Tracking Muscle Tissue Displacement during Plantarflexion Excursion using Non-linear Deformation of Magnitude MR Images.

Usha Sinha[1], Alec Biccum[1], and Shantanu Sinha[2]
[1]Physics, San Diego State University, San Diego, CA, United States, [2]Radiology, University of California at San Diego, San Diego, CA, United States

Purpose: Velocity encoded phase contrast (VE-PC) or spin tag (ST) MR imaging can quantitate muscle tissue displacements during dynamic motion of the lower leg. However, these sequences pose challenges both in terms of acquisition as well as post processing. For example, VE-PC with 3D velocity sensitization limits spatial coverage and/or temporal resolution, and need phase corrections from eddy current effects, while spin-tags typically decay to zero intensity in T1 timescales. Recovery of tissue displacements from magnitude images would preclude the necessity of acquiring velocity encoded/spin tag images. Further, since only morphological images have to be acquired to recover tissue deformations, the potential for higher spatial resolution/coverage and temporal resolution exists.

Aim: We propose a novel application of a non-linear warping algorithm based on optical flow to recover tissue displacements from dynamic magnitude images acquired during gated plantarflexion excursions.

Methods: Five subjects were recruited into the study after Institutional Review Board approval. Subjects were scanned on a 1.5-T GE whole-body scanner with a specially designed 8-Channel phased array coil: a gated VE-PC (water) imaging sequence (16.5 ms TR, 7.7 ms TE, 20º FA, 122Hz/pixel bandwidth, 10 cm/s velocity encoding in three directions, 4 views per segment, 22 phases, 2 excitations, 154 × 256-mm image matrix, 300 × 180-mm FOV, 1 slice, and 1:53 scan time) in an oblique-sagittal orientation to acquire tissue velocity encoded dynamic images of the lower leg during ankle plantarflexion. The magnitude images of the VE-PC images were used to extract tissue displacements during ankle plantarflexion. A 2D warping algorithm was implemented. The first image of the dynamic series was treated as the reference image and all subsequent images at the different dynamic phases were warped in turn to the reference image. Two approaches were explored: (i) using the entire image for the warping and (ii) warping the segmented/binarized gastrocnemiuss muscle alone. The registration algorithm computes the transformation iteratively using:

$$u_{n+1} = G_\sigma \otimes \left(u_n + G_\sigma \otimes \frac{1}{2}\left[\frac{C(T-S)\|\nabla S\|\|\nabla T\|}{(\|\nabla T\|^2 + \|\nabla S\|^2)(\|\nabla S\|^2 + \|\nabla T\|^2 + 2(T-S)^2)} \nabla S \right] \right),$$

where u_{n+1} is the correction vector field at iteration n+1, G_σ is a Gaussian filter with variance σ, $\otimes$ denotes convolution, C is a scaling factor and T and S are the reference and transformed image intensities respectively. The Gaussian filter size (standard deviation, filter size) = (1,4) and C = 4 were optimized to obtain the best overlay between corresponding structures in the test and reference images.

Results : The deformation vectors to warp the dynamic images to the reference image are recovered by the algorithm. The accuracy of the warping was confirmed by overlay of contours from the reference image to the warped dynamic image. The deformation vectors are then applied to a 2D grid and superposed on the reference magnitude images. Fig. 1a-e show the deformation fields for warping phase 4, 8, 12, 16 and 20 to the reference image. The undistorted grid can be seen at the edges of each image. Fig 2a-e shows the deformation fields obtained by mapping only the segmented gastrocnemius. Both figures show the distortion of the muscle (visualized in distorted grids). In both approaches, the tissue displacements are small at the beginning of the dynamic cycle and one can clearly see the grid lines moving up and to the right (SI and RL motion). An interesting feature is that the tissue (grid) displacements (arrow) are oriented along directions parallel to the (known) fiber directions in the MG.

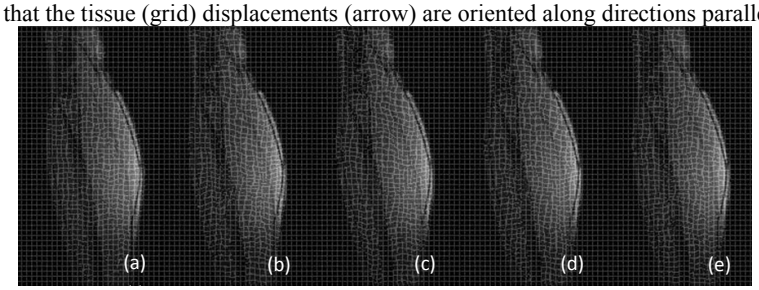

Fig 1: 2D grids warped by deformation vectors from registering image 1 to image n (a: n=4, b: n=8, c: n=12, d: n=16, e: n=20**).**

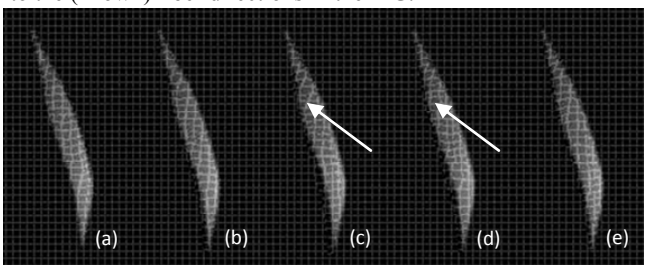

Fig 2: As in fig 1, the grids now overlaid on the segmented gastrocs

Discussion and Conclusions: This is the first study aimed at recovering the deformation of muscle tissue from a gated dynamic study with only magnitude images, using non-linear registration. A visual analysis of the deformation fields shows that they are in conformance with the pattern of anticipated tissue displacement. The non-linear deformation algorithm uses intensity information to estimate the deformation vectors. The accuracy obtained in the current registration shows that intensity information alone is sufficient to drive the algorithm; essentially there are several structures with different intensities (aponeurosis, bone) that are used as internal landmarks by the algorithm. Both methods yielded comparable results; however segmenting a single muscle and warping to successive frames is likely to be more accurate. A quantitative voxel level analysis correlating the tissue displacement from the phase contrast images with that extracted from the warping algorithm is currently underway. It should be noted that the advantages of this approach to compared to (1) VE-PC are: (i) no phase-shading artifacts, (ii) the pulse sequence lengths of these magnitude cine sequences are much shorter than those of VE-PC sequences because of the need to accommodate velocity-encoding gradients in the latter, leading to lower temporal resolution, (iii) calculation of trajectories in VE-PC images have to be based on a linear velocity model or some presumed higher order, while for the magnitude cines, one monitors the actual displacement not based on any presumed model. (2) Spin-Tags: (i) In the magnitude cines, the spatial resolutions are not limited by tag spacing or tag line widths, (ii) not encumbered by disappearance of tag lines. The study shows the potential for tissue deformations to be recovered directly from magnitude images.