Improved IVIM model fitting with non-rigid motion correction

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Target audience: Scientists with interest in liver MRI

Introduction: Respiratory motion is a major source of image artifacts in abdominal MRI. A commonly used method to reduce the motion during image acquisition, i.e. intra-scan motion, is to let the patient hold its breath. Whereas that method reduces respiratory artifacts of a single image there is a substantial risk of movement between imaging scans, i.e. inter-scan motion, where an important example is a change in level of expiration between consecutive breath-holds. When imaging the brain, it is often assumed that a rigid transformation can be used to correct for inter-scan motion. The same general assumption cannot be made for most organs in the abdomen, which may necessitate the use of more advanced image registration methods to correct for inter-scan motion.

Recently, Intravoxel Incoherent Motion[1] (IVIM) imaging has emerged as an interesting tool for studying the diffusion and perfusion properties of the liver. In order to acquire reliable model parameters an array of b-values are needed. With current clinical scan techniques images of the entire liver cannot be acquired for all b-values during a single breath-hold, due to the limited time a patient with a severe illness can hold its breath. As a result, multiple breath-holds are needed, which introduces the problem of inter-scan motion.

Purpose: The purpose of this work was to evaluate the effects of motion correction methods on the IVIM model fit when examining the liver. More specifically, the model fit was evaluated for 1) no motion correction, 2) rigid body registration and 3) registration using free form deformation[2] (FFD).

Methods: 5 patients with metastatic disease in the liver were examined with diffusion-weighted MR imaging (DWI), using an SE-EPI scan at a 3 T MR scanner (Philips Achieva) during breath-hold. The b-values used were 0, 10, 20, 30, 40, 50, 75, 100, 200, 400, 600 s/mm^2. One b-value was acquired at each breath-hold. Other imaging parameters were: TE = 50 ms, TR = 1900 ms, flip angle = 90°, SENSE = 2, NSA = 2, acquired voxel size = 3.0x3.1x5 mm^3, reconstructed voxel size = 1.4x1.4x5 mm^3, slice gap 2.5 mm. The patients were instructed to hold their breath after expiration.

All DWIs were registered to the b = 0 image using both rigid body registration and a registration based on free form deformation[2]. Normalized mutual information was used as measure of similarity. The FFD was initialized with the rigid body registration and regularized with bending energy and the determinant of the Jacobian of the transformation, which is used to prevent local volume scaling.

The IVIM model was fit on a voxel-by-voxel basis using a two-step procedure. First, D and A = S_0(1-f) were determined for b-values ≥ 200 s/mm^2 using a monoexponential model (eq.1). This simplification of the IVIM model (eq. 2) is valid at high b-values under the assumption that D << D*. Second, the complete IVIM model (eq. 2) was fitted for all b-values, with D and A fixed, to determine the remaining parameters f and D*. To assess the quality of the model fits, the sum of squared errors (SSE) was calculated for all voxels. To extract SSE values only from the liver and its metastases, a region of interest (ROI) covering the whole liver was drawn in the b = 0 image. As that image was the reference image in the registration processes, the same ROIs could be used for the three evaluated cases.

$$S(b) = S_0(1-f)e^{-bD} = Ae^{-bD} \quad [1]$$

$$S(b) = S_0\left((1-f)e^{-bD} + fe^{-b(D+D^*)}\right) = Ae^{-bD}\left(1+\frac{f}{1-f}e^{-bD^*}\right) \quad [2]$$

Results/Discussion: The IVIM model fit was substantially improved for all subjects when the FFD method was used for motion correction (figure 1). The corresponding improvement after the rigid body correction was insignificant. This clearly shows that a non-rigid motion correction is needed when correcting for inter-scan motion between multiple breath-holds.

Conclusion: Proper motion correction is crucial for voxelwise model fitting of the IVIM model. Free form deformation methods should be used rather than rigid body alignment.

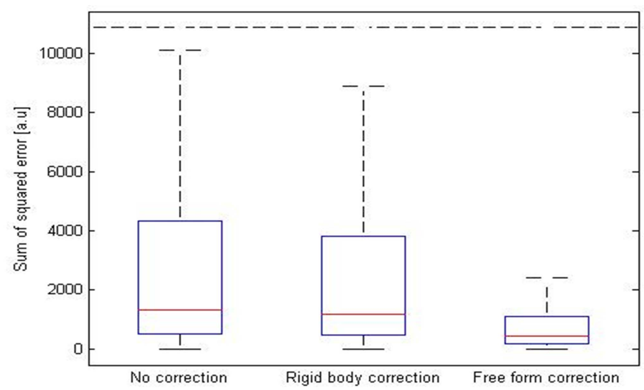

Figure 1. A typical case of the voxelwise model fitting error (SSE) within the liver ROI for the three analyzed cases used in this study, i.e. no correction, rigid body correction and correction with free form deformation. The red lines are the medians and the boxes show 1st and 3rd quartile, whereas the whiskers are limited to 1.5 interquartile ranges from the edges of the box. To improve visibility of the boxes and whiskers, outliers are not displayed in this plot. The outliers displayed a similar declining trend. Both smaller and larger improvements were seen among the patients.

References:

1. Le Bihan D, et al. Separation of diffusion and perfusion in intravoxel incoherent motion MR imaging. Radiology. 1988. 168(2):497-505
2. Rueckert D, et al. Nonrigid registration using free-form deformations: application to breast MR images. IEEE Trans Med Imaging. 1999;18(8):712-721