A METHOD FOR MEASURING RADIOIODINE UPTAKE WHICH CORRECTS FOR THYROID DEPTH

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A technique is presented for measuring radioiodine uptake by the thyroid which yields measurements corrected for variations in the depth of the organ, distance from the detector to the organ and scattering and attenuation by intervening tissue.

The techniques widely used at present for estimating activity within the thyroid using a standard phantom (such as the ORINS phantom) take account of these effects only insofar as the subject matches the phantom with regard to the shape of the neck and more significantly to the depth of the gland. The depth correction feature of this method should make it possible to extend the results of this study toward the development of an uptake system which uses a decreased detector-to-thyroid distance without the accompanying error introduced by an unknown distance to the gland. The increased sensitivity which would result might be used to decrease the administered dose or minimize statistical errors.

A further extension of this work would be the use of low-energy radioisotopes such as ^{125}I for thyroid uptake studies since the technique corrects for the effects of scattering and attenuation.

The general technique proposed may also find application in uptake studies in other organs such as the kidneys where unknown variations in depth can introduce significant errors in uptake estimates.

The method involves measuring the ratio of counts obtained with a flat-field collimator at two prescribed distances from the subject. On the basis of calibration measurements made with a special phantom this ratio can be used to provide an estimate of the effective depth of the activity distribution of the organ. Another calibration is made which relates the counting rate at the near reference position to the activity as a function of the effective depth. Combined with the initial estimate of depth, the latter calibration permits conversion of the counting rate at the near position to an estimate of the organ activity.

In the following sections the basic method is described and the calibration and phantom evaluation measurements are presented. Results of clinical uptake measurements made on 91 patients are described and compared with uptake measurements made by the standard technique. Finally, results of a study applying the technique with ^{125}I are presented.

METHOD

The basic principle underlying the two-distance method involves determining the ratio of counts obtained at two prescribed distances from a subject. This ratio is a function of the depth of the organ through attenuation, scattering and detector to organ distance. Consequently, calibration of the method requires a specially designed phantom which permits varying the depth of the simulated organ as well as a reference system for accurately positioning the detector at the two prescribed distances.

The phantom (Fig. 1) constructed of Lucite, measured 10.2 cm in dia and 10.2 cm in length. Each of two Lucite 9-cm-long cylinders had a source activity volume 1.25 cm in dia and 3.75 cm long representing the thyroid. A series of slots were milled into the phantom to approximate the angulation of the thyroid gland about the larynx. The source slots were positioned at depths ranging from 2.0 to 7.5 cm as measured from the anterior of the phantom to a line connecting the centers of two corresponding source slots as shown in Fig. 1. These distances relate to anatomical measurements made along a line, perpendicular to the central axis of the body, extending from the point on the surface of the neck anterior to the center of the isthmus of the thyroid, just below the thyroid cartilage to a line passing through the centers of the thyroid lobes. (In practice, the depth measurement will actually correspond to the distance to the mean center of "activity" of the two lobes.) Each lobe position in the

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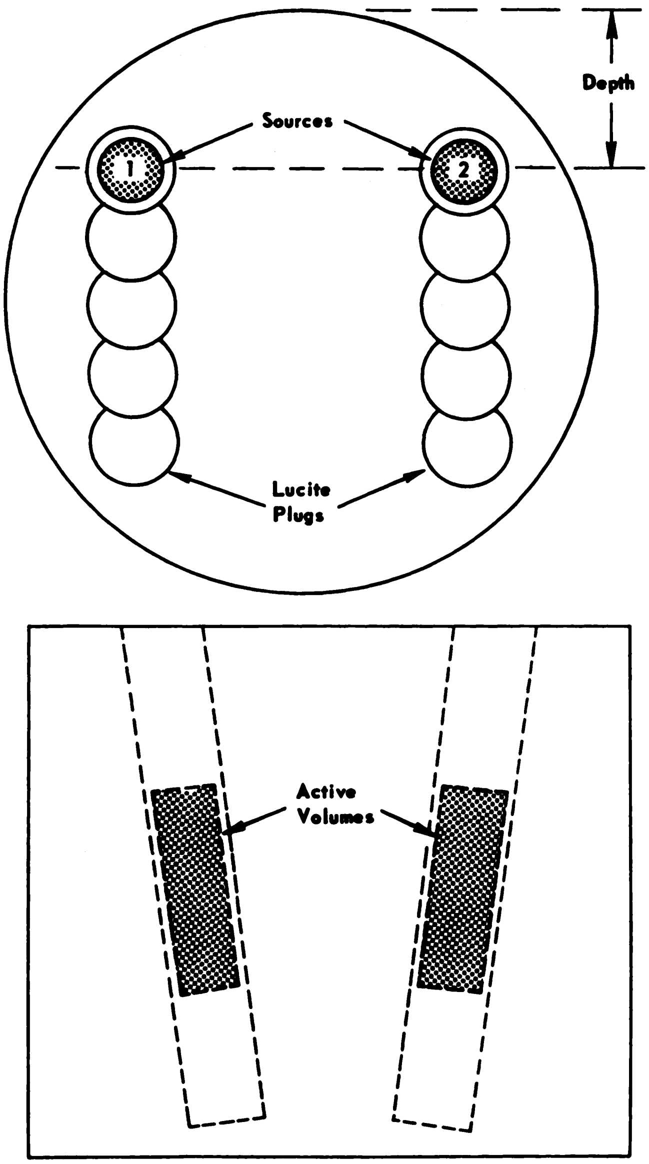

FIG. 1. Lucite neck phantom showing series of holes into which cylindrical thyroid phantom sources are inserted at varying depths. Geometry for measuring effective depth of organ activity is shown.

phantom not occupied by a source was filled with a removable Lucite plug to ensure continuity of the scatter medium.

The detector used in this study was a NaI(Tl) crystal measuring 7.5 cm in dia and 7.5 cm in thickness. The flat-field collimator measured 12 cm in length and at its open end had an internal diameter of 10 cm and an external diameter of 11 cm. At the detector end of the collimator the acceptance diameter was 6.8 cm. The instrumentation consisted of a standard analyzer-timer-scaler. All ^{131}I measurements were made with a pulse-height selector window setting of 324–404 keV.

Calibration curves were made by positioning the flat-field collimator at Position A, a distance of 10 cm from the face of the collimator to the front center of the phantom, as shown in Fig. 2 (yielding phantom-to-detector distance of 23 cm) and measuring the counting rate. A background counting rate was then taken at Position A with a 10 $\times$ 10 $\times$ 2.5 cm lead plate placed over the simulated thyroid gland. When the method is applied clinically, this background measurement includes the effects of extrathyroidal activity in the neck and body of the patient. The collimator-detector was then moved back 15 cm to Position B (yielding a phantom-to-detector distance of 38 cm), and the counting rate and background were again determined. Each counting rate was corrected for background and the counting-rate ratio of A to B determined. This procedure was repeated for each source depth position. These results were used to obtain the counting-rate ratio versus effective organ depth calibration curve shown in Fig. 3.

A second calibration curve (Fig. 4) was obtained by plotting the activity per unit counting rate (μCi/cpm) as measured at Position A against the effective organ depth.

In practice, when the method is applied to obtain thyroid uptake estimates, the counting rates at Position A and Position B are determined as described above. The ratio of counting rate at A to that at B (corrected for extrathyroidal background) is used to determine an effective depth of the gland from

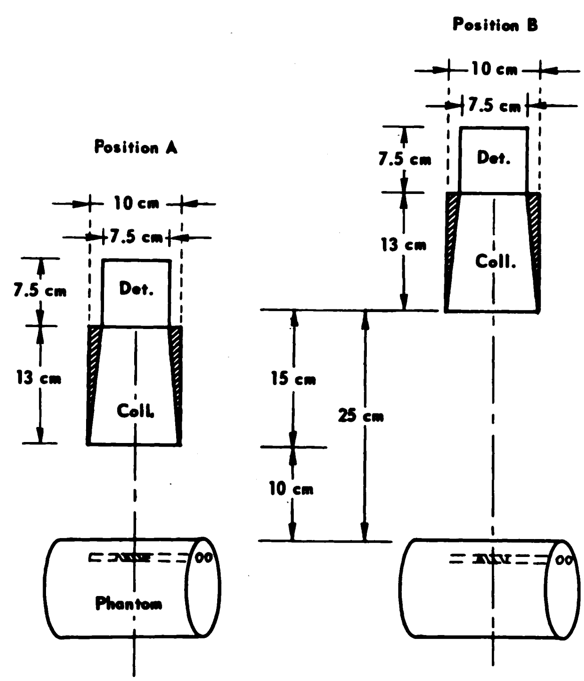

FIG. 2. Geometry used for counting-rate measurements at two distances. After measurement is made at Position A, collimator-detector is moved back 15 cm to Position B for second count.

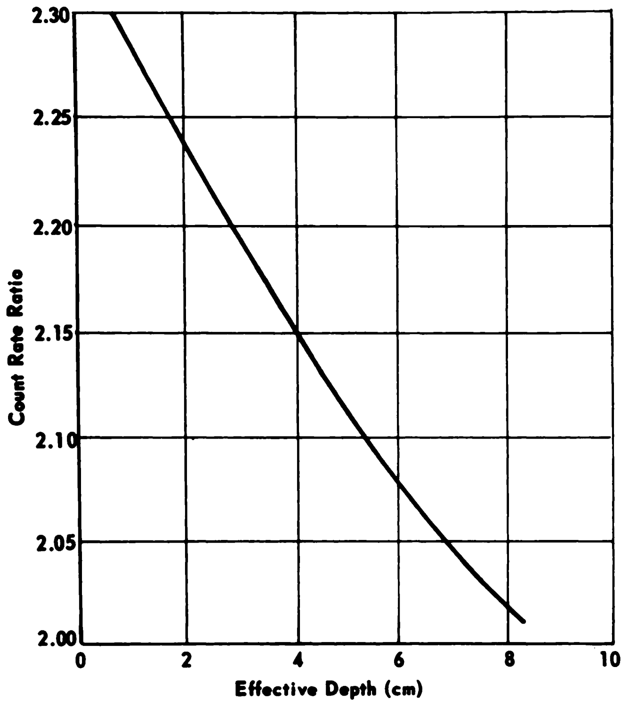

FIG. 3. Calibration Curve 1 relating counting-rate ratio as function of effective organ depth for ^{131}I.

Fig. 3. This effective depth is then used to read a value from Fig. 4 for the expected activity per unit counting rate at Position A. This value expressed in microcuries per unit counting rate (μCi/cpm) is multiplied by the measured counting rate (cpm) at A. The resultant activity of the gland expressed in microcuries (μCi) may be divided by the microcuries (μCi) of activity administered to the patient to obtain the conventional percentage uptake. For clinical applications where estimates of effective depth are not desired, it is possible to combine Figs. 3 and 4 through the common variable of effective depth to obtain Fig. 5 which relates the activity per unit counting rate at Position A to the counting rate ratio. With this calibration curve the measured ratio provides the multiplier which yields the activity from the Position A count in a single step.

TABLE 1. AVERAGE DIFFERENCE BETWEEN RADIOIODINE UPTAKE MEASUREMENTS DUE TO VARIATION OF THYROID DEPTH FOR 91 PATIENTS

Depth range (cm)	Average difference present method	Number of patients
Depth < 2.00	13% high	6
2.00 ≤ depth ≤ 4.75	Approximate agreement	66
4.75 < depth	66% low	19

Like the ORINS phantom technique, this method is dependent upon the relation between the actual geometry in a clinical measurement to that of the phantom used for calibration. This method corrects for one of the possible variations, namely, thyroid depth. Deviations between the shape of the patient's neck and that of the phantom will cause small errors. It is estimated that a neck so obese as to be essentially flat across the front (anterior to the thyroid) could give rise to an error of about 7% in the resultant uptake estimate. For expected variations in the shape of the thyroid, the errors would be less than this value. The detector shape does not have any significant effect.

A series of phantom experiments was conducted wherein the source depth and activity within the sources were varied to establish the accuracy and reproducibility of the method. In this ideal case it was demonstrated that the effective depth of the distribution of activity could be measured with a root-mean-square error of 1.5 mm and the activity could be estimated to an accuracy of 5% (root-mean-square error).

CLINICAL APPLICATIONS

The two-distance method was used to measure the effective organ depth and ^{131}I uptake of 91 patients on whom uptake measurements were also made using the conventional technique (ORINS phantom) (*1*). The frequency distribution of effec-

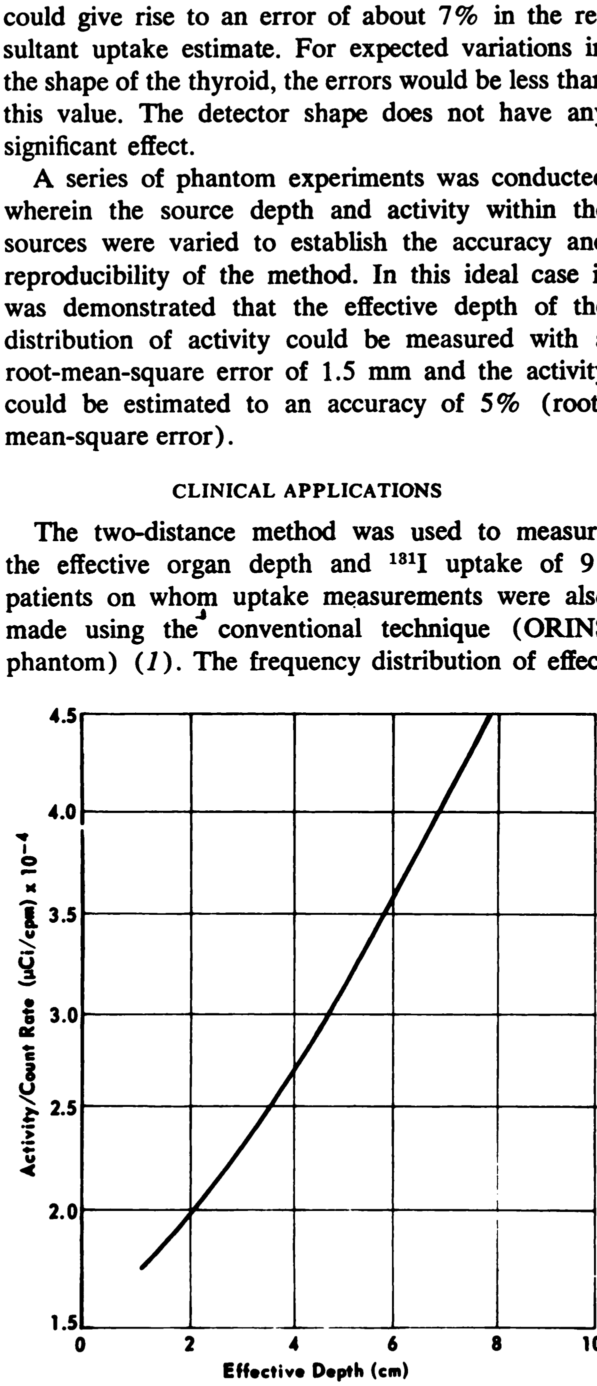

FIG. 4. Calibration Curve 2 relating activity (μCi) per unit counting rate as measured at Position A as function of effective organ depth for ^{131}I.

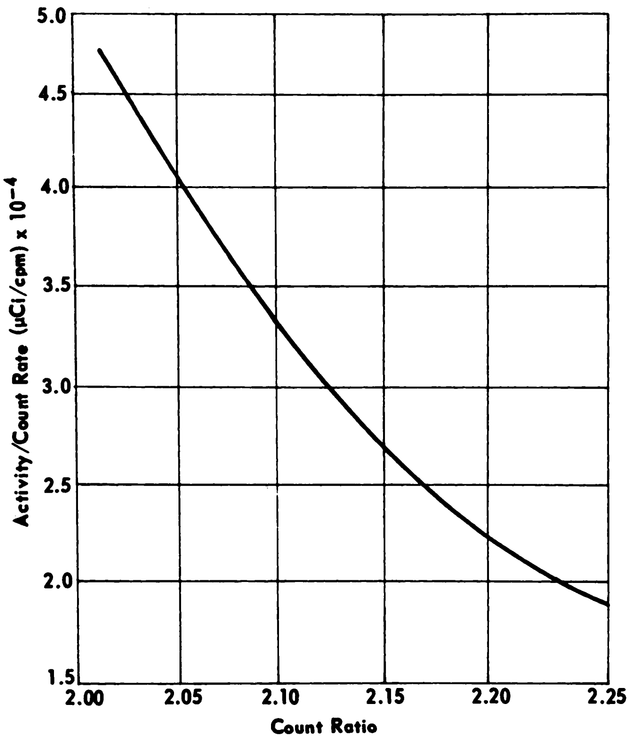

FIG. 5. Calibration curve relating counting-rate ratio to activity (μCi) per unit counting rate at Position A for ^{131}I.

tive organ depths for these patients is shown in Fig. 6. The mean effective depth for these patients, all of whom had possible thyroid disorders, was 3.85 ± 1.60 cm (root-mean-square error) as measured from the anterior of the neck (as indicated in Fig. 1). The distribution of depths ranges from approximately 1 to 7 cm. The distribution is broad with a large population well away from the reference depth used in the conventional standard phantom. The range and average value of the distribution agrees with the values published by Vennart (*2*). Vennart states that on a study of 100 patients with ^{131}I he obtained a mean depth of 3 cm with a standard deviation of 2 cm and that the range of depths varied from close to the surface to depths of 7 cm. These numbers are in agreement with those obtained in the present study.

Previously published estimates of thyroid depth made by Wellman (*3*) cannot be compared with this mean effective depth since the depth estimated in this study is measured from the anterior center of the neck whereas Wellman's measurements are for depths below the point on the neck nearest the gland.

The results of a comparison between uptake measurements made with the two-distance method and those obtained by the standard method are summarized in Table 1. It can be seen from the table that when the effective depth of the gland is between 2.00 cm and 4.75 cm, the two methods give comparable results. However, when the effective depth is greater than 4.75 cm, the conventional method gives uptake values which are on the average 66% lower than those obtained by the two-distance method. On the other hand, when the effective depth of the gland is less than 2.00 cm, the uptake obtained by the conventional method is on the average 13% higher than that obtained by the new method. These results clearly indicate that variations in thyroid depth can cause apparent inaccuracies in uptake measurements when made by the conventional method.

Further studies are planned to establish the mean effective depth of the thyroid gland of normal individuals as well as the relationship between the experimentally measured effective organ depth and true organ depth. A rigorous check on the method will require providing for an independent measurement of the position of the organ or the activity distribution, especially for those clinical cases where unusually large apparent depths are obtained.

When large effective depths were obtained in this study, the patient's medical record and thyroid scan data (if any) were checked. In those cases where reliable information was available, it was established that the patient was classified obese and/or the patient's scan disclosed an enlarged thyroid. This would suggest that some correlations between the effective thyroid depth and the physical characteristics of the patient may exist. This technique for estimating the depth of the radioiodine may be useful in investigating possible correlation between the effective thyroid depth and other physical characteristics of the patient such as neck size, body weight or surface area, etc.

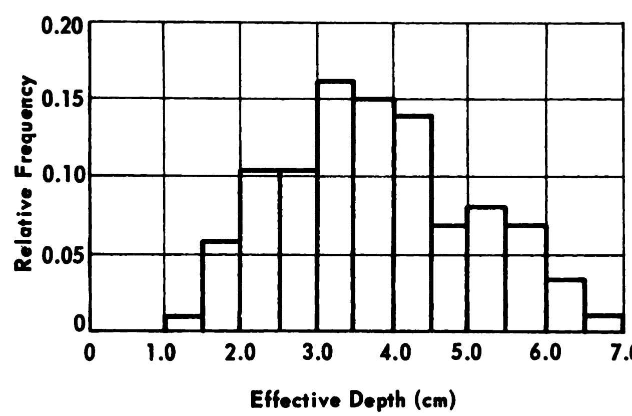

FIG. 6. Relative frequency distribution of effective thyroid organ depths for 91 patients, all of whom had possible thyroid disorders. Mean effective depth of population was 3.85 ± 1.60 cm as measured from front center of the neck.

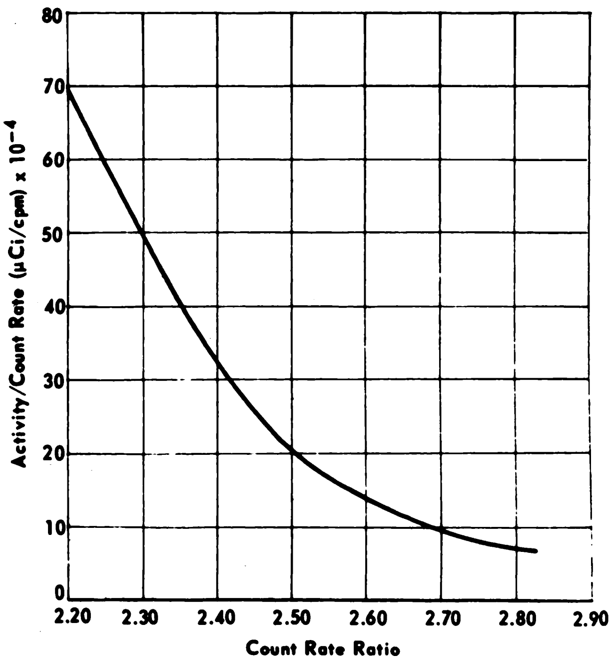

FIG. 7. Calibration curve relating counting-rate ratio to activity (μCi) per unit counting rate at Position A for ^{125}I.

Uptake measurements with ^{125}I. Myers and Vanderleeden (*4*) and Daniel *et al* (*5*) have suggested as early as 1960 that ^{125}I would be useful for radioiodine uptake measurements. Iodine-125 has a half-life of approximately 60 days and for each 100 disintegrations emits 144 ± 6 photons in the 27–35-keV energy range. The relatively long half-life of this radioisotope provides a shelf life that is convenient for synthesis, shipping and storage. Despite this long half-life, the character of the decay scheme of ^{125}I is such as to provide a relatively high photon yield per unit of administered dose for thyroid uptake measurement compared to that of ^{131}I, the current conventional radioisotope. With the detecting system used in this study, the counting rate over the thyroid gland with ^{125}I (20–60-keV window) is at least 3–4 times the counting rate obtained with an equal dose of ^{131}I (324–404-keV window).

Despite the length of time since the first published suggestion that ^{125}I be used, its application in uptake measurements using conventional methods has not developed, possibly due to the high susceptibility of the low-energy photons (27–35 keV) to scatter and absorption. These factors would cause inconsistent measurements and decreased sensitivity. The lack of consistency in the measurements could result from the much greater variation in photon density at the surface as the depth of the radioisotope distribution is varied. Since the two-distance method takes the depth into account, it automatically corrects for the effects of absorption and scattering, and, in addition, may be used at shorter detector-to-thyroid distances. On this basis, the technique proposed in this paper should make possible the use of ^{125}I for thyroid uptake studies.

In order to investigate the possibility, the calibration curve shown in Fig. 7 was determined with the variable depth phantom discussed earlier using ^{125}I as the radioisotope. In this study, the Position A measurements were made with a distance of 3 cm from the face of the collimator to the front center of the phantom (yielding a phantom-to-detector distance of 16 cm) while Position B measurements involved a distance of 15 cm from the front of the collimator face to the front center of the phantom (yielding a phantom-to-detector distance of 31 cm). An energy window passing photon energies between 20 keV and 60 keV was used.

A series of phantom experiments was conducted with the depth and the activity of the sources varied. It was established that the depth could be measured to an accuracy of 2 mm (root-mean-square error) and the activity (uptake estimate) to within 7% (root-mean-square error). These results include measurements made with both sources at the same depth level as well as cases where the depth of the individual sources was different. It will be noted that the accuracy of these results is comparable to those obtained with ^{131}I when the proposed technique is used. Because the counting rate from ^{125}I is very sensitive to the depth of the radioisotope, the accuracy of uptake estimates is more sensitive to the accuracy of the A count to B count ratio. The counting rates to be expected should give adequate statistical accuracy for the ^{125}I with uptakes corresponding to less than 5 μCi. The results reported here were obtained with conventional equipment without modification. If a system was designed to specifically exploit this technique with ^{125}I, it should not be difficult to obtain uptake estimates with root-mean-square errors of less than 5%.

In recent years several authors (*6–8*) have reported ^{125}I as the radionuclide of choice for routine thyroid scanning since the resolution obtained with this radionuclide is superior to that obtained with ^{131}I or ^{99m}Tc-pertechnetate. Since ^{125}I can be used routinely as a thyroid scanning agent, the development of the technique proposed in this paper for uptake measurements would permit the use of a single agent for total thyroid evaluation.

CONCLUSIONS

A method has been presented for measuring radioiodine uptake by the thyroid based on counting rate measurements made at two prescribed distances from the subject. The approach is simple and can be applied to any standard thyroid uptake system providing calibration curves are made for the system using a variable depth phantom such as that described in the text. The technique provides measurements which are corrected for variations in the depth of the gland, distance from the detector to the organ, and tissue scattering and attenuation. A series of phantom experiments show the method to be both reliable and accurate. Clinical studies on 91 patients show that variations in thyroid depth cause apparent inaccuracies in uptake measurements when made using a standard phantom, thereby indicating the importance of correcting for variation in organ depth. Because the two-distance method compensates for variations due to thyroid-detector distances, an obvious extension of the method presented would be the use of a decreased organ-detector distance in uptake measurements. This would result in an increased sensitivity which might be used to decrease the administered radionuclide dose.

The method corrects for the effects of attenuation and scattering which vary with the depth of the gland. Consequently, the method permits the use of low-energy radioisotopes where these effects have been especially critical. The results of phantom studies with ^{125}I verify this application of a low-energy radioisotope.

Preliminary phantom studies on the kidney indicate the applicability of the technique to other organs of the body (*9*).

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