ABSTRACT

A DICHROMATIC ATTENUATION TECHNIQUE FOR THE IN VIVO DETERMINATION OF BONE MINERAL CONTENT

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The determination of the composition of a two component substance by gamma-ray and x-ray attenuation has been studied. The particular application investigated was the measurement of human limbs, which were assumed to contain a bone mineral component and a soft tissue component. Radionuclides (^{125}I, ^{241}Am, and ^{153}Gd) have been used as sources of nearly mono-energetic photon beams. The attenuation was measured by securely and reproducibly holding the limb or other objects between a collimated NaI(Tl) scintillation detector and a source position. The collimated photon sources were mounted on a wheel, which permitted each source to be sequentially and reproducibly placed in the source position.

The formulas used in the dichromatic attenuation technique (DAT) were derived from simple exponential attenuation theory. The difficulties of such attenuation measurements were (a) the deviation of the attenuation of the photon beams from the exponential formulas, (b) the

variation of the composition of the human tissues, and (c) the problems of repositioning the body from measurement to measurement.

Deviation from exponential attenuation was related to the size of the photon beams, monochromaticity of the photon beams, and the scattered radiation detected. Of these factors the photon beam size had the most effect. The size of the photon beams, and the effects of size, were estimated from experimentally determined beam profiles. The size of the ^{125}I beams (28 keV) ranged from 1.5 mm to 3 mm in diameter, and the size of the ^{241}Am beams (60 keV) ranged from 2.5 mm to 4 mm. Using these beams the DAT estimate of the bone mineral component deviated from an accurate value by as much as 30% near the edge of the bone, and a 10% deviation was typical. The scattered radiation was measured by examining the transmission of the photon beams as a function of detector aperture size. The scattered radiation constituted 5% to 15% of the detected photons for the ^{125}I and ^{241}Am beams and for thicknesses of tissue of the limbs, but the exponential characteristic of the attenuation was not altered.

Deviation of the beams from monochromaticity was evaluated from the spectrum of the photon beams. The hardening of the ^{125}I beam caused a 3 mg/cm^2 decrease in the estimated bone mineral content (BMC) per g/cm^2 of soft tissue cover. Compensation for this small deviation was possible.

The effect of the variation in the composition of soft tissue and bone mineral was investigated. The lipid content of soft tissue was found to decrease the estimate of BMC 0.06 g/cm^2 per gm/cm^2 of lipid. This effect was essentially independent of the photon energies used. The variation of the composition of bone mineral had less than a 1% effect on the estimate of BMC.

The effects of the repositioning error could be large, especially for irregular distributions of BMC in the bone. Using casts of the body area measured, the repositioning error for measurements in vivo was minimized.

The BMC of the proximal phalanx was determined with the DAT on five patients undergoing chronic hemodialysis for the treatment of chronic renal failure, one normal subject, and a phantom. The ^{125}I beam was 2 mm in diameter, and the ^{241}Am beam was 3 mm in diameter. These beam sizes result in a less accurate measurement than is possible with smaller beams, but also reduce the repositioning error. The precision of the measurements in vivo was 1.4% (coefficient of variation) and of the phantom was 0.5%. The precision in vivo was limited by the ability to reposition the subject from measurement to measurement. The accuracy was affected by the size of the photon beams and the uncertainty of the actual soft tissue composition of the patients. Each effect resulted in a 10% deviation of the estimated BMC of the proximal phalanx from the accurate value and were independent of each other. No changes of BMC of the patients undergoing chronic hemodialysis was observed. The precision of the measurements was 3% per year with a 95% confidence.

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