Technical Development of Interventional Nuclear Imaging

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Several forms of medical imaging (e.g. MRI/CT) are, in addition to disease diagnosis, used for the guidance of interventional treatments. This dynamic setting places specific demands on the scanner designs, the acquisition protocols, and the subsequent data processing.
In diagnostic imaging, scanners can be large with a closed gantry (since no interaction with the patient is necessary), the acquisition time can be relatively long, and data processing can be performed in the hours following the acquisition.

For interventional imaging, however, scanners need to be flexible and compact to allow for smooth integration into the busy operation room and should preferably have an open gantry to enable easy access to the patient. Images are ideally obtained in real-time so that direct feedback on the procedure is obtained. Furthermore, image acquisition should be performed as fast as possible to not prolong the interventional procedure and processed data should be available within minutes.
For nuclear imaging (and especially hybrid imaging), it has proven difficult to translate the diagnostic scanner to an interventional setting. This is likely for two reasons. First, the SPECT and CT detectors are two separate entities on the gantry, which results in a relatively bulky device that is not flexible and has a closed gantry. And second, the nuclear and x-ray images are acquired in sequence instead of simultaneously. Such sequential imaging results in motion artifacts in a dynamic setting and limits the interpretation of real-time acquired nuclear images. Nuclear imaging in the intervention room has hence so far mostly consisted of imaging with small (hand-held) gamma cameras that lack the ability to complement the nuclear images with real-time anatomical details.
This dissertation aims to translate diagnostic SPECT/CT imaging to the intervention room. This requires a new scanner design that meets the criteria for use in the intervention room and furthermore needs several methodological contributions to optimise the acquisition protocols and to shorten the acquisition and data processing durations.

The dissertation starts by developing a SPECT scanner that can be used in the intervention room. A novel dual-layer design is proposed that accomplishes a compact and mobile scanner with an open gantry (based on the c-arm construction of the CBCT scanner, see figure 1) that can furthermore provide simultaneous anatomical images to complement the nuclear images. Three prototype configurations are evaluated through digital simulations and phantom experiments.

The dissertation continues with methodological contributions. Patient respiratory motion is a major degrading factor for the quality of nuclear images. Conventional methods to compensate for respiratory motion require either external apparatus (e.g. a respiratory belt) or high activity levels. Both of these methods are undesired in an interventional setting and hence a new approach to motion compensation for interventional nuclear imaging is developed and evaluated through simulations and phantom experiments.
Nuclear imaging scans conventionally need a long time (> 20 minutes) to acquire images with low noise. This scan duration should ideally be reduced to keep the interventional procedure as short as possible. One of the methods to reduce the scan duration is to improve the sensitivity of the system by making hardware modifications. This dissertation investigates the possibility of using collimators that focus specifically on the organ of interest to accomplish scan duration shortening.
A different method to accomplish scan duration shortening is to evaluate the radionuclide distribution characteristics during the acquisition so that the scan duration is personalised for every patient. This dissertation introduces a method for adaptive scan duration reduction that is performed by performing multiple fast detector rotations and terminating

Figure 1. The developed hybrid c-arm scanner (named 'IXSI') that is placed in the intervention room of the UMC Utrecht.

the scan when sufficient information on the distribution has been obtained.

And finally, reconstructed images should be available quickly after scanning in the intervention room to ensure that valuable time is not wasted. Current state-of-the-art SPECT reconstructors require several minutes to complete and should be accelerated. In this dissertation, a deep learning-based reconstruction method is presented that generates images with a quality close to that of state-of-the-art reconstruction software in a matter of seconds.

This dissertation has realised the development of a hybrid c-arm scanner that can be used for interventional nuclear imaging. Now that the technical work has been successfully completed, the performance of the scanner is currently being clinically evaluated in a 'first in man' study during ^{99m}Tc-MAA radioembolisation procedures. We are furthermore actively investigating the potential benefits of the scanner in other interventions, such as sentinel node procedures, parathyroidectomies, intra-arterial radionuclide therapies, interventional cardiology, and biopsies. We hope that interventional hybrid nuclear imaging will eventually have a similar impact as was achieved with diagnostic hybrid imaging.

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