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Instrumentation challenges in multi-modality imaging

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ABSTRACT

Based on different physical principles, imaging procedures currently used in both clinical and preclinical applications present different performance that allow researchers to achieve a large number of studies. However, the relevance of obtaining a maximum of information relating to the same subject is undeniable. The last two decades have thus seen the advent of a full-fledged research axis, the multimodal in vivo imaging. Whether from an instrumentation point of view, for medical research or the development of new probes, all these research works illustrate the growing interest of the scientific community for multimodal imaging, which can be approached with different backgrounds and perspectives from engineers to end-users point of views. In the present review, we discuss the multimodal imaging concept, which focuses not only on PET/CT and PET/MRI instrumentation but also on recent investigations of what could become a possible future in the field.

1. Introduction

To date, molecular imaging is globally recognized as a powerful tool to assess in vivo anatomical and functional structures within a living subject [1,2]. A wide range of imaging modalities based on different physical principles is available. Used individually, the value of modalities such as X-ray Computed Tomography (CT), Single Photon Emission Computed Tomography (SPECT), Positron Emission Tomography (PET), Magnetic Resonance Imaging (MRI) and Ultrasound (US) is well established, both in clinical and preclinical fields [3–12]. Although established for decades, these modalities are still subject of much research, both on the development of new detection components and/or the design of new probes to artificially improve the natural contrast induced by physical processes. More recently, a new effort has been put on new optical imaging modalities such as Bioluminescence (BLI), Fluorescence (FI) or Cherenkov imaging (CI) [13–19]. However, these studies are mostly confined to preclinical field due to the physical properties of visible and near-infrared light.

With different performance in terms of spatial and temporal resolutions, sensitivity and specificity, but also their ability to provide quantitative results, all of the previously mentioned imaging modalities allow us to achieve a large number of studies. However, the relevance of obtaining a maximum of information relating to the same subject is undeniable. The last two decades have thus seen the advent of a full-fledged research axis on multimodal in vivo imaging. The first proposed approaches simply were to move the patient from one machine to another and to co-register the data sets obtained from different imaging systems [20,21]. The main disadvantages of such methods could be the multiple imaging sequences that might be distressing for the patient and limit the overall patient throughput in clinical routine. In addition, the data co-registration uncertainty for a large number of body parts and the inability to correlate the changes of various parameters over time could represent the major drawbacks in diagnosis accuracy. To overcome these difficulties, an approach aiming at developing integrated systems (two or more modalities) stimulated a growing interest over the last 15–25 years, resulting in the advent of the first SPECT/CT in 1990 by Hasegawa et al. [22] and the first PET/CT in 2000 by Beyer et al. [23]. Although straightforward from the conceptual point of view, this challenging approach gave birth to a large number of systems, especially PET/CT and SPECT/CT systems. In 2006, Cherry presented a review with an evocative title: "*Multimodality In Vivo Imaging Systems: Twice the Power or Double the Trouble?*" [24]. In this review, the author described the emergence of multimodal imaging and discussed the benefits and challenges related to the development of multimodal systems, focusing on PET/CT, SPECT/CT and PET/MRI systems. Addressing these systems from a conceptual and instrumental point of view, Cherry proposed a comprehensive state of the art at the time. The same year, Hasegawa et al. wrote a book chapter touting the merits of multimodal imaging [25]. This chapter also presents the history, emergence and progress in multimodal imaging in 2006, most of which concerned the PET/CT

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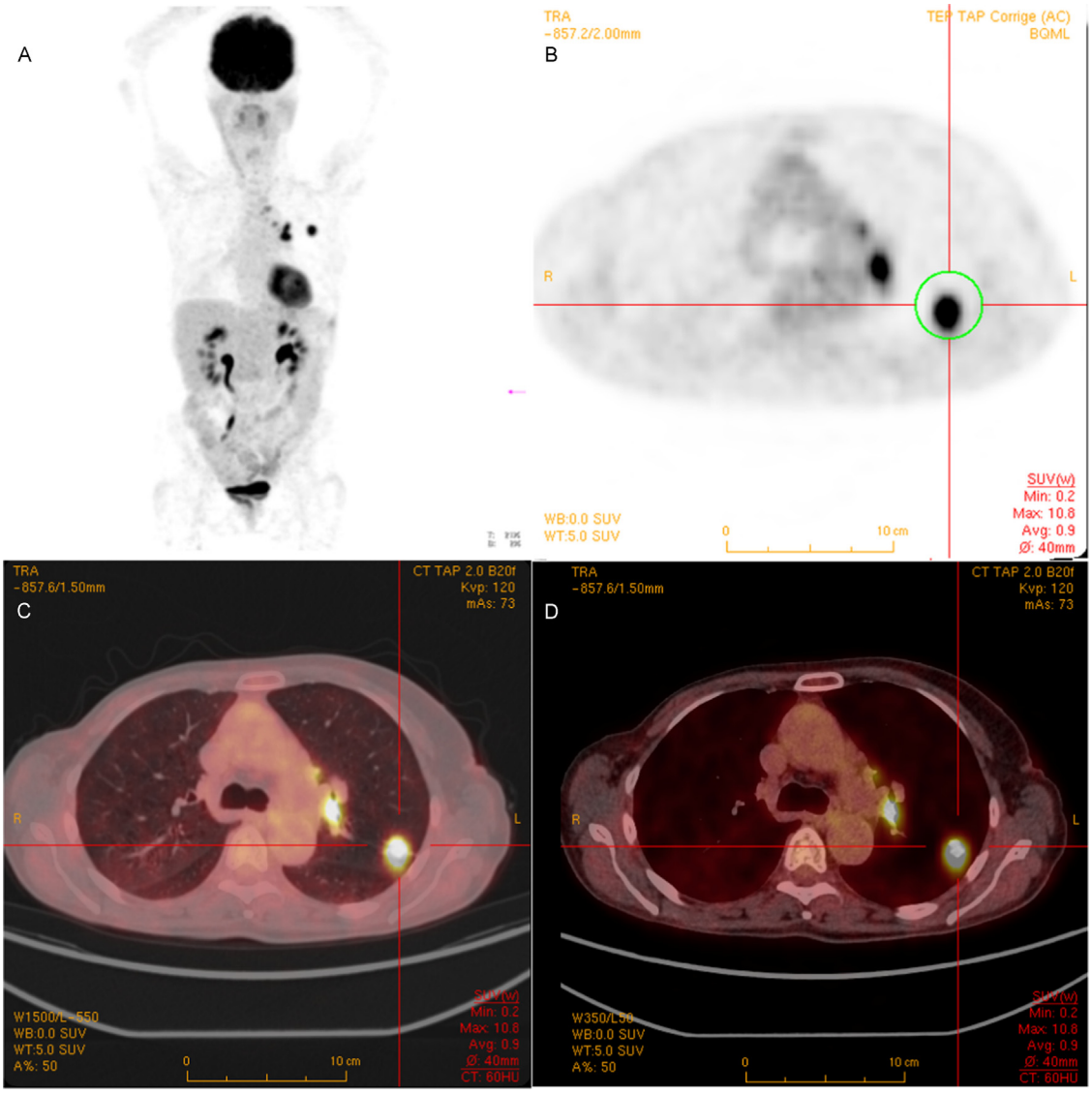

Fig. 1. PET/CT images of glucose metabolism. (A) Maximum intensity projection image representing the whole-body bio-distribution of FDG. (B) shows an axial PET slice positioned on a lung lesion highlighted by the circled region. (C, D) show two fusion images obtained with two different HU windows. (Courtesy of Doctor Khalil Bourahla from the Anticancer Paul Strauss Hospital, Strasbourg, France).

and SPECT/CT systems in both clinical and preclinical areas. The following year, Catana et al. focused on the simultaneous acquisition of PET and MRI information in vivo [26]. Their work showed the design and development of a preclinical PET insert compatible with MRI and discussed the advantages of their approach to the state-of-the-art of this dual-modality. Also in 2007, Beekman and Hutton addressed the multimodal imaging not from the point of view of integrated systems but from the perspective of optimizing multiple consecutive examinations and image registration via rails, tracks or trucks to transfer the patient bed between devices [27]. More recently, other multimodal combinations than the originals (S)PE(C)T/CT systems were presented [28]. Emission tomographic systems coupled to MRI were still addressed due to growing interest and the rapid technological advances in the field. However, the author suggested a new horizon of multimodal imaging combining optical and nuclear or MRI modalities. The relevant approach reflects once again the enormous potential of multimodal imaging and offers promising prospects.

The interest of multimodal imaging protocols is demonstrated from a biological and medical point of view. In 2007, Hsu et al. investigated glioblastoma growth inhibition using PET, MRI and BLI small-animal systems [29]. The very next year, Cai and Chen published a review on the multimodality imaging progress of tumor angiogenesis [30]. This review echoes the paper proposed by Cai et al. in 2006, which illustrates the importance of molecular imaging in the development of new drugs dedicated to research in oncology [31]. These papers highlight the strengths of different modalities such as PET, SPECT, MRI, or BLI and ultrasound in molecular medicine research. But they also reflect an important aspect of modern imaging pushing the development and use of new dedicated probes, a fact well illustrated by Louie in a review published in 2010 [32]. The author looks over all the different approaches used in the molecule development framework and describes the design of probes, such as contrast agents and nanoparticles. But the main interest focuses on multimodal probes, which represent, according to the author, a promising future. However, this requires to push investigations further due to numerous imaging modalities properties such as their difference