MASTER

RECEIVED BY TIC MAR 16 1973

BODY COMPOSITION BY ABSORPTIOMETRY OF MONOENERGETIC RADIATION

Richard B. Mazess, John R. Cameron and James A. Sorenson

Several authors have indicated that the fractional composition of a multi-component material can be determined through measuring the attenuation of gamma radiation by the substance at several energies. The attenuation of monoenergetic radiation in a single absorber is described by:

$$I = I_0 e^{-\mu x} \quad \text{or} \quad \log I_0 - \log I = \mu x \quad (1)$$

where I is the beam intensity after passing through the absorber, I_0 is the initial beam intensity, μ is the mass absorption coefficient (cm^2/g) of the absorber, and x is the mass of the absorber (g/cm^2) in the beam. For a complex absorber the total absorption coefficient (μ_t) at any single energy is the sum of the fractional absorption contributions of the various components of the material:

$$\mu_t = \mu_a f_a + \mu_b f_b + \dots + \mu_n f_n \quad (2)$$

where μ_a is the absorption coefficient of component a , and f_a is the fractional contribution of a to the total mass. For a material composed of n components it is possible to derive the fractional composition by solving a series of n equations of the form of (1), and using equation (2), where each equation describes an absorption measurement at a different energy. In practice, however, it is quite difficult to use absorptiometry at different energies for composition of complex mixtures because of the cumulative uncertainties of the measurements at each energy. Moreover, it is difficult to obtain convenient mono-

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

energetic sources in many of the most useful energy ranges.

We have previously suggested in several publications that absorption measurements at two energies could be used to measure the relative composition of: (1) lean cellular mass versus fat mass in soft-tissue in vivo and (2) organic versus inorganic (mineral) in excised bone. In most of our work to date absorption measurements were done with ^{241}Am (60 kev) or a tin-filtered ^{125}I source (27.4 kev). A conventional single channel analyzer system with scaler/timer and digital output has been used. The ratio of ^{125}I absorption to that with ^{241}Am provides a direct index of relative composition. For example, in bone 100% mineral gives a ratio of 7.0 and 100% collagen 2.0; in soft-tissue 100% lean gives a ratio of 2.10 and 100% fat 1.52. In typical dry bone a 2% uncertainty in the $^{125}\text{I}/^{241}\text{Am}$ gives a fractional uncertainty of 0.02. In typical human soft-tissue a 2% error in the ratio gives an uncertainty in fractional composition of about 0.06 to 0.07. Thus, soft-tissue composition measurements require absorption determinations of high precision and accuracy.

Our initial work in measuring the collagen-mineral composition of bone was incomplete, but suggested that relative composition could be measured within about 2%. Far more extensive work has been done in evaluating the composition of soft-tissue. Precision and accuracy have been assessed using various soft-tissue phantoms (polyethylene and sodium acetate; paraffin and water) as well as meat samples (fat content determined by lipid extraction). Measurements were made at a

single location in mixtures of known composition. The uncertainties in the $^{125}\text{I}/^{241}\text{Am}$ ratio were held to about 1 to 2%; use of water and lard as absorption standards halved the variability associated with varying measurement conditions. Fractional composition in these experiments was estimated within about 0.03 and the correlation coefficients were about 0.98.

The first applications of absorption methods for soft-tissue measurement were limited to single point measurements. With careful repositioning the reproducibility of these measurements was high, and with high total counts the error of the $^{125}\text{I}/^{241}\text{Am}$ ratio was held to 0.5%; this allowed an uncertainty of only 0.02 in the fraction of fat. However, small variations in positioning of a single point can lead to large compositional differences in the same person, and it is difficult to locate corresponding points in any series of subjects. Consequently a scanning method has been developed to allow determination of composition in a linear path across an accessible area, usually the middle of the upperarm. Scanning across a limb aids relocation in the same person, and facilitates intercomparison among individuals. Repositioning may alter the total tissue mass scanned but the relative composition of the limb is fairly uniform thus eliminating a major source of error. In addition, the scanning procedure permits direct determination of the lean cellular, fat, and bone mineral mass at the measurement site. Theoretically a third energy would be needed to have simultaneous absorptiometric measurement

of bone mineral together with soft-tissue. However, the absorption coefficient of bone mineral is much greater than that of soft-tissue and the mineral absorption is sharply demarcated in the typical scan. This permits separation of the mineral absorption without use of the third energy. Typical upperarm scans on a fat person, and on a thin person, are shown in Figure 1. Immediate reproducibility of these scans is high; in a series of replicate scans on 63 subjects the uncertainty for bone mineral content was 2% while that for soft-tissue absorption was about 0.5%.

There are several problems associated with this new scanning procedure. Subject movement can seriously affect results; we find it advantageous to use the average of several fast-speed scans to minimize this problem. Sources of high activity are needed to insure adequate counts during the scan of the tissue and bone. Such sources will give high count rates with an unattenuated beam and appropriate corrections must be made for loss of counts due to system deadtime. In scanning the upperarm we use a detector collimation of 3-mm with a 100 to 200 mCi source of ^{125}I and 6-mm with a 125 mCi source of ^{241}Am ; the source collimator distance is about 17 cm. Larger collimation produced problems with scattered radiation. The radiation from ^{241}Am is monoenergetic but ^{125}I has several low energy peaks and suitable tin filtering is necessary to insure a narrow spectrum. Contaminants in ^{125}I sources, including ^{126}I , may give problems. Brehmstrahlung sources, or other low energy sources such as ^{109}Cd or ^{210}Pb , may prove useful. To insure the best precision and accuracy calibration

standards should be used with the same geometry and general conditions as in subject measurement.

Replicate scan determinations of soft-tissue absorption were made on nine subjects after a six-month interval to assess long-term precision. The error for both ^{125}I and ^{241}Am scans was about 2.5%. The ratio of the ^{125}I to ^{241}Am tissue scans was more highly reproducible, indicating that part of the difference between scans at the two times reflected actual changes of soft-tissue mass, most probably due to repositioning. The mean difference between the ratios at the two times was about 1.7%. In two subjects remeasurements were made five times each during a nine month period (Table 1). Even without careful relocation of scan sites it appears that soft-tissue absorption can be determined reliably (2 to 3% error), and the $^{125}\text{I}/^{241}\text{Am}$ ratio can be measured with even higher precision (about 1%). An error of this magnitude is negligible with regard to the lean-tissue mass in a limb, but under usual conditions translates into an error of about 3 to 4% in the relative fat content.

Table 1 - Repeat measurements at 5 times over a 9-month period in two subjects

Subject		^{241}Am Tissue Scan	^{125}I Tissue Scan	Ratio $^{125}\text{I}/^{241}\text{Am}$
RW	Mean	69.6	144.2	2.070
	SD	1.95	3.72	0.006
	CV	2.80%	2.58%	0.27%
RBM	Mean	104.5	214.2	2.045
	SD	3.07	8.32	0.026
	CV	2.94%	3.88%	1.28%

On a standard measured several times the coefficient of variation was about 1.2% for both ^{125}I and ^{241}Am scans, as well as for the $^{125}\text{I}/^{241}\text{Am}$ ratio. This error amounted to 0.019 units or about .033 in fractional composition.

We are currently studying the composition relationships at different body sites and examining the association of these measurements with total body composition, as measured by whole-body ^{40}K counting, hydrometric body density, and tritium dilution. In 19 subjects measured in preliminary work we found a high correlation ($r = 0.98$) between the absorptiometric measure of soft-tissue mass and circumference of the upperarm. In these same subjects the $^{125}\text{I}/^{241}\text{Am}$ ratio was highly negatively correlated ($r = 0.91$) with the tricaps fatfold measurement (using Lange constant tension calipers).

We do not feel that the absorptiometric measures are merely costly and time-consuming elaborations of anthropometric and fatfold measures, but rather that soft-tissue absorptiometry eliminates the many errors inherent in the latter indirect measures and will provide precise and accurate indications of both local and total body composition. For example it appears that composition of the upperarm in young adults is about 16% fat, 81% lean-tissue, and 3% bone mineral. Similar values might be expected for total body composition. Total soft-tissue, lean-tissue, and bone mineral mass and the relative composition can be measured with very high precision and accuracy; the relative fat composition involves a somewhat greater error.

The absorptiometric measures have already been used to evaluate soft-tissue and compositional changes during low

protein-low calcium diet(see USAEC Report C00-1422-
Further data is being collected to define normative patterns
to aid in clinical and diagnostic applications, and to provide
ancillary information to absorptiometric evaluation of skeletal
status. We are also evaluating use ¹⁰⁹Cd to determine the
water and fat content of adipose tissue; this will provide
a clinical and diagnostic index of obesity.

FIGURE 1. Absorption scans of the upperarm in a heavy, fat person (left) and a thin, lean person (right). The unshaded area represents soft-tissue absorption and is proportional to the tissue mass; the shaded portion represents the absorption by bone and is proportional to the bone mineral mass. The fat person has greater soft-tissue absorption, particularly with americium; consequently the ratio of the iodine-125 scan to the americium-241 scan is lower in the fat person (1.72) than in the thin person (2.06). A ratio of 1.52 indicates 100% fat (0% lean) while a ratio of 2.10 indicates 0% fat (100% lean).