Partial-Volume Correction for Metabolic Imaging with Hyperpolarised [1-13C]Pyruvate

Rolf F Schulte[1], Martin A Janich[1], Ulrich Koellisch[1,2], Markus Durst[1,2], Florian Wiesinger[1], Eliane Ferral[2], Markus Schwaiger[2], Axel Haase[2], and Marion I Menzel[1]
[1]GE Global Research, Munich, Germany, [2]Technical University, Munich, Germany

Introduction

Metabolic imaging with hyperpolarised substances - such as [1-13C]pyruvate - suffers from low resolution due to limited SNR, despite signal enhancements of several orders of magnitude [1]. Low resolutions lead to partial volume effects, which can hamper quantification [2]. Specifically, a small and aggressive tumour with a high lactate signal cannot be distinguished from a larger tumour with a lower lactate level if the tumour size is smaller than the effective voxel size. Partial Volume Correction (PVC) is an active research field for correcting PET images [2]. Purpose of this work was to implement and explore the potential of PVC for metabolic imaging with hyperpolarised MR.

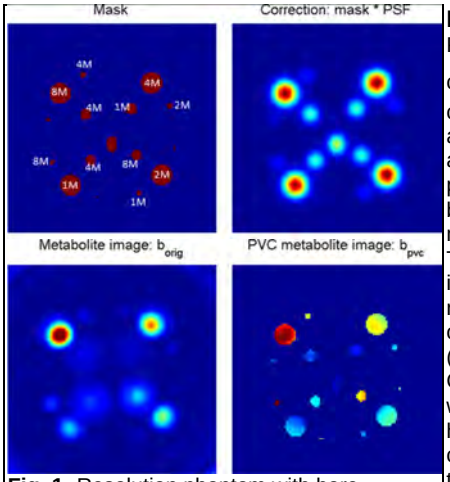


Fig. 1: Resolution phantom with bore diameters of 1,2,4,8 mm filled with 1,2,4,8 M [13C]urea solution. The mask is segmented from higher resolution 1H images, convolved with the point-spread function, and used to correct the low resolution metabolite images.

Methods

Partial Volume Correction (PVC) works by dividing the reconstructed metabolite images through the convolution of a mask and the point spread function (PSF) $b_{pvc} = {}^{b_{orig}}/_{mask * PSF}$ [2]. The mask is calculated by segmenting proton images into pixels containing tissue (and hence also metabolite signal) and areas outside the object or containing air (such as lungs or parts of the guts), assigning values of 1 and 0, respectively. This segmentation can be easily and robustly done by simple thresholding of the proton images. The PSF in MRI is the Fourier transform of sampling and filtering. The above equation is based on the assumption of small fluctuations about a larger mean and is only valid for the area where mask=1 [2].

The feasibility and effects of PVC were validated experimentally both in vitro and in vivo for metabolic imaging with typical resolutions using spiral encoding (13C, FOV=8cm, real resolution 16×16, nominal resolution 32×32, interpolated to 128×128, slice thickness=1cm). A resolution phantom with 4 bores each of 1, 2, 4 and 8 mm diameter, all differently filled with 1, 2, 4 and 8 M [13C]urea solution was measured (thermally polarised) with a single shot spiral and a mask was constructed from 1H images (standard Cartesian gradient echo with a resolution of 128×128; same spatial prescription as 13C). In vivo feasibility was shown in four rats bearing subcutaneous MAT BIII tumours injected with 2.5ml/kg 80mM hyperpolarised [1-13C]pyruvate solution, using the same spiral encoding as for in vitro validation, only combination with IDEAL encoding (nTE=7, dTE=1.12ms) [3]. Metabolic conversion rate images (pyruvate to lactate) were fitted according to [3].

Results

The effects of PVC on the resolution phantom are shown in Figs. 1 and 2. The metabolite images become much sharper and a lot of smeared out signal can be recovered at the boundaries of the objects. Fig. 2 shows that the quantitative values are higher with PVC and lower without for 8 mm diameter size. For smaller diameters, quantitative values are generally too low without PVC and start to disappear in the noise floor, while PVC still yields reasonable results for 4 mm diameter. In vivo results are shown in Fig. 3, again, demonstrating improved spatial resolution characteristics at the boundaries of the object in case of PVC.

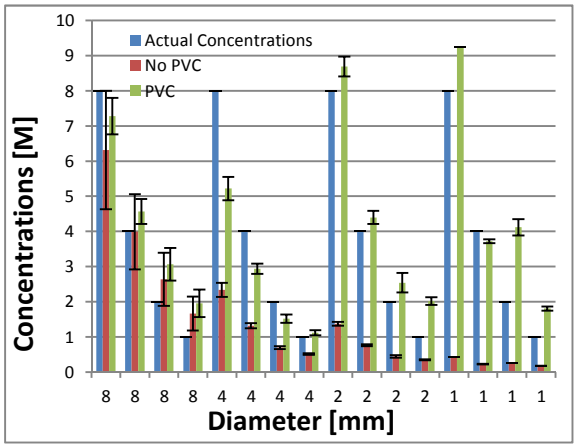
Discussion

PVC is particularly effective for correcting the resolution phantom, leading to much sharper and more accurate metabolite images. The effects on the turnover images in vivo are less pronounced, but it is still possible to recover signal from the edges of the tumour. Metabolic activity is spread throughout the whole body and not located at easily segmentable hotspots and PVC is only effective at edges of the object. This is in contrast to for instance PET in the brain, where cerebro-spinal fluid contains no activity and can be excluded. PVC is sensitive to misregistration errors between mask and metabolite images, as can be seen in Fig. 1 in the gradient on signal intensity in some bores. PVC can be extended to reconstruct different regions, e.g. tumour, background (abdomen) with low activity and areas with no activity. It could be highly advantageous for perfusion measurements, where signal remains in the vessels, which can be segmented out.

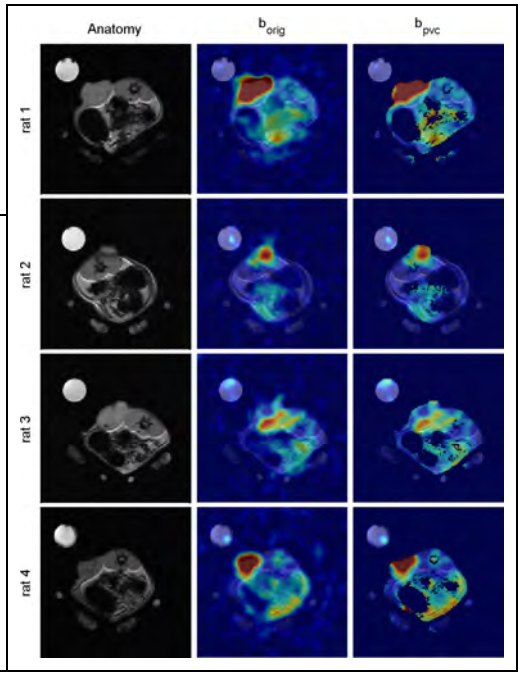
Conclusion

Partial volume effects are an important consideration in metabolic imaging with hyperpolarised substances, as SNR limits the achievable resolution. One approach to correct for these effects is PVC, where higher resolution proton images act as prior-knowledge for lower resolution metabolite images. Smeared out metabolite signal can be recovered at the edges of the object.

References: [1] Proc Natl Acad Sci USA 2006;103:11270-5. [2] J Nucl Med 199;40:2053-65. [3] NMR Biomed 2014;27:1256-65. **Acknowledgements**: co-funding BMBF grant #13EZ1114.



←**Fig. 2** (left): Concentrations measured in the resolution phantom plotted over the different bore diameters (mean±std over ROI). Measured signal levels were normalised to PVC=8M at 8mm.



→**Fig. 3** (right): Demonstration of PVC (right column) on metabolic turnover images (pyruvate to lactate conversion; middle column) in vivo in four rats (top to bottom) bearing subcutaneous MAT BIII tumours (1H images left column).