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Estimation of Chest Wall Attenuation of the Emissions from Iodine-123 in the Instance of Substernal Goiter: A Phantom Study

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Abstract

Objective

The underestimation of thyroid uptake measurements with iodine isotopes has been a generally accepted theory in patients with substernal goiter due to attenuation by the chest wall. The extent of this underestimation is not well known. In this study, we calculate the attenuation of the emissions from iodine-123 utilizing a cadaver chest wall with a thyroid probe in order to better understand the potential severity of this underestimation.

Methods

A capsule of 11.1 Megabequerels (MBq) of iodine-123 was measured using a thyroid probe directly, in a standard neck phantom and behind a cadaveric chest wall that included the soft tissues and bony structures (sternum).

Results

Using the thyroid probe, the calculated attenuation of the iodine capsule by the neck phantom was 18% and by the chest wall was 35%.

Conclusion

Thyroid uptake in the case of substernal goiter may be underestimated by standard techniques using a neck phantom. The composition of the chest wall can vary greatly and substernal extent of the goiter would be difficult to calculate with a high level of accuracy on a routine basis. Direct comparison with a cadaveric specimen leads to similar issues but does give us a rough estimation of the extent of this issue. This study suggests that the attenuation by the chest wall can be substantial. Knowledge of the extent of the substernal component of the thyroid gland may be useful if the uptake measurement is used to calculate doses for the treatment of hyperthyroidism in patients with a substernal goiter.

Introduction

Thyroid uptake measurements with radioactive isotopes are commonly performed procedures in patients with suspected thyroid dysfunction. They can be particularly useful in patients with planned radioactive iodine therapy for hyperthyroidism.(*1*) These measurements will indicate the fraction of the administered radioisotope administered that is located within the thyroid gland after a pre-determined set of time. The most commonly used isotopes are iodine-123 (I-123) and iodine-131 (I-131). The capsule of iodine is placed within a neck phantom and counted with a probe. After administration to the patient, the activity within the neck is then measured with the probe, typically 24 hours later. Some laboratories also obtain an early measurement at 4-6 hours. Measurements are corrected for background and for physical decay.(*2*)

For the uptake measurements, the thyroid probe is directed to the neck, the presumed location of the thyroid gland. Substernal goiter is an entity wherein a portion of the thyroid gland resides in a low position, posterior to the sternum. If the probe is directed at the neck and the gland lies inferior to this, the uptake measurement will be underestimated. However, if the thyroid gland is known to be substernal, and the probe is aimed properly, the thyroid uptake measurement may

still be incorrect because the attenuation of the neck phantom will not match the true attenuation created by the chest wall. There is no standard phantom for the chest wall.

The goal of our study was to obtain an estimate of the attenuation of emissions from I-123 by the sternum and to determine the level of error this will cause in a thyroid uptake measurement.

Materials and Methods

Attenuation of the gamma emissions from I-123 (159 KeV) through a cadaveric chest wall was measured by direct counting of the emissions with a thyroid probe (Biodex, Shirley NY).

A capsule of 11.1 MBq of I-123 was counted with the thyroid probe for one minute and then placed into a standard neck phantom (Biodex) and counted again for one minute (Figures 1, 2). For the phantom calculation, the probe was positioned 24 cm from the surface of the phantom, as is done with patients studies, meeting the guidelines of 20 to 30 cm set out by the ACR-SNM-SPR practice guideline (2009).

For counting without the phantom, the probe was positioned the 24 cm plus an additional 2 cm (26 cm total) which is the distance from the capsule holder within the phantom to the surface of the phantom. The capsule was then placed below the sternum of a female cadaveric chest wall (Figure 3). Probe counts for one minute were again obtained with the thyroid probe. Background activity (air) was counted for one minute. Background was subtracted from both capsule counts and from attenuated capsule counts. Attenuation of the emissions was calculated by comparing counts through the phantom or through the chest wall against counts from the capsule alone. The calculation is as follows:

Attenuation = 1 – ((capsule counts in the phantom or behind the chest wall – BKG) / (capsule counts – BKG))

Results

The results of probe counting are included in Table 1. Calculated attenuation by the neck phantom was 18%. Attenuation through the cadaveric chest wall was 35%.

Discussion

Substernal goiter is the process wherein all or a portion of the thyroid gland extends into the mediastinum. It has been estimated to occur in 6% of individuals being evaluated for thyroidectomy.(*3,4*) By including asymptomatic patients, the overall prevalence would be lower. Substernal goiter is often seen in elderly patients and is more common in women than men.(*5*) Although substernal goiters are more often hypofunctioning, patients with hyperthyroidism may have a substernal component of their thyroid gland.

Thyroid uptake is a commonly performed procedure in which the fraction of ingested iodine within the thyroid gland after a specified period (usually 24 hours and sometimes with the addition of a 4-6 hour measurement) is calculated. This test plays a role in characterizing a patient with hyperthyroidism. The measurement is often used to calculate a therapeutic dose of I-131 for the treatment of hyperthyroidism. There are multiple different strategies that can be utilized for this calculation.

We found that our neck phantom attenuates the capsule emissions by 18%. Presumably, this would approximate the attenuation of I-123 emissions from an average size neck. When we measured the attenuation of the chest wall containing, in particular, the sternum, the attenuation increased to 35%, essentially doubling.

The implication here is that the thyroid uptake is likely to be incorrect if a portion of the thyroid is substernal. This may have a consequence if the measurement is used to calculate therapeutic doses of I-131 for the treatment of hyperthyroidism. Uptake measurements may be underestimated leading to an increase in the calculated therapeutic dose. Administering higher than necessary doses of I-131 may lead to an increase in both short term side effects and long term unwanted consequences. It is even possible that, with uptake underestimation, the therapy will not be performed. This has a lower significance for the treatment of thyroid cancer with I-131: a majority of treatment patients will have undergone a thyroidectomy and uptake measurements are utilized less frequently in this patient population.

How would this translate into therapy dose calculations? Presume that the thyroid has an uptake of 50% and the goal is to administer 10 mCi for treatment of

hyperthyroidism. The administered dose would be 20 mCi. In the situation of a normally positioned, cervical thyroid gland, no additional calculation is needed. The phantom simulates neck attenuation. In the second scenario, the thyroid gland is completely substernal. Uptake would be ((1.00-0.35)/(1.00-0.18)) or 79% of what it would have been if the gland was normally positioned. The thyroid uptake would be measured as 0.50*0.79 or 0.40. The administered dose would be 10 mCi/0.40 or 25 mCi rather than 20 mCi. If the thyroid uptake is lower, the effect is magnified. In the case of an uptake of 30%, the administered dose would rise from 10 mCi/0.3 or 33 mCi to 10 mCi/(0.3*0.79) or 42 mCi. This is a "worst case scenario." Most substernal glands are not completely behind the sternum and measurement error would be less extreme.

Park et al, in a study evaluating the ability of thyroid scintigraphy to detect "intrathoracic" glands, briefly mention that measured 21% attenuation of I-123 photons through a "fresh adult cadaver sternum."(*6*) They do not say that a chest wall was used and do not provide a reference for this work.

There are several ways in which this analysis will differ from real life scenarios. First, as mentioned, the thyroid gland is rarely located completely behind the

sternum. The cadaveric chest wall is an approximation of that of a living human. Its constituent tissue will not have identical attenuation coefficients. Finally, we utilized one cadaveric specimen; chest walls in cadavers as well as in living patients come in many shapes and sizes. There is no phantom that can function as an exact representation of a patient. Our goal was to provide a rough idea of how severe the attenuation may be.

Another separate, though related problem, is that of improper aiming of the thyroid probe. The probe is a collimated device and moving the target away from its center point will lower the count. It would be interesting to investigate the effect of malpositioning a thyroid probe.

It is likely that many patients who undergo I-131 therapy will not have had their anatomy defined and it will be unknown if there is a substernal component of their thyroid gland. There are patients, however, in whom this is known. Patients may have had thyroid scintigraphy with a sternal marker performed prior to therapy. Some patients will have had a prior CT scan of their neck or chest. In this scenario, consideration might be given to lowering the treatment dose compared to that which would have been administered otherwise. There are also CT based

methods to calculate the actual attenuation coefficient of the interceding chest wall utilizing the thickness of the tissues, density calculation with Hounsfield units and the mass attenuation coefficients of the tissues. The chest wall may include soft tissue, cortical bone, cancellous bone, marrow, and cartilage. It would be highly doubtful that there would be benefit from this demanding calculation. We do not recommend actually performing a CT scan on hyperthyroid patients solely for this purpose. Our aim was to provide an understanding of the potential magnitude of the attenuation.

Conclusion

The standard neck phantom utilized in the routine calculation of radioactive thyroid uptake with I-123 will lead to an underestimation when a substernal goiter is present. The extent of error will differ from patient to patient but, based upon our evaluation, in the most extreme example, the impact can be substantial. When it is known that the thyroid has a substernal component, practitioners should consider lowering therapeutic doses of I-131 when using uptake measurements for calculation.

Disclosure

The authors have no conflicts of interest to disclose.

Acknowledgment

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References

1. McDougall IR. The importance of obtaining thyroid uptake measurement in patients with hyperthyroidism. *Nucl Med Commun*. 1990;11:73-76.

2. Czepczyński R. Nuclear medicine in the diagnosis of benign thyroid diseases. *Nucl Med Rev*. 2012;15:113-119.

3. Huins CT, Georgalas C, Mehrzad H, Tolley NS. A new classification system for retrosternal goitre based on a systematic review of its complications and management. *Int J Surg*. 2008;6:71-76.

4. Newman E, Shaha A. Substernal goiter. *J Surg Oncol.* 1995;60:207-212.

5. Wang LS. Surgical management of a substernal goiter. *Formos J Surg*. 2012;45:41-44.

6. Park HM, Tarver RD, Siddiqui AR, Schauwecker DS, Wellman HN. Efficacy of thyroid scintigraphy in the diagnosis of intrathoracic goiter. *Am J Roentgenol*. 1987;148:527-529.

Tables

Table 1. Thyroid probe counts of a capsule of 11.1 MBq of I-123 without an attenuator, within a neck phantom and behind a cadaveric chest wall.

Object	**Counts / minute**
Background	115
Capsule	1.581*10^6
Capsule + neck phantom	1.290*10^6
Capsule + chest wall	1.029*10^6
Calculated attenuation	
Neck phantom	0.18
Chest wall	0.35

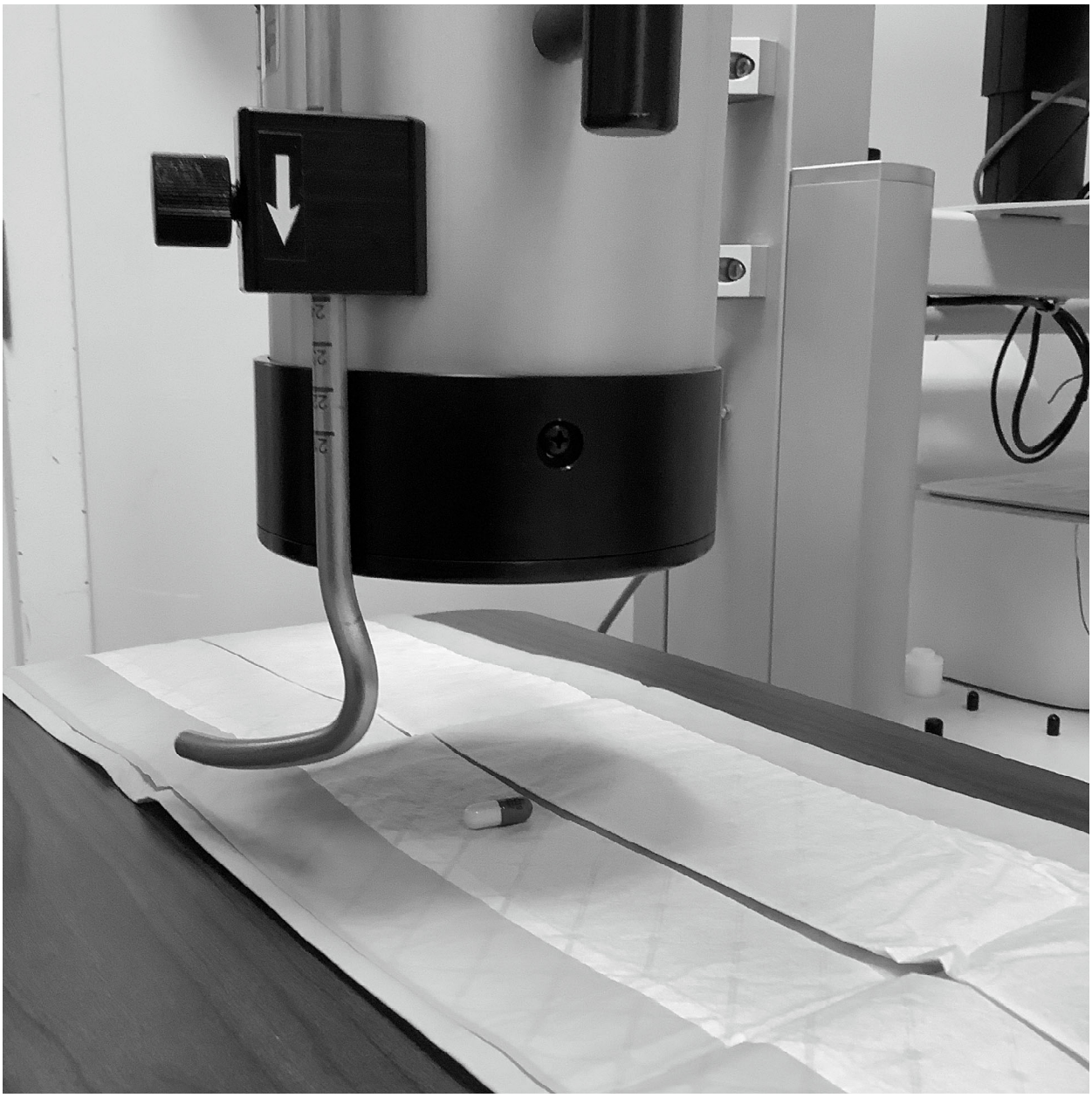

Figure 1. Demonstration of counting a capsule of iodine without an attenuator. The probe is positioned 26 cm from the capsule (equivalent to the 24 cm to the surface of the phantom, when used, plus 2 cm from the surface to the capsule,).

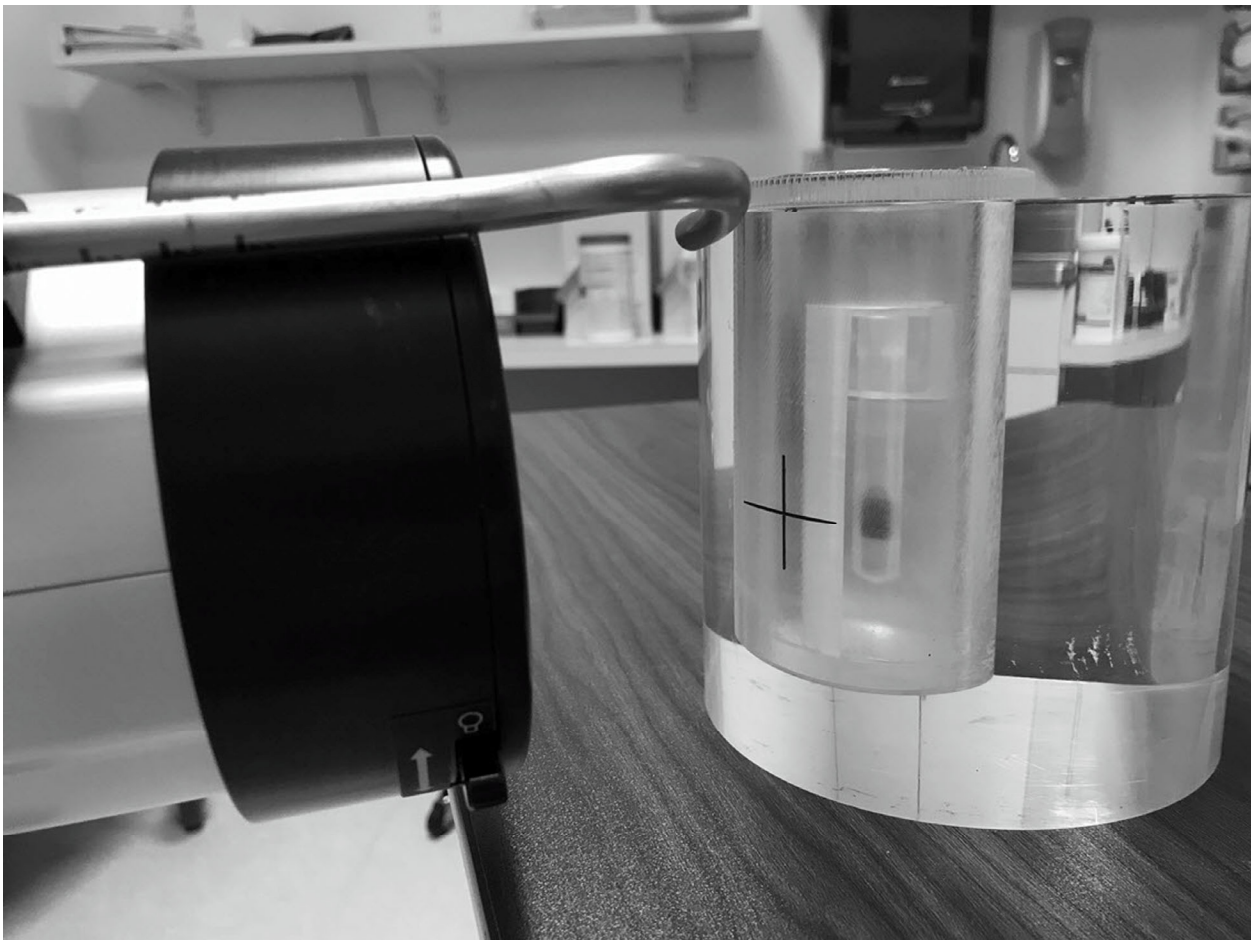

Figure 2. Demonstration of counting a capsule of iodine within a standard neck phantom utilizing a thyroid probe. The probe is positioned 24 cm from the surface of the phantom. The same position is utilized for patient studies.

Figure 3. Demonstration of counting of the iodine capsule attenuated by a cadaveric chest wall. The image demonstrates the capsule (within a sealed plastic bag), below the chest wall. The thyroid probe is positioned 24 cm above the chest wall.

Graphical abstract