

Strain Rate Mapping of the Lower Leg muscles during Plantarflexion Excursion using MR Velocity Mapping.

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Purpose: The objective quantification of regional muscle deformation will be a valuable clinical tool to evaluate normal and diseased muscle. Strain and strain rate are kinematic properties that have been used to characterize myocardial and lingual deformation. Strain describes how the tissue is deformed with respect to a reference state and requires 3D^{al} tissue tracking. Strain rate describes the rate of regional deformation and does not require 3D^{al} tracking, or a reference state since strain rate is an instantaneous measure of kinematic properties.

Aim: To map the strain rate tensor for contracting muscles from a series of velocity encoded images acquired during plantarflexion excursion.

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, 20° 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. Strain rate tensor was calculated in 2D after the phase images were corrected for phase shading artifacts. The spatial gradient tensor, L was calculated as:

$$L = \begin{bmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{bmatrix}$$

Since gradient images are noisy, two filters were evaluated for denoising: a Gaussian 2D filter and a 2D anisotropic diffusion filter. After smoothing with either filter, the symmetric part of the strain rate tensor was calculated as:

$$D = 0.5(L + L^T)$$

; the 2x2 strain rate tensor was diagonalized and the eigenvector corresponding to largest absolute eigenvalue was extracted (eigenvalues can be positive representing a expansion or negative representing a compression). The lead eigenvector was displayed as arrows on the xy plane, color coded red if eigenvalue is positive and blue if eigenvalue is negative.

Results: The spatially adaptive anisotropic diffusion filter was superior to the Gaussian filter in suppressing noise in the velocity gradient images. In addition, the anisotropic filter was adaptive to the edges in the magnitude images as the latter have a higher SNR (as opposed to the conventional method of being adaptive to the edges in the image being denoised). Fig. 1 shows the lead eigenvector of the strain rate map derived from the first frame of the dynamic images and the corresponding magnitude image. Figure 3 is a magnified image (of box in Fig 2) showing the images at select phases of the plantarflexion excursion. The strain rate mapping is clearly not homogenous in a given muscle and strain rate patterns changed from compression to expansion during the dynamic acquisition. In the zoomed insert, all arrows have the same size regardless of eigenvalue but reflect the direction of the vector and the sign of the eigenvalue. Close examination of the maps showed that positive eigenvalues (expansion) occur close to aponeurosis and fascicles while the regions in between have negative eigenvalues (blue). However a more in-depth visualization analysis is required to understand the spatial and temporal variation.

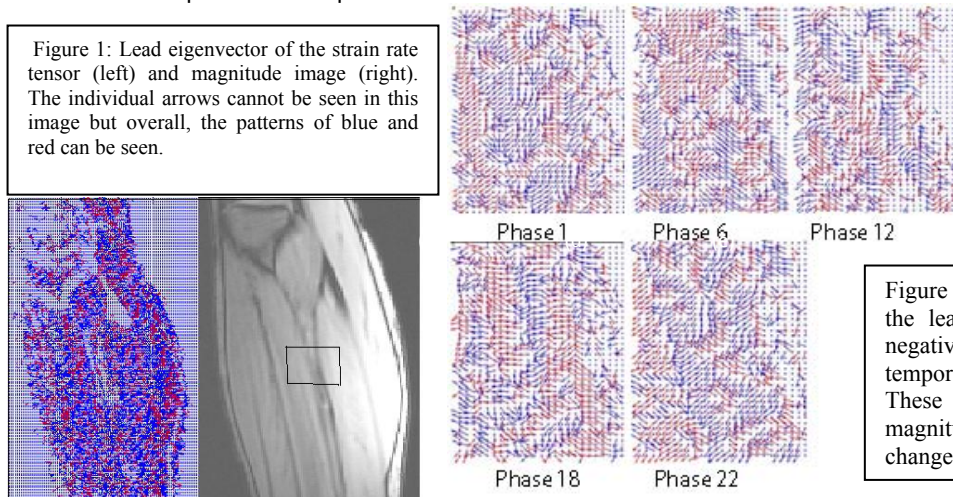


Figure 1: Lead eigenvector of the strain rate tensor (left) and magnitude image (right). The individual arrows cannot be seen in this image but overall, the patterns of blue and red can be seen.

Figure 2: Strain rate lead eigenvector color coded by the lead eigenvalue sign (red: positive) and (blue: negative). The Phase numbers correspond to the temporal images acquired during the dynamic scan. These vectors are not scaled by the lead eigenvalue magnitude. Clearly the patterns are complex and change with the plantarflexion excursion.

Discussion and Conclusions: Strain rate tensor mapping is challenging as the velocity gradient images are inherently noisy. The anisotropic filter used here was sufficient to reduce noise, so that the lead eigenvector of the strain rate tensor could be visualized. Strain rate mapping allows visualization of the expansion and compression as a function of the dynamic cycle. Establishing these spatial and temporal patterns in normal subjects will enable the detection of changes from muscle disease conditions.