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USING FIGURE-OF-MERIT IMAGE QUALITY CRITERION FOR NUCLEAR MEDICINE IMAGE OPTIMIZATION

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Abstract The quality of medical images for nuclear medicine examinations, such as bone scintigraphy, has long reached an adequate level for proper diagnostics. On the other hand, reference nuclear medicine guidelines, in the segment related to the optimization of administered activity, are still relatively conservative, considering the technical and technological advancements (improvements in detectors, electronics, ergonomics, AI software). Reducing the administered dose activity represents an optimization of individual practices, manifested through lower doses for the patient and cumulatively for the staff, as well as for the practice at the institutional level, since it allows a higher number of examinations to be performed with the same amount of radioactive material.

This study proposes an optimization of administered activity using the Figure of Merit (FoM) parameter on two gamma cameras. The Siemens E-cam gamma camera was used to adopt the reference value of image quality assessment expressed through FoM. After that, using FoM, the optimization of the administered activity was carried out on the Siemens Symbia S gamma camera. Optimization was considered successful when the FoM on the second camera was equal to or higher than the value on the first camera. Raw DICOM data were analyzed using Image J software.

The FoM value on the Siemens E-cam camera was determined based on the nuclear medicine routines used in its regular practice. In the second phase of the experiment, to evaluate the model of reduced administered activity, a Jaszczak phantom was used with different specific activities in the spheres. The third phase involved tests on the Siemens Symbia S camera until the condition for equal or higher FoM on the second camera was met. In addition to the metric assessments of image quality, the entire experiment was monitored by a team of physicians and nuclear medicine specialists, whose subjective evaluation was used to confirm the calculated values. At the end of the experiment, the optimized administered activity for bone scintigraphy was found to be 20%, which was adopted as the new standard practice.

Keywords: Administered activity optimization; bone scintigraphy; FoM; image quality.

1. BONE SCINTIGRAPHY, GAMMA CAMERA

For bone scintigraphy (Figure 1 (A)), the 99mTc radionuclide is used with a bisphosphonate tracer - (hydroxy)methylene diphosphonate ((H)MDP) or 2,3-dicarboxypropane-1,1 (DPD). Four hours after injection, 50-60% of the administered activity is bound in the bones, the unbound portion is excreted in the urine, and only 6% remains in circulation. The maximum accumulation in the bones is reached after 1 hour and remains constant for 72 hours [1].

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Imaging is performed using a general-purpose gamma camera with one or two detectors. The mono-energetic gamma photon beam of 140.5 keV passes through a collimator to the NaI:Tl crystal, where a complex conversion process into light photons occurs. These light photons, after passing through the light guide, are converted into electrons at the photo-multiplier's photo-cathodes. The electrical signal is amplified through a cascade system of dynodes and further processed through analog/digital positional logic and electronic corrections [2]. The result is a medical image that represents the biodistribution of the radionuclide.

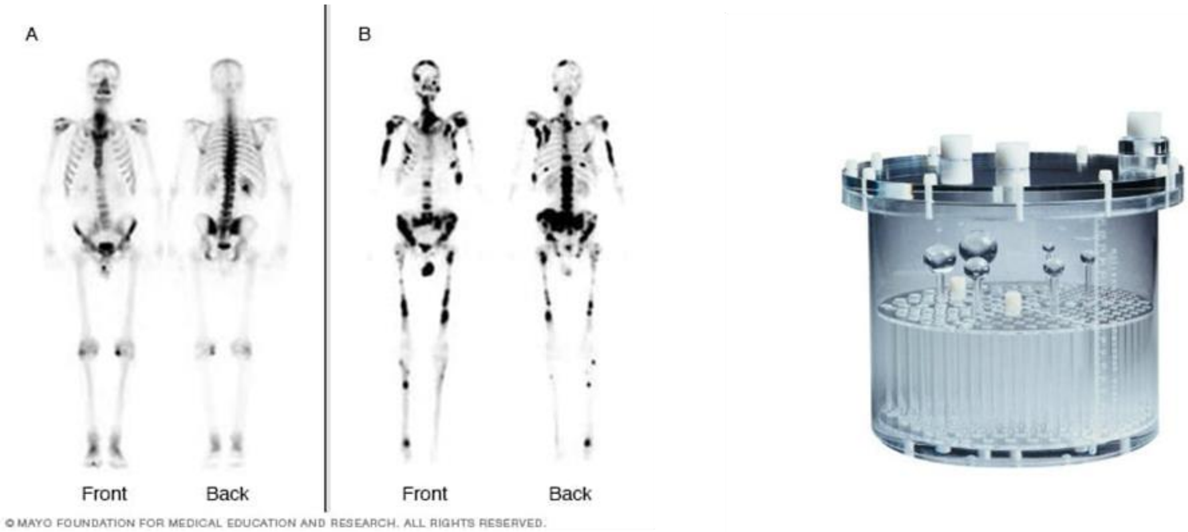

Figure 1. (A) Example of bone scintigraphy (Source: Mayo Clinic Homepage); (B) Jaszczak SPECT fantom (Source: Gamma Gurus Homepage).

2. OPTIMIZATION OF ADMINISTERED ACTIVITY, FOM, IMPACT ON EXPOSED WORKERS

Methods for optimizing administered activity are generally either based on Monte Carlo simulations using phantoms or ad-hoc visual methods. Our approach to optimization was based on the Figure of Merit (FoM) parameter [3], defined as:

$$FOM = \frac{CNR}{(administered\_activity)^2} \tag{1}$$

where CNR represents the contrast-to-noise ratio, calculated using the standard formula:

$$CNR = \frac{average\ count\ rate\ (signal) - average\ count\ rate\ (noise)}{\sqrt{\frac{\sigma^2\ (signal) + \sigma^2\ (noise)}{2}}} \tag{2}$$

While the patient is exposed to radiation only once or a few times, exposed workers are subjected to radiation on a daily basis. A lower administered activity consequently results in lower radiation doses

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for the staff, both during the handling of radiopharmaceuticals and as a direct consequence of the reduced exposure from irradiated patients, with whom the staff interacts.

3. MATERIALS AND METHODS

Using the formula mentioned, the FoM coefficient for bone scintigraphy obtained with the E-cam camera was calculated. Thirty patients with body masses between 67 and 73 kg were selected. Each patient received a radiopharmaceutical 20 minutes after the previous one, and each was imaged 2 hours after application.

Then, an experiment was conducted with the Jaszczak phantom (FIGURE 1 (B)), where the nominal specific activity of 0.2143 mCi/kg (15mCi/70kg) was reduced by 10% (13.5 mCi), 20% (12 mCi), and 30% (10.5 mCi), respectively, in the appropriate spheres (the requested specific activity was multiplied by the sphere's volume to determine the activity to be applied), and the FoM of each sphere was calculated. The spheres were filled carefully, without air bubbles. The procedure was conducted with various sphere sizes and settings to examine the impact of sphere size. After it was determined that sphere size had no significant effect, average FoM values from three measurements were calculated individually for spheres with the same percentage reduction in specific activity. The preliminary FoM value closest to the one determined for the E-cam was accepted, ensuring it was still higher. From there, the recommended administered activity was obtained by multiplying the corresponding specific activity by 70 kg.

4. RESULTS: DETERMINING FOM ON E-CAM GAMMA CAMERA IMAGES AND JASZCZAK PHANTOM SPHERES (SUMMARY)

For the standard administered activity of 15 mCi on the old E-cam camera, the average SNR value for 30 patients with body masses between 67 and 73 kg was 6.1525, and the FoM was 0.0325. Studies with the Jaszczak phantom provided the following CNR and FoM combinations (averaged over three measurements):

- 13,5 mCi: CNR= 7,92; FOM= 0,055:
- 12 mCi: CNR= 6,34; FOM= 0,045:
- 10,5 mCi: CNR= 4,176; FOM= 0,029.

5. DISCUSSION OF TECHNICAL AND TECHNOLOGICAL ADVANCEMENTS FROM E-CAM TO SYMBIA S GAMMA CAMERA

Reference nuclear medicine guidelines, particularly in the segment related to the optimization of administered activity, remain relatively conservative, considering technological advancements (detector improvement, electronics, ergonomics, (AI) software). Comparing, in this paper, Siemens devices, E-cam ("old" camera) and Symbia S ("new"), roughly, the new has:

- preamplifier two generations ahead (PED3 vs. PED1): detect a much wider range of light intensities;
- a better motherboard, integrated with the acquisition electronics: significant increase in speed;

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- upgraded the high voltage module: more stable;
- integrated detection controller (sampling frequency 300kHz vs. 100kHz) and a position calculator;
- more than 30 acquisition software upgrades advantage.

On the other hand, the quality of medical images for regular skeletal scintigraphy, the most common procedure in nuclear medicine, with high administered activity, whereby the entire stuff consequently has extensive experience, has reached a satisfactory level with previous one.

6. DISCUSSION OF RESULTS: CLINICAL ADOPTION AND NEWLY INTRODUCED OPTIMIZATION OF ADMINISTERED ACTIVITY FOR BONE SCINTIGRAPHY

The average FoM value (0.041) on the Symbia S gamma camera at an administered activity of 12 mCi is better than the average FoM value (0.0325) on the E-cam gamma camera at an administered activity of 15 mCi.

In the second phase, optimization was applied in clinical conditions, and FOM for the obtained nuclear medicine images on the new camera was calculated. As a still higher FOM was determined compared to the initially satisfactory images on the old camera, after additional subjective validation by nuclear medicine experts, the presented optimization of administered activity (15 mCi → 12 mCi) for skeletal scintigraphy in nuclear medicine imaging on the new camera was adopted as the standard.

7. DISCUSSION OF NEWLY ESTABLISHED OPTIMIZATION: IMPACT ON REDUCED EXPOSURE OF PATIENTS, EXPOSED WORKERS, AND THE POPULATION, WHILE INCREASING PRODUCTIVITY

Reduction in the applied activity leads to a decrease in the dose for the personnel working with radiopharmaceuticals in nuclear medicine departments. In this case, due to the linear dependence between the radiation source activity and the dose, this reduction has been estimated at 20%, corresponding to the 20% reduction in activity. However, considering the complexity of all phases involved in working with radiopharmaceuticals in nuclear medicine departments [4,5], such as work organization specifics, patients' health status, the professional skill of the personnel, and other factors, it is not possible to make a more precise estimate based solely on this result. At the same time, the exposure to the population that interacts with patients after the examination is also reduced (under the same conditions and by the same percentage), as well as the consumption of radioactive material, which allows for the examination of additional patients (at least one additional patient, for every four examined prior to optimization).

8. CONCLUSION

The optimization of the administered activity of radiopharmaceuticals, as one of the three fundamental principles of radiation protection, represents an important component of nuclear medicine practice. The aim of this study was to verify the possibility of using the Figure of Merit (FoM) as a parameter for evaluating nuclear medicine images. As a result of the successfully implemented optimization, we propose that this procedure be applied to every new gamma camera, particularly for different nuclear medicine examinations. Although this is essentially a technical

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generalization, meaning further optimization is possible based on individual patient characteristics - primarily their body mass, but also body mass index (BMI), age, and height - this result represents a significant advancement in both patient protection and the protection of workers in nuclear medicine departments, as well as the surrounding population (and other staff present in institutions where this practice is carried out).

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