Quantitative comparison of methods for spatial normalisation of CASL perfusion MR images

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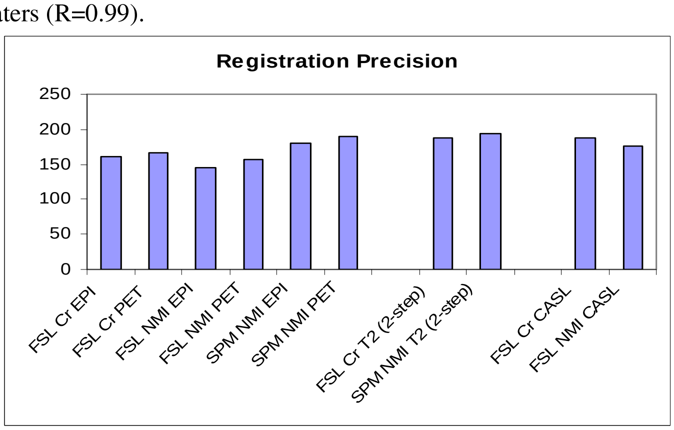
Introduction: Despite the growing number of voxel-based arterial spin labelling (ASL) perfusion MRI studies, the optimal methodology for spatially normalising ASL data has not been systematically assessed. While ASL perfusion data acquired with an EPI readout can be spatially normalised via the source EPI using standard methods for normalising BOLD fmri data, for ASL data acquired with other (eg spiral or FSE-based)[1] readout methods, inter-subject registrations must be performed with the reconstructed perfusion maps. Given the intrinsically low SNR of ASL perfusion data, the optimal registration algorithms, cost functions, and templates for spatial normalisation of ASL perfusion MRI may differ from those optimised for BOLD EPI and structural MR images. The primary objective of this work was to quantitatively examine the accuracy and precision of various registration software methods, cost functions, and templates for the spatial normalisation of continuous ASL (CASL) perfusion MRI data. A secondary objective was to investigate whether the quality of spatial normalisation could be improved using a specific CASL perfusion MRI template.

Methods: Perfusion imaging studies were performed with a 3T GE HD.x TwinSpeed MRI scanner (GE Medical Systems, Milwaukee, WI, USA) using a pseudo-continuous ASL tagging scheme with a 3D interleaved spiral FSE readout.[1] The subject group consisted of 15 healthy adult male subjects (mean age 24 years, range 19-43). The skull-stripped perfusion images for each subject were registered directly to the SPM (Wellcome dept. of Cognitive Neurology, London, UK) PET and EPI templates, using both the SPM and FSL FLiRT (FMRIB, Oxford, UK) software packages. The SPM normalisations were performed with normalised mutual information (NMI) as the registration cost function, and the FSL registrations were performed with both NMI and the correlation ratio (CR) as cost functions. Additional 2-step registrations were performed using the SPM T2 template and an intermediate registration via a structural T2 FSE acquired for each subject. Mean images were calculated from the average of the registered perfusion images for each registration method. The registration accuracy was defined as the average distance between a set of 6 predefined points on the boundary of each mean image and those of the relevant template, (measured by 2 independent raters). The registration precision was defined from profiles measured across the edge of the brain on predefined slices for each mean image, following the hypothesis that a more reproducible registration method would result in a sharper mean image and hence a steeper signal gradient at the boundary of the brain. The accuracy and precision results were then combined to derive a measure of overall registration quality for each method, (with the accuracy and precision weighted equally). Finally, the registrations were repeated using the mean image associated with the best overall registration quality as a CASL template image. The inter-rater reproducibility of the accuracy measurements was quantified by Pearson’s correlation coefficient (R).

Results: While the registration precision was broadly comparable across all methods, the registration accuracy varied considerably with choice of software, cost function and template (fig. 1). The most accurate registration with SPM was achieved with a direct normalisation to the EPI template (avg. offset = 1.2 mm), and the most accurate registration for FSL was achieved with a 2-step registration to the T2 template (via a T2 FSE; avg offset = 1.4 mm). The registration accuracy improved to 0.5 mm with FSL when using the CASL template (consisting of the mean image from the SPM/NMI/EPI registration), although the CASL template did not improve the SPM registration accuracy. The overall registration quality (expressed as the difference of |precision/(maximum precision)| - |accuracy/(maximum accuracy)| for each registration method) is given in table 1. The reproducibility of the accuracy measurements showed an excellent correlation between raters (R=0.99).



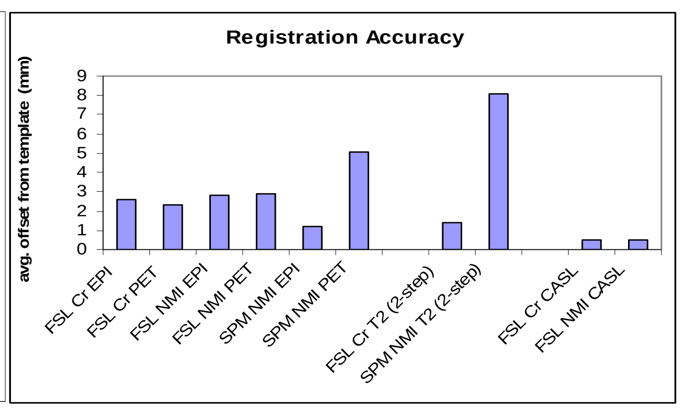


Figure 1: Precision (left) and accuracy (right) of the registration methods

Table 1: Registration quality

FSL, CR, T2, (2-step)	SPM, NMI, EPI	FSL, CR, PET	FSL, CR, EPI	FSL, NMI, PET	SPM, NMI, PET	FSL, CR, CASL	FSL, NMI, CASL
0.77	0.74	0.60	0.55	0.52	0.50	0.83	0.78

Discussion: Accurate and precise spatial normalisation is achievable with CASL perfusion data, although the registration quality (most notably accuracy) varies considerably depending on the software package, cost function, and template used. The registration quality may also be improved with certain registration methods by using a CASL perfusion template.

References: [1]Dai W, Garcia D, de Bazelaire G, Alsop DC. Continuous Flow Driven Inversion for Arterial Spin Labeling Using Pulsed Radiofrequency and Gradient Fields. *In press*, MRM