A Compact Probe for β^+-Emitting Radiotracer Detection in Surgery, Biopsy and Medical Diagnostics based on Silicon Photomultipliers

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Abstract: We present a new probe for radiotracer detection in vivo. The device is based on silicon photomultipliers coupled with a scintillator and wirelessly compensated for supply voltage and temperature variations. The probe is positron sensitive.

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1. Introduction

During the last decades, positron emission tomography (PET) has been established as the imaging technique of choice to identify and localise tumours and metastases prior to surgical interventions. Unfortunately, PET scans require a large machine, which cannot be used in the operating theatre. During the operation, the PET image recorded beforehand (fig. 1) can only give approximate information of the actual location of the tumour, as organs in the human body continuously move. The success of an intervention therefore depends to a large extend on accurately finding neoplastic lymph nodes and metastatic tissues and on choosing the resection margins. This may be difficult in case of prior surgery or chemo- or radiation therapy.

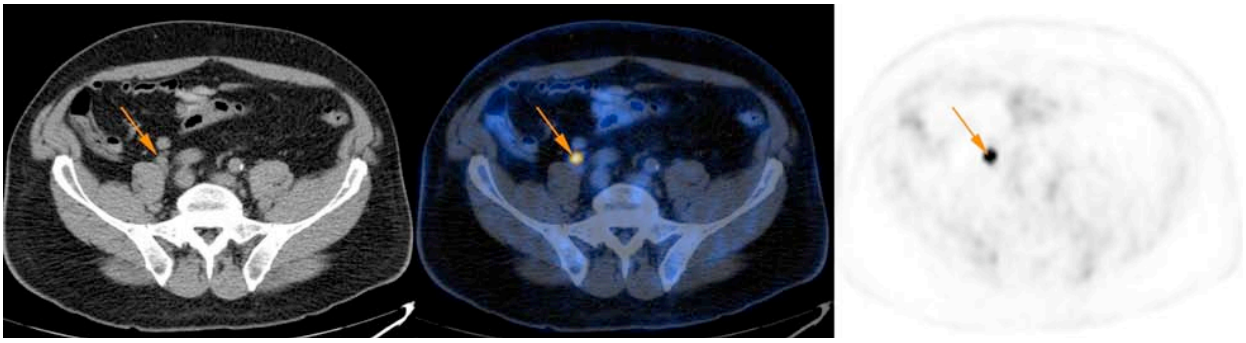

Figure 1. Metastatic right internal iliac lymph node in a 64-year-old men operated 2 years ago from a right thigh melanoma 3.1 mm Breslow index. Preoperative hybrid CT (left), PET/CT (middle) and PET (right)

To overcome this limitation, we propose to use a sensor that is small enough to be used during operations [1], while being sensitive to the same radioactive tracers utilised in PET scans [2]. This limits the radioactive dose to which the patient is exposed, to the amount required for a PET scan. A very common radiotracer is ^{18}F-fluorodeoxyglucose (FDG), a modified glucose analogue emitting β^+ radiation (positrons). FDG is metabolised in the same way as normal glucose but gets trapped and accumulates in the cells, the rest being eliminated by the kidneys, which entails a

considerable background signal in the urinary system. In order to have a meaningful measurement, the probe needs to have a large spatial resolution and low noise; it needs to withstand standard sterilisation procedures. As the probe is wireless, it is sufficient to sterilise only the handheld part which is in contact with the patient, thus significantly simplifying pre-operative handling.

2. Prototype

The prototype demonstrates the concept of detecting β^+ radiation with very low noise and high sensitivity in a wireless, handheld probe during operations. The β^+ particles can either hit the detector and generate a signal or annihilate and create two 511 keV photons, which can occasionally produce a signal in the scintillator. The visible photons are detected with two silicon photomultipliers, operated in coincidence mode in order to reduce the dark count rate to negligible levels [3]. The coincidence principle takes advantage of the fact that the element with the highest dark count rate is the photomultiplier, not the scintillator. Monitoring the very same scintillator with two different, independent photomultipliers will lead to a signal in both SiPMs in case of a real particle detection, while SiPM dark count will show as uncorrelated signals.

The block diagram of the probe, excluding the external control system, is shown in fig. 2.

The complete probe, including the module for wireless feedback used to stabilise the behaviour of the probe in an environment with temperature variations, is shown in fig. 3. It consists of a 44 mm long tip with a small diameter (9 mm), containing a scintillator and the photomultipliers, and an end part with a larger diameter (22 mm), which is housing most of the electronics. The surgeon holds the probe at the end part like a white-board marker pen. The total mass of a ready-to-use short probe is 80 g, including batteries.

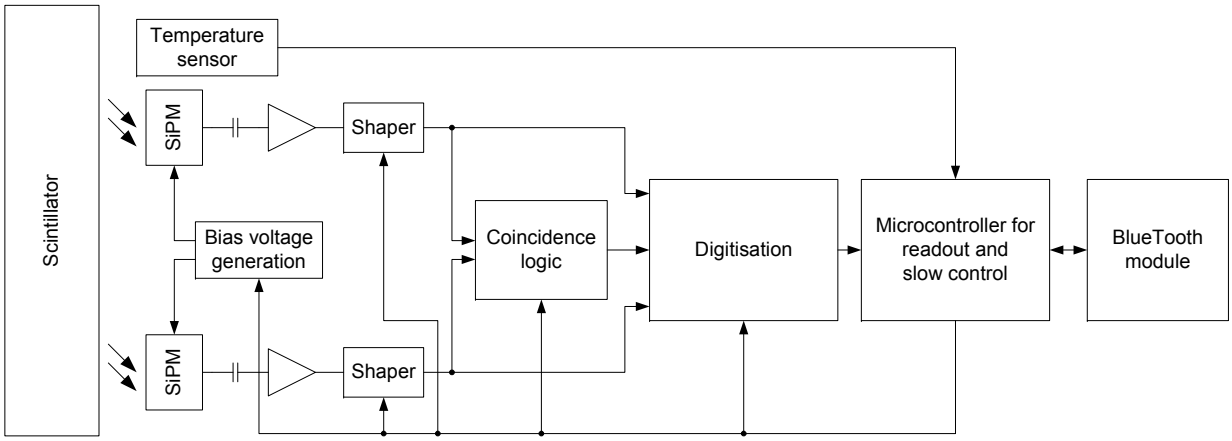

Figure 2. Block diagram of the probe

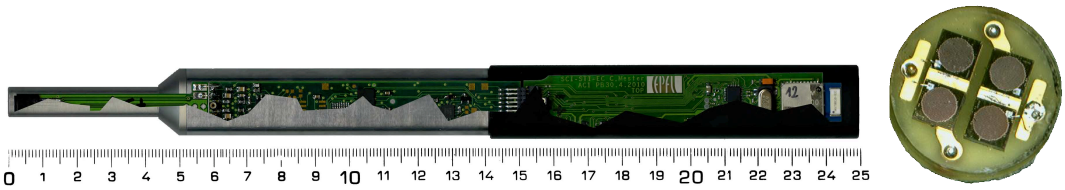

Figure 3. Probe prototype (left), sensor head for coincidence measurement (right)

3. Clinical Use

The first pilot clinical trials have been successful in a number of operations involving metastatic lymph nodes (fig. 4). For operations with large incisions and easily accessible regions of interest, the short version of the probe (fig. 3) is used. Further trials are expected to start in the second quarter of 2011. By then, a variant of the probe, specially adapted to laparoscopic operations, will be available. It contains the same electronics and provides the same functionality. The end part remains unchanged, while the tip with a diameter of 9 mm is elongated to 250 mm, so that it can be used in a mediastinoscope.

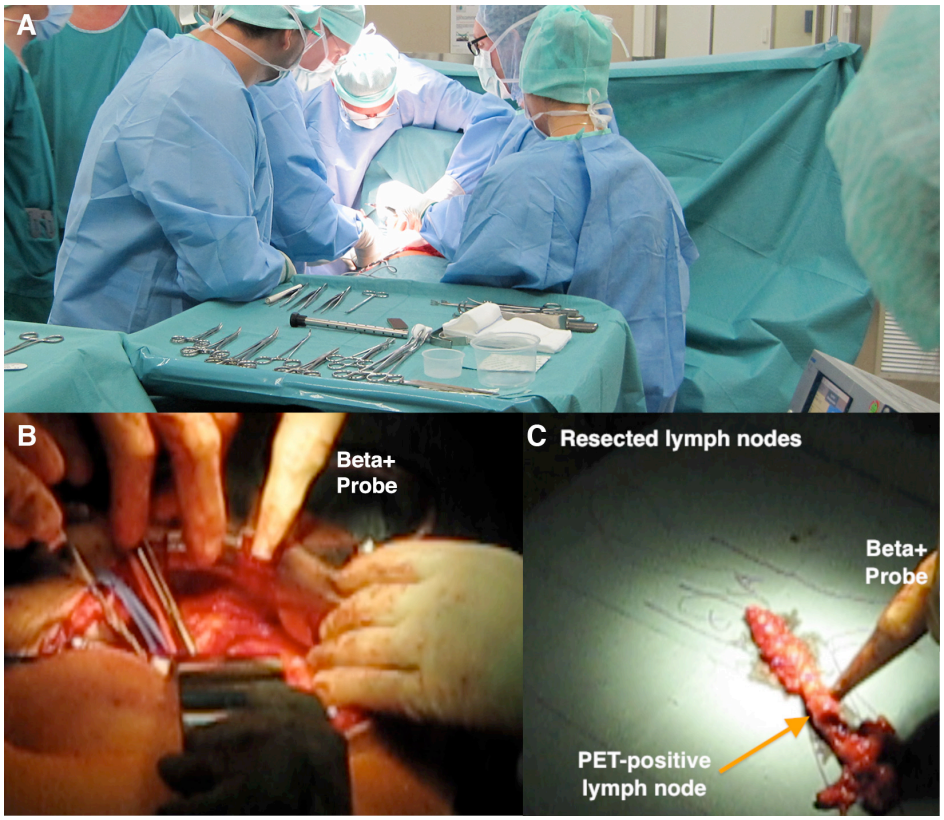

Figure 4. Early clinical trials: Surgical ablation of the metastatic lymph node
A: General setting in the operating room
B: Close view of the peroperative use of the β^+ probe
C: Ex vivo verification of the stripped right internal iliac lymph node chain showing only one PET+ lymph node, which was confirmed by histopathology as the only node with melanoma metastatic cells out of 19 removed lymph nodes.

As further refinement, adding a 3D positioning system to the probe would help associating measurements with the probe position at any moment in time, allowing to generate images of the region of interest.

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