Age Related Changes in 2D Strain Rate Tensor of the Medial Gastrocnemius under Passive Plantarflexion.

Usha Sinha[1], Ali Moghadasi[2], Ryuta Kinugasa[3], and Shantanu Sinha[4]

[1]*Physics, San Diego State University, San Diego, CA, United States,* [2]*University of California at San Diego, San Diego, CA, United States,* [3]*Human Science, Kanagwa University, Kanagawa, Japan,* [4]*Radiology, University of California at San Diego, San Diego, CA, United States*

Purpose: The objective quantification of regional muscle deformation is 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 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. Further, measurement of strain rate in young and old subjects will help characterize and elucidate age related changes in muscle structure and function.

Aim: To map the strain rate (SR) tensor from a series of velocity encoded (VE-PC) images acquired during plantarflexion (PF) excursion under passive conditions and to investigate age related changes.

Methods: Five female subjects (3 young, 2 old), recruited after IRB approval, were scanned on a 1.5-T GE whole-body scanner with a specially designed 8-Ch phased array coil. A gated VE-PC (water) imaging sequence (16.5ms TR, 7.7ms TE, 20º FA, 122Hz/pixel bandwidth, 10 cm/s velocity encoding in 3 directions, 4 views/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 were used to acquire tissue VE-PC dynamic images of the lower leg during ankle plantarflexion. A water-suppressed, fat-only image at the same location was also acquired to accentuate the fascicles, indirectly tracking the muscle fiber orientations in passive state. SR tensor was calculated in 2D after the phase images were corrected for p shading artifacts and denoised using a 2D anisotropic diffusion filter. The spatial gradient tensor, L, is defined in the adjacent inset. The symmetric part, D, of the strain rate tensor was calculated as defined in the inset; the 2x2 strain rate tensor was diagonalized and eigenvectors corresponding to the positive and negative values were analyzed separately (positive eigenvalues represent an expansion while negative ones represent a compression). A 'sum of the eigenvalue' images (out-of-plane strain rate values) were also calculated as equal to the sum of +ve and -ve eigenvalues at each voxel. The angle made by +ve eigenvectors with positive Y-axis was determined from the direction cosines of the eigenvector. ROIs identified at the ends of the fascicles (water-suppressed images) were tracked to determine fiber orientation through the passive plantarflexion.

$$L = \left[\frac{\partial u}{\partial x} \frac{\partial u}{\partial y} ; \frac{\partial v}{\partial x} \frac{\partial v}{\partial y} \right]$$

$$D = 0.5\left(L + L^T \right)$$

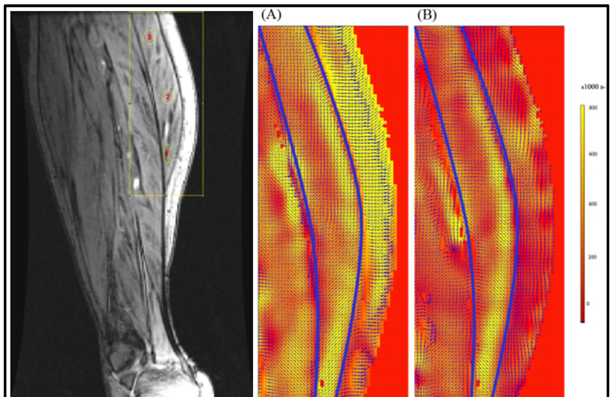

Fig.1 (left): Magnitude image with ROIs and yellow inset zoomed for the eigenvector display. Fig. 2: (A) +ve SR eignevectors are ~ parallel to fiber direction during extension and (B) ~ perpendicular to fibers during contraction.

Results: Fig. 1 shows the magnitude image with an yellow insert zoomed for the positive eigenvector images (Fig. 2 a, b) and 3 ROIs used for analysis. The results from ROI2 (middle) are shown in Fig. 3. In all regions and in both eigenvalues, the extension phase (phases 5-12) SR has a sharper peak whereas the contraction phase (phases 13-20) has rather broad, double peaks (Fig. 3a). The absolute peak values of the strain rate ranges from 0.5 s^{-1} to 0.8 s^{-1} and are higher in expansion phase (by a factor ranging from 0.9 to 0.6) than the corresponding value for the contraction phase. As muscle is incompressible, the sum of the two eigenvalues should be close to zero if the SR is completely in-plane. The sum of the eigenvalues is thus referred to as out-of-plane component of the SR tensor (Fig. 3c); in all 3 ROIs, the out-of-plane values are smaller than the first two eigenvalues by factors ranging from 1/8 to 3/8. Fig. 3d is a plot the average angle of the SR +ve eigenvector (wrt y-axis) as a function of the PF phase. Positive angle values are seen during the extension cycle of PF in a direction approximately along the muscle fiber direction. Negative angle values occur during contraction cycle of the plantarflexion when the direction of the +ve SR eigenvector is orthogonal to the muscle fiber direction. The large jumps in angle occur when the SR directions change abruptly when the cycle alternates between muscle extension and contraction. Figs 3 e & f and g & h refer to average angles and change in angle of SR and fiber directions.

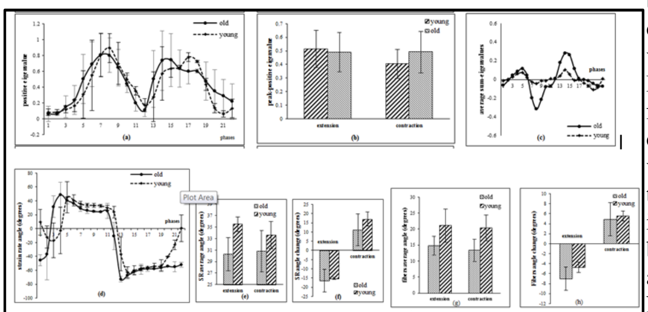

Fig. 3: (a) Positive Strain rate eigenvalue vs. the PF cycle, (b) peak +eigenvalue in expansion and contraction phases, (c) out-of-plane eigenvalue vs. the PF cycle, (d) +ve SR angle wrt yaxis vs. phases, (e) average extension and contraction SR angle, (f) change in SR angle in extension and contraction, (g) average extension and contraction fiber angle, (h) change in fiber angle in extension and contraction.

Discussion and Conclusions: The out-of plane SR component is smaller for younger subjects than older subjects ($p<0.05$). It has been postulated that asymmetry in deformation in fiber cross-section may arise from orientation of the curvature of fibers in 3Dal muscle structure or through incorporation of tensile materials oriented along the through-plane axis of the fiber to limit expansion in that direction[1]. The current study shows that asymmetric deformation reduces with age and may potentially elucidate the reduction in muscle function with age. Another important finding is that the SR orientation (25-30^o) is significantly different from the fiber orientation (15-20^0) ($p<0.01$) for both young and old subjects (SR rotated more towards the distal end of muscle than the fiber). The angle between SR and fiber direction may be an index of architectural integrity and tracking it may potentially enable objectification of disease conditions such as muscular dystrophy where architectural disruption decreases lateral force transmission [2].

References: [1] Kinugasa et al. J Appl Physiol. 2012 Feb;112(3):463-70.; [2] Englund et al. Am J Physiol Regul Integr Comp Physiol. 2011;300(5):R1079-9.