Relationship Between Intravoxel Incoherent Motion Metrics and Skeletal Muscle Performance in Individuals with Low Back Pain

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DISCLOSURES: None

INTRODUCTION: Blood flow plays a crucial role in oxygen delivery, nutrient transport, and metabolic waste removal, all of which are vital for muscle function and recovery. Quantification of the magnitude and spatial distribution of muscle blood flow changes following exercise may improve our understanding of the effectiveness of various exercise prescriptions. Intravoxel incoherent motion (IVIM) magnetic resonance imaging (MRI) is a technique that quantifies molecular diffusion and microvascular blood flow and can be used to evaluate a muscle's response to exercise. Recent studies demonstrate that IVIM MRI not only quantifies blood flow and diffusion changes in skeletal muscle but also correlates with exercise intensity, reflecting dose-dependent changes in perfusion and diffusion coefficients. This suggests that IVIM can capture the physiological response of muscles to varying workloads, making it a valuable tool for assessing muscle function and monitoring responses to exercise regimens. Importantly, IVIM has been shown to predict rehabilitation outcomes in individuals with low back pain (LBP), identifying patients who respond favorably to exercise-based therapy by detecting microvascular impairments in non-responders. However, no study has evaluated how IVIM-MRI parameters are correlated with functional muscle performance. In this study, we aim to evaluate how IVIM metrics at baseline and in response to an acute resistance exercise bout correlate with maximal muscle performance.

METHODS: This study was approved by the UC San Diego IRB. Informed consent was obtained from all participants. IVIM data were collected volunteers with a history of chronic (> 3 month duration) LBP, on a 3.0 T (GE MR 750) using a CTL (cervical thoracic lumbar) phased-array spine coil, with subjects positioned supine.. IVIM data were acquired with axial 2D diffusion-weighted spin echo EPI (FOV = 256×256 mm², 22 slices from L1–S1, TR/TE = 2295/52.5 ms, slice thickness = 8 mm, matrix = 128×128, averages = 4, fat saturation, three diffusion directions, b-values 0–700 s/mm²), for a total scan time of 347 s. Performance was measured via the torque produced during a maximal voluntary contraction (MVC) using an isokinetic dynamometer prior to the IVIM acquisition day. On the day of scanning, participants completed a 3-minute acute resistance exercise bout into lumbar extension at 60-80% of their measured MVC. Torque was normalized to body weight. Psychosocial (e.g., Pain Self Efficacy Questionnaire (PainSEQ), Hospital Anxiety and Depression Scale subscores (HADS-A and HADS-D), Tampa Scale of Kinesiophobia (TSK)) and physiological data (e.g., age, sex, BMI, blood lactate) were also collected. IVIM parameters were calculated to determine the average perfusion fraction (f), pseudo-diffusion coefficient (D*), and diffusion coefficient (D) in erector spinae and multifidus muscle. The change between pre- and post-exercise f, D, and D* was calculated. Primary analyses included univariate Pearson correlations between muscle performance and baseline IVIM or exercise-induced IVIM changes, and secondary correlations between performance and psychological/physiological variables were evaluated to identify potential covariates. A multivariate ordinary least squares linear regression (OLS) was then used to create a model adjusting for relevant ($p < .0.1$) covariates. Trends were defined as $p < .1$, and significance was set at $p = .05$.

RESULTS SECTION: The cohort included 51 individuals with either diagnosed disc herniation (HNP), multilevel degenerative disc disease (DDD), spondylolisthesis (Spondyl), scoliosis, or nonspecific back pain (NSP). There were 25 males and 26 females. The average age was 48.5 years and average BMI was 27.7. Psychological characteristics were consistent with mild to moderate symptom severity based on TSK and PainSEQ scores, though 11 (22%) had moderate-severe kinesiophobia (TSK ≥ 33) and 15 (29%) had low pain self-efficacy (PainSEQ ≤ 30). Exercise-induced changes in IVIM variables pre- to post-exercise did not correlate with muscle performance ($p > .1$). However, performance trended toward an association with baseline multifidus perfusion ($p = 0.092$) and was significantly associated with baseline erector spinae and multifidus diffusion, ($p < .036$), baseline erector spinae perfusion ($p = 0.007$), and sex ($p = .01$). Regression on resistance, sex, and pre-exercise f for erector spinae yielded an R-squared of .246 with significant coefficients for all covariates except sex.

DISCUSSION: Previous literature has shown that IVIM measures microvascular perfusion and molecular diffusion in muscle and can predict rehabilitation outcomes in individuals with low back pain. However, exercise-induced changes in IVIM measurements are not associated with muscle performance as measured by torque. Baseline IVIM measurements and psychosocial variables such as sex were more associated with muscle performance, suggesting muscle performance in individuals with LBP is more influenced by patient characteristics than task specific muscle physiology. Limitations include the relatively small sample size compared to the number of covariates in the analysis. Power was further limited by incomplete observations (4 observations omitted from the first regression due to incompleteness).

SIGNIFICANCE/CLINICAL RELEVANCE: This study demonstrates that baseline microvascular perfusion, microvascular blood volume, and molecular diffusion (as measured by IVIM) as well as demographic variables are more predictive of muscle performance in individuals with LBP than exercise-induced changes in perfusion and diffusion, highlighting the importance of patient-specific factors in guiding rehabilitation strategies. These findings may inform more targeted rehabilitation strategies and improve clinical outcomes.

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IMAGES AND TABLES:

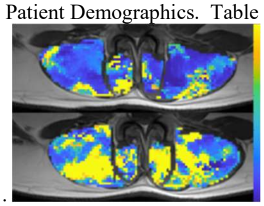
Table 1.

Characteristic	Mean (Std. Dev.)
Age	48.5 (15.9) years
Sex	25 Male, 49%; 26 Female, 51%
BMI	27.7 (5.1)
Diagnoses	17 HNP, 33.3%; 13 DDD, 25.5%; 3 Spondyl, 5.9%; 5 Scoliosis, 9.8%; 13 NSP, 25.5%
Symptom Severity	TSK 25.8 (6.2); PainSEQ 40.6 (12.9)
Performance	2.3 (1.1) Nm/Kg

Table 2.

Variable	Coefficient	Std. Error	Correlation
Intercept	3.031776 **	1.356930	NA
Resistance	0.017247 *	0.009796	0.34 **
Sex	0.277319	0.340422	0.35 *
Pre-ex ES F	-12.601611 *	7.282782	-0.38 **

Table 1. Patient Demographics. Table 2. Results. Output of multivariate OLS. R-squared: 0.2461. F-test significant at p = .006. Sig. codes: .05 (*), .01 (**).

Figure 1. 
Figure 1. Change in pseudo-diffusion (D*; a proxy for microvascular blood flow) in the paraspinal muscles before (top) and after (bottom) a bout of exercise. Yellow = high D*, blue = low D*.