Determining the feasibility of a novel Timepix3 detector for Compton imaging in Nuclear Medicine.

Bill Kamtchou[1], Seán Cournane[1][2] and Luis León Vintró[1]

[1] Center for Physics in Health Medicine, School of Physics, University College Dublin. [2] St. Vincent's University Hospital (SVUH), Dublin.

INTRODUCTION

Nuclear medicine is an imaging modality that uses small amounts of radioactive tracers (e.g. Technetium, ^{99m}Tc) to image the physiology of different organs for tumors and metastases (Procz et al., 2019)[1]. Nuclear Medicine imaging techniques have relied on the original design of the Gamma camera (Fig.1) which has not been updated since its conception in the 1950s. The current design includes the use of a collimator, which normally attenuates >99% of incident photons, subsequently requiring a significant radionuclide activity to be administered to patients in order to obtain clinically significant images (Fig.2). The development of a Compton Camera as an alternative gamma camera design, would eliminate the need for collimators, thus reducing patient dose. A Compton camera[1] is an imaging device that can determine the direction of gamma rays emitted by radioisotopes based on the kinematics of Compton scattering. For each interaction, the direction of an incident gamma ray of known initial energy can be reconstructed and limited to the surface of a cone, called the Compton cone (Fig.3). The interception of several reconstructed cone surfaces thus enables a radiotracer distribution to be determined. This study aims to establish the novel Timepix3 (TPX3) detector as a Compton Camera for imaging in Nuclear Medicine.

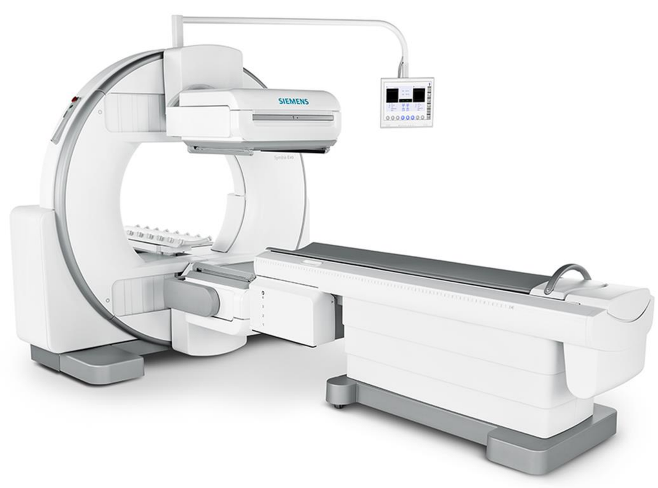


Figure 1. Symbia Intevo SPECT/CT Gamma camera taken from Siemens Healthineers.

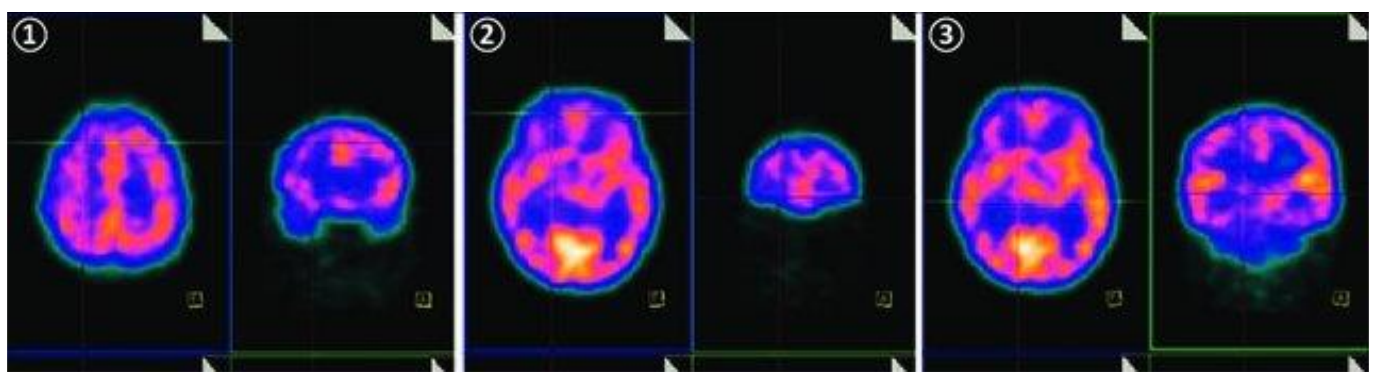
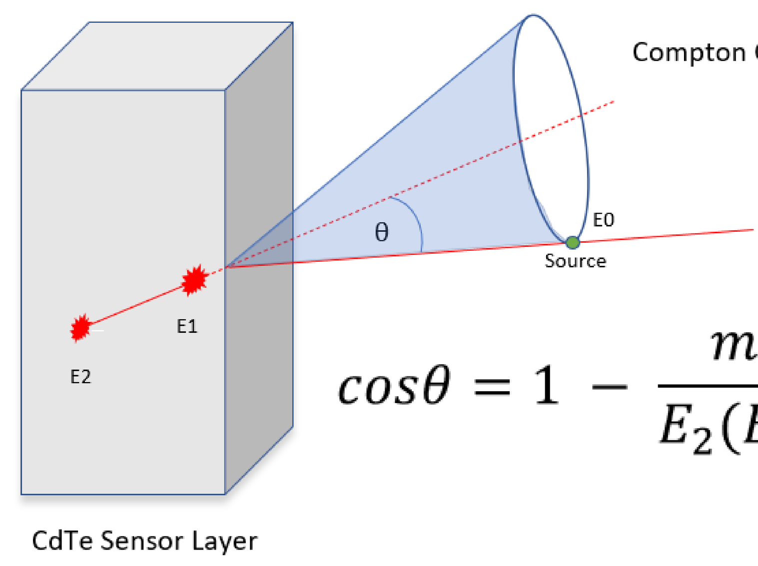


Figure 2. A Tc-99m SPECT/CT image showing moderate hypoperfusion at the right superior frontal cortex to identify traumatic brain injury (Molina-Vicenty et al., 2016).



$$cos\theta = 1 - \frac{m_e c^2 E_1}{E_2(E_1 + E_2)}$$

Figure 3. Schematic of the Compton camera and the Compton scattering equation.

MATERIALS & METHODS

The TPX3 is a high spatial, high contrast resolving 256x256 pixel read-out chip which can be combined with different semiconductor material sensors such as Cadmium Telluride (CdTe). Photons or charged particles incident upon the semiconductor sensors interact causing ionisation events. TPX3 detector, can operate in a Time-over-Threshold (ToT) mode, which enables for ionisation events to be time-stamped with a precision of approximately 1.5625ns. The Monte Carlo (MC) package EGSnrc was used to simulate the MINIPIX (unit that houses the TPX3) and different sources as shown in Fig. 5. The QR code below can be scanned to see a video of how Compton imaging (CI) works.

Figure 4. The MINIPIX camera that contains the TPX3 chip.

SCAN ME!

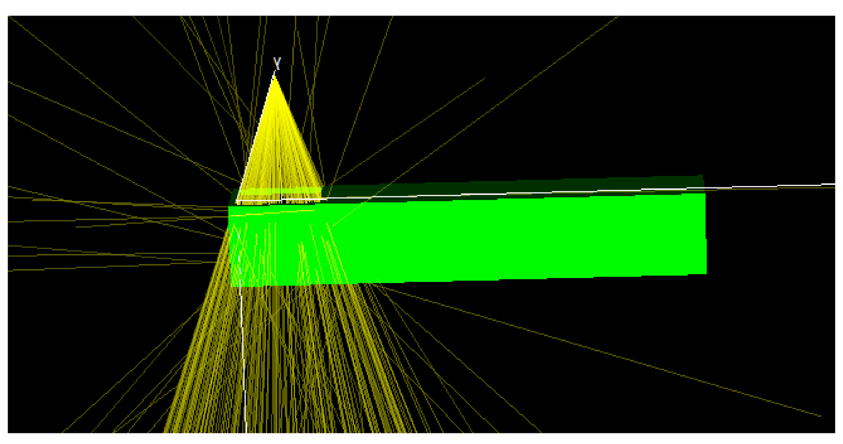
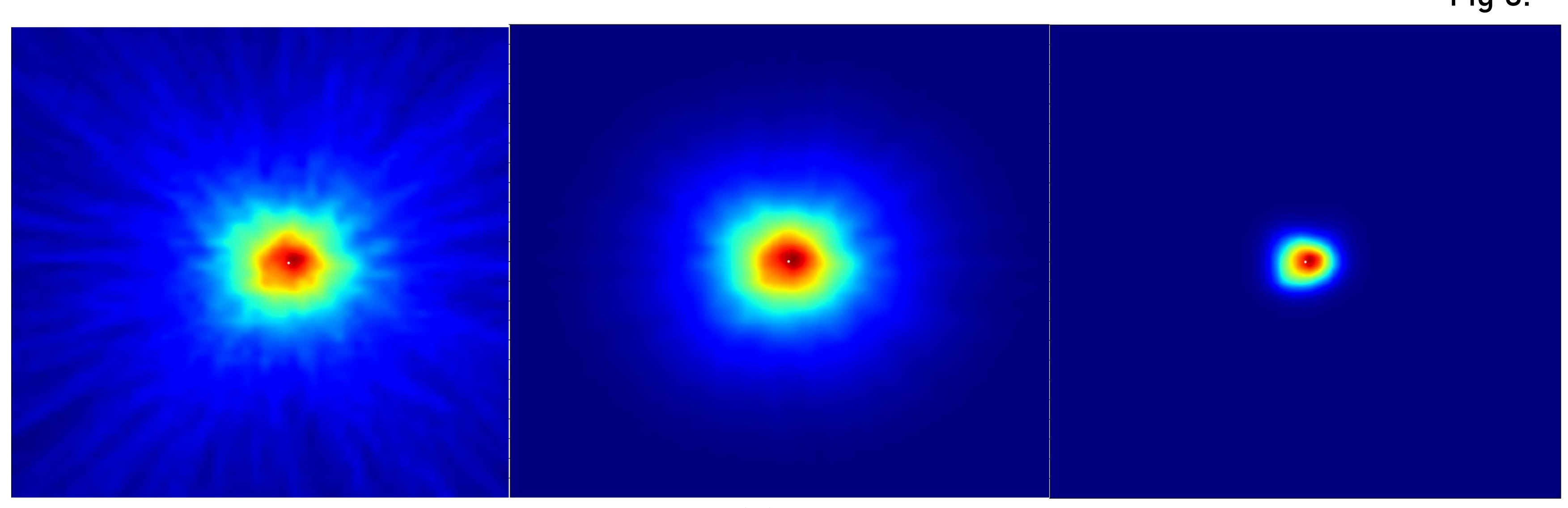


Figure 5. The MINIPIX simulated in EGSnrc being irradiated with monoenergetic photons.

Using advanced reconstruction techniques such as Filtered Back Projection (FBP) or List-Mode Maximum Likelihood Expectation Maximization (LM-MLEM) two reconstruction techniques currently employed clinically, we can greatly improve the spatial resolution of our images and increase our signal to noise ratio. This is demonstrated in Fig.8 (a, b, c) which is the same ^{137}Cs point source (MC) in Fig.6 (except with a distance of 1 cm) reconstructed using SBP (FWHM = 22.28 mm), FBP (FWHM = 20.67 mm) and LM-MLEM (FWHM = 10.84 mm) respectively.

Fig 8.



(a) (b) (c)

RESULTS

Computational (MC) and experimental (Exp) acquisitions (Fig.6 and Fig.7 respectively) of a ^{137}Cs (A = 152 Bq, distance from sensor = 0.5 cm, diameter = 1 mm) point source were reconstructed using simple back projection (SBP) and compared and show excellent agreement. A Full-Width Half Maximum (FWHM) of 16.78 mm (MC) vs 17.2 mm (Exp) were obtained These measurements were repeated for different distances (1, 2 and 3 cm) which all indicated that the computational model was correctly representing the TPX3 experimental results.

Fig 6.

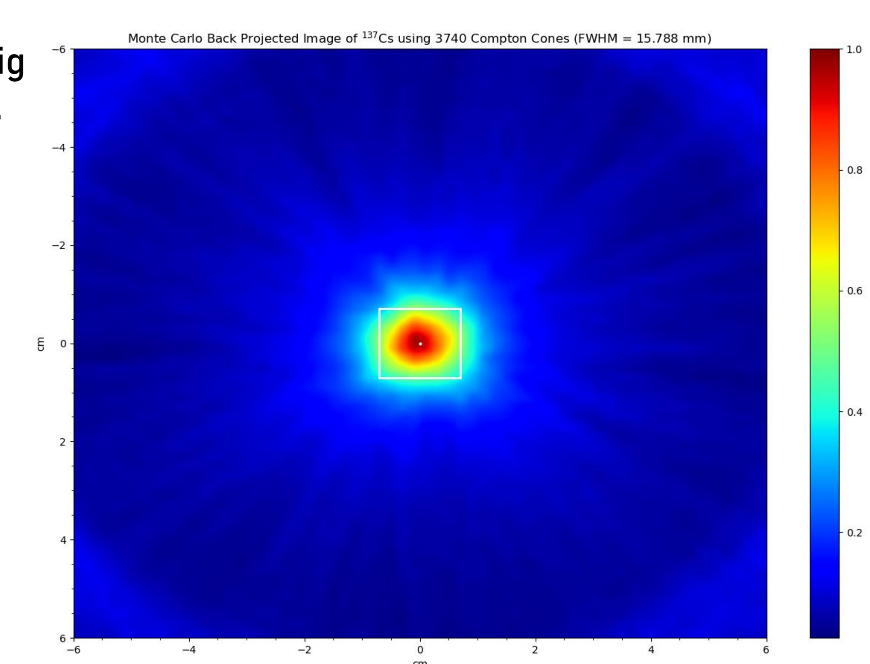
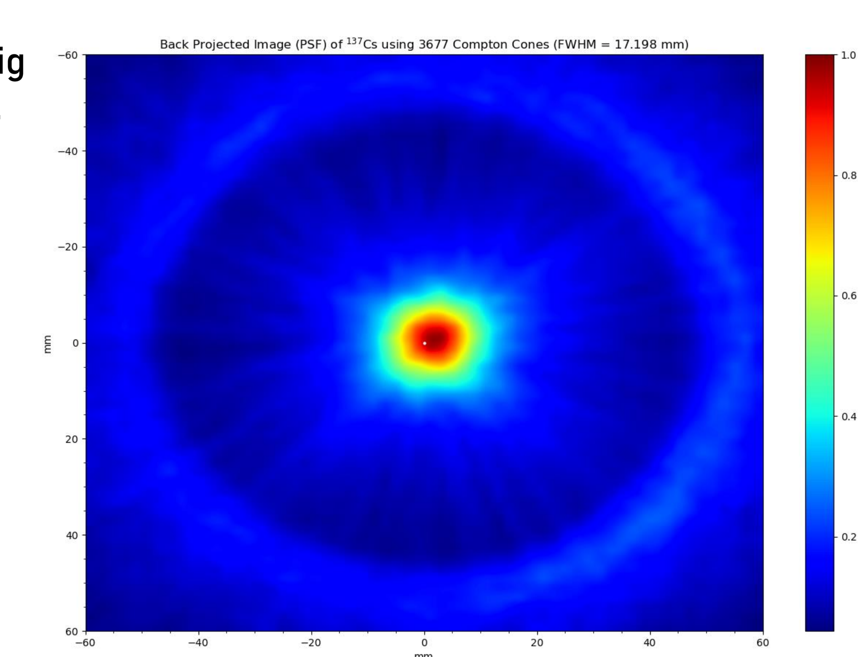


Fig 7.



Furthermore, as ^{99m}Tc is the most commonly used radionuclide in Nuclear Medicine, TPX3 must be able to reproduce spatial resolution in line with current gamma cameras. This is validated by Fig.9 and 10 which displays how TPX3 can resolve two ^{99m}Tc point sources (reconstructed using SBP and LM-MLEM via MC) separated by 2.5 cm.

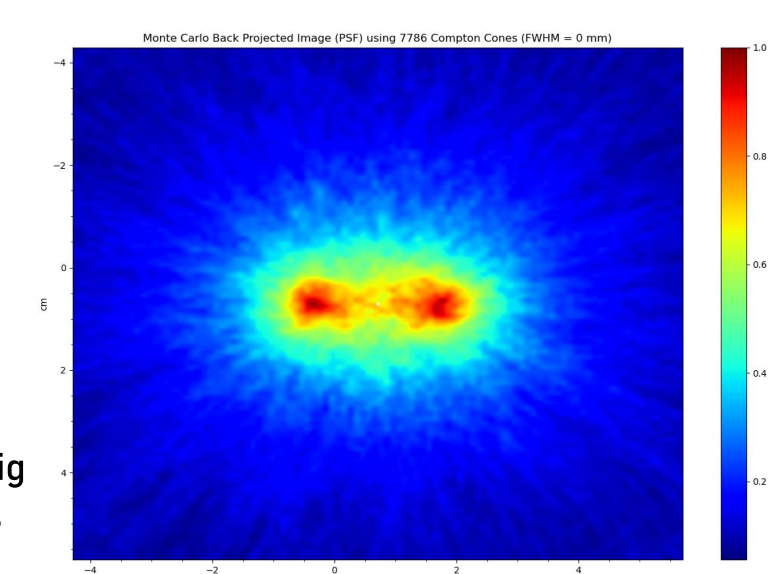


Fig 9.

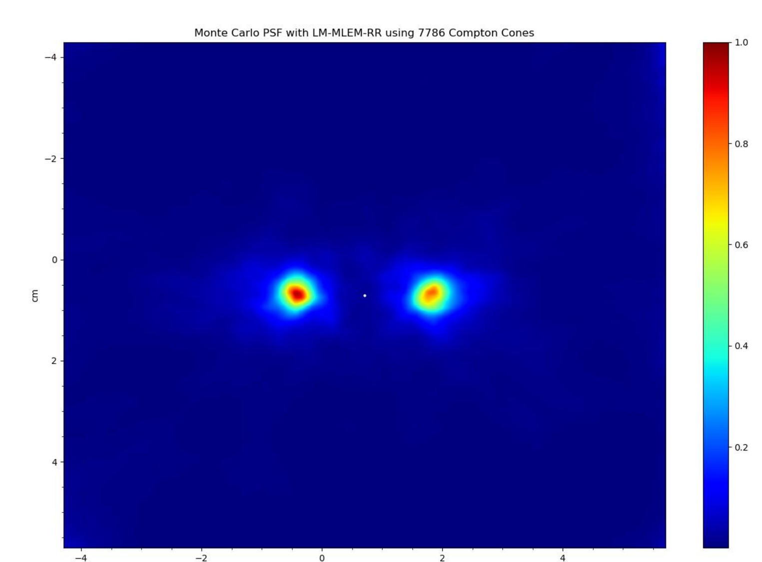


Fig 10.

CONCLUSIONS

TPX3 has been demonstrated as feasible detector to achieve Compton Camera imaging in Nuclear Medicine. TPX3 provides excellent spatial resolution as shown by the simulated and experimental point sources. Future work would look to evaluate the ensuing dose-saving via sensitivity achieved using Compton Imaging.

References:
[1] Procz, S., Avila, C., Fey, J., et al. 2019, Radiation Measurements, 127, 106104, doi: https://doi.org/10.1016/j.radmeas.2019.04.007
[2] Todd R, Nightingale J, Everett D. A proposed [gamma] camera. Nature. 1974;251:132-4.

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ST. VINCENT'S UNIVERSITY HOSPITAL Elm Park

Centre for Physics in Health and Medicine University College Dublin