CHESTWALL TISSUE MEASUREMENTS FOR LUNG COUNTING APPLICATIONS

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Abstract

Mound Laboratory's Whole Body Counter was designed and calibrated for the detection of ^{238}Pu in the lungs.

Quantitative measurements depend upon the detection of the 17 keV (average) x-ray associated with the decay of ^{238}Pu. Because the half-value layer for 17 keV x-rays in tissue is only 6-7 mm, the effective thickness of the tissue overlaying the lungs must be accurately determined for proper interpretation of the counting data.

The tissue thickness over the lungs is determined by ultrasonic measurements over the second, third, and fourth rib in the manner suggested by Ramsden, Peabody and Speight.

This paper presents a review of the instrumentation and technique used at Mound Laboratory to obtain the tissue thickness measurement based on our experience in making these measurements on more than 700 different persons.

Introduction

During the last several years, various ultrasonic instruments have been used for determining human chestwall thickness. The chestwall thickness is extremely important where low energy photons are counted for lung burden assessments.

Even though reproducibility of the chestwall measurement error itself can be maintained at ±5%, it can propagate very significant errors in lung burden assessments. For the case of ^{238}Pu assessments where 17 keV (average) photons are counted, an error of 6-7 mm would cause the final lung count to be misinterpreted by as much as 100%. It is therefore necessary to maintain the best possible accuracy and precision in making chestwall tissue measurements for lung deposition assessments.

This paper discusses the major problems of making chestwall tissue measurements and the effect they have on making ^{238}Pu lung deposition assessments. The instrumentation and techniques used at Mound Laboratory during the last four years are reviewed. A discussion of different methods of deriving the chestwall thickness that have been investigated is also included.

Calibration

The effect of the chestwall as an absorber when lung counting for ^{238}Pu must be considered during calibration. Mound Laboratory

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calibrates for lung counting using a Remab Hybrid phantom that has known quantities of $^{2-8}$Pu distributed uniformly throughout the phantom lungs.[1]

For ^{238}Pu, the most prevalent photons available for counting are the 17 keV (average) uranium L x-rays. The three ^{234}U L x-rays (13.6, 17.2, and 20.4 keV) are not attenuated by tissue at the same rate and therefore give a transmission curve similar to the beefsteak curve shown in Fig. 1.

Two 12.7 cm diam phoswich detectors were used in a "normal" counting geometry to obtain the data in Fig. 1, and thus the significant geometry effects are included.

When the statistical errors that would normally be considered in calibration procedures are disregarded, the error in relative transmission caused by an error in the chestwall tissue thickness can be readily observed from the dotted lines in Fig. 1. An error of 6 mm results in a transmission error of about 100%. The chestwall effect on minimum detectable activity (3σ greater than background) is shown in Fig. 2. A typical subject with no exposure and a counting rate of 7.5 counts/min for 4000 sec is used in the example.

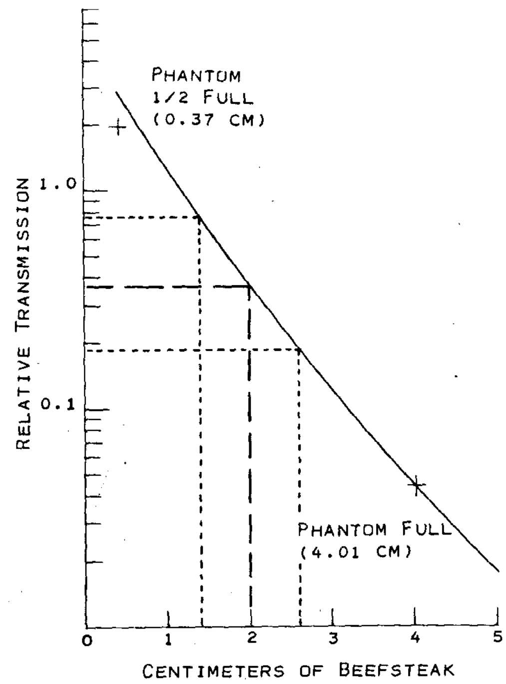

Fig. 1 17 keV (average) x-ray attenuation. [Absorber: beefsteak, ground and frozen. Source: phantom lungs (^{238}Pu spiked). Detectors: 2 each 5 in. NaI(Tl)-CsI(Na) Phoswich.]

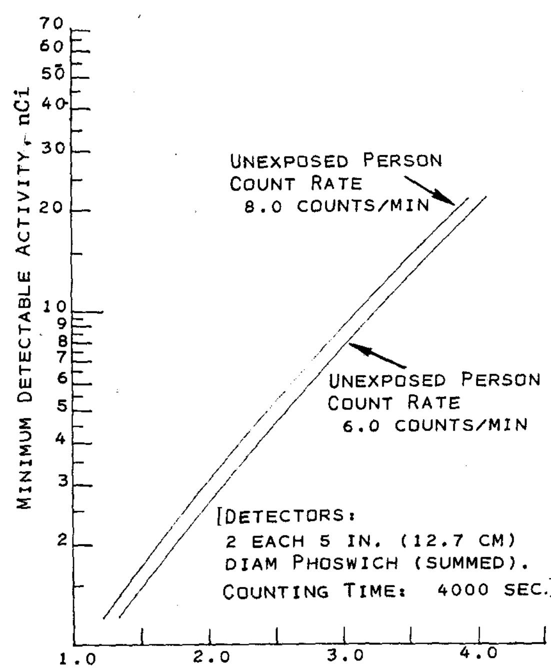

Fig. 2 Minimum detectable activity as a function of chestwall thickness

Instrumentation

In 1968 the only known investigation into making chestwall tissue measurements had been made by Ramsden et al.[2] Since lung counting of employes was to be routine, it was also desirable to determine the chestwall tissue thickness rapidly and accurately.

An ultrasonic sounding instrument was purchased from Hewlett Packard.[3] Instruments of this type are used in the medical profession for brain and heart studies. The transducer (0.64 cm diam) is electrically pulsed and produces an acoustic frequency of 2.5 MHz which is transmitted through a coupling medium into the subject to be measured. The acoustic pulses are partially reflected at any interface where the acoustic impedance changes. The reflected portion of the pulse is then detected by the transducer and the time delay from transmission is measured. This time difference is displayed on the horizonal axis of the cathode ray tube which is calibrated in centimeters of tissue. The position of any acoustic interface is a linear function of the velocity of sound in that medium and is converted to a depth measurement from the crystal transducer. The intensity of the reflected pulse is a function of the depth and acoustic impedance mismatch and is displayed on the vertical axis of the cathode ray tube. A typical trace on the instrument is shown in Fig. 3.

This instrument has an adjustable distance marker that is adjusted via a 10-turn potentiometer, and once it is aligned with the echo of interest, it reads the distance from the transducer to the interface producing the echo. This mode of operation is commonly referred to as the "A-scan mode." A calibration block of plastic is supplied with the instrument.

Methods and Procedures

Ultrasonic chestwall measurements were made on cadavers using various approaches followed by sectioning of the chestwall and physical measurements made with calipers.[4] Rather than measure directly to the lung interface between the ribs, it was advantageous to use the tissue to rib interface since the intensity of the echo was more sharply defined. However, to do this, additional rib thickness must be added to the tissue thickness overlying the ribs. After numerous rib thickness measurements on skeletons, this rib thickness was found to range from 0.3 to 0.5 centimeters[4] depending on general bone structure of the skeleton.

An average thickness of the chestwall was found for the area between the detectors and the lungs. The nine measured points are located as shown in Fig. 4 and on the right side of the chest.

The photon attenuation is a function $e^{-\mu x}$ where μ is about 1.15 cm^{-1} for tissue and x is the absorber thickness in centimeters. Therefore, the average thickness is not a simple mean of several measured thicknesses, but instead, is an "exponential average." The true average thickness was found by measuring nine points to the rib, averaging the values of $e^{-1.15x}$, equating this average to $e^{-1.15x}$, solving for x, and then adding the rib thickness.

Asymmetry between the right and left halves of the chestwall thickness could not be defined within the precision of measurement.

A highly developed technique was necessary in order to align the transducer to achieve a well defined structure as shown in Fig. 3. The most obvious difficulties occur on subjects with appreciable amounts of fatty or muscle tissue in the chest area.

A second method of measuring the chestwall thickness between the ribs in the same chest area was also briefly investigated.

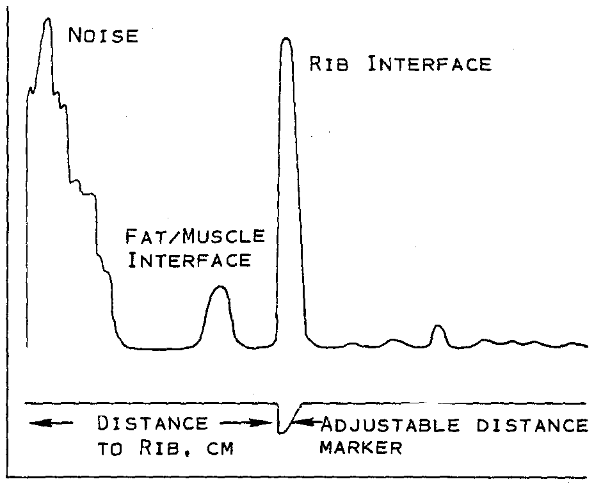

Fig. 3 Ultrasonic display of chest-wall measurement

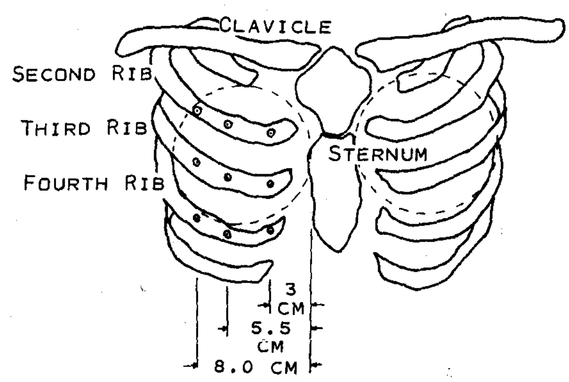

Fig. 4 Ultrasonic measurement points. (Approximate area covered by detectors shown in dotted lines.)

The same basic principles of measurement apply; however, the cathode ray tube display is slightly different.

Results and Discussion

After more than 1,000 chestwall determinations had been made, the possibility of discarding the procedure in lieu of a prediction method was investigated.

The average chestwall measurement for 741 different subjects was found to be 2.28 ± 0.748 cm (2σ). Therefore, in the simplest form, it is possible to use this value for all subjects but with an extremely large resultant error in plutonium lung assessments. The error could be in excess of 100% at the 95% confidence limit if this thickness is related back to Fig. 1.

Another prediction method used various physical body parameters, which can be quickly measured, to predict the chestwall thickness as investigated by Ramsden et al.[3] and Dean.[5] A stepwise multiple regression analysis was used to investigate different prediction equations for chestwall tissue thickness. The data used were limited to 644 different subjects for which all physical parameters were measured.

The stepwise multiple regression used is a statistical technique for analyzing a relationship between a dependent variable (chestwall thickness-T) and a set of independent variables (see Table I) in order of their importance. The criteria of importance is based upon a reduction of the total variation in the dependent variable. In each given step the independent variable most important in this reduction is entered in the regression. Unless the percentage of the total variation accounted for by an independent variable was greater than 1%, the variable was eliminated.

The results of these analyses for three major groups of independent variables are shown in Table I.

TABLE I Regression Analyses

1. Independent Variables: Weight (W), Height (H), Chest Circumference (CC), Waist Circumference (WC), Chest Thickness (CT) and Age (A)

Step No.	Variable	Regression Equation	Total Variation Accounted for by Regression	Multiple Correlation Coefficient	Standard Error of Estimate (cm)
1	W	T = a+bW	40.3%	0.634	0.292
2	H	T = a+bW+cH	46.1%	0.678	0.270
3	A	T = a+bW+cH+dA	51.7%	0.718	0.264

Example of Step 3 Regression Line: T = 4.0185 + 0.0107 -0.0475 -0.0088A
Standard Error of Estimate (σ) = 0.264 cm

2. Independent Variables: W/H, CC, WC, CT, A

Step No.	Variable	Regression Equation	Total Variation Accounted for by Regression	Multiple Correlation Coefficient	Standard Error of Estimate (cm)
1	W/H	T = a+b(W/H)	43.1%	0.657	0.285
2	A	T = a+b(W/H)+cA	48.2%	0.694	0.273

Example of Step 3 Regression Line: T = 0.8388 + 0.6880 W/H -0.0082A
Standard Error of Estimate (σ) = 0.273 cm

3. Independent Variables $(W/H)^{\frac{1}{2}}$, CC, WC, CT, A

Step No.	Variable	Regression Equation	Total Variation Accounted for by Regression	Multiple Correlation Coefficient	Standard Error of Estimate (cm)
1	$(W/H)^{\frac{1}{2}}$	$T = a+b(W/H)^{\frac{1}{2}}$	43.8%	0.661	0.284
2	A	$T = a+b(W/H)^{\frac{1}{2}}+cA$	48.3%	0.694	0.273

Example of Step 3 Regression Line: $T = 0.9690 + 2.2249\ (W/H)^{1/2} - 0.0077A$
Standard Error of Estimate (σ) = 0.273 cm

Of the two ultrasonic methods described, the first was the more objective and easier to use. The method of measuring between the ribs to the lung interface is more difficult to use because of the lesser intensity echo from that interface which therefore could introduce significant error in accuracy.

Because of errors involved in predicting the chestwall thickness in the upper chest area, the precision from ultrasonic measurement was investigated on 45 subjects using the first method described previously. Over a one year period, all plutonium operating personnel that were scheduled for lung counting and found to have had two or more chestwall measurements were considered. Only the data from those subjects whose weight and thickness (front to back) had not varied more than 4% were used. The results of applying these constraints left 45 suitable subjects and two standard deviations were found to be 0.112 cm.

One error that is generally not considered in discussion of chestwall thickness measurements is that resulting from the ratio of fat to muscle. Although a small error is introduced from the direct ultrasonic measurement, the propagated error in a plutonium lung burden assessment can be of the order of 10%.

Even though several methods of predicting the chestwall tissue thickness were investigated, the results indicate that the most precise technique of determining this value is by ultrasonic measurement. It is, however, possible to conserve time used for routine counting by making only four to six routine chestwall measurements weekly to maintain the technique needed in actual lung burden assessment cases.

Acknowledgements

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References

1. Nuclear Associates, Inc., 35 Urban Avenue, Westbury, New York 11590, USA.

2. D. Ramsden, C. O. Peabody and R. G. Speight, United Kingdom Atomic Energy Authority Report AEEW-R, 14 (1967).

3. Hewlett-Packard Company, 1501 Page Mill Road, Palo Alto, California 94304, USA.

4. E. Arnett, unpublished results.

5. P. N. Dean, Health Physics, 24, 439 (1973).