Hot and cold contrasts in high resolution Tc-99m planar scintigraphy: a survey of fifty-two camera heads using the PICKER thyroid phantom

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Abstract

This study aimed at comparing the sensitivity and hot and cold contrasts obtained when imaging the Picker thyroid phantom using gamma cameras fitted with either their ultra-high or high-resolution low energy parallel hole collimator.

Seventeen camera models from Elscint, General Electric, Siemens and Sopha Medical Vision were involved in the study for a total of 30 cameras and 52 camera heads. A single operator conducted the study in order to minimize the impact of human factors. The phantom contained about 74 MBq ^{99m}Tc and was imaged at 10-cm from the collimator face with the energy window recommended by the camera manufacturer. A total of 1 million counts were accumulated.

Hot and cold contrasts were in mean about 0.05 higher when using an ultra-high-resolution than when using a high-resolution low energy collimator. This higher contrast was obtained at the expense of a mean reduction in sensitivity of 30%. In particular, Elscint cameras demonstrated a 30% lower sensitivity whatever the collimator type. The Sopha Medical Vision DST and DSX cameras and the General Electric Magicam camera offered the lowest contrasts among the cameras with a high-resolution collimator. Although this was accompanied by a higher than the mean sensitivity for the DST and DSX, the Magicam demonstrated sensitivity roughly identical to the mean of all the cameras with a high-resolution collimator.

Key words: gamma camera; collimator; contrast; sensitivity

1. Introduction

Scintigraphy relies on imaging with a γ-camera the topological differences in the distribution of a γ-emitting radioactive tracer within the body [1]. The scintigraphic images should ideally reflect these differences with the highest fidelity. Over the last two decades, the scintillation detectors of γ-cameras have reached high standards of intrinsic performance in uniformity, spatial linearity and resolution. However, the quality of the patient images depends on extrinsic performance, i.e. the performance of both the detector and the collimator. The collimator is the limiting component in the resolution and sensitivity of modern γ-cameras [1].

The intrinsic and extrinsic performance of γ-cameras is measured according to well-established and standardized procedures [2, 3]. Each performance test focuses on the measure of one parameter with minimum interference from the other parameters. For planar images, the extrinsic NEMA performance tests concentrate on the spatial resolution measured with line sources at 10 cm from the collimator and on the sensitivity measured from a thin layer of activity deposited in a 10-cm diameter dish [3]. Although important in all imaging modalities, spatial resolution plays a crucial role in scintigraphy owing to the poor values attainable with collimated γ-cameras. Indeed, the spatial resolution is at best 5-6 mm full width at half-maximum (FWHM) in clinical conditions. As full contrast recovery can only be obtained for structures with a size larger than 2-3 times the FWHM [4, 5, 6], the detection of hypo- or hyper-activities can be dramatically hampered for infra-centimetric lesions.

Sensitivity is also a very important parameter in scintigraphy [1]. Indeed, the image acquisition always lasts for a few tens to several hundreds of seconds. The shorter the acquisition time, the lower the risk of patient movement and resulting image blurring. Or to put it another way, the higher the sensitivity, the higher the number of detected photons and the signal-to-noise ratio of the images.

This study aimed at describing and validating an easy-to-perform procedure to measure the contrast and sensitivity of γ-cameras in conditions mimicking clinical reality. The well-known PICKER thyroid phantom is easy to handle and contains centimetric hot and cold nodules and two different backgrounds. It was used here for measuring the contrast and sensitivity performance of 52 heads of 17 γ-camera models fitted with either their high-resolution (HR) or their ultra-high-resolution (UHR) low-energy (LE) collimator. The procedure was validated by long-term repetitive measurements and by measurements on several cameras of a particular model.

2. Materials and methods

2.1 Phantom

The same original PICKER thyroid phantom (Picker Nuclear, part 3602, 35 cc volume, Cleveland, OH) was used throughout the study. Before starting the study, the phantom was opened, cleaned, physically measured, closed and filled with laboratory deionised and distilled water. The left lobe compartment was 18.4 mm thick and the right lobe 9.2 mm, resulting in a 2:1 left-to-right activity ratio. The left lobe contained two cold nodules. The first (C6) was 6 mm in diameter and the second (C12) 12 mm in diameter. The right lobe contained an 8.7-mm diameter cold nodule (C9) and a 12-mm diameter hot nodule (H12). The 12-mm diameter nodules were in the lower part of the lobes and the smaller nodule in the upper part. The cold nodules consisted of cylindrical solid rods whose height was equal to the lobe thickness. The hot nodule was a 9.2-mm height cylindrical hole drilled into the back of the right lobe resulting therefore in a 2:1 nodule to background activity ratio.

2.2 Activity

The phantom was filled with 74 MBq (± 15%) Tc-99m pertechnetate using a syringe. The syringe activity was measured before and after filling using the local activimeter. These activimeters were subject to periodic quality control, which should ensure an error level on the measured activity of less than 5%. After filling, the phantom was gently shaken for at least 1 minute before imaging.

2.3 Cameras

The phantom was imaged once on 30 γ-cameras from four constructors (Tables I and II). There were 17 different models (listed in the second column of Tables I and II), and 10 single-head, 18 dual-head and 2 triple-head cameras. In total, 52 cameras heads were investigated. The procedure was repeated once after 12-24 months on four cameras in order to evaluate the long-term reproducibility. The camera heads were fitted with their locally available parallel high-resolution (HR) or ultra-high-resolution (UHR) low-energy (LE) collimator. For one SMV DST-XLi camera, both HR and UHR collimators were available and they were both used.

2.4 Imaging parameters

The phantom was placed horizontally and behind the camera head. A 10-cm long cylindrical spacer helped to position the top cover of the phantom at 10 cm from the collimator. The spacer was also helpful for centring the phantom in the field of view.

One end of the spacer was positioned just above the thyroid isthmus and the other end on the collimator marks, which indicate the centre of the field of view. In the absence of any marks, centring was achieved visually with the help of the camera persistence tool.

Two 256*256 images were recorded in static mode with a stop condition of 250 and 1000 kcounts. The basic idea was to use the higher statistics image (1000 kcounts) for ROI positioning and the lower statistics image (250 kcounts) for measurements. Indeed, the images obtained in clinical practice present a statistics count closer to those of 250-kcount images than to those of 1000-kcount images. For example, the Society of Nuclear Medicine recommendations for thyroid imaging are 100-200 kcounts in the image [7]. A hardware zoom was used to obtain a pixel size of between 0.8 and 0.9 mm. However, due to a limitation in available zoom values, the pixel size was roughly 1.1 mm for all the Elscint cameras and for the General Electric Millennium VG. The energy window was centred at 140 keV. Its width was chosen following the camera manufacturer's recommendations: 20% for Elscint, General Electric and Sopha Medical Vision, 15% for Siemens. For multi-head cameras, the heads were systematically used following their number. Taking into account the positioning time, the images were obtained in less than 8 minutes with a single head camera, in less than 15 minutes with a dual-head camera and in less than 20 minutes with a triple head camera.

2.5 Image analysis

The images were imported to a Vision Powerstation (Sopha Medical Vision, Buc, France) using Interfile, DICOM or proprietary (Sopha Medical Vision) image file formats. The region of interest (ROI) and the statistics tools of the display application of the Vision software were used for image analysis. Several ROIs were defined as follows. A background ROI of 12-pixel diameter (area = 115 pixels) was positioned in the middle of each lobe. An 8-pixel diameter circular ROI (area = 52 pixels) was positioned on each 12-mm nodule and a 6-pixel diameter circular ROI (area = 30 pixels) on the 9-mm cold nodule. The ROI sizes given above are for pixels of 0.8-0.9 mm. For larger pixel sizes, the ROI size was adapted using linear interpolation. The ROIs were always drawn on the high count image, which was of superior visual quality, and copied onto the lower statistics image. The nodule contrast was calculated from the mean number of counts per pixel measured in the nodule and background ROI using the following formula:

$$CC = 1 - (N_N/N_B), \text{ for a cold nodule,} \quad (1)$$

$$HC = (N_N/N_B) - 1, \text{ for a hot nodule,} \quad (2)$$

where N_N is the mean number of counts per pixel in the nodule ROI and N_B is the mean number of counts per pixel in the background ROI. From the mean number of counts in the left ($N_{B,L}$) and right ($N_{B,R}$) lobe background ROIs, the left-to-right ratio was calculated:

$$L/R = N_{B,L} / N_{B,R} \quad (3)$$

The true total number of acquired counts (N_T) and the acquisition time (T) of the images were read from the display application of the Vision software. Using the measured activity in the phantom corrected for the delay between phantom filling and mid-acquisition time (A_c), the sensitivity (S) was calculated:

$$S = (N_T - N_0)/ A_C\, T \quad (4)$$

where N_0 is the number of counts recorded within T in the same acquisition conditions but without the phantom. N_0 was linearly extrapolated from a 30-s image recorded when the phantom was still in the hot laboratory.

2.6 Statistical processing

We deliberately chose for a single operator to perform the full imaging and analysis procedures. This choice was made to avoid the impact of human factors that had been shown to mask the technical characteristics in previous inter-laboratory studies [8].

Groups of cameras with a UHR collimator and with an HR collimator were compared using the student t-test and an Anova with two parameters (collimator type and camera model) [9]. Test significance was set at 0.05.

3. Results

The left-to-right ratio, contrast for the hot nodule, contrasts for the two largest cold nodules and sensitivity when imaging the PICKER thyroid phantom are reported in Tables I and II for γ-cameras fitted, respectively, with an ultra-high-resolution or a high-resolution low-energy collimator. For the multi-head cameras, no systematic difference could be observed between the results issued from the different heads. Both the t-test and Anova found no significant difference for the left-to-right ratios between the group of cameras with a UHR collimator and the group of cameras with an HR collimator. However, significant differences ($p < 0.05$) between the two groups were found for the hot and cold contrasts and for sensitivity. Figure 1 compares the left-to-right ratios, contrasts and sensitivities from images recorded at a 12-24 month interval on four different cameras (DST-XL, DST-XLi, DSX, Magicam) using the Bland-Altman analysis [10].

4. Discussion

The choice of the PICKER thyroid phantom was based on several considerations. It is one the oldest, if not the oldest, widely used phantoms in nuclear medicine and is still available today for a moderate price. This phantom mimics an organ, and presents three small cold areas and a hot small area in a non-zero background as well as two large regions of different activities. It fits in one hand and is therefore easy to handle and to transport. Finally, it necessitates only a very moderate activity (a few tens of MBq) and therefore generates a limited irradiation of the users.

Two images (250 and 1000 total kcounts) were systematically recorded for each camera head. However, the results obtained from both images were so close that it was decided to finally present the values obtained with the 1000-kcount images because these images were really needed for accurate positioning of the nodule ROIs. To be precise, the 250-kcounts appeared to be less useful and, to those willing to make similar measurements, we would recommend the recording of a second 1000-kcount image instead of the 250-kcount image. The absence of a systematic error in the results issued for the different heads of multi-head cameras indicates that the technetium dispersion in the phantom did not change in a measurable way during the imaging procedure.

The results obtained with the five DST-XLi dual-head cameras fitted with an ultra-high collimator (Table I) showed that the methodology was highly reproducible. Left-to-right ratio and contrast values from the images obtained with these ten camera heads showed a very low dispersion: the standard deviation-to-mean value ratio was lower than 3.6% for all four parameters. The sensitivity values were slightly more dispersed. It should, however, be kept in mind that the sensitivity relies on the measure of the phantom activity with an activimeter. Although the activimeters were subject to periodic quality control, which should ensure an error level on the measured activity of less than 5%, the error on the measured activity needs to be considered when comparing sensitivity values. The standard deviation-to-mean sensitivity ratio was only 5.8% for the ten DST-XLi camera heads. Therefore, the dispersion of sensitivity values for these ten camera heads obtained using five different activimeters can be considered as being remarkably small.

The long-term (12-24 months) reproducibility of the measurements was assessed by repetitive imaging on four cameras (Figure 1). These cameras covered the range of contrast values obtained in the study for both single-head and multi-head cameras. Moreover, they all belong to nuclear departments where a quality control programme for both the cameras and the activimeters has been set up for many years [11].

As far as possible, two cameras of an identical model were investigated. However, this was not always possible. Indeed some cameras (for example the Multispect-2) were unique or, to the best of our knowledge, were the last surviving example of their type in the south of Belgium (Brussels and Wallonia). It should, however, be emphasized that when the measurements could not be repeated on a second camera of identical model (for example another Multispect-2), there was in the department a camera of a different model (in the above example a Mutlispect-3) for which this repetitive measurement was carried out (Table 2). Together with the demonstrated reproducibility, this allowed us to assess the reliability of the measurements even when the measurements could not be repeated on a second camera of identical model.

The activity ratio between the two lobes and between the hot nodule and its background is 2:1 for the Picker thyroid phantom. The photons emitted in the half-lower part of the left lobe or of the hot rod have to travel through the half-upper part of the lobe or of the rod where attenuation occurs. The left-to-right ratio should therefore be lower than 2 and the mean observed value was around 1.82 (Tables I and II). The phantom design is such that the maximum value of HC is L/R – 1. Therefore, a value of HC equal to 0.82 corresponds to full hot contrast recovery. In contrast, full contrast recovery for the cold rods corresponds to a value of CC equal to 1.

Although systematically slightly lower for the DSX cameras, the contrasts for the cameras with a UHR collimator were very similar (Table I). The Elscint Helix showed a poor level of sensitivity, about 30% lower than the mean sensitivity of all the cameras with a UHR collimator (Table I). Along with the DST, this camera was also the oldest of the multi-head cameras involved in the study. The Elscint SP6 and SPX6 cameras with their HR collimator also showed a sensitivity of about 30% lower than the mean sensitivity of all cameras with an HR collimator (Table II). These three Elscint cameras belong to two different nuclear medicine departments. Moreover, some of them were in the same department as one of the Infinia cameras involved in the study, for which no large sensitivity variation could be observed (Table II). Therefore, the lowest sensitivity observed for the Elscint cameras could hardly be attributed to a problem with the measuring of the activity in the phantom.

There were more differences in the contrasts recorded for the cameras with an HR collimator (Table II). This can be easily related to the presence of more constructors and models in this camera group. The collimator is the limiting component for γ-camera spatial resolution [1]. These differences therefore reflect differences in collimator design and performance. Large differences in sensitivity were also observed (Table II). As explained above, the methodology used in this study should exclude large differences in sensitivity solely due to the activimeters. The Magicam, DST and DSX cameras delivered images with a reduced contrast (Table II). For the DST and DSX, this was accompanied by a slightly (DSX) or clearly (DST) higher sensitivity (Table II). However, the sensitivity of the Magicam was comparable to the mean sensitivity of cameras with an HR collimator (Table II). Excluding the DST, DSX and Magicam cameras from the group of cameras with an HR collimator led to almost identical mean value and slightly reduced standard deviation for all four parameters. The largest differences were for the sensitivity that decreased to 71.83±8.57 count/MBq/s. However if the two Elscint cameras are also excluded, the sensitivity was 73.45±6.76 count/MBq/s.

Comparing UHR and HR collimators, the contrasts were on average 0.05 higher with the UHR collimator and these differences were found to be statistically significant ($p < 0.05$). However, the sensitivity showed itself to be significantly ($p < 0.05$) lower for the UHR than for the HR collimators. On average, the sensitivity was 30% higher with the HR collimators. The differences were almost identical and remained statistically significant if the three camera models with the lowest contrast (DST, DSX and Magicam) were excluded from the group of cameras with an HR collimator. This held true if the two Elscint cameras were also excluded from the group. It is, however, not clear whether the higher contrasts obtained will be reflected in a higher detection rate in clinics. This question could only be answered by a large multi centre study. It is worth noting that a previous inter-laboratory study failed to demonstrate a higher level performance for hot or cold lesion detection of cameras with a high-resolution collimator in comparison with cameras with a general purpose collimator [8].

It is also interesting to compare the contrasts and sensitivity of the Infinia cameras with different crystal thicknesses. In the same department and therefore for the same phantom activity measurement, this camera demonstrated an 8% higher sensitivity (data not shown) when fitted with the 1-inch crystal instead of the classical 3/8-inch crystal without compromising the contrasts (Table II). The 8% higher sensitivity is in good agreement with theoretical expectations [12].

A drawback of the choice for a single operator for all the imaging and analysis process is that the number of investigated systems is inevitably limited. If we consider Elscint and Sopha Medical Vision as part of General Electric, who took them over some years ago, the study is restricted to General Electric and Siemens cameras. This limitation somewhat reflects the situation in south Belgium where the majority of the cameras are from General Electric (including Elscint and Sopha Medical Vision) and Siemens. Nevertheless, most of the camera models that were produced by General Electric and Siemens since 1990 could have been included in the study.

5. Conclusion

Hot and cold contrast in images of the Picker thyroid phantom were on average about 0.05 higher when using an ultra-high-resolution than when using a high-resolution low energy collimator for the thirty Elscint, General Electric, Siemens and Sopha Medical Vision cameras involved in the study. This slightly higher level of contrast was found to be statistically significant but was obtained at the expense of a mean reduction in sensitivity of 30%. Therefore, the use of ultra-high-resolution collimators instead of high-resolution collimators could be questionable in particular when time stop conditions are used. Indeed, it is not clear that slightly improved contrasts in a noisier image would help the lesion detection task. Another drawback could be the injection of higher doses to maintain the level of noise in the images.

The contrasts were measured for a 10-cm distance between the phantom and the collimator. The results should not be directly extended to other distances. Indeed the system resolution and the system scatter fraction, which interplay in the final contrast, vary with the distance between the imaged object and the collimator in a way that depends on the collimator design. For the same reason and also because it is a complex process where many technical and camera parameters are involved, the results should not be extended to single photon emission studies. Finally it is worth mentioning that a previous study carried out with the same phantom and in clinical conditions demonstrated that a pinhole collimator allowed to obtain higher contrasts than the best ultra-high-resolution parallel hole collimator [13].

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Table I: Left-to-right ratio, hot and cold contrasts and sensitivity for the PICKER thyroid phantom imaged by cameras with a low energy ultra-high-resolution collimator

Constructor	Model	Type*	# investigated cameras$	L/R	HC	CC12	CC9	S (count/MBq/s)
Elscint	Helix	D	1	1.857±0.066	0.558±0.063	0.725±0.003	0.451±0.030	41.753±0.066
SMV	DSX	S	2	1.760±0.022	0.539±0.005	0.709±0.020	0.452±0.009	56.885±6.389
SMV	DST-XL	D	2	1.818±0.029	0.578±0.028	0.716±0.017	0.460±0.020	58.153±2.920
SMV	DST-XLi	D	5	1.812±0.025	0.576±0.021	0.723±0.016	0.466±0.014	59.277±3.414
Mean ± SD			10	1.813±0.036	0.570±0.028	0.720±0.015	0.461±0.016	56.814±6.384

*M : single-head, D : dual-head

$ all heads of multi-head cameras were systematically investigated

Table II: Left-to-right ratio, hot and cold contrasts and sensitivity for the PICKER thyroid phantom imaged by cameras with a low energy high-resolution collimator

Constructor	Model	Type*	# investigated cameras$	L/R	HC	CC12	CC9	S (count/MBq/s)
Elscint	SP6-HR	S	1	1.757	0.543	0.588	0.410	54.745
Elscint	SPX-6HR	S	1	1.739	0.525	0.670	0.457	51.696
General Electric	MAGICAM	D	1	1.805±0.043	0.493±0.012	0.605±0.005	0.378±0.001	75.429±0.341
General Electric	Millennium MPS	S	1	1.859	0.551	0.609	0.406	66.561
General Electric	Millennium VG	D	1	1.825±0.009	0.536±0.000	0.681±0.006	0.411±0.013	68.250±4.455
General Electric	Infinia 3/8-inch	D	2	1.836±0.014	0.517±0.054	0.649±0.008	0.406±0.010	67.969±2.596
General Electric	Infinia 1-inch	D	1	1.817±0.036	0.551±0.069	0.640±0.006	0.407±0.019	71.283±0.690
General Electric	AC/T	S	1	1.854	0.560	0.660	0.370	73.706
General Electric	XC/T	S	1	1.756	0.540	0.659	0.391	94.237
Siemens	e-cam	D	2	1.837±0.014	0.521±0.042	0.660±0.023	0.432±0.009	79.715±2.717
Siemens	MS-2	D	1	1.873±0.027	0.540±0.029	0.703±0.013	0.447±0.005	73.048±1.070
Siemens	MS-3	T	2	1.798±0.021	0.546±0.030	0.682±0.022	0.439±0.043	73.443±4.649
SMV	DST-XLi	D	1	1.816±0.023	0.521±0.001	0.699±0.006	0.421±0.008	69.295±0.659
SMV	DST	D	1	1.844±0.004	0.499±0.009	0.640±0.011	0.386±0.017	91.906±0.225
SMV	DSX	S	3	1.823±0.024	0.492±0.028	0.637±0.044	0.367±0.010	80.567±9.174
Mean ± SD			20	1.819±0.036	0.530±0.033	0.659±0.034	0.413±0.033	74.129±9.544

*M : single-head ; D : dual-head ; T : triple-head

$ all heads of multi-head cameras were systematically investigated

Figure captions

Figure 1: Plots of a second measurement versus the first measurement performed 12-24 months earlier for one single head (DSX circle) and three dual-head (DST-XL diamond, DST-XLi triangle, Magicam square) cameras. For the dual-head cameras the results obtained for each head are reported. (A) left-to-right ratio, (B) hot contrast, (C) cold contrast for the 12-mm (open symbol) and 9-mm (closed symbol) nodule, (D) sensitivity.

Figure 1