Simulation study of a coincidence detection system for non-invasive determination of arterial blood time-activity curve measurements

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Abstract

Background: Arterial sampling in PET studies for the purposes of kinetic modeling remains an invasive, time intensive and expensive procedure. Alternatives to derive the blood time-activity curve (BTAC) non-invasively are either reliant on large vessels in the field of view or are laborious to implement and analyse as well as being prone to many processing errors. An alternative method is proposed in this work by the simulation of a non-invasive coincidence detection unit.

Results: We utilized GATE simulations of a human forearm phantom with a blood flow model, as well as a model for dynamic radioactive bolus activity concentration based on clinical measurements. A fixed configuration of 14, and also separately, 8 detectors were employed around the phantom, and simulations performed to investigate signal detection parameters. BGO crystals proved to show the highest detection efficiency and sensitivity to a simulated BTAC with a maximum coincidence rate of 575 cps. Repeatable location of the blood vessels in the forearm allowed a half-ring design with only 8 detectors. Using this configuration, maximum coincident rates of 250 cps and 42 cps were achieved with simulation of activity concentration determined from 15 O and 18 F arterial blood sampling. NECR simulated in a water phantom at 3 different vertical positions inside the 8-detector system (Y=-1 cm, Y=-2 cm and Y=-3 cm) was 8360 cps, 13041 cps and 20476 cps at an activity of 3.5 MBq. Addition of extra axial detection planes to the half-ring configuration provided increases in system sensitivity by a factor of approximately 10.

Conclusions: Initial simulations demonstrated that the configuration of a single half-ring 8 detector of monolithic BGO crystals could describe the a simulated BTAC in a clinically relevant forearm phantom with good signal properties, and an increased number of axial detection planes can provide increased sensitivity of the system. The system would find use in the derivation of the BTAC for use in the application of kinetic models without physical arterial sampling or reliance on image-based techniques.

Full-text

Due to technical limitations, full-text HTML conversion of this manuscript could not be completed.

However, the manuscript can be downloaded and accessed as a PDF.

Figures
Figure 1

Left - Cross section of the lower forearm (left) detailing the anatomical location of the vessels and bones near the wrist. Right - Schematic diagram showing a cross section of the basic wrist phantom (not to scale).
Figure 2

Schematic detailing layout of the wristPET1 (A) system. wristPET1 consists of 14 detectors in a closed ring design, whereas a second system (wristPET2 (B)) was projected to employ an open-ring design with a subset of detectors (numbers 4-11) only. All other properties of the detectors between wristPET1 and wristPET2 are identical.
Figure 3

Schematic of the wristPET2 model with 2 (6cm FoV) , 3 (9cm FoV) and 4 (12 cm FoV) total axial planes of detectors.
Single, prompt and true count rates for each crystal material used in the simulation of a physically recorded BTAC using wristPET1. All simulation criteria were constant except the crystal material. The highest response for both singles and coincident rates can be noted for BGO crystals. There was no venous return of blood in this simulation, only arterial blood at a uniform velocity. Similar responses can be noted for LaBr3 and CeBr3 crystals and the appear as overlapping on the figure.
Figure 5

Count rate performance of the wristPET2 (8 detector system) using a point source at different Y-positions inside an 8 cm diameter water phantom at (A) Y=-1cm below centre (B) Y=-2 cm below the centre and (C) Y=-3 cm below the centre of the scanner (D) comparison of NECR at Y=-1 cm, Y=-2 cm and Y=-3 cm where NECRmax is 8360 cps, 13041 cps and 20476 cps at an activity of 3.5 MBq.
Singles and prompt count rate of a pulsatile flow model using models of BTAC for $^{18}$F (top row) and $^{15}$O (bottom row) activities through the simulated wrist phantom.
Figure 7

Total singles, prompt and true event rates for wristPET2 system simulated for an increasing number of detection planes (1, 2, 3 and 4) for 18F simulation (top row) and 15O simulation (bottom row). All variables were constant except the number of detection planes.