# Estimation of Chest Wall Attenuation of $^{123}$I Emissions in Substernal Goiter: A Phantom Study

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In patients with substernal goiter, the generally accepted theory is that thyroid uptake measurements with iodine isotopes are underestimated because of attenuation by the chest wall. The extent of this underestimation is not well known. In this study, we calculated the attenuation of $^{123}$I emissions using a cadaver chest wall with a thyroid probe to better understand the potential severity of this underestimation. **Methods:** A 11.1-MBq capsule of $^{123}$I was measured using a thyroid probe directly in a standard neck phantom and behind a cadaver chest wall that included the soft tissues and bony structures (sternum). **Results:** The calculated attenuation of the iodine capsule was 18% for the neck phantom and 35% for the cadaver chest wall. **Conclusion:** Thyroid uptake in cases of substernal goiter may be underestimated by standard techniques using a neck phantom. The composition of the chest wall can vary greatly, and the substernal extent of the goiter would be difficult to calculate with high accuracy on a routine basis. Comparison between the cadaveric specimen and the phantom does give us a rough estimation of the differences in attenuation. Our findings suggest that 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 treating hyperthyroidism in patients with substernal goiter.

**Key Words**: endocrine; instrumentation; radionuclide therapy; radioactive iodine therapy; radioactive iodine uptake; substernal goiter

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Thyroid uptake measurements with radioactive isotopes are common in patients with suspected thyroid dysfunction. Such measurements can be particularly useful in hyperthyroidal patients for whom radioactive iodine therapy is planned (*1*). These measurements will indicate the fraction of administered radioisotope that is within the thyroid gland after a predetermined time. The most commonly used isotopes are $^{123}$I and $^{131}$I. 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 h later. Some laboratories also obtain an early measurement at 4–6 h. Measurements are corrected for background and for physical decay (*2*).

For the uptake measurements, the thyroid probe is directed at the neck, the presumed location of the thyroid gland. In substernal goiter, a portion of the thyroid gland is in a low position, posterior to the sternum. If the probe is directed at the neck and the gland lies inferior to that point, the uptake measurement will be an underestimate. 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 by 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 estimate the sternal attenuation of $^{123}$I emissions and the resulting level of error in a thyroid uptake measurement.

## MATERIALS AND METHODS

Attenuation of the γ-emissions from $^{123}$I (159 keV) through a cadaver chest wall was measured by direct counting with a thyroid probe (Biodex).

A 11.1-MBq capsule of $^{123}$I was counted with the thyroid probe for 1 min and then placed into a standard neck phantom (Biodex) and counted again for 1 min (Figs. 1 and 2). For the phantom calculation, the probe was positioned 24 cm from the surface of the phantom, as is done in patient studies, meeting the 20–30 cm set by the 2009 practice guideline of the American College of Radiology, Society of Nuclear Medicine and Molecular Imaging, and Society for Pediatric Radiology (*3*). For counting without the phantom, the probe was positioned at 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 cadaver chest wall (Fig. 3). The probe count for 1 min was again obtained with the thyroid probe. Background activity (air) was counted for 1 min. Background was subtracted both from the capsule count and from the attenuated capsule count. The attenuation of the emissions was calculated by comparing the count through the phantom or through the chest wall with the count from the capsule alone: attenuation = 1 – [(capsule count in phantom or behind chest wall – background)/(capsule count – background)].

## RESULTS

All counts are shown in Table 1. Calculated attenuation by the neck phantom was 18%. Attenuation through the cadaver chest wall was 35%.

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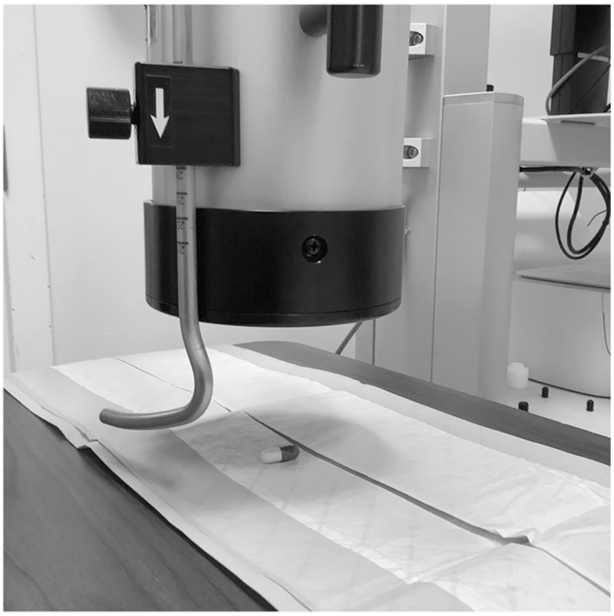

**FIGURE 1.** Demonstration of counting of capsule of iodine without attenuator. Probe is 26 cm from capsule (equivalent to 24 cm from surface of phantom, when used, plus 2 cm from surface to capsule).

## 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 (*6*). Although substernal goiters are more often hypofunctioning, patients with hyperthyroidism may have a substernal component to their thyroid gland.

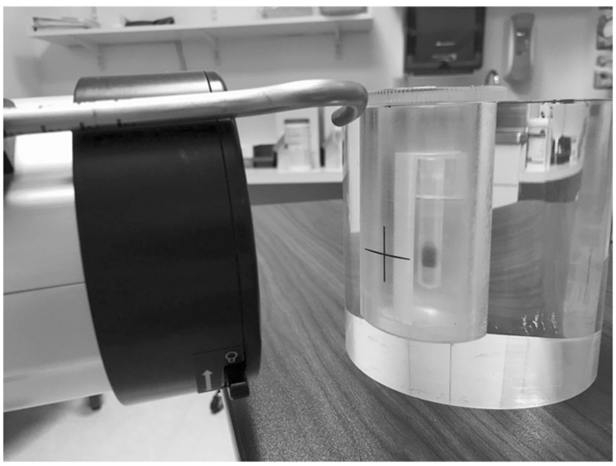

**FIGURE 2.** Demonstration of counting of iodine capsule within standard neck phantom using thyroid probe. Probe is 24 cm from surface of phantom. Same position is used for patient studies.

**FIGURE 3.** Demonstration of counting of iodine capsule attenuated by cadaver chest wall. Capsule is within sealed plastic bag below chest wall. Thyroid probe is 26 cm from capsule.

Measurement of thyroid uptake is a commonly performed procedure in which the fraction of ingested iodine within the thyroid gland is calculated after a specified period (usually 24 h and sometimes with the addition of a 4- to 6-h measurement). This test plays a role in characterizing a patient with hyperthyroidism. The measurement is often used to calculate the dose of $^{131}$I for treating hyperthyroidism. There are several different ways that this calculation can be done.

We found that our neck phantom attenuated the capsule emissions by 18%—presumably, the approximate attenuation of $^{123}$I emissions for an average-sized neck. For a cadaver

**TABLE 1**
Thyroid Probe Counts of 11.1-MBq Capsule of $^{123}$I Without Attenuator, Within Neck Phantom, and Behind Cadaver Chest Wall

| Object | Data |
|---|---|
| Background | 115 counts/min |
| Capsule | $1.581 \times 10^6$ counts/min |
| Capsule + neck phantom | $1.290 \times 10^6$ counts/min |
| Capsule + chest wall | $1.029 \times 10^6$ counts/min |
| Calculated attenuation | |
| Neck phantom | 18% |
| Chest wall | 35% |

chest wall containing the sternum, the attenuation increased to 35%, essentially doubling.

The implication is that the thyroid uptake measurement is likely to be incorrect if a portion of the thyroid is substernal—a possibility that may be of consequence if the measurement is used to calculate $^{131}$I doses for treating hyperthyroidism. Uptake measurements may be underestimated, leading to an increase in the calculated therapeutic dose. Administering doses of $^{131}$I higher than necessary 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 $^{131}$I: most treated patients will have undergone thyroidectomy, and uptake measurements are used less frequently in this population.

How would this translate into therapy dose calculations? Presume that the thyroid has an uptake of 50% and the goal is to administer 370 MBq (10 mCi) for treatment of hyperthyroidism. The administered dose would be 740 MBq (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 were normally positioned. The thyroid uptake would be measured as $0.50 \times 0.79$, or 0.40. The administered dose would be 370 MBq (10 mCi)/0.40, or 925 MBq (25 mCi), rather than 740 MBq (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 370 MBq (10 mCi)/0.3, or 1,221 MBq (33 mCi), to 370 MBq (10 mCi)/($0.3 \times 0.79$), or 1,554 MBq (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 an article (*7*) describing their study evaluating the ability of thyroid scintigraphy to detect intrathoracic glands, briefly mentioned that they measured 21% attenuation of $^{123}$I photons through a fresh adult cadaver sternum. Details regarding how this was calculated were not provided.

There are several ways in which this analysis will differ from real-life scenarios. First, the thyroid gland is rarely located completely behind the sternum. The cadaver chest wall is an approximation of the chest wall of a living human. Its constituent tissue will not have identical attenuation coefficients. Finally, we used 1 cadaver specimen; chest walls in cadavers, 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 of a thyroid probe.

It is likely that many patients who undergo $^{131}$I therapy will not have had their anatomy defined, and it will be unknown whether 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 before 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 from what would have been administered otherwise. There are also CT-based methods to calculate the actual attenuation coefficient of the interceding chest wall using 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 is 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 used in the routine calculation of radioactive thyroid uptake with $^{123}$I will lead to an underestimation when a substernal goiter is present. The extent of error will differ from patient to patient, but on the basis of 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 $^{131}$I when using uptake measurements for calculation.

## DISCLOSURE

No potential conflict of interest relevant to this article was reported.

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