Correcting patient movement in Dynamic Contrast Enhanced MRI

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Purpose: The length of time required to obtain a dynamic contrast enhanced (DCE) MRI series has lead to the use of retrospective automatic image registration techniques to correct subject movement between imaging volumes prior to physiological model-fitting used to extract salient features of the enhancement pattern. These techniques are often modified for the DCE setting and one reason for the reported success of the algorithms is that they attempt to separate motion artefacts from contrast enhancement by restricting the applied transformation or improving the validity of the image similarity measure used to optimise the algorithm. Due to the proliferation of techniques a taxonomic review is worthwhile so that knowledge of the technical details of image registration can be made more widely available.

Outline of Content: Briefly, an image registration algorithm establishes a point correspondence between locations in two images; the algorithm outputs a transformation that is used to deform the original image, which requires an interpolation strategy [1,2]. The registration algorithm is optimised by minimisation of a cost-function penalising both the image intensity dissimilarity and deviations from smoothness in the resulting transformation. Due to the image dissimilarity measure being minimised between identical images and therefore not between images with contrast change, within the DCE-MRI setting, automatic image registration algorithms can perform poorly in regions of local contrast change and result in mis-registration. This stimulated a number of efforts to modify registration algorithms for DCE-MRI alignment.

Image registration techniques for DCE-MRI can loosely be drawn into three categories: first, since a common mis-registration artefact is volume change of enhancing regions, algorithms might restrict the applied transformation in the presence of a sub-optimal image similarity measure [3] or make assumptions about the rapidity of contrast change to justify the use of a conventional algorithm [4]. Second are those algorithms that attempt to suppress the enhancement effect; enhancing regions in the image registration can be down-weighted locally if some heuristic detects their occurrence. Thirdly a number of recent registration methods take the latter further (an exemplar is [5]) by considering the time-series nature of a dynamic sequence. The method in [5] and many others take an appropriate pharmacokinetic model and subsequently apply the model-fitting procedure to the uncorrected motion-corrupted data and obtain a set of parameters. These parameters can be used to generate artificial data by using the forward pharmacokinetic model, which to some extend will have fitted though the original image motion. If we link each timepoint of the original data to the corresponding timepoint of the artificial data, we can carry out a set of pairwise registrations which, since the images are matched according to the timing of the enhancement, no longer incorporate contrast change. A subsequent round of model-fitting to the registered data in theory generates improved parameter estimates and the process can be iterated if required. If the model-fitting is carried out using generic data analysis techniques such as principal or independent components analysis, the need for a physiological model in the registration process is reduced, which can improve computationally efficiency and algorithm generality.

Techniques for assessing the quality of image registration primarily focus on the model-fitting residuals or properties of the resulting deformation field. Lower model-fitting residuals are assumed to reflect better image alignment and it is possible to assess the temporal nature of motion artefacts or bias in the model choice by assessing the temporal correlation of residuals at each timepoint. The registration deformation field may be analysed for volume change by calculation of the determinant of the matrix of first order derivatives at each location. Tissue volume change over the duration of a DCE-MRI acquisition is usually unlikely and so very low-levels of volume change are considered a good result. Within the menagerie of DCE-MRI registration techniques there remains no standard image registration framework for DCE-MRI. This work provides an illustrative review of these techniques and will describe their assumptions, applications and the extent to which each technique has been validated.

Summary: Image registration may be able to remove visible motion but the importance is the impact of registration on the extraction of accurate pharmacokinetic data. Of fundamental importance is whether the clinical assessment is improved and, crucially, is the data made more predictive of outcome, hence great importance should be attached to obtaining reproducible and accurate parameter values via model-fitting. A review of DCE-MRI registration strategies is a crucial step toward a comparative study (on both simulated and clinical data) assessing interpretation before and after registration and the sensitivity of parameter values to motion. Ideally this comparison of algorithms would take place in the open-source setting applied to freely available standardised data so that subsequent authors may reproduce the results.

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