An Improved Bone Standard Containing
Dipotassium Hydrogen Phosphate Solution for the
Intercomparison of Different Transmission
Bone Scanning Systems

MASTER

by

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I. Introduction

This report covers progress made during the past year towards the development of a stable bone equivalent material which can be made reproducibly and can serve as a bone reference material. Our current work with dipotassium hydrogen phosphate (K_2HPO_4) and water solutions was first reported last year (1). Since this material has a physical density and mass attenuation coefficient near those for compact bone, phantoms have been constructed with dimensions similar to the external dimensions of diaphyseal bone. Assuming a simple thin-wall tube model for the shafts of the appendicular skeletal bones, a new plastic block phantom was designed with 3 annular chambers each simulating a different bone. Since many problems arose when attempting to design and construct a mailable, water-tight solution chamber, the new standards only recently have been distributed (May, 1970) to other laboratories making bone scans with the transmission scanning technique.

II. K_2HPO_4 Solution

The higher the concentration of the K_2HPO_4 in water at room temperature, the closer the solution's mass attenuation coefficient approaches that of compact bone. In order to obtain the highest concentrations stable at room temperature the solution was made as follows: mix any amount of salt and water in proportions greater than the maximum solubility limit at 20°C of 167g of K_2HPO_4 to 100g of H_2O (2). Typically they are mixed in a ratio of 1.75 to 1.0 by weight. The solution is heated and stirred with a magnetic stirrer, to help dissolve the large amount of salt. The salt completely dissolves in about 45 min. at which time the solution becomes completely clear again. The solution is then allowed to cool to room temperature. As the super saturated solution cools, the excess salt should begin to crystallize. The crystallization can occur quite quickly (<12 hrs.) or over an extended time period of from 3 days to 7 days. If crystallization fails to occur either heat the solution and add more salt or seed the solution with a hydrated K_2HPO_4 salt crystal. The resulting supernatant is the reference standard solution.

The above procedure to obtain saturated solutions of K_2HPO_4 in water appears to be highly reproducible. A total of six different solution batches have been made. For the last four batches, precise

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density determinations were made by measuring the mass of a 50 ml volume of the solution. The mass was measured with an electronic balance and the volume was measured with a 50 ml volumetric flask. The average solution density for the last four solution batches was $1.711 \pm .004$ ($\sim 0.2\%$). Since this precision is better than the precision in either the mass attenuation coefficient determinations or the mineral content scan measurements, batch to batch variations have been undetectable.

III. Bone Reference Standards

During the past year phantoms were constructed according to several different designs. A phantom constructed from our latest design, Figure 1, represents an improvement over our first plastic block phantom (3). This latest design has three annular regions with diameters whose dimensions approximate the midshaft dimensions of the radius for both the adult male and female and the metacarpal for an adult female.

In both of our last two phantom designs the K_2HPO_4 solution is contained in tubular cavities in the methylnmethacrylic (Plexiglass) or equivalent) blocks. The K_2HPO_4 solutions have mass attenuation coefficients near those for compact bone (1). Since the plastic has a lower mass attenuation coefficient than water for low photon energies ($E < 100$ keV), but a density greater than 1.0; it has a linear attenuation coefficient near the value for tissue. Therefore, the K_2HPO_4 solution filled cavities in the plastic blocks closely simulate bones in uniform soft tissue.

In addition to closely simulating bones in soft tissue, the plastic block phantoms have other advantages. They are stable, leak proof, durable, and can be scanned by most types of transmission bone mineral scanning systems. And unlike the older phantoms (1), they need not be immersed in water or other tissue equivalent substances to achieve the constant tissue thickness necessary for the transmission bone scanning technique.

The plastic blocks also can be made reproducibly. Nine block reference standards for the intercomparison and calibration study were machined as a group. The blocks were filled with the K_2HPO_4 solution and scanned with the analogue system (4). The percent coefficient of variation for the 9 standards as a group was approximately equal to the percent coefficient of variation for each block, and for all chamber sizes the percent coefficient of variation was less than the scanning system's longterm reproducibility of 2 percent.

IV. Intercomparison Study

Even though these K_2HPO_4 plastic block phantoms do not exactly simulate a bone in soft tissue, they still can serve as reference standards to intercompare and calibrate the scan results from different scanning systems and different laboratories (3).

The preliminary results from the six laboratories participating in the intercomparison study are quite good (Table 1). The percent coefficient of variation for the three different chambers ranged from 1.5 to 2.5 percent, as reported by the six laboratories. These differences should be compared to the 1.0 to 2.0 percent longterm reproducibility for scans of the same reference standard by a single laboratory. To intercompare the results from the different laboratories all scan values were expressed as "Integral Bone Mineral Content" which is defined as the product of the summation of the natural logarithms of the ratio of I_0 and I_1 and the distance the scanner travels between each data point, ΔX . All results are for transmission scans made with I-125 as the photon source.

The different scanning systems are assembled from many different commercial components which digitally output the count rates. Each laboratory analyzes its scan data with a digital computer with a different algorithm for determining the bone-tissue edge and some have a different algorithm for computing the integral. Except for Rochester, each laboratory has a custom built scanner with scanning rates and source-detector collimations different from Wisconsin's. All of these differences can lead to systematic errors between the centers greater than 2 percent (5).

Therefore, the good agreement among these preliminary results is encouraging and tends to indicate that different laboratories are measuring the same quantity of bone mineral content. Moreover, it should be possible to calibrate all scanning systems with the bone reference standard used in this intercomparison study.

I would like to thank the participating laboratories for providing these preliminary results so that they could be included in this report.

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Figure 1. The improved methacrylate (Plexiglass or equivalent), K_2HPO_4 bone standard with three chambers whose dimensions approximate the midshaft dimensions of the adult male and female radius and the adult female metacarpal.

Table 1. Comparison of Integral Bone Mineral Content^a based on measurements of the University of Wisconsin 3 chamber K_2HPO_4 bone reference standard.

Chamber	Small	Medium	Large
Laboratory			
Indiana	7.6	12.8	27.2
Philadelphia	7.93	13.14	28.38
U.S.P.H.S.H.	7.91	13.10	28.05
Rochester	7.47	12.78	28.51
New York	7.82	13.02	27.81
Wisconsin	7.92	13.24	28.69
Average	7.77	13.01	28.11
Std. dev.	$\pm .194$	$\pm .187$	$\pm .546$
Percent			
Coef. of Var.	2.5	1.4	1.9

^a Integral Bone Mineral Content = $\Delta X \cdot \sum \log(I_o^*/I_d)$; where ΔX = distance traveled between data point.