# Development of a Spin Tag Sequence with Spiral Acquisition for Elucidating Shear at the Deep Gastrocnemius Aponeurosis and other Dynamics of the Musculoskeletal Elements of the Lower Leg.

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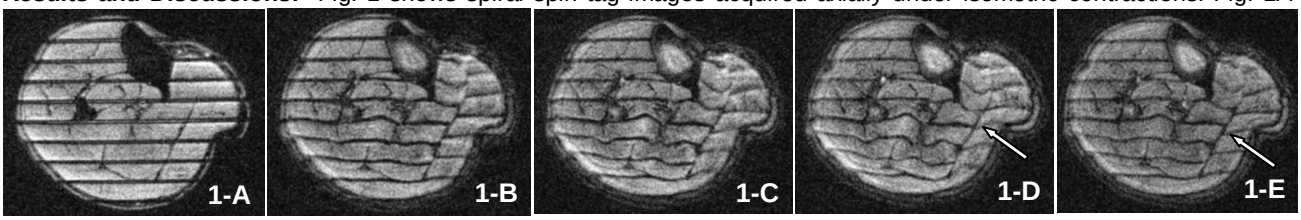
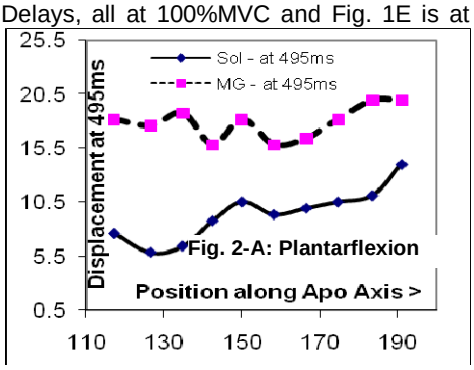
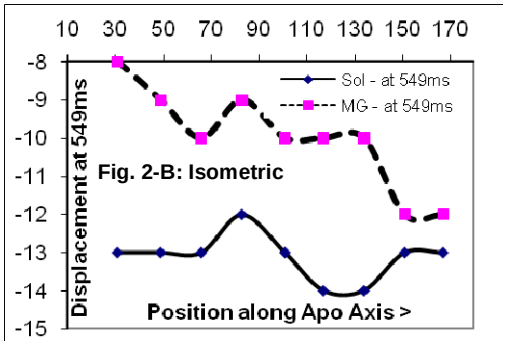
**Introduction:** Dynamics of the musculoskeletal systems have till now being studied typically with rectilinear acquisition, with either velocity-encoded phase-contrast (VE-PC) [1,2], spin-tag (ST) [3,4] or displacement-encoding (DENSE) sequences [5], with the exception of spiral acquisition with PC in Ref. [6]. This typically requires ~70~128 phase encoding lines, necessitating reducing the total force exerted by the subject to well below maximum voluntary contraction (MVC), to typically ~40%MVC. Active tissue of the muscle and passive tissue of the aponeurosis/tendon interact in ways which influence the mechanics of muscle at all levels of contractile effort, reflected in the deformation of muscle observed in MRI. Aponeurosis shear is one measure of importance, for strain measurements using the displacement of points located in different muscles [7] and where attempts are made to relate strain to stress in aponeuroses [8]. We therefore developed a spiral acquisition method combined with spin tag, to study the dynamics of the various aponeuroses and muscle groups of the lower leg in humans during isometric, concentric and eccentric contractions. With reduced number of spiral arms, the entire image can be acquired with the subject exerting only 12~21 contractions and therefore being able to achieve full MVC force.

**Materials and Methods:** Pulse programming was carried out on a GE platform using EPIC, on both 1.5T and 3T platforms. A seven-component binomial series was used for the spin tag RF pulses, and attached to either the product spiral acquisition or FGRE (fast gradient recalled echo) sequence. Both line or grid tagging could be implemented. The flexibility of the product sequence could thereby be completely exploited, including gating at a predetermined threshold of force exerted by subject, for each arm of the spiral (or rectilinear scan). A MR compatible foot pedal device [details in Ref.9] was used, in which the foot rested on a pedal which could be flexed using a computer-controlled hydraulic pumping system. The time, angle and force exerted by the foot on the pedal during either isometric, concentric or eccentric motion, data were digitized and stored in a laptop. Using the scout scans, a sagittal oblique slice showing the largest extent of the tendon and aponeurosis was prescribed. Both gated velocity-encoded phase contrast and spiral spin tag scans were acquired on six subjects (after IRB approval), in the isometric and passive plantarflexion modes, both in this one sagittal and 3 axial orientations. Analysis of the tensile strains along the soleus and gastrocs sides, and shear strain across the aponeurosis were calculated along the proximo-distal length from the oblique sagittal as well as the axial slices.

**Results and Discussions:** Fig. 1 shows spiral spin tag images acquired axially under isometric contractions. Fig. 1A is at rest (for both 100% and 40% MVC), Fig.1B-D images at 284, 436 and 588 ms Trigger Delays, all at 100%MVC and Fig. 1E is at 40% MVC at 588ms Td. A few of the more notable points in these figures are: (1) the remarkable distortions uniquely characteristic of each of the different muscle groups at this high MVC, (2) the clearly opposite behaviors of the synergistic and antagonistic muscle groups (3) the differential movements of the soleus and gastrocs at their common deep aponeurosis causing shear strain along that interface, in 1-B, 1-C and 1-E, (4) the difference between the the soleus and gastrocs strain between 40% and 100%MVC, indicated by the arrows in 1-D and 1-E. The displacement (in pixels) for the soleus (broken line) and the gastroc (solid) as a function of proximo-distal axis of the aponeurosis is shown in Fig. 3.A during isometric and in Fig. 3.B during passive plantarflexion. The displacements of the soleus and gastrocs is quite significantly different during the isometric, and no as large but still significant during plantarflexion. Thus a large degree of shear is observed in this aponeurosis during either movement.




**Conclusions**: The spiral spin tag method developed allows high MVC imaging of muscle kinematics. Our data indicate significant (6 mm) shear between the gastocnemius and soleus aponeuroses near the distal margin of the gastrocs, suggesting that the calculation of strain from displacement of one landmark in the distal soleus and a second landmark at the distal end of the gastronemius may not provide an accurate measure of strain in the free gastrocnemius tendon (although the shear in isometric contractions was somewhat less). The data also indicate significant shear in more proximal regions of the soleus and gastrocnemius aponeuroses, even in passive ankle rotations. These findings suggest minimal mechanical interactions between the soleus and gastrocnemius aponeuroses above this region and suggest significant functional disparity between the adjacent regions of the soleus and gastrocnemius muscles.

**References:** [1] Drace, Pelc, JMRI 4:157.163(1994); [2]Sinha et al JMRI 20:6:1008-1019(2004); [3] Axel et al Radiology 171:841-845 (1989); [4] Ryf et al MRM 51:237-242 (2004) ; [5] Aletras et al JMR 137, 247-252(1999); [6] Asakawa et al JMRI 18:734-739 (2003); [7] Magnusson SP et al. J Physiol. 531:277-88 (2001) ; [8] Magnusson SP et al. Acta Physiol Scand. 177:185-95 (2003); [9] Shin D et al. Proceedings of 16th ISMRM, Toronto, 2008; pg 3671. **Acknowledgement:** NIAMS Grant RO1 AR-53343 and Prof. Eric Wong, UCSD.