A High Sensitivity Gamma Imaging Probe for Sentinel Lymph Node Detection

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Introduction

The sentinel lymph node (SLN) is any lymph node/s in a regional lymphatic basin, which receive lymphatic drainage from a primary tumor [1]. Thus, SLNs are the first nodes to receive lymph-borne metastatic cells. The sentinel lymph node biopsy (SLNB) is an alternative method to elective and systematic lymph node dissection and it is an important tool for the evaluation of its status.

Preoperative lymphoscintigraphy is performed to provide the surgeon with an intraoperative roadmap of the lymphatic mapping before the SLN radioguided procedure. In order to increase the accuracy of SLN detection intraoperatively, both blue dyes and radiocolloids are used in combination [2, 3]. Intra-operative gamma counters are used for the localization and detection of SLN during surgery. They provide an acoustic signal proportional to the radioactivity level [4]; however this procedure can be improved by mapping the radiolabelled tissues with gamma imaging probes [5].

The aim of this study is the construction and performance evaluation of "λ-eye", a gamma imaging probe, optimized in terms of sensitivity for SLN mapping.

Gamma Imager's Characteristics

The gamma imaging probe is based on a Position Sensitive Photomultiplier Tube (PSPMT) R8900-00-C12, Hamamatsu. A combined structure of collimator - scintillator was chosen based on simulation results and theoretical models to achieve high sensitivity and adequate spatial resolution for the SLN mapping [6].

The collimator has square holes 2x2x16 mm^3 and 100 single CsI(Tl) crystals with 5 mm thickness were inserted inside the collimator.

The 6X+6Y anode signals of the PSPMT were reduced to 2X+2Y using a standard resistive chain. Custom analog circuits were designed for the amplification of the PSPMT anode signals. The data acquisition system (DAQ) is based on free running Analog-Digital Converters (ADCs) and the LX9 Microboard with the Spartan-6 Field Programmable Gate Array (FPGA) by Xilinx.

The whole detector module, including the custom electronic boards, are placed inside a custom shielding made of tungsten, 8 mm thick around the collimator and 5 mm thick around the rest of the detector.

Parts of the system and an actual image of the "λ-eye" is presented in Figure 1.

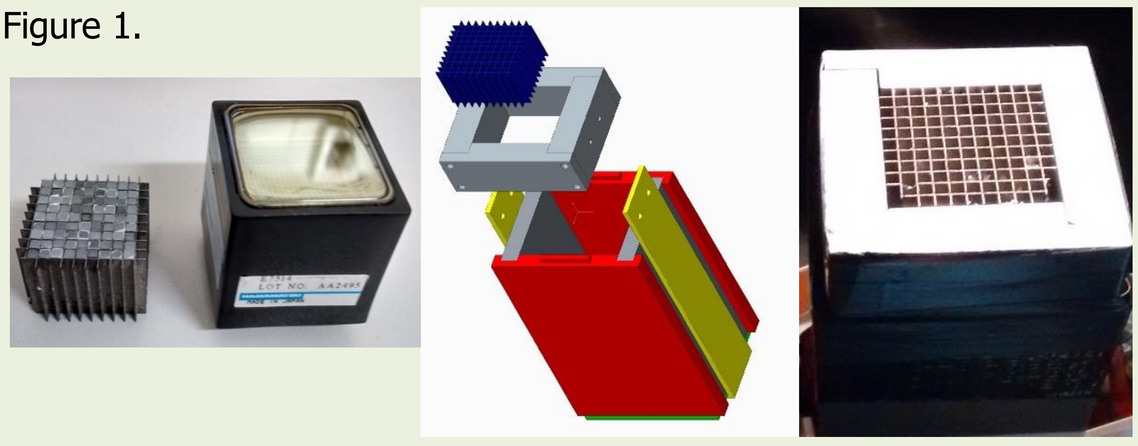

Figure 1. Integrated structure collimator-scintillator and PSPMT (left), mechanical schematic of the shielding (middle), upper photo of the imaging probe (right)

Gamma Imager's Results

A series of tests were carried out according to the bibliography for similar systems to evaluate the performance of the "λ-eye" gamma imaging probe. The main performance parameters of the "λ-eye" imaging probe are summarized in Table 1.

Table 1. Summary of performance parameters of the "λ-eye" gamma imaging probe

Parameter	Measured value
Sensitivity (30% en.window)	1.5 cps / kBq
Energy Resolution @140keV	36% ± 2%
Spatial Resolution @ 2 mm	2.2 mm
Integral Uniformity (UFOV)	5.2 %
Integral Uniformity (CFOV)	2.1 %
Differential Uniformity (UFOV)	1.7 %
Differential Uniformity (CFOV)	0.75 %
Counts linearity – Pearson's coefficient, R^2	0.9988

Animal Imaging Studies

A proof-of-concept mice experiment was carried out to assess the clinical performance of the "λ-eye" gamma imaging probe for lymph node mapping.

A normal mouse was injected with the clinical tracer ^{99m}Tc-Nanocoll via its footpad and a second mouse was injected with a novel mannosylated dextran DCM40 derivative, radiolabelled with ^{99m}Tc. The $^{99m}Tc(CO)_3$–DCM40 complex, an analogue of DCM20 with higher molecular weight, is designed for the SLN detection, showing high accumulation in the lymph nodes and fast injection site clearance [7].

The mouse injected with the ^{99m}Tc-Nanocoll was imaged with the "λ-eye" gamma imaging probe for 5 min acquisition time at 30 min after injection (p.i.). Without changing its position on the mouse-bed, the mouse was imaged for the same time with a whole-body mouse sized gamma camera, which is coupled to an X-ray detector model C10900D-40 (Hamamatsu) to obtain a comparative full view of the mouse. A simple fusion method was used in post-processing mode for the presentation of the scintigraphic/X-ray images. In the same way, the mouse injected with the DCM40 complex was imaged with the "λ-eye" gamma imaging probe at 30 min p.i.. The images are presented in Figure 2, where the upper ones correspond to the "λ-eye" and the bottom ones to the scintigraphic camera.

The "λ-eye" provides ~20 times higher number of counts in the region of LNs than the scintigraphic camera.

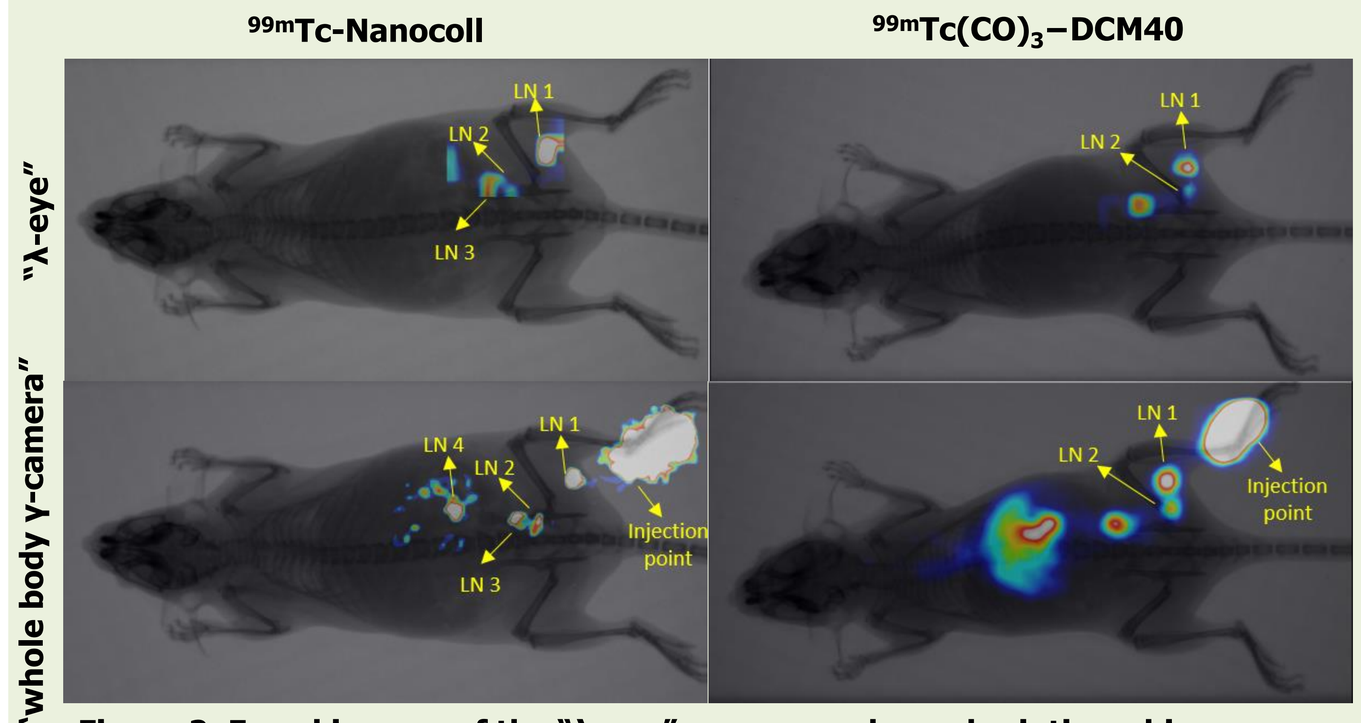

Figure 2. Fused images of the "λ-eye" gamma probe and scintigraphic camera with the X-ray images of the mice.

The experimental evaluation of "λ-eye" shows its high sensitivity and adequate resolution for SNL mapping. The "λ-eye" probe provides high quality images even at 10 sec acquisition time with accurate quantitative results. Its compact size (40mm×40mm×100mm) allows its use during surgery and/or for the detailed scan of a suspicious region.

References

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