The Challenge of Attenuation Correction in PET/MR Studies of the Brain

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In neurological PET/MR studies, correcting for PET photon attenuation is of high importance for quantitative evaluation of the PET data. Attenuated PET photons are either absorbed or scattered: absorbed photons do not contribute to image formation at all, scattered photons add to non-specific background image intensity. Severe image artifacts can be the result of lacking or incomplete attenuation correction.

In PET/CT, an attenuation map can be readily obtained from a CT scan, since both PET and CT attenuation are closely related to the electron density in any material. With an attenuation map, photon attenuation and scatter can be corrected for in PET image reconstruction. In PET/MR, however, no X-ray source is available, and the attenuation map needs to be obtained from the PET data or from MR images. Methods based on segmentation of MR images are state of the art in clinical practice [1-2], while other MR-based approaches relying on additional a-priori information have also been proposed [3-4].

The most fundamental problem in MR-based attenuation correction in studies of the brain is cortical bone, for three reasons. First, unlike in whole-body imaging, nearly every photon originating within the brain needs to pass through the skull to reach a detector. Second, cortical bone contributes highly to photon attenuation due to its high electron density. Third, low proton density and short relaxation times in the sub-millisecond range imply that cortical bone is hard to distinguish from air in most MR sequences.

As one possible solution to this problem, ultrashort-echo-time (UTE) MR sequences [5] have been used successfully to obtain attenuation maps which take cortical bone into account [4,6-8]. In these sequences, acquisition of a gradient echo virtually immediately after signal excitation anticipates the decay of short-lived signals. Using this information, air, bone and other tissues can be discriminated. In addition, UTE sequences can be extended by additional echoes [6-8] to obtain more detailed attenuation maps in a single acquisition. For example, a triple-echo sequence is capable of distinguishing fat and soft tissue by the phase of their respective signals [8].

Local artifacts in attenuation maps translate straightforwardly into the reconstructed PET images. However, due to the broad spectrum of MR-based PET attenuation techniques proposed, the pool of potential artifacts is diverse. For example, image segmentation tends to be problematic mainly near metal implants and at large tissue-air interfaces, such as in the paranasal sinuses [7,8].

References

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