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Comparison of Low Energy and Medium Energy Collimators for Thyroid Scintigraphy with 123I

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Abstract

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

Introduction

123I is a more ideal radioisotope than iodine -131 for thyroid imaging because it is comparable to Tc99m, has less septal penetration with improved image quality, and less radiation to patient compared to iodine-131 (*1*,*2*). It has the most abundant gamma rays at 159 keV that is comparable to the 140 keV from technetium-99m, and can be imaged with pinhole, low energy, or medium energy collimators (*3*). A pinhole collimator provides more details for imaging small organs such as thyroid glands. However, a pinhole collimator cannot be used to estimate the functional thyroid size and volume, which is 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 due to its advantage for imaging technetium-99m labeled radiopharmaceuticals. The LEHR collimator has been frequently used for 123I thyroid scintigraphy with the major advantage of avoiding collimator switching between studies using technetium-99m labeled compounds and shorter acquisition time.

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

Materials and methods

Patient demographics, imaging methods including thyroid scintigraphy and ultrasonography, imaging analysis, and statistical analysis methods are described below.

Patients: A total of 47 consecutive patients referred for thyroid scintigraphy with 123I were prospectively recruited at Veterans Affairs Greater Los Angeles Healthcare System between October 2015 and November 2016. There were 35 males and 12 females with an average age of 61. Thyroid scintigraphy was performed for evaluation of hyperthyroidism (37 patients) and thyroid nodules (10 patients).

Thyroid scintigraphy: All patients received thyroid scintigraphy with both rectangular large field-of-view Siemens BiCore LEHR collimator and ME collimators sequentially with the same camera. Specifications of the LEHR and ME collimators are listed in Table 1. To reduce the influence of different imaging time after 123I administration, half of our patients received LEHR collimator imaging first, immediately followed by ME collimator imaging, and the other half of our patients received ME collimator imaging first, immediately followed by LEHR collimator imaging. All patients received 200 µCi of 123I. Thyroid imaging started at approximately 4 hours 30 minutes immediately after the 4 hours thyroid uptake measurement. Image acquisition was performed using a Siemens Symbia T16 SPECT/CT gamma camera. The following acquisition parameters were used: anterior view, 128x128 matrix, zoom factor 1, pixel size 2.4 mm, acquisition time 7 minutes for both LEHR and ME collimators, an energy window 15% centered at 159 keV. The distance between the collimator and the patient's face was kept at to an inch or as close as the patient could tolerate.

Ultrasonography: There were 22 patients who also received thyroid ultrasonography within 3 months of thyroid scintigraphy. Thyroid ultrasonography was performed by using either the Philips EPIQ 7G or the GE XDclear real-time ultrasound scanner with high resolution 6-15 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) =π/6 x length (cm) x width (cm) x depth (cm).

Image analysis: All scintigraphic images were viewed and analyzed using an Oasis general NM package including a thyroid analyzing application (Segami Corporation, Columbia, MD). 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/pixel were calculated within the thyroid isocontour. Thyroid length for each thyroid lobe was manually measured by 5 nuclear medicine physicians using the Oasis thyroid application. The thyroid area size was automatically calculated with the Oasis thyroid application by applying different threshold values (20%, 25%, 30%, 35%, 40%, 45%). The thyroid volume was calculated by using the empirical method that is being used at VA Greater Los Angeles Healthcare System: Thyroid volume (ml) = area of thyroid gland (cm2) x length (cm) x 0.321. The differences between the LEHR and ME collimator for thyroid length measurement and volume estimation were compared by using ultrasonography as the gold standard for thyroid measurement.

Statistical analyses: GraphPad Prism 8 (GraphPad Software, LA Jolla, CA, USA) was used to perform statistical analyses. Data distributions were assessed using the D'Agostino-Pearson omnibus test. Normally distributed data are summarized as mean $\pm$ standard deviation (SD) and non-parametric data are summarized as median and interquartiles (IQR). Variables from different groups were compared using the Student's t-test (two tailed paired samples assuming unequal variance) for parametric variables and the Mann-Whitney test (two-tailed paired samples) for non-parametric variables. Significance was defined as a p-value < 0.05 and the 95% confidence interval (CI) are reported where 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, increased thyroid to background contrast, and an overall much cleaner image compared to the LEHR collimator images. The LEHR images demonstrated a slightly better spatial resolution over the ME images, although the difference is very subtle by visual inspection. There were 10 patients who were referred for evaluation of known thyroid nodules. There was no difference between LEHR and ME collimator images to identify these nodules (data not shown).

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

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

The automatically calculated area size by using the threshold of the maximum average pixel is inversely proportional to the cutoff threshold percentage being used. For the same image, the lower cutoff threshold resulted in larger area size, and a higher cutoff threshold resulted in smaller area size. For volume estimation using LEHR collimator images, it was observed that a 35% of the threshold yielded closest volume estimation with the least bias as compared to ultrasonography (Fig 4A). For volume estimation using ME collimator images, the same threshold

(35%) yielded overestimation with increased bias, and 40% of threshold yielded closest volume estimation with least bias as compared to ultrasonography (Fig 4B, 4C). The LEHR and ME collimators demonstrate a similar spread of limits of agreement in both thyroid length and volume estimation as compared to ultrasonography.

Discussion

The most striking difference between the LEHR and ME collimator images is the background noise. The ME collimator images demonstrate significantly less noisy background with much cleaner images compared to the LEHR collimator images. This effect is related to a reduction of septal penetration of high-energy photons from 123I. 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's interesting to notice that the LEHR collimator yielded increased total counts for the large field of view covering the whole collimator surface (Fig. 2A), but significantly less total counts from thyroid tissue as compared to the ME collimator (Fig. 2B-D). Other studies have demonstrated that the LEHR collimator has a higher sensitivity than the ME collimator for 123I imaging using phantoms (*5,7*). The increased sensitivity of the LEHR collimator is probably due to more scattered photons from background. Scattered photons detected by the detector maybe more obvious in patients compared to 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 123I scan in clinical patients. The increased sensitivity for thyroid scans in ME collimator is mainly due to the increased diameter of the collimator holes. This will allow more photons parallel to the collimator holes to be detected.

The ME collimator has lower spatial resolution than the LEHR collimator, however the difference is not very obvious for thyroid 123I imaging in patients (Fig. 1). This is probably due to 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 contributes 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 suggest that images can be acquired with less scanning time compared to the LEHR collimator if a fixed count imaging protocol is used. This advantage may potentially benefit SPECT imaging which requires significantly longer scanning time 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 to estimate thyroid size or volume, it is still convenient to have an estimation of functional thyroid volume using thyroid scintigraphy. This is especially helpful for iodine-131 treatment with calculated dose protocol, which is frequently used clinically. The LEHR collimator imaging resulted in slightly underestimation of the thyroid length compared to ultrasonography measurement as the standard. Manual measurement of thyroid length is more accurate in the ME collimator images than in the LEHR collimator images. This is probably due to increased collimator sensitivity and improved thyroid to background contrast with ME collimator.

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

It was observed that a 35% threshold in the LEHR collimator images yielded the closest volume estimation as compared to ultrasonography estimation, and a 40% threshold in the ME collimator images yielded similar results. These thresholds are higher compared to other studies which used thresholds between 20% and 30% (*11,12*). This is probably due to different imaging protocols and different formulas being used to calculate thyroid volume. Our image acquisition time was 7 minutes. Other studies used 5 minutes, had 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 ultrasonography and was also depending on different formulas (*12,14*). Appropriate threshold cutoff value should be based on different volume calculation formula, different imaging protocol, 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 cutoff threshold. Therefore, a higher cutoff 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 volume between LEHR and ME collimator images demonstrate a similar spread of 95% limits of agreement, suggesting that the LEHR and ME collimators have similar precision and variation when compared to ultrasonography measurement. In terms of thyroid volume estimation using planar thyroid scintigraphy, either the LEHR or ME collimator could generate relatively reliable result 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 ME collimator could improve the imaging quality and volume estimation for thyroid tissue in SPECT imaging still needs to be determined.

Conclusion

123I thyroid imaging with ME collimator produces less scattered background noise, improved thyroid to background contrast, and higher collimator sensitivity compared to LEHR collimator. Manual measurement of thyroid length is more accurate with the ME collimator, however different thyroid cutoff threshold should be used to estimate the thyroid area size and volume between the LEHR and ME collimators.

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Key Points

Question: This study is to evaluate the impact of collimator choice between LEHR and ME collimators on 123I thyroid scintigraphy in clinical practice.

Pertinent Findings: 123I thyroid imaging with ME collimator produces statistically significant improved thyroid to background contrast, and higher collimator sensitivity compared to LEHR collimator. Different thyroid cutoff threshold should be used to estimate the thyroid area size and volume between the LEHR and ME collimators.

Implications for Patient Care: Findings have direct impact on improving the thyroid scintigraphy in clinical practice.

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Table 1: Siemens BiCore collimator specifications.

Collimators	LEHR	ME
Hole shape	Hex	Hex
Number of Holes (x1000)	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	202 cpm/uCi (Tc-99m)	275 cpm/uCi (Gallium-67)
Geometric Resolution at 10 cm	6.4 mm (Tc-99m)	10.8 mm (Gallium-67)
System Resolution at 10 cm	7.5 mm (Tc-99m)	12.5 mm (Gallium-67)
Septal penetration	1.5% (Tc-99m)	1.2% (Gallium -67)
Weight	22.1 kg	63.5 kg

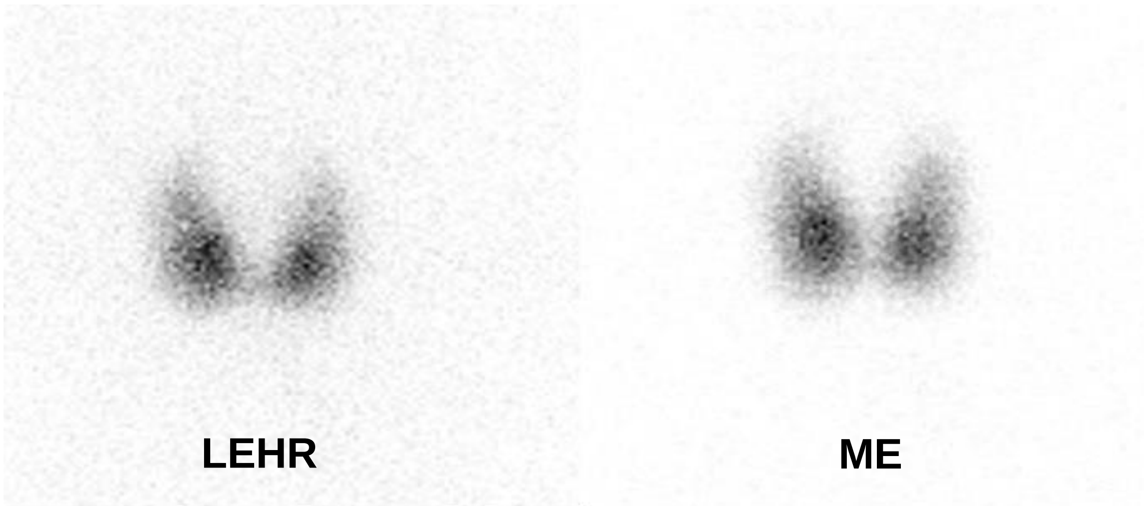


Figure 1. Planar anterior view of thyroid scintigraphy from low energy high resolution collimator (LEHR) and medium energy collimator (ME).

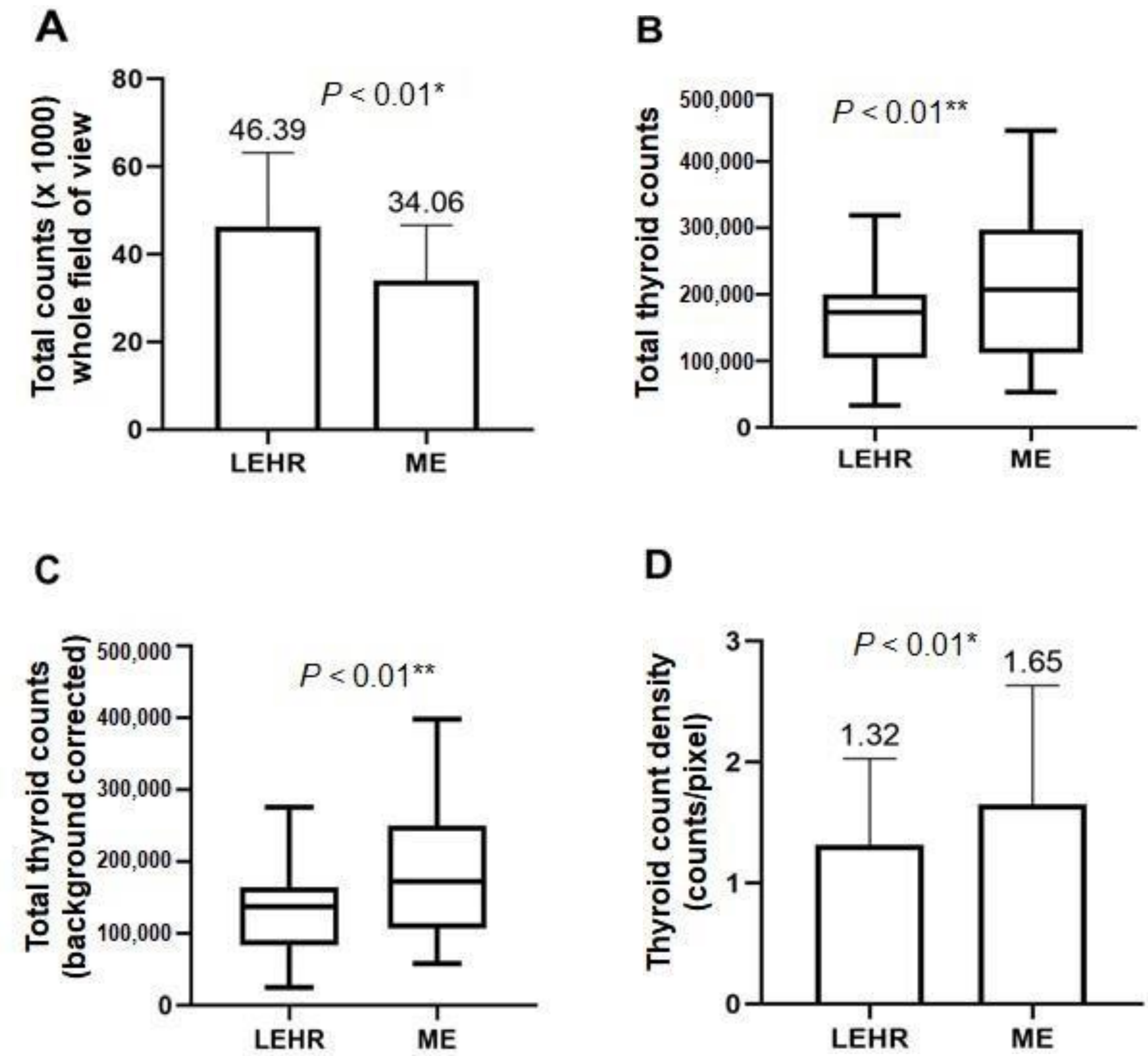


Figure 2: Comparison of photon counts between low energy high resolution collimator (LEHR) and medium energy collimator (ME). Fig. 2A represents total counts from the whole rectangular field of view of the collimator. Fig. 2B, 2C, and 2D represent counts measured within the thyroid isocontrour by applying 30% of cutoff threshold. A and D represent mean with standard deviation. B and C represent median with IQR.

* Significance was determined by Student's t-test.

** Significance was determined by Mann-Whitney test.

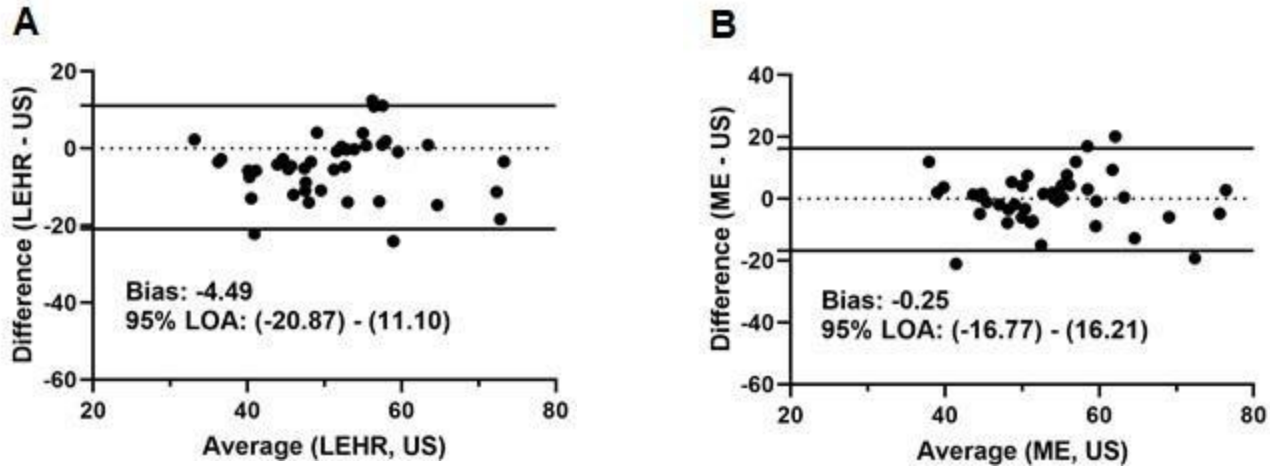


Figure 3. Bland-Altman plot analyses of thyroid length measurement between ultraultrasonography with either LEHR (A) and ME (B) collimators.

US: ultrasonography. LOA: limit of agreement.

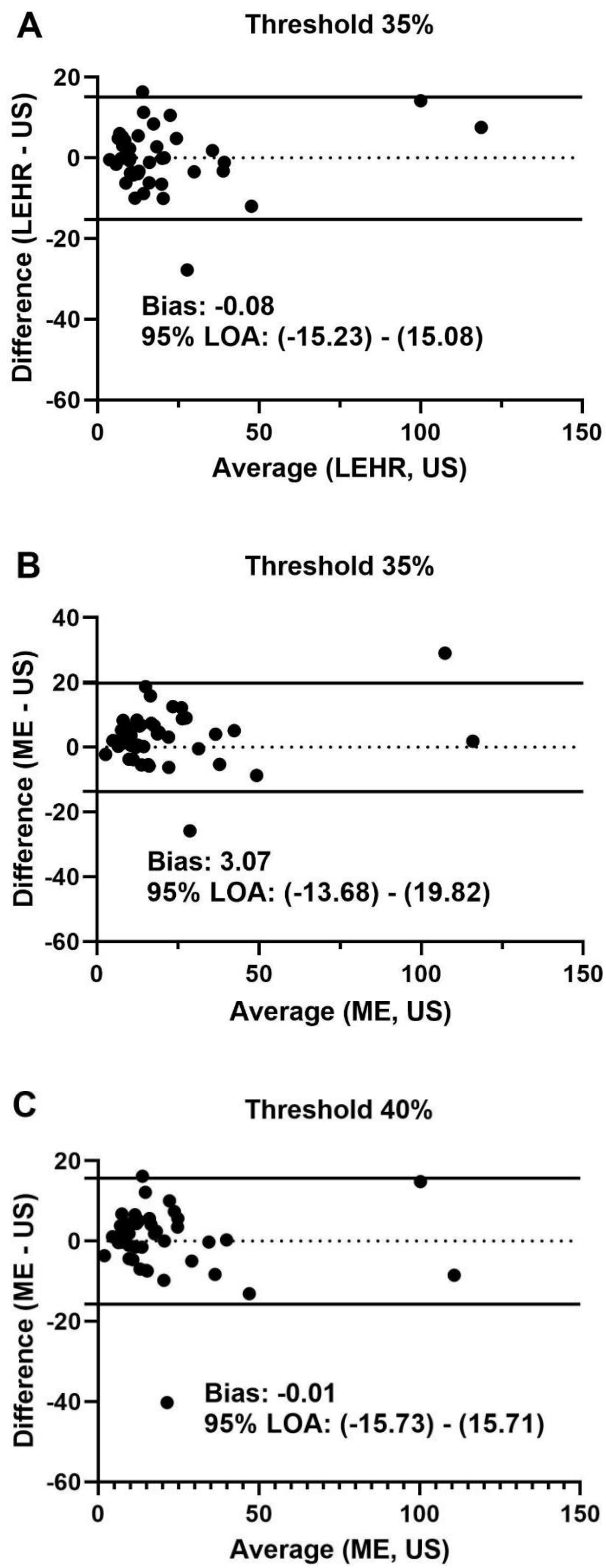
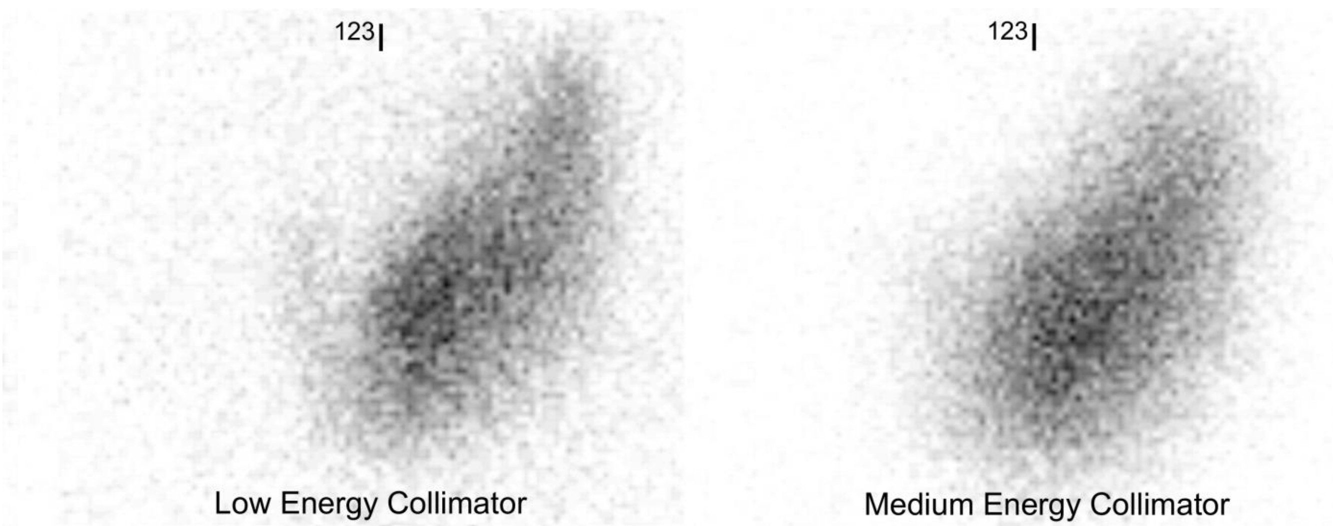

A
Threshold 35%
Difference (LEHR - US)
Bias: -0.08
95% LOA: (-15.23) - (15.08)
Average (LEHR, US)
B
Threshold 35%
Difference (ME - US)
Bias: 3.07
95% LOA: (-13.68) - (19.82)
Average (ME, US)
C
Threshold 40%
Difference (ME - US)
Bias: -0.01
95% LOA: (-15.73) - (15.71)
Average (ME, US)

Figure 4. Bland-Altman plot analyses of thyroid volume estimation between ultraultrasonography with either LEHR (A) and ME (B, C) collimators by applying different cutoff threshold.



Graphical abstract