The effect of an asymmetric energy window on bone scintigraphy image quality

Short running title:
Asymmetric energy window in bone scans

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Abstract:

**Purpose** Bone scintigraphy is one of the most common nuclear medicine tests. Previous work investigated the effectiveness of an asymmetric energy window (ASW) for planar bone scintigraphy using simulation and phantom data. Phantom studies concluded that the ASW improved both the resolution and contrast-to-noise ratio when imaging objects with high scatter. The aim of this study is to confirm this increased image quality in patients. This study also investigated whether the differences between a standard (SW) and ASW depended on body mass index (BMI).

**Methods** 58 patients had two scans: a standard scan using an energy window of 140keV ±10% (SW) and an asymmetric window of 140keV +10%, -7.5% (ASW). Three readers independently compared the two image sets and scored them using a 5-score scale (ranging from 1 = asymmetric better (clinically important) to 5 = standard better (clinically important)). Scores from all radiologists were pooled and analysed statistically. A p-value <0.05 was considered statistically significant.

**Results** In 93 cases (53%) the readers scored the ASW images better the SW images. In 5 cases (3%), the ASW images were preferred with the difference considered clinically important; there were no cases where the SW was similarly preferred. For the sign test, we test whether the total of 93 scores of 1 or 2 (ASW preferred) was significantly different from the 15 scores of 4 or 5 (SW preferred). The p-value was p<0.00001, demonstrating that the difference is significant.

**Conclusions** In patients with a request for bone scintigraphy, ASW provides an improvement in image quality which in some cases was judged as clinically important.

**Keywords**

Bone scintigraphy, asymmetric energy window
Introduction

Bone scintigraphy is one of the most common nuclear medicine procedure performed in the United Kingdom and in the USA, representing 29.6% (in 2003/2004 – the most recently available national survey) and 17% (in 2011) of nuclear medicine procedures, respectively (1,2). Although the bone scintigraphy is considered to be one of the most reliable nuclear medicine examinations (3), the detection of lesions is affected by image quality, which depends upon a number of different variables, such as age (4,5), time between dose and scan (6,7), radiopharmaceutical (8), excessive distance between the patient and the collimator (3), and increased body mass (9).

Scatter is an important process in Nuclear Medicine imaging which usually refers to Compton scattering. A gamma ray undergoes an interaction with matter (e.g. patient) which results in a decrease in energy as well as a deflection from its original path (10). Scattered photons are one of the main defects that degrade the image quality in Nuclear Medicine which sometimes represents more than half of the total counts in clinical imaging (11,12). It causes deflection of photons with a concomitant loss of energy, which leads to blurring, loss of image contrast, and consequently to poor image quality (13,14).

Detector technology has advanced at a rapid pace, but there are still profound challenges in diagnostic imaging in regards to scatter radiation, particularly in obese patients. Increased body mass results in photon attenuation by the absorption and the scatter of photons within the soft tissue which leads to reduced signal-to-noise ratio, increased scatter and non-diagnostic results (9,15).

Most nuclear medicine departments use predefined protocols that are designed to exclude scattered photons. This is achieved by using a suitable energy window which is an accepted trade-off between minimizing the acceptance of scattered photons, and maximizing the acceptance of unscattered radiation (16).

The photopeak is the peak formed by the case where an incident gamma ray is completely absorbed in the crystal caused by photoelectric effect (17). The detection of events accepted to produce an image lie in a window around the photopeak energy which is typically a 15% or 20% energy window centered symmetrically (SW) over the 140 kilo-electron volts (keV) photopeak of Technetium-99m (99mTc). This is equivalent to a window spanning of 130-
151 keV and 126-154 keV, respectively (18,19). An asymmetric energy window (ASW) is produced when the photopeak energy is not at the centre of the window and the energy window is shifted to the right side on the spectrum (20). It can be used in practice to avoid lower energy photons and to minimize the amount of scatter that is recorded (21). The number of counts collected is reduced thus elevating noise, and scatter is still present but at a reduced level (22). Its use must be supported by a physicist who can help in determining the limits of asymmetry (18,19). In this paper, an asymmetric energy window of -7.5% and +10% over the 140 keV photopeak of $^{99m}$Tc has been investigated, which is equivalent to a window spanning of 129.5-154 keV.

While attempts have been made to evaluate the effect of an asymmetric energy window on contrast resolution (23), scatter and attenuation correction (24) and flood field uniformity (25), there are no data about the use of an asymmetric energy window in the improvement of image quality in whole-body bone scans on contemporary equipment. This study aims to transfer the results of our phantom work into patients to confirm the improvement of image quality by using an asymmetric energy window in whole-body bone scans. Associations were examined between image quality scoring and Body Mass Index (BMI).

**Material and Methods**

**Patient Population**

There were 36 male and 22 female patients with an age range of 31-87 years from January 2014 to February 2016. Among the 58 patients, most presented with prostate cancer (n = 32) or breast cancer (n = 12). Patient weight averaged 79.8 kg.

All patients underwent SW whole-body imaging first followed by ASW whole-body scan. Each patient was divided into 4 groups according to BMI classification. BMI was categorised using the National Health System categories: underweight (BMI < 18.5 kg/m²), healthy weight (BMI 18.5-24.9 kg/m²), overweight (BMI 25-29.9 kg/m²) and obese (BMI 30-39.9 kg/m²).
Approval for the study was obtained from the Bristol Research Ethics Centre (IRB equivalent) and all subjects signed a written informed consent. All procedures performed in this study were in accordance with the 1964 Helsinki declaration.

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

**Imaging technique**

The study was done using a dual-head gamma camera Infinia Hawkeye (General Electric Healthcare), equipped with low-energy high resolution (LEHR) collimators and capable of simultaneous anterior and posterior acquisition. Quality assurance testing was conducted on a daily basis prior to scanning. A new uniformity map was acquired for the ASW acquisition.

A SW whole-body scan was obtained 2-3 hours after injection of 546-640 MBq of technetium-99m-hydroxydiphosphonate ($^{99m}$Tc-HDP) as per the British Nuclear Medicine Society guidelines for bone scintigraphy [26]. Patients were invited to empty the bladder before the first part of acquisition. Directly after the SW whole body, an ASW whole-body scan was performed.

For the SW whole-body acquisition, the scan ranged from the top of the head to the bottom of the feet. For the ASW acquisition, a whole-body from the top of the head to knees was performed. The field of view of the ASW was shorter to reduce the acquisition time as well as to avoid the patient from moving, and consequently, affect the image quality.

The two sets of images were obtained in both anterior and posterior projections, with the patient in supine position and a Velcro strap that helped the patient to keep their arms by their side. A pillow was used to support the head for the duration of the examination. Scan speed was 10 cm/min, exposure time of 240 seconds, matrix size 256 x 1024 and zoom 1.0. The energy window was defined relative to the photon energy peak of $^{99m}$Tc (140 keV) for both
scans. The window width was set at -10% and +10% (126-154 keV) for the first (SW) scan and -7.5% and +10% (129.5-154 keV) for the second (ASW) scan, as illustrated in Fig. 1.

After both scans were performed, the patient’s weight and height were measured.

**Image assessment**

To assess the impact of an ASW on clinical images, three experienced radiologists with a specialist interest in nuclear medicine who were unaware of the clinical information examined the scans using a dedicated image analysis workstation (Xeleris®; GE Healthcare). A coding system was used to anonymise the patient data prior to image analysis.

The two whole-body images were displayed on the same screen and on the same colour scale. Briefly, the visual evaluation consisted of assessing the lesions with abnormal tracer uptake by comparing the intensity of uptake in both images. Each scan (SW and ASW) results in a pair of images; the two pairs of images were compared, and the differences scored as in Table 1. No comparison was made by radiologists between the BMI and the image outcome.

**Statistics assessment**

We tested the following hypotheses:

- **H0:** a preference for SW or ASW is equally likely.
- **H1:** a preference for either SW or ASW is more likely

The Sign test was used for statistical analyses. A score of 1 or 2 indicates that the asymmetric window is preferred; the numbers scoring these values were added together to get a total number where ASW is preferred (N_A). Likewise, the total scored either 4 or 5 gives the total number where SW is preferred (N_S). The sign test is a test of whether N_A is drawn from a binomial distribution (N_A \sim \text{bin}(N_{\text{tot}}, q) with N_{\text{tot}} = N_A + N_S and q = 0.5. An alpha value of 0.05 was used to determine whether a p value indicated a significant result. The calculations were performed using a freely available online binomial calculator (http://stattrek.com).
Results

A total of 58 patients were enrolled. In these patients, a total of 116 images were analysed: 58 SW whole-body and 58 ASW whole-body. Three independent radiologists scored according to a five-point scoring system which resulted in a total of 174 scores.

Example images from whole-body symmetric and asymmetric acquisition are shown in Fig. 2 and 3.

Table 2 and Fig. 4 show the results of the image comparison performed by the 3 independent readers. These are ordinal data which allow the median calculation. We have five categories, where the middle category (score of 3) represents no preference; most sets of images were assigned this category. Scores of 1, 2, 4 and 5 represent a preference for SW or ASW; it is these scores where a preference was expressed which we have analysed using the sign test. A total of 93 (53.5%) and 15 (8.6%) scores of <3 and >3, respectively, represent the number of images when asymmetric and standard whole-body were preferred. Using the sign test to compare N_A = 93 to N_S = 15 gives a p-value < 0.000002 so we reject the null hypothesis that ASW and SW are equally likely to be preferred.

A mean BMI of 27.7 kg/m² was identified within the population. Fig. 5 presents the imaging scores analysed by patient BMI. Obese patients (BMI 30.0-39.9 kg/m²), were very similar in terms of proportion of patients within the group of scores <3 as compared with non-obese patients (BMI < 30 kg/m²). A score <3 was reported in 70% of healthy weight patients (BMI 18.5-25 kg/m²), 92% of overweight patients (BMI 25.0-29.9 kg/m²) and 85% of obese patients (BMI 30.0-39.9 kg/m²), respectively. No significant differences across BMI categories were observed for different imaging scores.

Discussion

In this study, we evaluated the effectiveness of using an asymmetric energy window in planar bone scans. To our knowledge, this study is the first one to explore the impact of using an ASW in image quality in planar bone scans on contemporary equipment.
Further, the imaging parameters may be adapted according to the clinical indication, which can be done by decreasing the time between injection and imaging, reducing the acquisition time, or increasing the administered activity [14]. The work presented here has not taken into consideration these factors.

As Asgari et al. [18] indicated, using an ASW seems to reduce scatter fraction against SW when using $^{99m}$Tc and $^{153}$Sm radionuclide with solid water slab phantom and Teflon bone phantoms. In an earlier study [17], Collier et al. found that contrast resolution was significantly improved by switching to an ASW in anterior views of the abdomen and lumbar spine three hours after the injection of 740 MBq of $^{99m}$Tc-MDP.

Using an ASW, the energy window is smaller and more counts will be rejected. In order to maintain the number of counts in the final image, one would have to increase injected activity or scan time. However, in this case we used a fixed standard couch-speed for both the ASM and SW scans. The ASM images are still preferred despite the reduced overall counts. Increasing the acquisition time may increase the quality of images still further.

Shifting the $^{99m}$Tc window to the right has been shown to be effective in reducing scatter. In most cases where a preference was expressed, an ASW is preferred. We did not randomise the order of the scans – we did SW first because that is standard care and patients should be able to decline the second scan at any time. It is therefore possible that the ASW were preferred because of the systematic timing difference leading to differences in e.g. uptake and washout, rather than because of the ASW itself. However, it is well established that whole-body images are usually acquired 2h to 5h after injection. We therefore presume that the ASW is more likely to be the reason for the expressed preference.

Obesity is well known to present challenges in various imaging modalities. Problems associated with dose to be administered, image acquisition time as well as image noise are still being discussed in literature. There are no clear conclusions about how we could overcome these challenges, but efforts have been made in the past years to investigate the weight-based dosing and imaging time [9,15]. Our findings in this study suggest that we did observe similar results in the different BMI groups which might be due to the limited number of patients included. There
were no comparisons made between males and females, or between different clinical indications. Moreover, the effects of obesity on image quality were not directly analysed. An alternative approach would be to monitor the activity injected to patients, for both normal, overweight and obesity groups.

Our study has some limitations. Whilst we have found a highly significant overall result, we did not find any statistically significant effect related to the BMI. We suspect that a larger number of patients would be needed in order to demonstrate such an effect.

We did not undertake quantitative measurements of SNR; this may have disentangled the effect of uptake/washout.

We have relied on qualitative comparison scores not quantification of contrast as has been done in phantom work. This is because we are interested in clinical practice and the utility of the images to the radiologists.

Finally, we decided on a shorter field of view for ASW to avoid motion. However it is important to not exclude this shorter field of view as a possible confounder due to the inability to identify lesions in lower limbs and the resultant impossibility of blinding the scorers.

Nonetheless, after many years of clinical evaluation, bone scintigraphy continues to have a significant impact on patient management, mainly in the evaluation of metastatic disease. There are no comprehensive guidelines for an ideal strategy in using an ASW but we have proved the feasibility of our technique in whole-body scans which can be used in clinical practice. We expect that this technique will be clinically used and will have impact on lesion detection.

In summary, the incorporation of the ASW in the acquisition protocol for bone scintigraphy presents an important tool in the optimisation of these scans. We expect that this technique will be clinically used and will have impact on lesion detection.
Conclusions

Our study demonstrated that using an asymmetric energy window is preferred by radiologists interpreting bone scintigraphy, in some cases in a way that is judged to be clinically important. Further research is necessary to determine the influence of using an asymmetric energy window in obese patients.

Financial disclosure

No funding was used as part of this study.

Acknowledgements

The authors gratefully acknowledge the assistance of our Nuclear Medicine Technologists, for their help with data acquisition.
References


Figures

(a)

(b)

**Fig. 1** Gamma spectrum and photopeak parameters of $^{99m}$Tc isotope using an SW (a) and ASW (b) recorded during a whole body acquisition. Screen shots are from the GE Healthcare Discovery NM/CT 670 workstation.
**Fig.2** SW *left* and ASW whole-body *right* bone scintigraphy in a breast cancer patient with co-existence of bone metastases. Whole-body scintigraphy shows widespread foci of abnormal tracer activity within the skull, thoracic spine, ribs, shoulders, lumbar spine and proximal femora in keeping with widespread bony metastatic disease. All readers rated the asymmetric whole body as preferred but not clinically important.
Fig.3 SW (left) and ASW whole-body (right) bone scintigraphy in a breast cancer patient. Whole-body scintigraphy shows a minor increased uptake in the region of the thoracolumbar junction which appears to correlate with degenerative change seen on plain film at T12-L1. One reader rated the asymmetric whole body as preferred but not clinically important. Another reader rated the asymmetric whole body as preferred and clinically important as it potentially improves the assessment of L-spine. On the other hand, the third reader rated as neither preferred.
Fig. 4 Bar graph showing the comparison of the two pairs of images for all 58 patients. Results are expressed as radiologists 1, 2 and 3 against different imaging scores.

Fig. 5 Bar graph showing the comparison of the two pairs of images according to patient BMI. Results are expressed as BMI intervals against different imaging scores.
Tables

Table 1

Five-point scoring system

<table>
<thead>
<tr>
<th>Result of comparison</th>
<th>Score</th>
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<tbody>
<tr>
<td>Asymmetric better (clinically important)</td>
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</tr>
<tr>
<td>Asymmetric better (not clinically important);</td>
<td>2</td>
</tr>
<tr>
<td>Neither preferred</td>
<td>3</td>
</tr>
<tr>
<td>Standard better (not clinically important)</td>
<td>4</td>
</tr>
<tr>
<td>Standard better (clinically important)</td>
<td>5</td>
</tr>
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</table>
Table 2
Percentages of comparison scores for 3 independent readers

<table>
<thead>
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<th></th>
<th>Asymmetric better</th>
<th>Neither preferred</th>
<th>Standard better</th>
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<tr>
<td></td>
<td>Clinically important</td>
<td>Not clinically important</td>
<td>Clinically important</td>
</tr>
<tr>
<td>Radiologist 1</td>
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<td>22</td>
<td>66</td>
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<tr>
<td>Radiologist 2</td>
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<tr>
<td>Radiologist 3</td>
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<td>24</td>
</tr>
<tr>
<td>Overall</td>
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