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BIOELECTRICAL IMPEDANCE METHODOLOGIES FOR BODY COMPOSITION STUDIES

INCAP

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I. EXECUTIVE SUMMARY

INCAP is pursuing a number of projects which require body composition data (as fat or fat-free mass). These include: a) cross-population comparisons of nutritional status; (b) ranking of individuals for risk prediction (e.g., low birthweight); c) assessment of dynamic changes (e.g., seasonal, recovery from malnutrition); d) assessing absolute levels of nutritional status. The purpose of this consultancy was to review and advise on current INCAP methodologies for assessing body composition through bio-impedance techniques.

Various groups in INCAP expressed frustration with the inadequacies of body composition methods, however, these are unavoidable. The advantages and limitations of each method should be examined so that the final method selected is appropriate to the hypotheses being tested. Hypotheses relating to fat mass are best tested by anthropometry or under-water weighing. Hypotheses relating to fat-free mass may use bio-impedance. Nevertheless, bio-impedance should not over-shadow other techniques. INCAP should continue with its own validations of bio-impedance, and would benefit greatly by obtaining the necessary apparatus for measuring body composition by water dilution.

II. INTRODUCTION

This report is a short summary of discussions held with personnel from the Institute for Nutrition of Central America and Panama (INCAP), concerning currently used bioelectrical impedance analysis (BIA) and other aspects of the field of body composition.

The purpose of the consultancy was to advise on:

1. The biological concepts on which indirect methods of assessing body composition are based;

2. The formulae used in densitometry, BIA, deuterium dilution and anthropometry;

3. Special biological situations during which such methodologies may be inappropriate; and

4. Practical aspects and possible modifications of techniques currently in use at INCAP.

A timetable of the meetings held with different groups is attached but the discussions are not individually summarized. Instead the conclusions are discussed according to the five types of application envisaged or already in progress at INCAP.

Discussions were also held concerning INCAP's studies of pregnancy outcome and lactational performance, in view of the close parallels between the work in INCAP and the Dunn Nutrition Unit's research program in the Gambia.

Finally, a number of INCAP staff expressed interest in the doubly-labeled water (DLW) method. The validation, errors and potential applications of the technique were discussed.

III. REQUIREMENTS FOR BODY COMPOSITION ANALYSIS

A. Inter-group Comparisons of Nutritional Status

This is potentially one of the most difficult applications since all indirect methods of body composition analysis rely on certain assumptions which may not apply equally in different groups being studied. The theoretical problems with the techniques in use at INCAP include the following:

1. BIA - potential differences in the viscera/muscle ratio, the water/fat-free ratio, or deep body fat distribution which may affect resistance measurements;

2. Total body water by isotope dilution - differences in the water content of fat-free mass;

3. Underwater weighing - potential differences in bone density, e.g., American blacks who often appear to have negative fat stores when Siri's formula is used;

4. Anthropometry - differences in distribution of subcutaneous fat or in subcutaneous/internal or deep fat ratio.

The extent to which these assumptions are constant between different individuals within a relatively homogenous group of subjects is also unknown. These differences, however, are measured as part of the inter-individual error and are less likely to appear as bias or error than in inter-group comparisons.

B. Ranking, Outcome Prediction and Risk-Factor Analysis

The primary requirement of any technique in this field of application is simplicity, so that it can be applied to large numbers of subjects under field conditions with minimal inter-observer error.

The BIA holds considerable promise in this respect and is already being applied by INCAP.

Several points required emphasis:

1. BIA measures fat-free mass and only predicts fat mass by difference. Although this was well understood by all INCAP personnel, attempts were being made to develop regression equations to predict fat from resistance (R) and reactance (Xc) values. It was agreed that this could mislead others and that only formulae which predict fat-free mass should be developed.

2. R and Xc values may be sufficiently informative. It was stressed that in this type of application, height^2/R (H^2/R) or Xc values need not be converted into absolute values of fat-free mass or fat but can be entered into regression or discriminant analysis directly. (Height refers to standing height.)

3. Anthropometry may be more useful than BIA under certain circumstances. BIA is an imprecise way to estimate body fat (see section E). For hypotheses related to fat mass, as opposed to fat-free mass, skinfolds may be a more appropriate index. (Underwater weighing would be best but has to be done at INCAP and may not be feasible in some groups.)

C. Expressing Dietary Requirements

It was suggested that certain nutrient requirements should be expressed in relation to fat-free mass rather than total body mass. This would be somewhat analagous to the use of basal metabolic rate (BMR) as the denominator in the new UN/WHO/FAO energy requirements. Although the logic of this approach was clear, it was felt that it would not be applied in the foreseeable future.

D. Absolute Assessment of Fat-free and Fat Mass

Underwater weighing is considered the reference method for assessment of either fat-free mass or body fatness. However, the accuracy of the method for determining percent body fat has been computed to be only about 2.5% of total body weight. This was taken as the maximum probable accuracy using currently available techniques.

Cross-validation of the BIA method suggests that under optimal conditions, it has an accuracy of 2.5 kg fat-free mass when compared with densitometry. Estimation of body fatness using impedance predictions of fat-free mass and body weight has an error of about 3% body fat (expressed as a percent of body weight) or 2.3 kg of fat mass.

The accuracy of anthropometric predictions of body fat can be better than 5% body weight when specific regression equations are used for different sex and age categories.

If absolute values of fat-free mass or fat mass are required, it is necessary to generate new predictive equations for each of these techniques within a sub-sample of the population to be studied. Densitometry is recommended as the reference technique, although it must be remembered that densitometry itself is dependent on various assumptions. The best that can be achieved is a statement of the predictive accuracy of a given technique against densitometry. INCAP has the necessary equipment and resources to prepare its own (population sub-group specific) equations and to calculate the predictive error of each equation.

Considerable confusion was generated by the expression of the error of predicting body fatness using the cross-validation approach. This method gives an error of prediction, the standard error of the estimate, from the linear regression equation relating the measured and predicted variables. Using this approach to cross-validate the BIA method, the standard error of the estimate of percent body fat was 2.91% (e.g., body fat mass expressed as a percent of body weight). Stated in more practical terms, this error amounted to 1.46 kg of body fat in a 50 kg person (e.g., .0291 = $^{x}/50$). In order to obtain a predictive error in

estimating body fat mass, a cross-validation would be performed on the measured and predicted fat mass. The calculated standard error of the estimate would be the error in predicting fat mass.

It would be inappropriate to use the predictive error of estimating body fatness (e.g., percent of body weight as fat) to calculate the error in fat mass as follows. For a 50 kg person with 20% body fat, a 2.91% error in percent body fat would give an error of 0.29 kg in fat mass. This is incorrect because the 2.91% is a percent of body weight as fat mass and not a percent of body fat mass.

E. Assessment of Dynamic Changes

1. Long-term

a) Seasonal

b) Effectiveness of supplementation programs

When an assessment of dynamic change is required, the accuracy of a method becomes less important than its precision, which can be assessed as the coefficient of variation of repeated measurements within individuals under standardized conditions. Theoretical computations and practical measurements of coefficients of variation both indicate that the precision of most methods is considerably better than their accuracy. Several techniques can therefore be useful in assessing dynamic changes.

The following rough calculation is an example of the type of exercise which should be undertaken at the planning stage of any study involving body composition measurements.

Example:

Assume a subject is 60 kg with 10% body fat. Assume 90 days supplementation at 500 kcal/day.

Total calories = 45,000 kcal. Assume 70% deposition = 31,500 kcal deposited.

Assume weight gain is 30% fat-free and 70% fat tissue by weight. Weight gain would be 3.250 kg fat and 0.875 kg fat-free mass. Thus composition changes would be:

	Start	Finish	% Change
Fat	6.000 kg	9.250 kg	+54%
Fat-Free	54.000 kg	54.875 kg	+ 1.6%

This type of calculation indicates that: a) a method specific for fat (e.g., densitometry or anthropometry) would be more appropriate than one assessing fat-free mass; b) if the hypothesis concerns fat-free mass, then a large number of subjects will be needed to resolve the small differences; and c) assessment of energy balance or imbalance over the short-term (e.g., 2 weeks or less) is quite impossible with current methods.

2. Short-term

a) Assessment of recovery from malnutrition
b) Effectiveness of clinical treatments
c) Energy balance within individuals
d) Assessment of dehydration and edema loss

For many of these applications, body composition methods are neither sufficiently accurate not precise. For instance, the possibility of using BIA to assess dehydration during phototherapy of neonates was raised. In this case, simple weighing the baby before and after treatment would be at least 30 timesas precise as BIA. This illustrates the danger of trying to use BIA to measure everything.

IV. RECOMMENDATIONS

The above comments only summarize the overall principles which were discussed with INCAP personnel. The topics were covered in considerably greater depth with individual groups and detailed recommendations were made in a number of fieldswhich are outside the scope of this report.

However, since the major interest concerned BIA our detailed recommendations in this field are listed below.

The measurement of R and Xc across the longitudinal axes (ipsilateral and contralateral) of the body was stressed. These measurements are necessary to determine the lowest R value which is used in prediction equations for fat-free mass, total body water, and extracellular fluid volume. The use of equations provided by the manufacturer of the BIA instrument was discouraged because these equations were derived using improper densitometric procedures.

Measurements of R and Xc could be improved with the following suggestions. Subjects should have a clean, dry skin surface for application of electrodes. For field studies, R and Xc should be determined in a relatively cool, shady area and not in direct sunlight. No measurements should be made on subjects with perceptibly warm skin or accumulation of sweat on skin. Use of a wide, horizontal table or cot was recommended to avoid direct approximation of skin surfaces between the lower limbs and between

the torso and upper limbs. All measurements should be made under consistent and standardized conditions, such as after a light breakfast, not postabsorptive state, after voiding, and not after exercise. If impedance measurements are intended for body composition assessment, factors such as dehydration and fever must be avoided.

The type of electrode used for reliable BIA measurements is important. The electrode must be disposable and not reusable. The spot aluminum foil electrodes (Contact Products, No. M6001; Dallas, Texas) with a light application of electrocardiographic gel is recommended. Electrodes should be placed on the subject who rests supine and horizontal on the table or cot for five minutes before any measurements are performed.

With the exception of infants, the electrodes should be positioned in the middle of the dorsal surfaces of the hands and feel proximal to the metacarpal-phalangeal and metatarsal-phalangeal joints, respectively, and also medially between the distal prominences of the radius and the ulna and between the medial and lateral malleoli at the ankle. Specifically, the proximal edge of one detector electrode was in line with the proximal edge of the ulnar tubercle at the wrist, and the proximal edge of the other detecting electrode was in line with the medial malleolus of the ankle. The current-introducing electrodes are placed a minimum distance of the diameter of the wrist or ankle beyond the paired detector electrode.

For infants, the detecting electrodes should be placed at the wrist and ankle as in adult. However, the current-introducing electrode must be placed a distance equal to or greater than the diameter of the wrist and ankle. Drs. Torun and Solomons should be consulted about their findings on this topic.

Investigators at INCAP are encouraged to estimate the precision of BIA measurements both under field conditions and strictly controlled conditions. Such estimates are useful in establishing the technical errors in applying this technique in research protocols. Using precision ($\pm$ 1%) resistors, the calibration of the BIA instrument should be checked <u>before</u> each testing session. If this check fails, the instrument must be returned for repair to the manufacturer. To facilitate prolonged operation of the BIA instrument, proper charging of the battery must be maintained.

As mentioned previously, qualitative information can be obtained from changes in R, Xc, and H^2/R. Even though prediction models are not available for the populations under study by INCAP, meaningful information on changes in fat-free mass, total body water can be inferred from impedence variables alone.

The continuation of development and validation of body composition models using BIA measurements and reference values from densitometry is encouraged. If possible, the direct chemical analysis of cadavers of accident victims would be useful in establishing the validity of densitometry with particular reference to bone mineral density, muscle/visceral protein ratio, water/protein ratio, and subcutaneous/internal fat ratio.

V. OVERALL CONCLUSIONS

1. BIA will be a useful tool to INCAP, but it must be used with equal, if not greater, prudence than would be applied to other techniques.

2. BIA should not be seen as a panacea and should not overshadow more traditional methods such as anthropometry.

3. INCAP is well equipped to perform their own validations of BIA, but care must be taken to ensure that the method does not become an end in itself merely because it is novel.

4. INCAP has already produced some very interesting data using BIA in certain fields and these should be pursued.

5. The acquisition of appropriate instrumentation to measure total body water by isotope dilution would be a great advantage to INCAP. This could be a mass spectrometer with a dual capacity to make doubly labeled water measurements which have many potential applications in a number of INCAP's basic research and applied programs.

APPENDIX: TIMETABLE OF ACTIVITIES

Monday 18th August	07.00-15.45	Initial discussions with Eric Diaz and Hernan Delgado. Tour of INCAP. Introductions to personnel. Discussion of INCAP's BIA validation studies.
	15.45-17.30	Meeting to plan consultancy timetable with Hernan Delgado, Eric Diaz, Noel Solomons, Rafael Flores, Benjamin Torun, Fransisco Chew, Maarten Immink, Edgar Khestler, Rosa Amurrio, Oscar Pineda.
Tuesday 19th August	07.30-10.30	Discussion of Noel Solomon's present and projected uses of BIA. Short visit to CESSIAM.
	10.30-12.30	Detailed discussion and inspection of data with Eric Diaz.
	13.15-16.00	Meeting with Benny Torun and Fransisco Chew.

	16.00-17.00	General presentation to INCAP staff by Henry Lukaski. "Assessment of Body Composition with Emphasis on BIA".
Wednesday 20th August	08.30-12.30	Meeting with Benny Torun, Rafael Flores, Eric Diaz, Maarten Immink. Discussion of deuterium dilution technique. Presentation on "Double Labelled Water Technique for Measuring Free-Living Energy Expenditure" by Andrew Prentice. Discussion of potential applications in INCAP.
	12.30-15.00	Detailed statistical scrutiny of INCAP's BIA cross-validation data with Eric Diaz and Rafael Flores.
	15.00-16.00	Further meeting with Benny Torun. Possible collaboration discussed.
	16.00-17.45	Presentation to INCAP staff by Andrew Prentice on "Maternal Nutrition and Lactational Performance".

Thursday 21st August	08.00-12.45	Meeting with Hernan Delgado, Berta Garcia, Patricia Palma, Elena Brineman, Maggie Fisher, Rosa Amurrio, Lisa Welman, Clara. Discussion of body composition applications. Nutrition-lactation interactions. Pregnancy supplementation. Presentation of latest Gambian supplement results by Andrew Prentice.
	15.30-17.30	Meeting with Eric Diaz, Maarten Immink, Edgar Khestler and Rafael Flores. Further scrutiny of BIA vs underwater weighing validation.
Friday 22nd August	07.30-10.00	Detailed practical inspection of INCAP's BIA, underwater weighing and anthropometric techniques.
	10.00-12.45	Visit to IGSS neonatal care unit. Discussion of pregnancy monitoring studies with Dr. Menendez, Eric Diaz, and Edgar Khestler. Discussion of neonatal applications of BIA with Rolando Figueroa, Roland Cevezo,

Fransisco Chew, and Eric Diaz.

13.00-15.30 Preparation of summary.

15.30-16.15 Discussion of post-partum measurements, with Edgar Khestler, Eric Diaz, Eric Boy, Dr. Menendez.

16.15-17.30 Summary of conclusions and recommendations by Henry Lukaski and Andrew Prentice.