# Dynamic Functional Imaging of Quadriceps and Hamstring Muscles under Isometric and Active Extension-Flexion Contraction.

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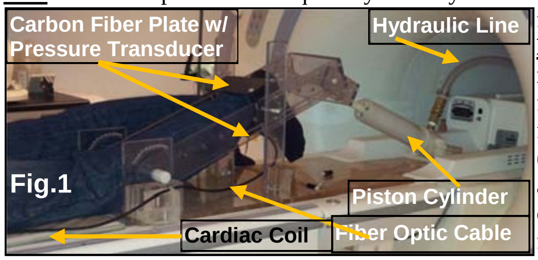
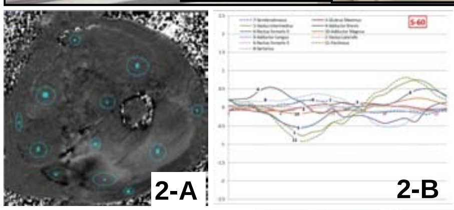
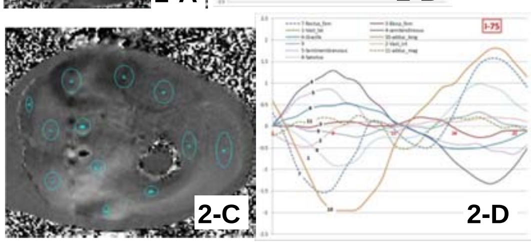
**Purpose:** Musculoskeletal conditions such as knee osteoarthritis are associated with quadriceps atrophy and weakness [1] while Duchenne muscular dystrophy is associated with fat infiltration of the quadriceps [2]. A detailed understanding of the dynamics of quadriceps femoris and hamstring muscles will be a valuable clinical tool to evaluate association of muscle function with disease conditions such as osteoarthritis and dystrophy.

**Aim:** To develop methods to quantify velocity and strain rate changes in different muscle groups of the thigh during knee isometric and extension-flexion contractions using an MR compatible computer controlled servo-motor driven device.



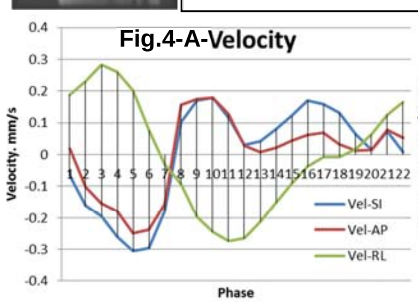

**Methods:** The upper leg extension-flexion device was driven by a computer-controlled, motorized hydraulic actuator, allowing clamping at any angle of flexion [Fig. 1]. Two optical force transducers mounted on carbon-fiber plates, could be used either for active extension or flexion contractions or for stroke or dystrophy patients who cannot flex on their own. Five (IRB approved) subjects, laying prone on a 1.5-T GE whole-body scanner, were scanned with a phased array cardiac or torso coil, while performing isometric or active extension-flexion contractions (at 40% MVC) synchronized to an audio cue. The imaging trigger was derived from the output of the force transducer allowing gated acquisition synchronous with the contractions. The output was also projected on a screen for visual bio-feedback. 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/segment, 22 phases, 2 excitations, 154×256-mm image matrix, 300×180-mm FOV, 1 slice, and 2:44 min scan time) in sagittal and axial orientations was used to acquire tissue velocity encoded dynamic images of all the thigh muscles. Velocity and 2D Strain rate (SR) tensor was calculated in 2D after the phase images were corrected for phase shading artifacts from the symmetric part of spatial gradient of velocity vector field.




**Results:** Axial PC images and corresponding velocities plots in the SI direction, as a function of active extension-flexion cycle, at 0.33 and 0.66 of femoral length, with ROI's indicating vastus lateralis, intermedius, rectus femoris, sartorius and other muscles of the thigh, are shown in Fig.2-A,C with corresponding numbered plots in B,D. The synergistic and antagonistic muscle groups can be distinguished by the opposing velocity directions in Fig. 2 B and D. Importantly, heterogeneity of velocity pattern and hence strain distribution is observed not only in the axial plane but along S/I direction of the femur by comparing 2-A,B with 2-C,D. The sagittal image positioned to capture the aponeurosis between the Rectus Femoris and Vastus Intermedius muscle group is shown in Fig. 3 with a ROI in yellow in the Rectus Femoris (RF). Fig. 4-A,B show the 3D velocity and positive and negative strain rate eigenvalues in the ROI as a function of isometric contraction cycle, while Fig. 5A,B show the eigenvectors corresponding to the positive eigenvalue for isometric contraction for the same ROI at peak of the contraction (frame 3) and in the relaxed state (frame 18).

**Fig. 3:** Magnitude sagittal image with yellow ROI in RF muscle. **Fig. 4a**: 3D velocity plots as a function of the isometric contraction for the ROI. **Fig. 4b** shows a sharp positive eigenvalue (extension) during maximum contraction, the corresponding negative eigenvalue is broad. **Fig. 5a** shows the direction of the positive eigenvector during contraction (frame 3), this orientation is thus perpendicular to the muscle fiber. In frame 18 **(Fig. 5b)**, the fiber is extending and thus the direction is along the muscle fiber in this frame. The arrow is not of any consequence since the SR eigenvectors are 180° degenerate.



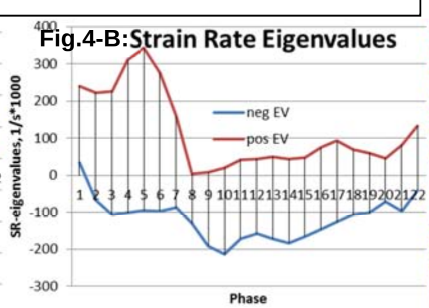
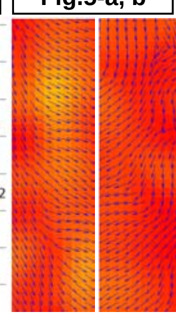




**Fig.5-a, b**



**Discussion and Conclusions:** Dynamic MR images of different thigh muscles under isometric and active flexion-extension contractions could be successfully acquired at 1.5 T. Images in the axial and sagittal planes clearly demonstrated the tissue deformation as a function of the different types of contractions. The spatial heterogeneities in velocity and strain distribution have been explained previously as due to not only heterogeneities in motor pool recruitment but also to architectural factors such pennation angles and inhomogenous elastic strain tensors of the muscle-aponeurosis-tendon complex [3]. The potential to study velocity profiles will help assess the functional status of the quadriceps/hamstrings in greater detail. Strain rate maps derived from the velocity maps can identify the direction of principal shortening or lengthening; other studies of strain rate in the calf have shown that the strain rate orientation deviates from the fiber direction. Since these deviations may be related to lateral transmission, alterations in the fiber and SR orientations may potentially help identify altered muscle function as in patients with repaired ACL. **References**: [1] Vaz MA. J Orthop Res. 2012 Nov 8. doi: 10.1002/jor.22264.[2] Fischmann A. J Neurol. 2012 Nov 9. [Epub]; [3] Hodgson JMBBM (2012)