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Development of a Simple Method for Determining the Absorbed Activity Concentration by the Thyroid Gland of Nuclear Medicine Staff

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ABSTRACT

Introduction: The occupational safety of nuclear medicine staff working with radioactive iodine (^{131}I) has always been a major concern in nuclear medicine. Since ^{131}I is a volatile substance, it may enter the body during respiration and be absorbed by the thyroid gland of the hospital staff, causing major health problems. This study aimed to develop a simple method for determining the activity concentration of absorbed ^{131}I in the thyroid gland of nuclear medicine staff, using a home-made anthropomorphic neck-thyroid phantom.

Materials and Methods: For this purpose, ^{131}I, with an activity of 370 kBq, was injected inside the thyroid glands of the phantom. The dose rate was measured by placing a portable detector on the thyroid gland at the surface of the neck phantom. The measurements were repeated for two months. Next, a calibration curve was drawn for iodine activity inside the thyroid versus dose rate at the neck surface. The calibration curve was then used to estimate the absorbed activity in the thyroid of the staff in one of the main hospitals of Shiraz, Iran. Finally, a new software program was developed for assessing and recording the activity concentration of ^{131}I accumulated in the thyroid gland. Every day, the dose rate was measured by placing the detector on the neck of the staff. The dose rates were converted to activity concentrations inside the thyroid, using the mentioned calibration curve.

Results: The results indicate that using the calibration factors for every detector, one can have the estimate of the radio-Iodine activity inside the thyroid.

Conclusion: The method proposed in this study can be applied for internal contamination determination in normal working conditions and in accidents.

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Introduction

Radioactive iodine (^{131}I) is a radiotoxic volatile fission product that can be easily dispersed in the workplace when there is no suitable ventilation. Therefore, the risk of internal contamination or external exposure in normal working conditions (i.e., source transportation or preparation) is always high. Assessment of internal and external doses received by the patients, caregivers, and hospital staff is very important in nuclear medicine departments [1-6]. In Iran, the use of unsealed ^{131}I sources in nuclear medicine departments for medical purposes has increased significantly in the past decades. For example, the use of ^{131}I in one of the largest hospitals of Shiraz increased by more than 200% in a ten-year period.

The exposure of nuclear medicine staff due to the intake of radionuclides can be assessed using direct and indirect methodologies, proposed by the International Atomic Energy Agency (IAEA) (6). If internal contamination is related to gamma-emitting radionuclides, direct measurements can be performed by *in vivo* counting of emissions from the body, using scintillation detectors. For contamination with radionuclides that do not emit strongly penetrating radiation, indirect measurements, based on the calculation of activity concentration in biological samples taken from the staff's body, are suitable (6). Overall, direct or indirect measurements of radioactivity concentration are performed for estimation of committed effective doses to occupationally exposed people or those involved in accidents (7-9).

Thyroid-neck phantoms have been widely used for direct measurement of internal contamination in the thyroid gland (10-12). In this regard, Mehdizadeh Naderi et al. in 2016 designed and fabricated male and

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female thyroid phantoms for internal dosimetry. They fabricated a neck phantom with removable thyroid parts. The average size of the phantom for the female and male thyroids was obtained by ultrasound and CT scan of the thyroid gland in several mature patients (10). Moreover, Karimi et al., in 2018, used epoxy resin and poly (methyl methacrylate) (PMMA) to prepare a tissue-equivalent thyroid head and neck phantom. Their results showed that the new thyroid phantom was similar to the human thyroid gland. They prepared a scintigraphy image of the new phantom captured by a gamma camera and revealed that the thyroid phantom was similar to the human thyroid gland (11). Moreover, Amin et al., in 2020, used paraffin wax and NaCl to fabricate a cost-effective neck-thyroid phantom for dosimetry studies in nuclear medicine (12).

Direct measurements of ^{131}I activity concentration in the thyroid gland have been performed in several studies. In 2007, Dantas et al. used a neck-thyroid phantom for calibration of gamma cameras to estimate the internal contamination of the thyroid gland with ^{131}I. They cut a filter paper in the shape of a thyroid gland and distributed barium-133 (^{133}Ba) uniformly on its surface. Next, a filter was inserted in a cylindrical neck phantom. The neck-thyroid phantom was used for the calibration of gamma cameras for the assessment of internal contamination (13).

Besides, Vidal et al. (2007) calibrated a thyroid uptake phantom for individual monitoring of ^{131}I internal contamination. They used three different thyroid phantoms for calibration of a thallium-doped sodium iodide (NaI(TI)) detector. The calibration factors (CPM/Bq) of the thyroid neck probe were obtained for different distances between the detector and the neck phantom (14). Moreover, Frank et al. (2012) developed mobile laboratories for monitoring internal contaminations. A plastic thyroid phantom was loaded with ^{133}Ba to obtain a calibration factor for determining the ^{131}I concentration in the thyroid gland (15).

Generally, direct measurement of radionuclides inside the body requires anthropomorphic phantoms. Cerqueira et al., in 2013, introduced two anthropomorphic neck phantoms, containing several types of thyroids, that is, thyroids with hypothyroidism, hyperthyroidism, and normal thyroid gland (16). In 2014, another anthropomorphic thyroid phantom was developed by Hermosilla et al., using polyester resin for determination of internal contamination and imaging control (17). Overall, the increased use of radiopharmaceuticals in developing countries poses a great challenge to the implementation of dose management programs, since in these countries, radiation protection programs are not implemented adequately by the personnel, and there is an urgent need to focus on internal contamination assessments of the staff.

Internal contamination assessments are usually performed using scintillation detectors. Therefore, this study aimed to establish a simple method for quantifying the activity concentration of ^{131}I in the thyroid glands of nuclear medicine staff exposed to ^{131}I, using our home-made phantom and a scintillator or gas portable survey meter.

Materials and Methods

Calibration factor

To investigate the ^{131}I activity in the thyroid gland, a home-made neck phantom, containing the thyroid gland, was used. The neck phantom was composed of PMMA as soft tissue and aluminum as bone. In our previous investigation, it was found that the average size of male and female thyroids was different (10). The average length of the right thyroid lobe was 4.20 cm and 4.80 cm in males and females, respectively. Also, the average length of the left thyroid lobe was found to be 4.15 cm and 4.75 cm in males and females, respectively. Besides, the average height of the isthmus in women and men was 1.8 cm and 1.2 cm, respectively.

In the present study, the radiopharmaceutical ^{131}I, with an activity of 370 kBq, was inserted inside the male and female thyroid glands of the phantom. The dose rates were measured at distances of 0 to 16 cm from the thyroid with a 1-cm increment. The measurement device geometry for d=0 cm is shown in Figure 1. As shown in this figure, the measurements were performed on the anterior-posterior axis of the neck (0° angle). They were performed for four different portable detectors, used in different hospitals for radiation monitoring. The characteristics of the dosimeters are shown in Table 1.

The measurements were performed every day for two months. Each measurement was repeated at least ten times, and the mean value and standard deviation of the mean (S) were measured as follows:

$$S = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x}_e)^2$$

where S is the standard deviation of the mean, N is the number of measurements, x_i is the ith measurement, and $\bar{x}_e$ is the mean value of measurements. The activity of ^{131}I inside the thyroid gland was calculated every day by the exponential decay equation, considering the known half-life of ^{131}I ($t_{1/2}$=8 days) and the initial activity of ^{131}I (A_0=370 kBq).

Several calibration curves were plotted for finding the relationship between the accumulated activity by the thyroid gland and the dose rate measured by the detector at different distances from the thyroid, i.e., calibration factor ((nSv/h)/Bq). Finally, the results were obtained by another initial activity (A_0=250 kBq).

Table 1. The characteristics of dosimeters used in different hospitals

Detector name	Type	Model	Minimum detectable level	Range
Thyac	NaI(Tl)	Thyac V, Model 190 Survey Meter	70 nSv/h	X-ray and gamma >25 keV
Rados	Geiger gas detector	RDS-110 Multi-Purpose Survey Meter	80 nSv/h	50 keV-1.25 MeV
Monitor 5	Geiger gas detector	Radiation Alert Monitor 5 (Summertown)	80nSv/h	30 keV-1 MeV
identiFINDER	NaI(Tl)	identiFINDER-N	50 nSv/h	15 eV-3 MeV

Figure 1. The measurement device geometry

Dose measurements in the hospital staff

In this study, the doses received by the neck surface of the nuclear medicine staff were measured for several days in one of the most important hospitals in south of Iran before and after working with ^{131}I, using the abovementioned survey meters. This hospital was selected, because it has the main nuclear medicine center in Shiraz in south of Iran. Radiation to the staff's neck was measured according to the IAEA recommendations for direct measurements. A specific protocol was also used for dose measurements outside the thyroid.

To reduce the effect of other contamination sources other than thyroid, measurements were performed in a place far from radiation, when the worker's body was free of surface contamination, his/her clothing was clean, and all his/her accessories (i.e., working clothes, jewelry, and watches) were removed. To fix the position of the detector during measurements, a mechanical device was designed and fabricated, which could be adjusted according to the height of the staff. This device is similar to a mechanical arm. The staff was asked to sit on a chair behind this device, and the detector was fixed on this arm. The distance of the detector from the thyroid was also adjustable.

Recording of dose measurements

Calibration factors can be used for converting the dose rate measured outside the neck to the activity concentration of ^{131}I inside the thyroid. The dose rate measurements were performed routinely before and after working with ^{131}I. A new software program was developed in this study for recording the activity concentrations inside the thyroid (see Figure 2). Therefore, the history of internal contamination of each radiation worker in normal working conditions could be documented in a database. Also, calibration curves could be used for emergencies and accidents when the thyroids absorbed very high levels of activity. In such cases, measurements could be performed in longer distances from the thyroid to reduce the effect of having a dead time on the measurements.

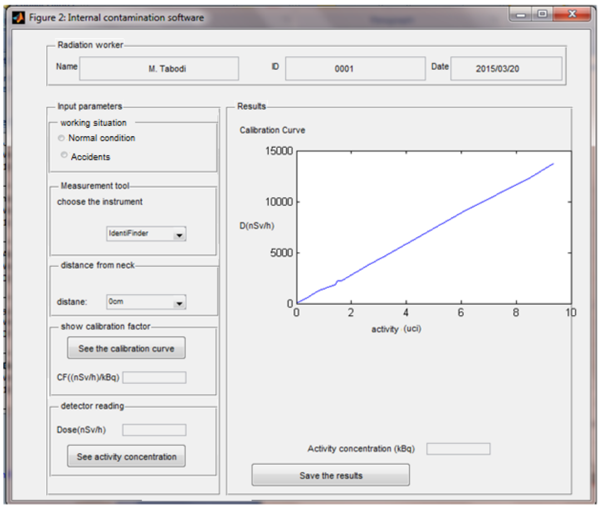

Figure 2. The software developed for activity assessments

Results

Calibration curves at different distances

The calibration curves were drawn for finding the relationships between activities absorbed by the thyroid and the dose rate measured by the detectors at different distances. Figure 3 shows the dose rate at different distances from the thyroid for a thyroid activity of 10 µCi with an identiFINDER detector. This detector was calibrated by the Secondary Standard Dosimetry Laboratory (SSDL). The dose rates were corrected for background radiation, which was nearly 50 nSv/h. As previously stated, the calibration curves were obtained for distances of 0 to 16 cm, with a 1-cm increment. Several examples of curves for distances of 0, 6, and 11 cm (as short, intermediate, and large distances, respectively) are shown in Figures 4-6 for both male and female thyroids.

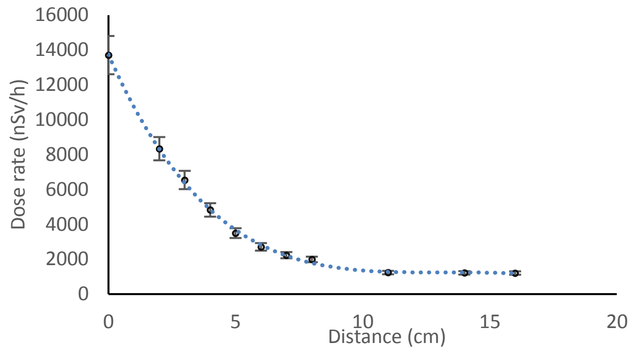

Figure 3: Variations in dose rates at different distances from the thyroid.

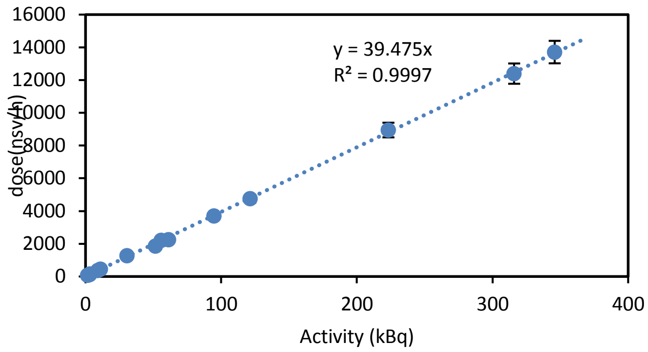

Figure 4. The calibration curve for a detector-to-neck distance of d=0 cm.

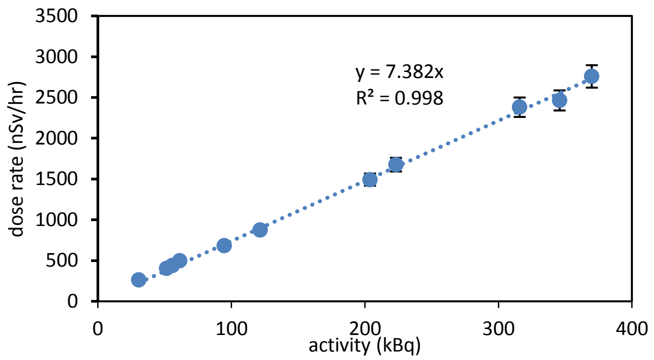

Figure 5. The calibration curve for a detector-to-neck distance of 6 cm.

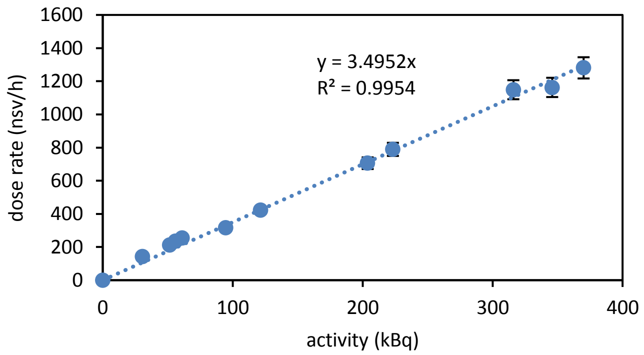

Figure 6. The calibration curve for a detector-to-neck distance of d=11 cm.

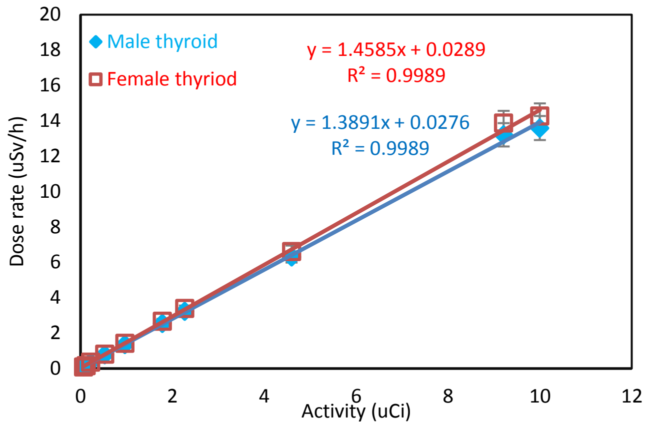

Figure 7. Comparison of calibration curves obtained by the identiFINDER detector for male and female phantoms at d=0 cm.

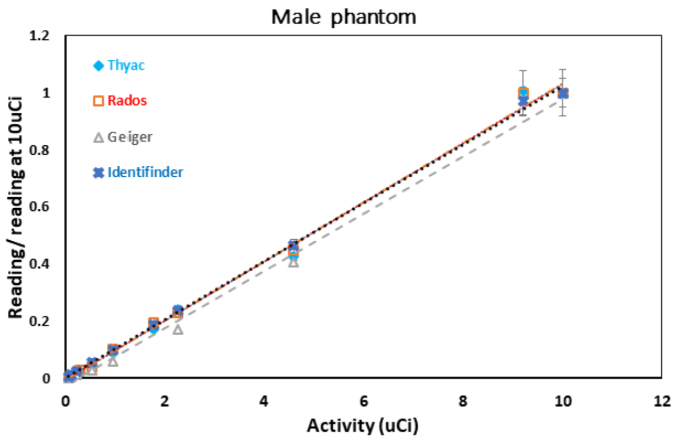

Figure 8. Comparison of calibration curves for the male phantom obtained for different detectors at d=0 cm.

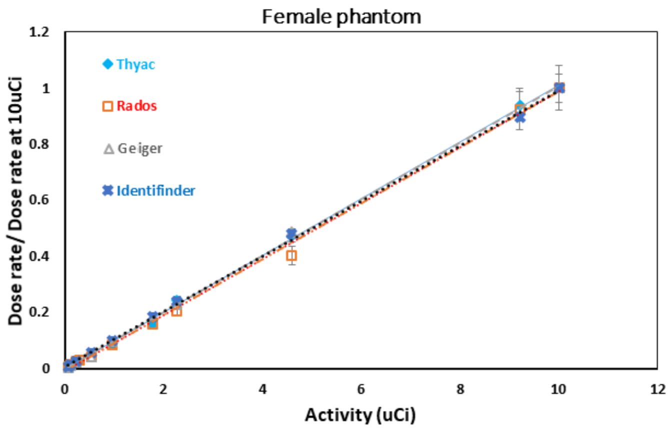

Figure 9. Comparison of calibration curves for the female phantom obtained for different detectors at d=0 cm.

The gradient of these curves (i.e., 39.47, 7.38, and 3.49) could be used as the calibration factor for converting the measured dose rate to the activity concentration inside the thyroid. Similar curves were drawn for other distances, and calibration factors of 25.52 and 2.061 were obtained for 1-cm and 16-cm distances, respectively. According to the results of this study, a detector-to-neck distance of 0 cm can be considered as the best distance, not only because of the good dose-activity correlation, but also because of the ease of detector position fixation. However, the measured calibration factors at other distances could be used in case of accidents, when high amounts of activities are absorbed by the thyroid.

Calibration curves for male and female phantoms

Figure 7 compares the calibration curves obtained by the identiFINDER detector for male and female phantoms at d=0 cm. The results indicated that for similar activities, the dose outside the female thyroid was about 5% higher than the male thyroid. This is because of differences in the geometry and size of female and male thyroids. To validate the measurements, a calibration factor was obtained for A_0=250 kBq. The calibration factors obtained with this activity were in close agreement, that is, <5% difference with those obtained for 370 kBq.

Calibration curves for different detectors

Doses were measured by three other calibrated detectors, including two Geiger-Mueller (GM) detectors (RADOS and Monitor 5) and one scintillation detector (Thyac 190). To compare the response of different detectors, the dose measured by each detector at each activity level was divided by the dose at 10 µCi. Figure 8 compares the normalized calibration curves of different detectors for the male phantom at a distance of 0 cm. The curve shows the normalized dose versus the activity inside the thyroid. The normalized dose is the dose at any activity level divided by the dose at 10 µCi activity. The normalized calibration curve for the female phantom is shown in Figure 9.

Results of measurements in the staff

Although in some cases, the dose rate measured at the thyroid surface was six times higher than the background dose, the activity accumulated in the staff's thyroid was less than the allowable limit (0.04 µCi). The results indicated that the activity concentration in the thyroid gland of the staff was reduced significantly when the health protocols were implemented, as suggested by the IAEA (18, 19).

Discussion

In this study, a simple methodology was introduced for the estimation of activity concentration inside the thyroid of the nuclear medicine staff. For this purpose, an ^{131}I activity concentration of 370 kBq was inserted inside the thyroid gland of a home-made neck-thyroid phantom. The dose rates at different distances from the thyroid were measured for two months, using different portable radiation detectors. Calibration curves were obtained for each distance, the gradients of which were used for converting the dose rate outside the thyroid to the activity inside the thyroid. The measurements were performed for both male and female thyroids of the neck phantom.

Different investigations for direct thyroid activity estimation suggest measurements using gamma cameras or spectroscopy with scintillation detectors. In this study, we found that every portable radiation monitoring device can be calibrated for this purpose. This method can be used for estimation of ^{131}I concentration inside the thyroid of the staff for daily monitoring in normal working conditions. In the present study, a routine monitoring protocol was established for the nuclear medicine department of the hospital. The dose rate outside the thyroid gland should be assessed twice a day for each radiation worker, once before and once after working with ^{131}I. The measured values are entered into the software to estimate the activity inside the thyroid. The software converts the values of dose rate to activity by using an appropriate calibration factor, which has been already entered in its database for different distances, different detectors, and different phantoms (male/female).

Generally, ^{131}I is a volatile radiotoxic material that can easily enter the body and be absorbed by the thyroid glands of the hospital personnel. The risk of thyroid abnormalities or cancer by ^{131}I increases by increasing the internal contamination; therefore, routine monitoring of ^{131}I inside the thyroid can be very effective in estimating the staff's safety in nuclear medicine departments. This method can be also generalized for determining the activity concentrations in accidents, when the staff's thyroids absorb activities more than the allowed activity concentration (0.04 µCi).

Conclusion

A simple method was developed in this study for estimation of the internal contamination of thyroid with the ^{131}I. Using this method, every nuclear medicine department can monitor its staff using the monitoring devices available in the department.

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