Evaluation of 3D Non-Rigid Algorithms for the Registration of the Lower Legs in MRA

Daniel Foley[1], Barry Sheane[1], Mark Knox[1], Dearbhail O'Driscoll[1], Niall Sheehy[1], James F. Meaney[1,2], and Andrew J. Fagan[1,2]

[1]Centre for Advanced Medical Imaging (CAMI), St. James's Hospital, Dublin, Ireland, [2]School of Medicine, Trinity College, University of Dublin, Ireland

INTRODUCTION: The registration of the pre- to post-contrast images of the lower legs in MR angiography has been previously shown to improve the quality of the final subtraction image [1], wherein a rather simple registration algorithm developed in 1992 (Automatic Image Registration (AIR) [2]) was used. Registration techniques have developed considerably since then, often with algorithms tailored to specific application areas. Recent examples are algorithms designed to deal with signal intensity differences which may exist between the images to be registered, as occurs for example in dynamic contrast enhanced (DCE) studies [3]. The use of such algorithms was hypothesised to better suit MRA data, where similar large intensity differences exist between the pre- and post-contrast images, and hence the aim of the current study was to assess the performance of two such algorithms, compared to the original AIR algorithm, in a whole body MRA study where significant registration artefacts were present due to the motion of the table between image acquisitions.

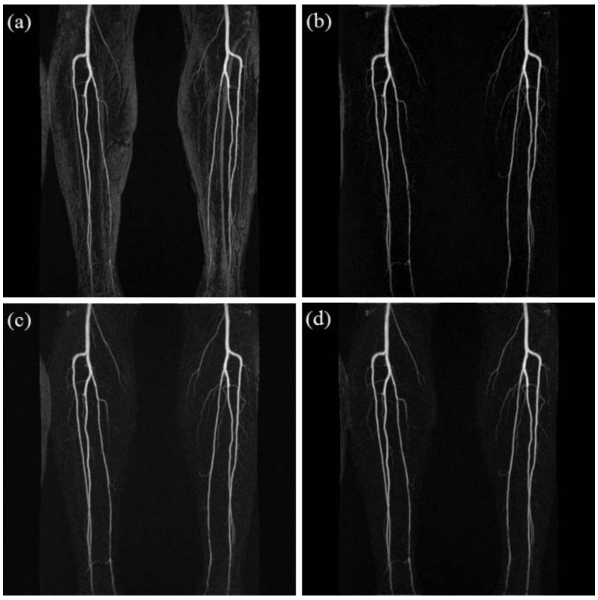

Fig 1: Maximum intensity projection images of the lower legs (a) unregistered and (b-d) following registration using the AIR, Slicer and SEMI algorithms respectively.

METHODS: The algorithms used were: (i) the original AIR algorithm, (ii) the ITK registration algorithm, implemented in the software 3D Slicer [3], which has been successfully applied to register breast MR images with and without contrast agent present [4], and (iii) the Spatially Encoded Mutual Information (SEMI) algorithm, which was developed to register images from DCE-MRI of the liver and *in vivo* cardiac studies [5]. Images of the lower legs from 27 patients were retrospectively processed using all three algorithms. Images were acquired on a 3T Achieva system (Philips Medical Systems, the Netherlands) using a T_1-weighted 3D Fast GRE sequence (coronal orientation with an isotropic spatial resolution of 0.9 mm^3 in the lower legs). The unregistered and registered images were visually assessed by four expert observers using a randomised display order for the images, an example of which is presented in Fig. 1; both subtracted and maximum intensity projection images were available. The images were ranked on a scale of 1 to 4, with images of the same apparent quality allocated equal scores. The contrast to noise ratio (CNR) was determined for each processed image using $CNR = (SI_{Artery} - SI_{Tissue})/SD_{Tissue}$. The vessel integrity was determined by segmenting out a vessel within a region of interest for each patient (using the ITK-SNAP software), and calculating the resulting vessel volume. Statistical analysis was performed using the Friedman nonparametric analysis on ranks for the clinical evaluation, and a paired-samples t-test was used to analyse the CNR and vessel volume for each algorithm.

RESULTS: All four observers confirmed that each algorithm increased the image quality compared to the unregistered subtraction image ($p < 0.05$). SEMI was found by all four evaluators to be superior to AIR ($p < 0.05$), while Slicer was found to be better than AIR by 3 out 4 of the observers ($p < 0.05$). The improvement of SEMI compared to Slicer was significant only for one observer ($p < 0.05$). Each observer noted that AIR seemed to remove the most background tissue signal, but also that AIR reduced the vessel sharpness and integrity. Quantitative analyses of the images showed that both AIR and SEMI had a significantly higher CNR than Slicer, however no significant difference existed between AIR and SEMI. Analysis of the segmented vessel volumes showed that both Slicer and SEMI had significantly larger vessel volumes than AIR ($p < 0.05$) but the same as the unregistered images ($p < 0.05$), which illustrates the degradation of the vessel integrity caused by the AIR algorithm; a surface rendered view of this effect is shown in Fig 2.

DISCUSSION: To gain clinical acceptance, any image registration process applied to MRA must be carefully validated to ensure it does not introduce artefacts. The AIR algorithm assumes that the difference between images to be registered may be described by a single multiplicative factor. However, in MRA this is patently not the case due to the presence of the contrast agent in one of the images, with the result that, although AIR successfully reduces background tissue signal it does not adequately deal with the vessel signal intensity differences. The consequent degradation observed in the vessel integrity could lead to mis-diagnoses of apparent stenoses. The algorithm employed by Slicer uses normalised mutual information as the similarity metric, wherein the registration is affected by a minimisation of the joint entropy in both images (where entropy in this context refers to a measure of an image's histogram dispersion) is not affected by signal intensity differences between the two images. The SEMI algorithm is a recent extension of this approach, which includes spatial information within the images in addition to the mutual information when determining the optimum transformation parameters. The results of the current study demonstrate the superior performance of the Slicer and SEMI algorithms compared to that used in AIR. Indeed, although the data was suggestive of an improved performance for SEMI compared to Slicer, further work will be required to verify this. Furthermore, the introduction of edge artefacts by all algorithms, which could be easily removed in a post-processing step, warrants further investigation. It is nonetheless clear that scope exists for further refinement of registration algorithms to MRA applications.

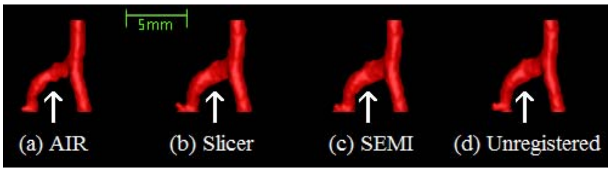

Fig 2: Surface-rendered view of a segmented section of a vessel from one patient following registration using each algorithm, demonstrating the introduction by AIR of a narrowing of the vessel.

CONCLUSIONS: The use of a simple voxel-by-voxel ratio-based registration algorithm (as represented by AIR and used in previous clinical MRA studies) has been shown to introduce significant artefacts into the resultant images, and hence such algorithms should not be used for MRA image registration. Two alternative algorithms based on ideas of optimising the mutual information were shown to better deal with signal intensity differences and to significantly improve the diagnostic image quality

ACKNOWLEDGEMENTS: Dr. Zhuang (UCL) for supplying access to the SEMI algorithm. Grant funding: Health Research Board Ireland.

REFERENCES: [1] Menke, J., Eur J Radiol, 2010. **75**(3): p. e1-8. [2] Woods, R.P., et al., J Comput Assist Tomogr, 1992. **16**(4): p. 620-633. [3] Rueckert, D., et al., IEEE Trans. Med. Img., 1999. **18**(8): p. 712-21. [4] Denton, E.R., et al., J Comput Assist Tomogr, 1999. **23**(5): p. 800-5. [5] Zhuang, X., et al., IEEE Transactions on, 2011. **30**(10): p. 1819-1828.