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

by

MASTER

Philip F. Judy, Michael G. Ort,
Kianpour Kianian, and Richard B. Mazess
Department of Radiology
University of Wisconsin Medical Center
Madison, Wisconsin 53706

INTRODUCTION

The modular electronic components used to process and record the data for the dichromatic attenuation technique (DAT) are described in this report. Also, the use of these components in the scanning mode of the DAT is described. Factors affecting the DAT measurement of vertebral bone mineral content are also described. The principles of the DAT were previously reported (Judy and Cameron, 1969; Ort and Cameron, 1970; and Judy, 1971).

EQUIPMENT

The electronic components, listed below, used to collect and process the DAT information are shown in the block diagram of Figure 1. In this figure they have been connected to form a dual channel analyzer. The first seven components of the list were manufactured to Nuclear Instrument Module (NIM) standards.

1. High Voltage Supply
(ND-537, Nuclear Data¹)
2. Amplifier
(ND-520, Nuclear Data¹)
3. Two Single Channel Analyzers
(Model 1431, Canberra Industries²)
4. Two Scalers with buffers
(NS-30A, The Harshaw Chemical Company³)
5. Timer
(NT-29, The Harshaw Chemical Company³)
6. Parametric Data Module
(NY-20, The Harshaw Chemical Company³)
7. Modular Magnetic Tape Interface
(NE-25, The Harshaw Chemical Company³)

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.

-
- 1) 100 West Golf Road, Palatine, Ill. 60067
 - 2) 45 Gracey Avenue, Meriden, Connecticut 06450
 - 3) 6801 Cochran Road, Solon, Ohio 44139

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.

8. Magnetic Tape Unit
(Model 1337-200, Digi-Data Corp.⁴)

9. Bin/Power Supply
(Model 140D, Canberra Industries²)

The computer programs which were used for the point DAT (Ort and Cameron, 1970) and the single photon technique (Sorenson and Cameron, 1967) have been modified to accept magnetic tape input. Figure 2 illustrates this equipment in use.

USE OF THE EQUIPMENT IN THE SCANNING MODE OF THE DAT

Gadolinium-153 was used as a source of dichromatic photons. The NaI(Tl) scintillation detector had sufficient energy resolution to separate two photopeaks of the Gd-153 spectrum at 43 keV and 100 keV. The output of the amplifier was fed into both single channel analyzers. In the scanning mode of the DAT the counts of each channel are collected at regular time intervals as the source and detector move at a constant rate over the material of interest. The lower level setting for the 43 keV photopeak was 27 keV and for the 100 keV photopeak was 82 keV. The window for both analyzers was 28 keV. The attenuation of these "beams" has been shown to be sufficiently exponential to be useful for the DAT (Mazess et al., 1970).

The output of each single channel analyzer was fed into a buffered scaler. Both scalers were controlled by a single timer. The counts from the scalers were outputted every 0.6 sec as the scanner moved across the limb or phantom. The scanner used has been described (Witt et al., 1968). Other digital information was put on the magnetic tape by setting the thumb switches of the parametric recorder. Because this system collects data from both channels simultaneously, the radiation dose to the patient is half that which was received using the older system (Ort and Cameron, 1970) which alternated between the two channels.

The results of measurements on a bone phantom constructed of methyl methacrylate and a saturated solution of dipotassium hydrogen phosphate (a solution which closely resembles bone in its attenuation of x-rays, Witt and Cameron, 1969) are shown in Figure 3. The cross section and orientation of the phantom are also indicated. The precision of the sum of individual point measurements across the scan was 3%. The intensity of the Gd-153 was low and these measurements were made at a scan speed slower than is practical for human studies. The preliminary measurements were encouraging and indicated the measurement of bone mineral content of the limbs could be made with this technique, using a source of Gd-153 with an activity greater than 40 mCi.

MEASUREMENT OF VERTEBRAL BONE MINERAL CONTENT USING ¹⁵³Gd

Dichromatic attenuation measurements of phantoms and excised bones and vertebral bodies in vivo were made. The equipment used for these measurements was described in detail by Ort and Cameron (1970). A specially adapted multi-channel analyzer contained a single channel

4) 4315 Baltimore Avenue, Bladensburg, Md. 20710

analyzer whose lower level and window were alternately set, electronically, for the 43 keV photopeak and 100 keV photopeak of Gd-153. The memory of the multi-channel analyzer served as a buffer from which the data was punched into paper tape. The data was then processed by computer.

The mass attenuation coefficients of water, a saturated solution of dipotassium hydrogen phosphate, soybean oil, pressed board and aluminum were determined for the two photopeaks of Gd-153 and are tabulated in Table 1. The mass attenuation coefficients were measured for two beam sizes, 1 x 3 cm and 1 x 1.5 cm (beam size at the level of the attenuators). Within the limits of the experiment, the coefficients measured for each beam size were the same. This suggests that for this range of beam size, there is little variation in these coefficients with beam size.

These materials were used to construct phantoms to evaluate the effects of the position of the bone and the variation of the composition of soft tissue on the determined bone mineral content. Using a phantom of aluminum and pressed board, the dichromatic attenuation determination of the mass of each component was found to be independent of the order in which the sheets of aluminum and pressed board were stacked. DAT point measurements were made on a three component phantom: soybean oil, saturated solution of dipotassium hydrogen phosphate, and water. The amount of soybean oil was varied to simulate the variation of the lipid content of soft tissue. Our results were in agreement with those previously reported by Jacobson (1970). The error introduced by a uniform layer of lipid can be corrected (Roos et al., 1970), however, there is no simple correction for the lipid in the lumen of the bone (Sorenson and Mazess, 1970).

The bone and soft tissue mass of an excised human femur in 6 cm of water were determined using the DAT with Gd-153. In Figure 4 the results of the point by point measurements are shown. The bone mineral content determined differed by 2.5% from results obtained using the scanning monochromatic technique (Sorenson and Cameron, 1967). The vertebral bone mineral mass of two human subjects was measured. The results were encouraging, but because of the low activity of the Gd-153 (~30 mCi) source, and consequently long counting times, only a few points were measured. Using a more active source* of Gd-153 (200 mCi) and the dual channel analyzer, we hope to make either point by point or continuous scans on human patients in a practical amount of time.

* On loan from Oak Ridge National Laboratory

REFERENCES

1. Jacobson, B. Bone Salt Determination by X-ray Spectrophotometry. In: Proceedings of Bone Measurement Conference, J.R. Cameron (Ed.), CONF-700515, USAEC, Division of Technical Information, p. 237, Oak Ridge, Tennessee (1970).
2. Judy, P.F. and Cameron, J.R. A Dichromatic Absorption Method for the Measurement of Bone Mineral Content In Vivo. USAEC Progress Report COO-1422-60 (1969).
3. Judy, P.F. A Dichromatic Attenuation Technique for the In Vivo Determination of Bone Mineral Content. Ph.D. Thesis, University of Wisconsin-Madison, Madison, Wisconsin (1971).
4. Mazess, R.M., Ort, M.G., Judy, P.F., and Mather, W.E. Absorptiometric Bone Mineral Determination Using Gd-153. In: Proceedings of Bone Measurement Conference, J.R. Cameron (Ed.), CONF-700515, USAEC, Division of Technical Information, p. 308, Oak Ridge, Tennessee (1970).
5. Nuclear Instrument Module (NIM) Standards, USAEC Report TID-20893 (Rev).
6. Ort, M.G. and Cameron, J.R. Determination of Vertebral Bone Mineral In Vivo. USAEC Progress Report COO-1422-79 (1970).
7. Roos, B., Rosengren, B., and Sköldbörn, H. Determination of Bone Mineral Content in Lumbar Vertebrae by a Double Gamma-ray Technique. In: Proceedings of Bone Measurement Conference, J.R. Cameron (Ed.), CONF-700515, USAEC, Division of Technical Information, p. 243, Oak Ridge, Tennessee (1970).
8. Sorenson, J.A. and Cameron, J.R. A Reliable In Vivo Measurement of Bone Mineral Content. J. Bone Joint Surg. 49A: 481 (1967).
9. Sorenson, J.A. and Mazess, R.M. Effects of Fat on Bone Mineral Measurements. In: Proceedings of Bone Measurement Conference, J.R. Cameron (Ed.), CONF-700515, USAEC, Division of Technical Information, p. 255, Oak Ridge, Tennessee (1970).
10. Witt, R.M., Sorenson, J.A., and Cameron, J.R. An Improved Bone Mineral Scanner. USAEC Progress Report COO-1422-40 (1968).
11. Witt, R.M. and Cameron, J.R. Bone Standards. USAEC Progress Report COO-1422-42 (1969).

ACKNOWLEDGEMENT

This work is supported in part by the U.S. Atomic Energy Commission under Contract AT-(11-1)-1422.

Table 1. Experimentally determined mass attenuation coefficients (cm^2/gm) for Gd-153.

	Low Energy Peak ($\sim 43\text{keV}$)	High Energy Peak ($\sim 100\text{ keV}$)
Water	$0.233 \pm .003$	$0.166 \pm .003$
Pressed board	$0.220 \pm .002$	$0.160 \pm .001$
Saturated Dipotassium Hydrogen Phosphate Solution	$0.530 \pm .005$	$0.176 \pm .003$
Soybean Oil	$0.211 \pm .001$	$0.166 \pm .001$
Aluminum	$0.490 \pm .002$	$0.169 \pm .002$

Figure 1. Schematic of the electronic components used for the DAT measurements.

Figure 2. The modular electronic components and the incremental magnetic tape unit of the DAT.

Figure 3. Results of a DAT scan of a phantom with ^{153}Gd .

Figure 4. DAT scan using ¹⁵³Gd of midshaft of an excised human femur in 6 cm of water.