Ankle orientation alters bulk susceptibility and residual dipolar couplings during plantar flexion and dorsiflexion of skeletal muscle

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Introduction: Quantifying intramyocellular (IMCL) and extramyocellular lipid (EMCL) content in skeletal muscle is of substantial interest due to their correlation with obesity, insulin resistance, and type 2 diabetes (1). However, skeletal muscle MRS spectra display bulk magnetic susceptibility shifts resulting in variable separation between IMCL and EMCL resonances in different muscle compartments, as well as residual dipolar couplings between nuclei of certain metabolites (2, 3) which influences the transverse relaxation rates of oriented metabolites. Both effects are dependent upon the orientation of muscle fibers with respect to the main magnetic field and can have a substantial influence on the reproducibility of skeletal muscle MRS spectra and hence on the ability to quantify resonances. In this work we assess these effects in different muscle compartments as a function of plantar- and dorsiflexion of the foot.

Methods: An MRI-compatible boot was developed to control the planter- or dorsiflexed angle of the ankle joint of human subjects. The position of the ankle while standing was measured as the angle formed by the line through the medial malleolus and the medial distal head of the first metatarsal bone relative to a horizontal plane. The plantar- and dorsiflexion movements were defined with reference to this neutral angle (Fig. 1). Localized PRESS MRS spectra were acquired using a whole body MRI scanner (GE Signa HD) scanner over a volume of $2cm^3$ with TR/TE of 2s/30ms from the soleus, tibialis, and gastrocnemius muscle compartments at neutral, neutral + 15°, + 30°, and + 45° during plantar flexion, and neutral – 10° and – 20° during dorsiflexion.

Results: Figure 2 shows PRESS spectra acquired from the soleus muscle for several plantar- and dorsiflexion angles. The IMCL and EMCL separation increased with plantar flexion and decreased with dorsiflexion. The residual dipolar coupling effects on the CH_3 and CH_2 groups of creatine and trimethyl ammonium (TMA) containing molecules are clearly noticed in terms of changes in amplitude and splitting pattern. The effect of residual dipolar coupling progressively decreased during plantar flexion and was absent beyond the angle of neutral + 15°. The tibialis anterior and gastrocnemius muscle spectra also displayed shifts in the separation of IMCL and EMCL resonances. However, the residual dipolar coupling effects were present at all angles in these muscles.

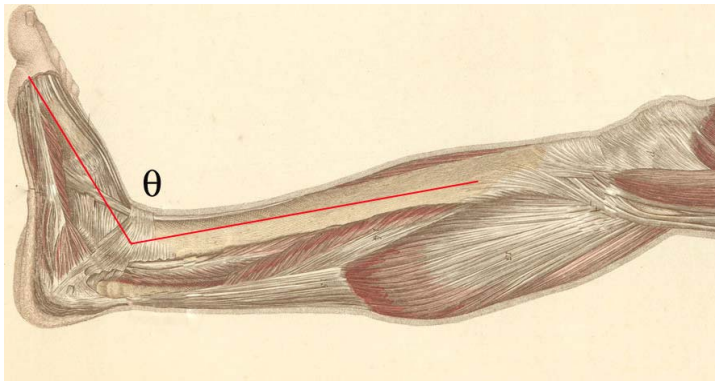

Fig 1. The angle θ is defined as the plantar- (+ angles) or dorsiflexion (– angles) angle with respect to the neutral foot angle

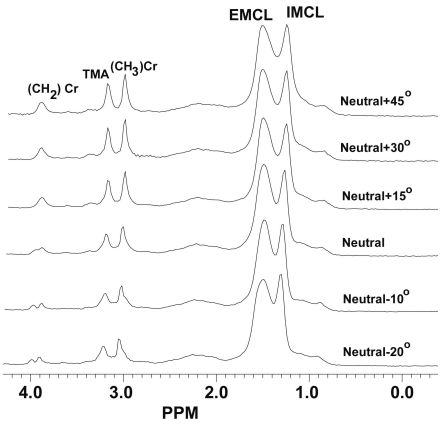

Fig 2. Orientation-dependent soleus muscle spectra

Discussion: The musculoskeletal geometry of the leg is complex, with muscle fiber orientation differing between muscle compartments. Changes in muscle fiber length with plantar- and dorsiflexion influence bulk susceptibility, resulting in variable separation between IMCL and EMCL resonances. Changes in muscle fiber pennation angle with respect to the main magnetic field influence residual dipolar couplings within lipid pools, and hence metabolite T_2s, leading to intensity variations as a function of ankle position.

Conclusion: We have demonstrated bulk susceptibility effects and residual dipolar interactions in lipid pools within skeletal muscle of the lower extremity. Consideration of these effects is required for accurate quantification of lipid pools.

References:

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