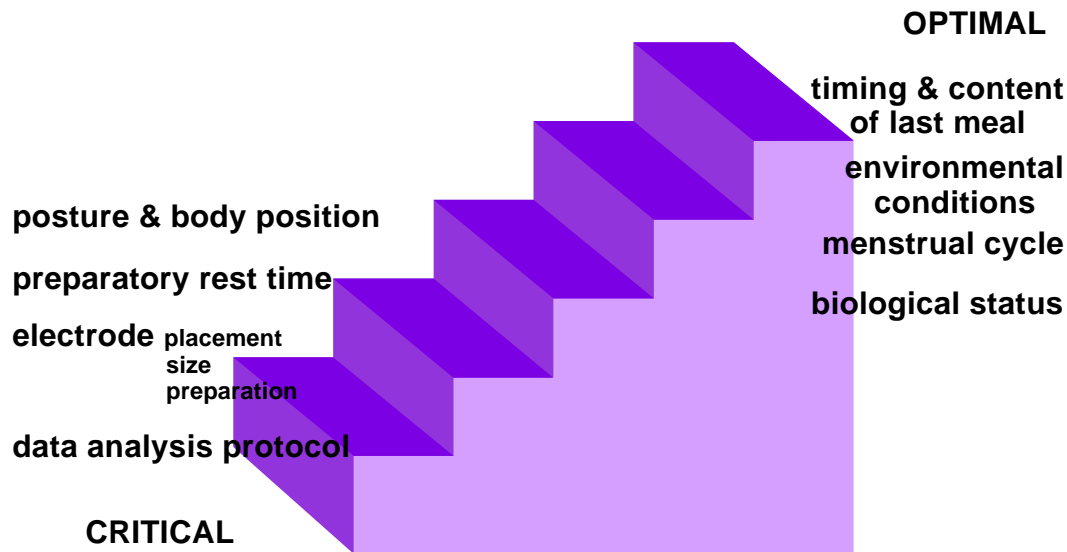
OPTIMAL

timing & content
of last meal

environmental
conditions

menstrual cycle

biological status

posture & body position

preparatory rest time

electrode placement
size
preparation

data analysis protocol

CRITICAL

Figure 2 : MFBIA protocol considerations

Protocols for experimental studies are commonly stricter than those utilised in clinical settings. Therefore, as a function of the restrictions inherent in an experimental protocol, the application of a methodology may be limited in the clinical setting. For example, clinical protocols are generally less demanding on the individuals being tested. Factors influenced in the case of bioelectrical impedance may include the preparatory rest time prior to measurement; time and content of the last ingested meal; the nature of energy expenditur and alcohol ingestion in the 12-24 hours prior to testing; the level of hydration; and the time within the menstrual cycle. However, despite the setting in which measurements are taken, there are a number of factors which will dictate the critical level of control that is the foundation of a standard protocol (see Figure 2).

Baumgartner *et al* (1990) recognised that "a greater understanding of the complexities of BIA and improvement in the methodology will help to place the technique in its rightful place alongside other instrumentation." Given that little research has considered the influence of the factors outlined in Figure 2 on impedance measurements taken with multi-frequency machines there is a need for further studies in this area. As noted by Smye (1993), although the instrumentation to undertake measurements of body impedance is available commercially, correct application and standard protocols must be employed to obtain meaningful results.

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