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A brief history of body composition – from F.D. Moore to the new Reference Man

Abstract The history of applying body composition measurements to physiology is short, well less than a century. Progress has been phenomenal, on three different fronts: tracer dilution methods, neutron activation methods, and imaging methods. The latter have seen the most recent and exciting advances, and we have probably just "scratched the surface" for the futures of imaging, with spectroscopy showing great promise. However the physiological principles established in the 1950-1980 era are the reason we are here; measurements that lead to diagnosis, treatment, and understanding of disease mechanisms. The future is very bright.

Key words Cadaver analysis • Gold standard • Tracer dilution • Imaging • In vivo neutron activation • CT • MRI • MR spectroscopy • Cancer • AIDS • Wasting disease • Numerator/denominator • Reference Man

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The measurement sciences that have been applied to the study of body composition have improved remarkably in precision, scope, and experience during the 60 years since the first efforts by Al Behnke, who made quantitative measurements of body composition in normal young sailors, and the inspired work of Moore a few years later with measurements in critically ill patients. Large databases were created, occasionally in coordinated studies of normal subjects, more frequently in the study of disease states [1, 2], with increasing inputs from the disciplines of statistics and population ecology. By contrast, the sciences of cadaver analysis by dissection and chemistry, the gold standards to which indirect methods have traditionally had recourse, have changed little in a century, and are rarely referenced in publications of Phase Five in the history of body composition research (Fig. 1).

The move from anatomy to physiology as the lodestone to body composition research began with Frances Moore as pathfinder and prolific contributor, starting with medical/physiological measurements in the 1940s and culminating in his seminal book *The Body Cell Mass and Its Supporting Environment*, published in 1963 [3]. His great contribution, using tracer dilution measurements for potassium, sodium, and the fluid compartments, focused attention on the ions that charge the batteries of cell function. The great scientist and disciplinarian Elsie Widdowson kept anatomy in view, but the merging of anatomical and physiological information bases swung strongly to physiology and medical applications between 1950 and 1980, injecting these disciplines strongly into the research components of clinical medicine, providing the basis for a potential utility to medical practice and clinical care, with special attention to the diagnosis and management of the malnutritions and chronic diseases, and to experimental, frequently aggressive treatments applicable to cancer, AIDS [1], and other wasting diseases [2], in which the balance between anabolic and catabolic forces was studied and interventions applied.

Body Composition: A Small Specialty

I. A Short History: The Tyranny of Methods

First Epoch:	1850–1942	Precision without biology
Second Epoch:	1942–1963	Biology without precision
Third Epoch:	1963–1986	In search of precision
Fourth Epoch:	1986–	In search of accuracy

II. Definition of Terms

The Four-Compartment Model

III. The Quality of the Body Cell Mass	**Why should we measure it?**
To solve the Nernst equation	Physiology of the cell membrane
To describe growth and development	Epidemiology and public health
To describe aging	Cell physiology in aging
To understand disease states	Medical research
To guide interventions	Clinical medicine

IV. The Methods: **Submission to tyranny** ***When methods are inadequate***
Escape from tyranny? ***The power of orthogonal methods***

The Numerators

Anthropometry	Body fat, regional
Densitometry	Body fat
Indicator dilution methods	Water, ECW, plasma volume, RBC mass, Na_e, K_e, Cl_e, argon,
Potassium	Total body potassium
BioImpedance Analysis	Practically everything
In vivo neutron activation analysis	The gold standard? High-tech
Gamma resonance spectroscopy	High-tech plus
PET	Regional metabolism

The Denominators

Dual-energy absorptiometry	Bone, soft tissue, “for the middle income”
CT/MRI	Tissue volumes, “for the wealthy”
MR spectroscopy	The sky is the limit

Metabolic spaces and other transients — Physiology of disease states

V. The Third Millennium, The Fourth Epoch: Today and Tomorrow

The costs and benefits of clinical interventions — AIDS, malnutritions, cancer
The research agenda

Fig. 1 History of body composition research

In order to apply body composition methods to manage and to intervene optimally in the medical conditions in which normal homeostatic mechanisms have failed, we require measurements in normal subjects, when homeostasis is functioning normally, and we require them at just the level of physiological and anatomical sophistication relevant to the disease and its proposed remedy. Thus, surgeons, physiologists, immunologists, and molecular biologists became our colleagues and our sources, both of patients and of hypotheses, as well as interventions to be tried. Each of these classes of investigators, approaching from the operating room or the bedside, required a library of “normal averages and normal ranges”, and these are influenced by gender, age (a huge task when the intricacies of pediatric growth and development are added), size, exercise status, and race, all of them potent influences on a benchmark reference person [4].

Beginning in 1979, Steve Heymsfield [5] led in the reintroduction of anatomy to the science of body composition, by recognizing the power of computed tomography (CT) scanning, applied across many body sections, to provide a new, precise, in-vivo series of denominators, organ-specific tissue volumes, where the numerator-ions reside. In the following 25 years, the explosion of imaging technologies, dual-energy photon methods, and then MRI brought back anatomical measurements as the most active research frontier in our small field [6]. Consider the profusion of papers at this meeting in which an imaging technique is a basic component.

Two other research streams must be listed: (a) the nuclear-based methods of neutron activation, which have been developed with Stan Cohn, Ken Ellis, and a great family of collaborators at Brookhaven, the site of two of the five Body Composition Symposia, the cornerstone criterion methods to my work over the past 40 years; and (b) perhaps just around the corner, the very high-tech, high-promise method of gamma resonance spectroscopy.

All of these premiere methods are high-tech, relatively invasive, expensive, and most require large immobile laboratories. Alongside these methods, calibrated by them, are the bedside and field methods of bioimpedance analysis, anthropometrics, and a series of exercise response and function tests highly relevant to the clinical imperatives for preoperative screening and fitness evaluation, which might serve as entry points for referral for more precise measurements.

In providing this lightning review of the field which has grown in clinical relevance during the lifetimes of most of us on this podium this morning, I will mention, as prologue and summary, a goal in which I invite the collaboration of many members of this audience. It is time that we collect the fruits of 40 years of research to produce a new reference standard, a Reference Man, Woman, and Child. With the same type of shared effort that is now producing the Human Genome, we invite your participation in collecting the data that have come from all of our laboratories to provide to our own small community of body composition scientists and to the much larger medical, public health and perhaps also anthropological communities where the data may be used. And there are new dimensions since the mammoth International Committee on Radiation Protection Report 23, first published in 1975 [7]: we now recognize that Asian, Hispanic, and African normal subjects are different from one another. The data now available for women and children have increased greatly. And the effects of aging must be projected at least to the ninth decade [8], and soon to beyond the centenarian target, reflecting continuing increases in the average life span.

We are far more prepared now than then to add measurements that reflect the health of a tissue; bone, muscle, and brain functions interact. Many of these domains will map directly into a genetic reference map, a connection that the current authors are equipped to recognize, but not to fulfill.

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