Introduction aux Cameras TEP-TDM digitales.

An Introduction to Digital PET-CT.

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In PET cameras the replacement of conventional photomultiplier tubes (PMTs) by solid state readout systems was largely motivated by the need for compatibility with magnetic fields to achieve simultaneous PET-MRI. Siemens was the first to achieve this using avalanche photodiodes (APDs), initially for a brain insert and soon afterwards for their whole body mMR system [1]. A problem with APDs is their relatively slow speed which renders them unsuitable for time-of-flight PET. Instead silicon photomultipliers (SiPM) can be used, which consist of a large number of small APDs operated in Geiger mode. A typical PET detector configuration is based on a block of small scintillation crystals connected to on an array of SiPM tiles, each tile consisting of thousands of elements that each can acquire single light photons. The light distribution across several neighbouring tiles is used to determine location of the scintillation in much the same way as PMTs [e.g. 2]. An alternative design couples individual SiPMs to each individual crystal. An important feature of SiPM technology is the time-of-flight (TOF) timing achievable (now better than 250ps for one commercial system [3]), which is already significantly better than that achieved using conventional PMTs. This provides SiPM-based PET (so-called ‘digital’ PET) with a distinct advantage compared to conventional PET systems. Consequently, vendors have adopted similar technology in the design of recently released PET-CT systems [4].

The main advantage of TOF is the improvement in signal to noise that can be achieved, particularly for large objects. The improvement is a consequence of having more exact information on the location of the positron annihilation which can be encoded in the reconstruction algorithm. Further gains will be obtained as the technology develops. In

practice the emphasis tends to be on reducing scan time, trading off, at least in part, the gains in image quality. TOF data do provide additional advantages. It has been shown that the additional spatial information can contribute to improved determination of attenuation (in absence of transmission data) [5], improved speed in automated alignment of an attenuation map derived from CT with respiratory gated PET data [6], and improved data-driven detection of respiratory motion [7]. With the rapid improvement in SiPM technology we can expect further gains in TOF performance; for example a TOF of 100ps would provide a signal to noise gain of around 4.5 for a 30cm diameter patient compared to PMT technology. There are, however, concerns regarding the temperature stability of SiPMs and the need for cooling and/or temperature compensation to optimize performance.

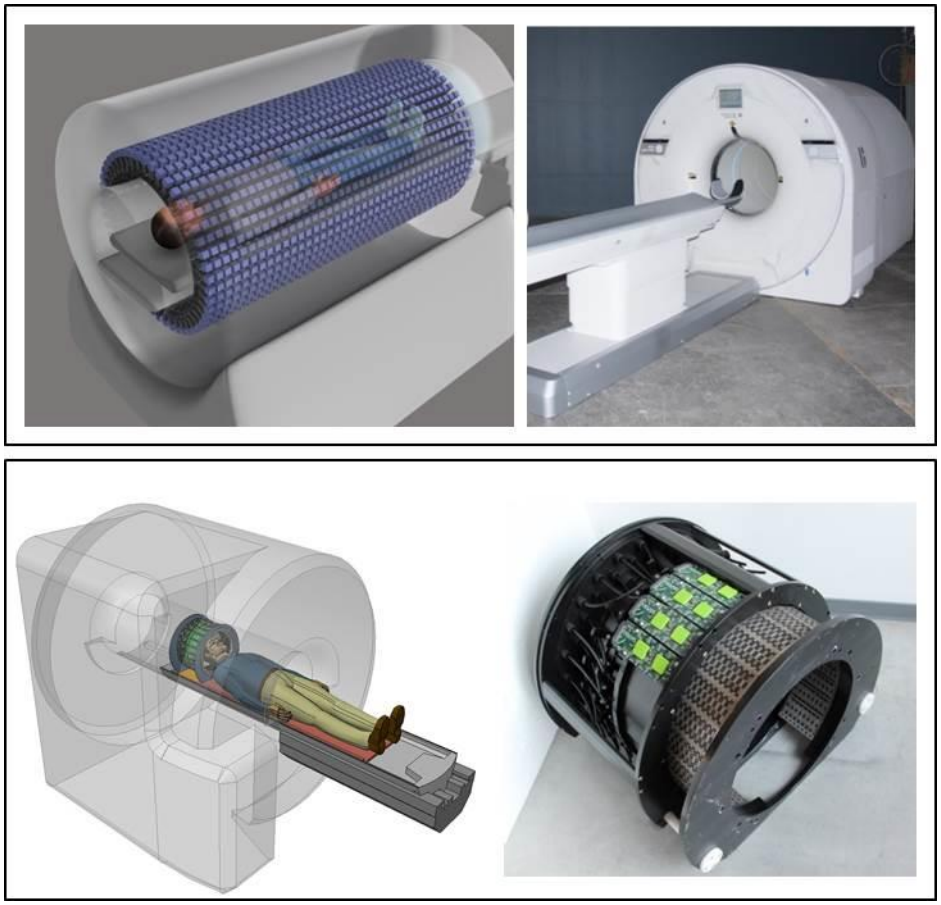
There are further advantages of SiPM technology. Firstly it enables compact design and motivates possible novel designs for future PET systems such as dedicated brain PET systems that utilise wearable technology [e.g. 8]. The TOF gains also make this particularly attractive for total body PET e.g. the EXPLORE project [9] (Fig 1 top). There are also SiPM-based PET systems being introduced where the PET is combined with either a linac for real-time monitoring of metabolic activity [10] and the achievable TOF resolution would be favoured for verification of dose delivery in proton therapy systems [11]. SiPM technology has also been used in the first clinical SPECT brain insert intended for application in simultaneous SPECT-MRI [12] (Fig 1 bottom).

Figure 1: Total body PET. Sensitivity is maximized by extending the detector axial length to cover the whole body (top left). A mock model of the system is illustrated (top right). **SPECT/MRI.** The compact clinical brain SPECT is inserted in the MRI bore (bottom left); the partially constructed prototype illustrates the compact design with novel slit-slat collimator (bottom right).

Figure 1: Examen TEP du corps entier : la sensibilité est maximisée par extension de la longueur axiale des détecteurs afin de couvrir le corps entier (cf. figure en haut à gauche).

Une illustration du modèle est donnée sur la figure en haut à droite.

Tomoscintigraphie/IRM : le système dédié à l'étude cerveau est inséré dans l'ouverture du scanner IRM (cf. figure en bas à gauche) ; le prototype partiellement assemblé (cf. figure en bas à droite) illustre la compacité de sa conception au moyen de nouveaux collimateurs de type *slit-slat.*



References

1. Delso G, Furst S, Jakoby B, Ladebeck R, Ganter C, Nekolla SG, et al. Performance measurements of the Siemens mMR integrated whole-body PET/MR scanner. *J Nucl Med*. 2011;52(12):1914-22.
2. Delso G, Khalighi M, Hofbauer M, Porto M, Veit-Haibach P, von Schulthess G. Preliminary evaluation of image quality in a new clinical ToF-PET/MR scanner. *EJNMMI Physics*. 2014;1(1):1-2.
3. Casey M, Burbar Z, Rothfuss H, Panin V, Bharkhada D, Howe W, Bradley Y (2017) First human images from a next generation SiPM based PET/CT system with

improved time and spatial resolution. *Eur J Nucl Med Mol Imaging* 44 (Suppl. 2):S303.

4. Liu Z, Pizzichemi M, Auffray E, Lecoq P, Paganoni M (2016) Performance study of Philips digital silicon photomultiplier coupled to scintillating crystals. *Journal of Instrumentation* 11 (01):P01017
5. Rezai A, Defrise M, Bal G, Michel C, Conti M, Watson C, Nuyts J. (2012) Simultaneous reconstruction of activity and attenuation in time-of-flight PET. *IEEE Trans Med Imaging* 31: 2224-33.
6. Bousse A, Bertolli O, Atkinson D, Arridge S, Ourselin S, Hutton BF, Thielemans K. (2016) Maximum-Likelihood Joint Image Reconstruction and Motion Estimation with Misaligned Attenuation in TOF-PET/CT. *Phys Med Biol* 61: L11-19.
7. Bertolli O, Arridge S, Stearns CW, Wollenweber SD, Hutton BF, Thielemans K. (2016) Data driven respiratory signal detection in PET taking advantage of time-of-flight data. In *Proc IEEE Nucl Sci Symp Med Imaging Conf*. 10.1109/NSSMIC.2016.8069426
8. Tashima H, Yamaya T. (2016) Proposed helmet PET geometries with add-on detectors for high sensistivity brain imaging. *Phys Med Biol* 61: 7205
9. Cherry SR, Jones T, Karp JS, Qi J, Moses WW, Badawi RD. (2018) Total-body PET: maximizing sensitivity to create new opportunities for clinical research and patient care. *J Nucl Med* 59: 3-12.
10. Yang J, Yamamoto T, Maxin SR, Graves EE, Keall PJ. (2014) The potential of positron emission tomography for intratreatment dynamic lung tumour tracking: a phantom study. *Med Phys* 41: 021718-1 - 021718-14.
11. Surti S, Zou W, Daube-Witherspoon ME, McDonough J, Karp JS. (2011) Design study of an in situ PET scanner for use in proton beam therapy. *Phys Med Biol* 56: 2667-85.
12. Hutton BF, Occhipinti M, Kuehne A et al. (2018) Development of clinical simultaneous SPECT/MRI. *Br J Radiol* 91(1081) 20160690.