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Technical notes

A scheme for assessing the performance characteristics of small field-of-view gamma cameras

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ABSTRACT

Existing protocols for assessing the performance characteristics of large field-of-view (LFOV) gamma cameras can be inappropriate and require modification for use with small field-of-view (SFOV) gamma camera systems. This communication proposes a generic scheme suitable for evaluating the performance characteristics of SFOV gamma cameras, based on modifications to the standard procedures of NEMA NU1-2007. Key differences in methodology between tests for LFOV and SFOV gamma cameras are highlighted along with the rationale for these changes. It is envisaged that this scheme will provide more appropriate methods for equipment characterisation, ensuring quality and consistency for all SFOV cameras.

Introduction

Gamma cameras have traditionally been large devices comprising of inorganic scintillators, photomultiplier tubes, lead collimators and bulky lead shielding. These devices are generally not portable and so cannot be used for intraoperative procedures.

The development of smaller portable gamma cameras has enabled imaging procedures to be undertaken at the bedside, in intensive care units, clinics and in the operating theatre [1,2]. High-resolution small field-of-view (SFOV) gamma cameras have been designed for specific applications such as tumour resection and sentinel node localisation [3,4]. These aim to combine the advantages of large field-of-view (LFOV) gamma cameras and non-imaging gamma probes while addressing some of the limitations of these devices. Designs for SFOV systems include: scintillation-based detectors - with scintillators coupled to position sensitive photomultiplier tubes (PSPMTs) [5–8], electron multiplying charge coupled detectors (EMCCDs) [9,10] or silicon drift arrays [11] - and solid state detectors such as cadmium telluride (CdTe) [12–14] and cadmium zinc telluride (CdZnTe) [15].

Manufacturers of LFOV gamma cameras routinely use standardised protocols such as the NEMA Standard NU1-2007 [16] to assess performance and provide specifications. In the clinical environment, modified protocols arising from these standards have been developed for ease of use, for example, IPEM Report 86 in the UK [17]. The European Directive 97/43/EURATOM mandates a quality assurance programme for all medical devices used in diagnostic radiology, nuclear medicine and radiotherapy [18]. Routine quality control recommendations for LFOV gamma cameras and handheld gamma probes are well documented by the European Association of Nuclear Medicine (EANM) [19,20]. While LFOV gamma cameras are routinely tested using these standardised protocols [16,17,21] such protocols are not always appropriate for or easily translated to SFOV gamma cameras. This communication proposes updated procedures for evaluating the performance characteristics of SFOV gamma cameras based on modifications to the NEMA NU1-2007 standard [16].

Rationale

This section outlines the current standard characterisation approach used for LFOV systems and any modifications necessary for assessing SFOV systems. The assessed parameters are spatial resolution, spatial distortion, spatial uniformity, count-rate capability, sensitivity, and energy resolution.

The duration of imaging for all tests should be sufficient to limit the effects of statistical noise. In line with LFOV measurements, a minimum of 150 counts per pixel should be collected, with higher counts per pixel when only a small area of the detector is irradiated

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[16]. Additional performance tests for collimator performance and shield leakage are discussed elsewhere [19,21].

Intrinsic spatial resolution

This is defined as the full-width at half-maximum (FWHM) of a line spread function (LSF) or of a point spread function (PSF) without an imaging collimator installed. This measurement should be supplemented by the full-width at tenth-maximum (FWTM) as the PSF or LSF may deviate from a Gaussian profile.

Standard methodologies for LFOV gamma cameras [16,17,19,21] use a capillary line source of approximately 40MBq activity, of internal diameter of 0.5 mm. This is positioned parallel to the principal orthogonal axes of the camera to avoid broadening of the LSF. The source is placed directly on top of the uncollimated scintillator crystal.

The intrinsic resolution of a LFOV gamma camera is typically in the region of 3 mm [22]. If an imaging matrix of 256 × 256 pixels is used, the pixel dimension of a 540 mm diameter gamma camera (to choose a single example) will be around 2.1 mm. NEMA NU1-2007 [16] states the "pixel size should be less than or equal to 0.1 FWHM", that is $\leq$0.3 mm for a 540 mm diameter gamma camera. To achieve the specified "pixel size" the analogue to digital conversion gain is increased perpendicular to the line source for each orthogonal axis simultaneously, and the "zoomed" portion of the fieldofview is imaged.

SFOV cameras have reported values of spatial resolution of less than 1.0 mm [5,9–11,14], suggesting that the NEMA "pixel size" should be at most 0.1 mm (equal to 0.1 FWHM).

For a typical LFOV resolution of 3 mm, the use of a 0.5 mm line source will not have a large effect on measured resolution; at submillimetre resolution, however, the width of the same source becomes significant. Following the standards for LFOV systems, line source width (or the diameter of the point source) would need to have dimensions less than 0.1 mm The uniform filling of capillary tubes with diameters of the order 100 μm is difficult to achieve. On this scale even the manufacture of a slit transmission phantom becomes challenging. This method of intrinsic spatial resolution measurement is therefore not suitable for high-resolution SFOV systems.

An alternative derivation of the FWHM can be obtained using the edge response function (ERF) method [16,23]. This can be obtained using a mask with a machined edge. When irradiated with a uniform radioactive source such that incident gamma photons can be assumed to be perpendicular to the mask plane, the detected counts across the edge of the mask ideally correspond to a step function, the derivative of which gives a LSF [23] which may then be analysed as in LFOV protocols.

System spatial resolution

This is defined as the FWHM of a LSF or of a PSF with the imaging collimator in place.

The protocol for LFOV gamma cameras uses a capillary line source (internal diameter less than 0.5 mm) with FWHM response measured in air and with scattering media (such as Perspex) positioned between the line source and the collimator surface [16]. The Perspex acts to scatter photons as would be expected from a source inside a patient. Typically, LFOV system resolution measurements are stated in the context of the collimator used either at the collimator face or at a known distance (usually 100 mm) away from the collimator. System resolution is typically limited by the type of collimator used rather than the intrinsic resolution of the detector.

Similar to intrinsic resolution measurements, for SFOV cameras the line source width or point source diameter would ideally be smaller than that used for LFOV measurements, again proving difficult to manufacture and fill [24]. The benefit of a consistent approach across all gamma cameras outweighs the effects of a finite source and the standard LFOV method, with a 0.5 mm diameter line source, may be used.

It may be possible to use a point or line source of a known diameter and then deconvolve the expected profile from the resultant image to determine the resolution; this is not ideal and requires specific knowledge of the expected profile of the source [10] and so may produce inconsistent results for different systems.

Many SFOV cameras use pinhole collimators rather than the more widely used parallel-hole collimator. This means that a line source imaged at the collimator face would appear to be a flood source in the resultant image. Instead of reporting resolution at the collimator face, measurements for pinhole systems should be stated at the non-magnifying point. As resolution varies significantly with aperture to source distance (through scattering material), the relationship between these two factors should also be reported so that resolution may be calculated by the end user for any source distance.

Intrinsic spatial distortion

Spatial distortion is a measure of how accurately event positions are mapped to the resulting image. For LFOV gamma cameras, spatial non-linearity is assessed using a lead transmission mask with an uncollimated detector [16]. A least-squares fit for the imaged line position is calculated. The differences between the imaged and fitted lines at 10 mm intervals are obtained to specify the spatial non-linearity differences across the geometric field-of-view (GFOV). In this paper, the GFOV is the whole non-magnified fieldofview of the gamma photon detector. Reported values are the standard deviation, mean and maximal difference between the imaged and fitted lines.

For LFOV cameras the mask used is a parallel line equal spacing (PLES) phantom, which consists of a series of parallel 1 mm wide lead lines spaced at 20 mm apart, embedded in uniform grooves within Perspex. A PLES phantom scaled to a ~40 mm fieldofview would require precise manufacturing.

With smaller fields of view, spatial distortion in SFOV cameras can be measured with a line source at a range of orientations. Where several measurements are required to cover the FOV, multiple images can be acquired.

Intrinsic spatial uniformity

Spatial uniformity describes the variation in counts per pixel within the GFOV relative to the mean counts per pixel over the field of view. Intrinsic measurements are performed with the collimator removed. A point source at a distance of at least five times the useful field-of-view (UFOV) away from the crystal is used to irradiate the detector uniformly – this method can translate directly to SFOV systems. The UFOV is the collimated field-of-view of the gamma camera.

Uniformity should be reported with both an integral (across the entire detector) and differential (for localised groups of pixels) parameter. The typical measure for integral uniformity (IU) is calculated, as Equation (1) [17] where C indicates number of detected counts per pixel in the image. Differential uniformity may be calculated using Equation (1) for small groups of adjacent pixels. Across the whole image differential uniformity values can be combined to a single reporting parameter [17], as described later in Sections analysis and reporting parameters.