Comparison of Low-Energy and Medium-Energy Collimators for Thyroid Scintigraphy with ^{123}I

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^{123}I thyroid scintigraphy can be performed with either a low-energy or a medium-energy (ME) collimator. The high-energy photon emissions from ^{123}I cause septal penetration with scattered photons, which deteriorate image quality. The aim of this study was to evaluate the impact of collimator choice on ^{123}I thyroid scintigraphy in clinical practice. **Methods:** Forty-seven patients who underwent thyroid planar scintigraphy with both a low-energy, high-resolution (LEHR) collimator and a ME collimator were prospectively recruited using the same imaging protocol. Image quality, collimator sensitivity, and estimation of thyroid size were assessed between LEHR and ME collimators and were compared with thyroid ultrasonography as the gold standard. **Results:** Images acquired with the ME collimator demonstrated reduced scattered background noise, improved thyroid-to-background contrast, and increased sensitivity in the thyroid gland compared with images acquired by the LEHR collimator. Manual measurement of the thyroid length is more accurate using the ME collimator. Automatic estimation of the thyroid area using the same thyroid threshold is larger in ME collimator images than in LEHR collimator images. **Conclusion:** Compared with the LEHR collimator, the ME collimator generates cleaner ^{123}I thyroid scintigraphy images with less background noise and has higher collimator sensitivity for thyroid imaging. Different thyroid thresholds should be used to estimate the thyroid area and volume between low and ME collimators.

Key Words: endocrine; image processing; collimator; iodine-123; medium energy; thyroid scintigraphy

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For thyroid imaging, ^{123}I is a more ideal radioisotope than ^{131}I because ^{123}I is comparable to ^{99m}Tc, has less septal penetration with better image quality, and exposes the patient to less radiation (*1,2*). It has the most abundant γ-rays, at 159 keV, which is comparable to the 140 keV from ^{99m}Tc, and can be imaged with pinhole, low-energy, or medium-energy (ME) collimators (*3*). A pinhole collimator provides more details for imaging small organs such as the thyroid glands. However, a pinhole collimator cannot be used to estimate the functional thyroid size and volume, which are used frequently for dose calculation in radioiodine therapy. A low-energy, parallel-hole collimator, especially the low-energy, high-resolution (LEHR) collimator, is the most widely used collimator in nuclear medicine imaging, mainly because of its advantage for imaging ^{99m}Tc-labeled radiopharmaceuticals. The LEHR collimator has been frequently used for ^{123}I thyroid scintigraphy, with the major advantage of avoiding collimator switching between studies using ^{99m}Tc-labeled compounds and shorter acquisition times.

^{123}I also emits a small percentage ($<3\%$) of higher-energy photons exceeding 400 keV. These high-energy photons can penetrate the collimator septum and generate scattered photons, which are detected in the 159-keV window (*4*). Septal penetration leads to reduced imaging quality, especially for the LEHR collimator with a thinner septum, resulting in more septal penetration. A ME collimator with a thicker septum results in less septal penetration for ^{123}I imaging than does a low-energy collimator. The ME collimator has been recommended for several nuclear medicine studies using ^{123}I with semiquantitative evaluation (*5–8*). However, whether the ME collimator is superior to LEHR for thyroid scintigraphy with ^{123}I in clinical practice has not been well documented. This study was designed to evaluate the impact of choosing between LEHR and ME collimators on ^{123}I thyroid scintigraphy in clinical practice.

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MATERIALS AND METHODS

Patients

In total, 47 consecutive patients referred for thyroid scintigraphy with ^{123}I were prospectively recruited at the Veterans Affairs Greater Los Angeles Health Care System between October 2015 and November 2016. There were 35 men and 12 women, with an average age of 61 y. Thyroid scintigraphy was performed for evaluation of hyperthyroidism (37 patients) or thyroid nodules (10 patients).

Thyroid Scintigraphy

All patients underwent thyroid scintigraphy with both a large-rectangular-field-of-view Siemens BiCore LEHR collimator and ME collimators sequentially with the same camera. The specifications of the LEHR and ME collimators are listed in Table 1. To reduce the influence of different imaging times after ^{123}I administration, half our patients underwent LEHR collimator imaging first, immediately followed by ME collimator imaging, and the other half underwent ME collimator imaging first, immediately followed by LEHR collimator imaging. All patients received 7,400 kBq (200 μCi) of ^{123}I. Thyroid imaging started at approximately 4 h 30 min after the 4-h thyroid uptake measurement. Images were acquired using a Siemens Symbia T16 SPECT/CT γ-camera. The following acquisition parameters were used: anterior view, 128 × 128 matrix, zoom factor of 1, pixel size of 2.4 mm, acquisition time of 7 min for both LEHR and ME collimators, and an energy window of 15% centered at 159 keV. The distance between the collimator and the patient's face was kept to 2.54 cm (1 in) or as close as the patient could tolerate.

Thyroid Ultrasonography

There were 22 patients who also underwent thyroid ultrasonography within 3 mo of thyroid scintigraphy. Thyroid ultrasonography was performed using either the Philips EPIQ 7G or the GE Healthcare XDclear real-time ultrasound scanner with high-resolution 6- to 15-MHz linear array transducers. Each thyroid lobe was scanned in both transverse and longitudinal planes. The maximum length, width, and depth of each thyroid lobe were measured. The volume of each thyroid lobe was calculated with the standard formula for ellipsoid volumes: volume (mL) = $\pi/6$ × length (cm) × width (cm) × depth (cm).

Image Analysis

All scintigraphic images were viewed and analyzed using an Oasis general nuclear medicine package, which included a thyroid analyzing application (Segami Corp.). Using a lower threshold of 30% of the maximum pixel counts in the image frame, an isocontour of the thyroid gland was created automatically with the Oasis thyroid application. Total thyroid counts, background-corrected total thyroid counts, and counts per pixel were calculated within the thyroid isocontour. The length of each thyroid lobe was manually measured by 5 nuclear medicine physicians using the Oasis thyroid application. The thyroid area was automatically calculated with the Oasis thyroid application by applying different thresholds (20%, 25%, 30%, 35%, 40%, and 45%). The thyroid volume was calculated using the empiric method that is being used at the VA Greater Los Angeles Health Care System: thyroid volume (mL) = area of thyroid gland (cm^2) × length (cm) × 0.321. The differences between the LEHR and ME collimator for thyroid length measurement and volume estimation were compared using ultrasonography as the gold standard for thyroid measurement.

Statistical Analysis

GraphPad Prism 8 was used to perform statistical analyses. Data distributions were assessed using the D'Agostino–Pearson omnibus test. Normally distributed data are summarized as mean ± SD, and nonparametric data are summarized as median and interquartile range. Variables from different groups were compared using the Student *t* test (2-tailed paired samples assuming unequal variance) for parametric variables and the Mann–Whitney test (2-tailed paired samples) for nonparametric variables. Significance was defined as a *P* value of less than 0.05, and the 95% CIs are reported when appropriate. Comparison of thyroid size measurements among different methods was analyzed with linear regression and Bland–Altman plot analyses (*9*).

RESULTS

There was a clear difference in image quality between LEHR and ME collimators, as demonstrated in Figure 1. ME collimator planar images demonstrated significantly less background noise, better thyroid-to-background contrast, and an overall much cleaner image than did LEHR collimator images. The LEHR images demonstrated a slightly better spatial resolution than the ME images, although the difference was very subtle by visual inspection. Ten patients were referred for evaluation of known thyroid nodules. There was no difference between LEHR and ME collimator images in identifying these nodules.

TABLE 1
Siemens BiCore Collimator Specifications

Parameter	LEHR	ME
Hole shape	Hexagon	Hexagon
Number of holes (×1,000)	148	14
Hole length	24.05 mm	40.64 mm
Septal thickness	0.16 mm	1.14 mm
Hole diameter	1.11 mm	2.94 mm
Sensitivity at 10 cm	5.46 cpm/kBq (^{99m}Tc)	7.43 cpm/kBq (^{67}Ga)
Geometric resolution at 10 cm	6.4 mm (^{99m}Tc)	10.8 mm (^{67}Ga)
System resolution at 10 cm	7.5 mm (^{99m}Tc)	12.5 mm (^{67}Ga)
Septal penetration	1.5% (^{99m}Tc)	1.2% (^{67}Ga)
Weight	22.1 kg	63.5 kg

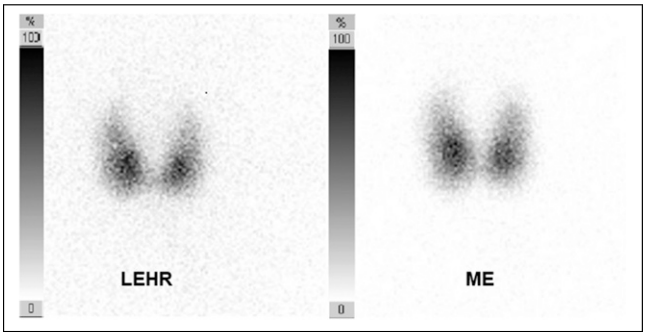

FIGURE 1. Planar anterior view of thyroid scintigraphy from LEHR collimator and ME collimator.

The total photon counts from the whole large-field-of-view camera were 36% higher in the LEHR collimator images than in the ME collimator images (Fig. 2A). In contrast, the total thyroid counts (thyroid area was defined by applying 30% of threshold), background-corrected total thyroid counts, and count density as determined by counts per pixel in thyroid tissue from the LEHR collimator images were significantly less than those from the ME collimator images (Figs. 2B–2D).

By visual inspection, the ME collimator images demonstrate a slightly larger thyroid size than the LEHR collimator images for most patients. When thyroid length was measured manually from the planer scintigraphy images, the LEHR collimator measurement and ME collimator measurement correlated similarly with the ultrasonography measurement, as determined by the Pearson correlation coefficient ($r = 0.69$ for LEHR and $r = 0.66$ for ME). The Bland–Altman plot analyses demonstrated less bias from the ME collimator measurement than from the LEHR collimator measurement, as compared with ultrasonography (Figs. 3A and 3B). Interobserver variations in thyroid length measurement were similar between LEHR and ME as determined by the intraclass correlation coefficient (LEHR, 0.92, with 95% CI of 0.88–0.96; ME, 0.91, with 95% CI of 0.87–0.95).

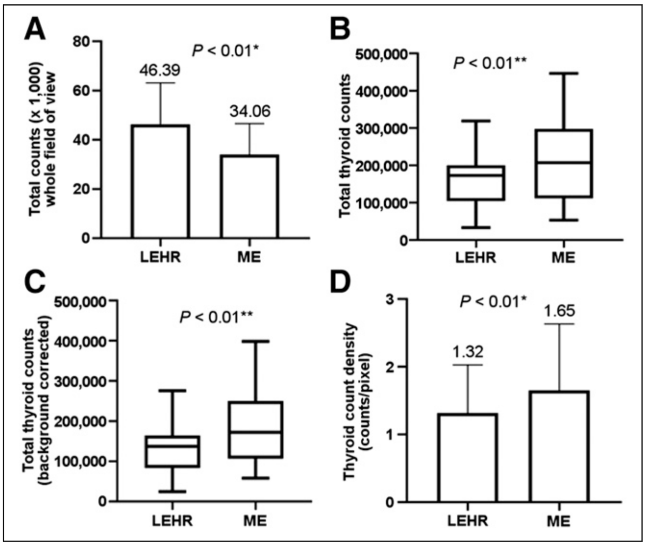

FIGURE 2. Comparison of photon counts between LEHR collimator and ME collimator. (A) Total counts from whole rectangular field of view of collimator. (B–D) Counts within thyroid isocontour measured by applying 30% of threshold. A and D represent mean with SD. B and C represent median with interquartile range. *Significance was determined by Student *t* test. **Significance was determined by Mann–Whitney test.

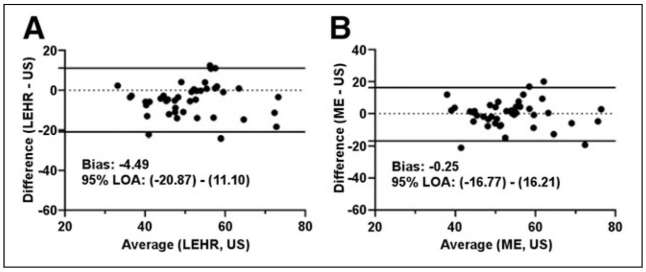

FIGURE 3. Bland–Altman plot analyses of thyroid length measurement between ultrasonography with LEHR collimators (A) and ultrasonography with ME collimators (B). LOA = limit of agreement; US = ultrasonography.

The automatically calculated area using the threshold of the maximum average pixel is inversely proportional to the threshold percentage being used. For the same image, the lower threshold resulted in a larger area, and a higher threshold resulted in a smaller area. For volume estimation using LEHR collimator images, 35% of the threshold yielded the closest volume estimation with the least bias, as compared with ultrasonography (Fig. 4A). For volume estimation using ME collimator images, the same threshold (35%) yielded an overestimation with increased bias, and 40% of the threshold yielded the closest volume estimation with the least bias, as compared with ultrasonography (Figs. 4B and 4C). As compared with ultrasonography, the LEHR and ME collimators demonstrated a similar spread of limits of agreement in both thyroid length and volume estimation.

DISCUSSION

The most striking difference between the LEHR and ME collimator images is the background noise. The ME collimator images demonstrate a significantly less noisy background and are much cleaner than the LEHR collimator images. This effect is related to a reduction of septal penetration of high-energy photons from ^{123}I. Septal penetration is most prominent in the low-energy collimator, which has a thinner collimator septum (Table 1). Septal penetration produces scattered photons, which pass through collimator holes and reach the sodium iodine crystals from the detector. The noisy background counts are barely visible from the ME collimator images but are quite obvious from the LEHR collimator images.

It is interesting to notice that, as compared with the ME collimator, the LEHR collimator yielded more total counts for the large field of view covering the whole collimator surface (Fig. 2A) but significantly fewer total counts from thyroid tissue (Figs. 2B–2D). Other studies have demonstrated that the LEHR collimator has a higher sensitivity than the ME collimator for ^{123}I imaging using phantoms (*5,7*). The

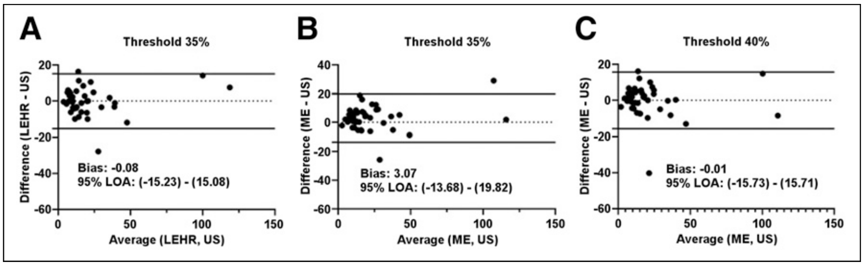

FIGURE 4. Bland–Altman plot analyses of thyroid volume estimation between ultrasonography with LEHR collimators (A) and ultrasonography with ME collimators (B and C) by applying different thresholds.

increased sensitivity of the LEHR collimator is probably due to more scattered photons from background. Scattered photons detected by the detector may be more obvious in patients than in the phantom study, as the higher-energy photons may undergo scattering in the human body before they reach the collimator. These scattered photons deteriorate image quality and increase background noise. For thyroid tissue evaluation, the ME collimator demonstrates significantly higher sensitivity than the LEHR collimator for thyroid ^{123}I scanning in clinical patients. The increased sensitivity for thyroid scans with the ME collimator is due mainly to the increased diameter of the collimator holes, allowing detection of more photons parallel to the collimator holes.

The ME collimator has lower spatial resolution than the LEHR collimator; however, the difference is not very obvious for thyroid ^{123}I imaging in patients (Fig. 1), probably because of an improved imaging quality with less septal penetration and scattering from the ME collimator. In addition, the increased total thyroid counts from the ME collimator also contribute to improved image quality, thus partially compensating for the disadvantage of lower spatial resolution. No difference was observed in identifying functional nodules between LEHR and ME collimators in this study. However, the patient sample size was fairly small, and only 10 patients were referred for evaluation of known thyroid nodules. The increased sensitivity of the ME collimator with improved thyroid-to-background contrast suggests that images can be acquired with less scanning time than for the LEHR collimator if a fixed-count imaging protocol is used. This advantage may potentially benefit SPECT imaging, which requires significantly longer scanning times using a ME collimator for SPECT imaging and may subsequently reduce the chance of patient motion.

The slightly larger thyroid gland visualized in ME collimator images is most likely due to increased thyroid photon counts in ME collimator images. Although thyroid scintigraphy is less precise than anatomic imaging modalities such as MRI or ultrasound in estimating thyroid size or volume, it is still convenient to have an estimation of functional thyroid volume using thyroid scintigraphy. This is especially helpful for ^{131}I treatment with a calculated dose protocol, which is frequently used clinically. The LEHR collimator imaging resulted in slight underestimation of the thyroid length compared with ultrasonography measurement as the standard. Manual measurement of thyroid length is more accurate in the ME collimator images than in the LEHR collimator images, probably because of increased collimator sensitivity and improved thyroid-to-background contrast with the ME collimator.

Various thyroid volume calculation methods using scintigraphy include either manual measurement of thyroid size or automatic calculation of thyroid area (*10*). No universal method has been widely accepted by the nuclear medicine community. The automatic calculation of thyroid area by applying different thresholds of the maximum average pixel using software is the most commonly applied method to estimate thyroid size. This method is more precise than a manually drawn thyroid contour or thyroid border, which usually generates significant variability. Because of the significant difference in thyroid photon counts and sensitivity between LEHR and ME collimators, applying the same threshold will result in an increased area estimation in ME collimator images when compared with LEHR collimator images. Therefore, different thresholds should be used to estimate the thyroid areas for LEHR and ME collimator images.

A 35% threshold in the LEHR collimator images yielded the closest volume estimation as compared with ultrasonography estimation, and a 40% threshold in the ME collimator images yielded similar results. These thresholds are higher than in other studies, which used thresholds of between 20% and 30% (*11,12*). This difference is probably due to different imaging protocols and different formulas to calculate thyroid volume. Our image acquisition time was 7 min. Other studies used 5 min, had a longer distance between the collimator and the patient, or used a fixed-count protocol (*11–14*). In addition, volume estimation from planar thyroid scintigraphy reported by others was larger than from ultrasonography and was also dependent on different formulas (*12,14*). Appropriate thresholds should be based on different volume calculation formulas, different imaging protocols, and different scanners. Measurement from the ME collimator images was consistently higher than measurement from the LEHR collimator images when both used the same imaging protocol and same threshold. Therefore, a higher threshold should be used for ME collimator images. Alternatively, the difference could be adjusted by applying a different formula or scaling factor.

Measurement of both thyroid length and thyroid volume between LEHR and ME collimator images demonstrated a similar spread of 95% limits of agreement, suggesting that the LEHR and ME collimators have similar precision and variation when compared with ultrasonography measurement. In terms of thyroid volume estimation using planar thyroid scintigraphy, either the LEHR or the ME collimator could generate relatively reliable results if an appropriate formula is being used. It has been reported that SPECT is more accurate and precise than planar scintigraphy to estimate thyroid volume (*12,13*). Whether an ME collimator could improve the imaging quality and volume estimation for thyroid tissue in SPECT imaging still needs to be determined.

CONCLUSION

^{123}I thyroid imaging with ME collimators produces less scattered background noise, improved thyroid-to-background contrast, and higher collimator sensitivity than does imaging with LEHR collimators. Manual measurement of thyroid length is more accurate with the ME collimator; however, different thyroid thresholds should be used to estimate the thyroid area and volume for the LEHR and ME collimators.

DISCLOSURE

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

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