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A decade of combined imaging: from a PET attached to a CT to a PET inside an MR

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Over the past decade we have witnessed the rise of combined imaging technologies. The combination of single photon emission tomography (SPECT) and computed tomography (CT), or SPECT/CT, for example, has opened the door to quantitative SPECT [1] and led to an acceptance of SPECT imaging for a wider range of clinical indications [2]. The intrinsic combination of positron emission tomography (PET) and CT, or PET/CT, has lead to a 10–15% increase in diagnostic accuracy compared to standalone PET or CT imaging [3]. SPECT/CT and PET/CT have demonstrated a direct impact on patient management and, thus, have changed radiology, and, perhaps more so, nuclear medicine imaging strategies drastically.

Despite the proven benefits for patients and clinical workflow, combining two complementary imaging modalities from two traditionally apprehensive fields has led to vivid skepticism as well. This skepticism still persists [4] although combined imaging modalities have become an integral part of non-invasive diagnostic imaging today. This supplement is dedicated to the latest technological advance in medical imaging: combined PET and magnetic resonance (MR) imaging: PET/MR.

While combined PET/CT and SPECT/CT started out at about the same time [5, 6], SPECT/CT faced little skepticism for it was used in nuclear medicine without rivaling the radiology market clinically or technically. PET/CT, on the other hand, provided a proof-of-concept for a more accurate oncology staging than CT-only imaging, and, therefore, became competitive with routine radiology procedures. Nonetheless, there is convincing and growing evidence for the benefits of intrinsic image fusion in oncology patient management [7] and, to a somewhat lesser degree, in cardiology and neurology. It is also clear to many of us that by fusing the competencies of radiology and nuclear medicine experts as well, image fusion can become even more powerful and beneficial to patients [8, 9].

Now, with the new hardware combination of PET and MR on the horizon, it is interesting to reflect upon the development path of PET/MR and PET/CT. In essence, the development of PET/MR has been the reverse experience to that of PET/CT: The first PET/CT design emerged from industry–academia collaboration and was a prototype for human clinical use that stimulated a commercial response and later led to the development of PET/CT for imaging small animals. In contrast, PET/MR began in the mid-1990s began with small-animal designs [10, 11]. Then, over a decade later, a prototype PET/MR was developed for human brain scanning that acquired the first images in November 2006 [11, 12]. This prototype design is based on a PET insert for a 3T MR, and offers a transverse field-of-view limited to scanning the brain, or the extremities. As of today, three such insert PET/MR systems have been installed worldwide and industrial backing for this human PET/MR prototype development is impressive and exceeds that of the early PET/CT developments. Following the recent announcement of alternative concepts for whole-body PET/MR imaging systems we can expect to see first prototype systems as early as in 2009.

This supplement issue of the *European Journal of Nuclear Medicine* brings together perspectives from experts

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in radiology and nuclear medicine imaging alike on the potential of research and clinical applications of combined PET/MR. With PET/MR being still in its technological infancy this supplement will remain speculative and subjective in many ways. However, we believe that the expertise of the authors of this supplement, who are known as clinical experts and imaging researchers with many years of experience, lends itself to a useful and critical review of the opportunities and potential pitfalls of this new and exciting imaging modality.

This supplement is divided into four major sections: Methodology, Technology, Applications and Healthcare. In the Methodology section, Schulthess and Schlemmer as well as Hicks and Lau share their vision of a combination of PET and MR: two perspectives from two sides of the globe. Mawlawi and Townsend summarize the technological level and major clinical applications of PET/CT, which conceivably could remain the biggest challenge to combined PET/MR in clinical practice. Moser and colleagues follow with an introduction to MR technology and imaging. The first section is completed by Slomka and Baum with an overview on strategies for software-based image alignment and fusion involving PET, CT, and MRI.

In the Technology section, Wehrle and colleagues reviews the technology for pre-clinical PET/MR imaging. Lecomte discusses design concepts for PET detector technology in view of the required adaptations to the MR in order to limit PET–MR interference and cross-talk effects. Delso and Ziegler review viable design concepts for clinical PET/MR systems. This section is completed by a review of existing approaches to using the MR information for attenuation correction of the PET by Hofmann et al.

Following the Technology section are contributions by clinical experts whom we invited to review the perhaps most debated aspect of clinical and, to a lesser degree, research applications of PET/MR. Here, potential applications are divided into neurology, oncology, and cardiology, and discussed by Heiss, Antoch and Bockisch, and Nekolla et al., respectively.

The supplement is concluded by a review of the safety aspects of PET/MR by Brix et al.. Finally, Goyen and Debatin discuss the important aspect of healthcare cost management in light of ever-advancing healthcare technology.

At this point we would like to thank all authors as well as the reviewers for their commitment to this project. We sincerely believe that the time is right to generate a forum to critically review the technology as well as the potential benefits and risks of combined PET/MR.

A mere two years after the advent of commercial PET/CT, Johannes Czernin from UCLA commented that "PET/CT is a technical *evolution* that has led to a medical *revolution*". Today, at the dawn of PET/MR, we may adapt his phrase by adding: "PET/MR is a medical *evolution* based on a technical *revolution*". PET/CT appears to have replaced stand-alone PET for most oncology indications. This supplement supports the notion that PET/MR may well become the preferred imaging research tool, particularly in pre-clinical imaging. It remains to be seen (and studied jointly) as to what extent PET/MR can supplement or replace PET/CT imaging in the clinic.

We believe that both PET/CT and PET/MR are here to stay, because both platforms incorporate the diagnostic power of PET. In fact, with PET/CT being a "*dual*-modality imaging" platform by virtue of combining functional (PET) and anatomical (CT) imaging, PET/MR offers true "*multi*-modality imaging" by virtue of combining function (PET) and anatomy and function (both MR). This will open, without a doubt, new avenues in non-invasive imaging as part of clinical patient management and clinical research.

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