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NON INVASIVE TECHNIQUES FOR DETERMINING MUSCULOSKELETON BODY COMPOSITION

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NON-INVASIVE TECHNIQUES FOR DETERMINING MUSCULO-SKELETAL BODY COMPOSITION

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The development of in vivo neutron activation analysis (IVNAA) and its combination with gamma spectroscopy has opened a new era of research into the elemental composition of human beings. Such research holds, of course, interest for the space program.

Until fairly recently, remarkably few data had been recorded on the exact amounts of the elements of which the human body is composed. With IVNAA, a number of elements have been measured: calcium, phosphorus, sodium and chlorine. With a refinement of IVNAA, cadmium and nitrogen can also be measured.

From the basic data, a four-compartment model of the body is constructed: bone mineral, lean body tissue, body cell mass (muscle) and total body fat (Fig. 1). The bone mineral compartment is quantified by neutron activation of total body calcium. As 99% of the calcium resides in skeletal tissue, a direct measure of the skeletal mass is obtained. The muscle mass and viscera (body cell mass) and lean body tissue are determined from the nitrogen and potassium measurements. The difference between the total of these three compartments and total body weight yields the measure of total body fat.

Neutron activation is an analytic tool based on nuclear reactions rather than chemical reactions. The essential physical parameters involved include the isotopic abundance, cross-section, half-lives of the product isotopes, and energy emission of the product.

Brookhaven Laboratory has facilities for both prompt gamma neutron activation and delayed gamma neutron activation. IVNAA systems generate a moderated beam of fast neutrons to the subject. Capture of the neutrons by atoms of the target elements creates unstable radionuclides which revert to a stable condition by the emission of one or more gamma rays of characteristic energy. The energy level identifies the element, and the level of activity reveals its abundance.

For the delayed gamma radiation, fourteen 50 Ci ^{238}Pu,Be sources are positioned in two banks, one above and the other below the subject (Fig. 2). Uniformity of the thermal neutron flux in the body is enhanced by the use of a premoderator, which accommodates variations in body habitus among subjects. For an exposure time of 5 min, the total body dose is approximately 270 mrem.

The activity induced in the subject, in the delayed gamma technique, is measured in the 54-detector whole body counter (Fig 3). The detection facility is located in a highly shielded room (1.3 m concrete, 20 cm steel, and an inner liner of Pb, Cu and Al). The detection system consists of two sets of 27 detectors arranged in 3 x 9 arrays above and below the subject. The subject lies in the supine position and is counted for 15 min.

The IVNAA technique has an accuracy and precision of $\pm 1\%$ for total body calcium (TBCa), and ± 2-3% for total body chlorine (TBCl) and total body sodium (TBNa), and $\pm 4\%$ for total body phosphorus (TBP). Calibration was accomplished with the use of an anthropomorphic phantom containing these elements at physiological levels (corresponding to the values listed for the ICRP Standard Man). Prior to the irradiation, the patient's natural level of body potassium is determined by counting ^{40}K. The accuracy and precision for TBK is $\pm 3.3\%$, based on measurements with the anthropomorphic phantom.

The prompt gamma technique is particularly well-suited to the measurement of nitrogen and hydrogen. The technique is based on the $^{14}N(n\gamma)^{15}N$ reaction. The fast neutrons are derived from an 85 Ci source of ^{238}Pu,Be located about 50 cm below the subject. A rectangular beam (30 x 60 cm) is developed at the level of the bed upon which the subject rests, with the use of shielding. The subject is scanned in both the prone and supine positions (Fig 4). Irradiation and detection are performed simultaneously, as the decay in the prompt gamma technique is so rapid (10^{-15} sec). With the use of the restricted beam size and good collimation, the clinician or nurse may remain near the subject during the activation measurement process.

With a measurement time of 200 s per section, the accuracy and precision are ±4% for total body nitrogen (TBN) in the anthropomorphic phantom, and ±2% for total body hydrogen (TBH). The estimated total body dose for the measurement is approximately 40 mrem (0.0004 Sv). (A quality factor of 10 is assumed). The dose equivalent to the bone marrow is approximately one-third of that.

The detector geometry yields a quite uniform composite sensitivity (i.e., equal number of counts per unit mass of nitrogen per unit dose). The use of an internal standard based on body hydrogen further increases the uniform composite sensitivity and hence increases the accuracy of the measurement.

Counting is accomplished with two 6" dia x 6" thick NaI(Tl) detectors, positioned above the subject, just out of direct view of the neutron beam. The detectors are shielded for mixed neutron-gamma background with polyethylene bricks doped with boron and lead. A 2" lead annulus directly surrounding the detectors reduces background contributions to the hydrogen peak. Fractional charge collection techniques are also used to reduce electronic pile-up problems in the NaI detectors that result from high count rates.

BODY COMPOSITION STUDIES

The model formed for body composition is a four compartment model made feasible by the data obtained through the application of in vivo neutron activation analysis. Since nuclear rather than chemical reactions are measured, it is of no importance in what chemical combination an element is found.

The compartmental view of the human body is considerable more abstract than the traditional view of tissues and organs. It is capable of yielding new insights concerning the range of values for various elements in normal individuals, and the quantitative and qualitative nature of variations corresponding to age, sex, body habitus, various diseases and metabolic disorders, and the stress of environmental changes. An example of the change in a body element, calcium, with age [illegible] lation is shown in Fig. 5. Loss of calcium in other [illegible] in astronauts during periods in a gr[illegible] envir[illegible] n be documented and analyzed.

Similarly, the loss of potassium and nitrogen, in addition to calcium, as a function of age is shown in Fig. 6. Fig. 7 shows the relationship between lean body mass and body cell mass in two age groups: 20-49 and 50-79 yr. Baseline data on body composition of age- and sex-matched individuals provide a basis for comparison and evaluation of individuals with various diseases and dysfunctions. There is a large data bank for normal individuals, and numerous studies of a variety of disorders have been performed along with studies of the natural effects of aging. These studies also cover the evaluation of a variety of therapies developed to ameliorate specific disorders.

Summary

In vivo neutron activation analysis, combined with gamma spectrometry, has ushered in a new era of clinical diagnosis and evaluation of therapies, and well as investigation into and modelling of body composition in both normal individuals and patients suffering from various deseases and dysfunctions.

Although the techniques are relatively new, it is already clear that considerable advances are at hand with increases in accuracy and precision, increase in the number of elements susceptible to measurement, enhancement of uniformity and reduction of the dose required for the measurement.

Body composition studies have provided baseline data on such vital constituents as nitrogen, potassium and calcium. The non-invasive measurement techniques are particularly suitable for study of the musculo-skeletal changes in body composition. Of particular relevance here is the measurement of calcium loss in astronauts during prolonged space flights.

It seems likely that, by the end of this century, significant progress will have been made with this research tool, providing exciting insights into the composition and dynamics of the human organism.

Question

In your curves of bone loss in men, is there anything at age 65 to explain the rapid loss of calcium or potassium? Have you looked at differences in these variables in an exercising versus a non-exercising population?

Answer

The loss of potassium and calcium in older men may be related to decreased physical activity. All we know, for sure, is that the calcium loss and the potassium loss in men and women are universal phenomena. As you know, exercise in one of the techniques used for treating osteoporotic patients. Exercise is effective in decreasing the rate of loss of calcium and also the loss of muscle mass (potassium).

Question

What is the radiation dose involved in both of these procedures?

Answer

The radiation dose required for measuring total body calcium, phosphorus, sodium and chlorine is 270 mrem (using a quality factor of 10 for the neutrons). For the nitrogen determination, the radiation dose is <50 mrem. These radiation doses, that I just gave you, are to the skin, the actual dose to the bone marrow (the target organ) is approximately 1/3 of the above value.

CAPTIONS

Fig. 1 Body Composition Model for a Standard Man (74 kg).

Fig. 2 Total body neutron activation facility. Patient is positioned between upper and lower Guide tubes which are used to position fourteen 50-Ci sources of $^{239}Pu,Be$.

Fig. 3 Brookhaven 54 detector whole body counter.

Fig. 4 Prompt-gamma neutron activation facility for the measurement of total body nitrogen.

Fig. 5 Total body calcium in a female population as a function of age.

● = normal o = osteoporotic

Fig. 6 Loss of total body calcium, potassium and protein (nitrogen) as a function of age.

Fig. 7 Relationship between lean body mass and body cell mass.