

ASSESSMENT OF IMMOBILIZED MUSCLE USING MRE

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INTRODUCTION

Joint immobilization often results in contracture (Chesworth and Vavndervoort, 1995). Muscle and articular structures both contribute to this (Trudel and Uhtoff, 2000). Magnetic Resonance Elastography (MRE) is a possible method to assess the contributions of individual muscles.

MRE is a novel imaging technique that allows measurement of tissue shear modulus *in vivo* (Muthupillai et al, 1995). In this technique a small amplitude shear wave is induced in a tissue. At the same time a motion-sensitizing gradient synchronized to the shear wave is applied. From this process a phase shift can be measured using phase-contrast MRI. The displacement at each voxel can be directly calculated from this phase shift and the shear wave can be imaged as it moves through the tissue.

The purpose of this study is to determine the feasibility of using magnetic resonance elastography (MRE) to non-invasively measuring shear stiffness of muscle following immobilization.

METHODS AND PROCEDURES

Six pairs of dog forelimbs were harvested for this study following 42 days of one forelimb immobilization in a maximally flexed position. The biceps from each limb was tested using MRE. All procedures were approved by the Institutional Animal Care and Use Committee.

Specimens were prepared for the MRE testing by mounting them onto a custom-made acrylic jig capable of adjusting the elbow joint angle and immobilizing the shoulder joint. The MRE measurement was conducted in 1.5T scanner (Signa, General Electric, Fairfield, CT). Vibration was applied to the distal muscle belly at 175 Hz, generating shear waves propagating along the length of the muscle. The immobilized specimen was scanned with a maximally extended elbow. The control specimen was scanned in two positions: the joint angle matching the extended position in the immobilized limb and full extension. Maximum extension in both specimens was defined as the joint angle that produced a torque of 0.6 Nm. Muscle belly lengths were measured in each position.

Before stiffness inversion the data was phase unwrapped and a directional filter was applied (Manduca et al., 2001). Shear modulus was calculated at each voxel by determining the phase gradient for a small window around each point (Manduca et al., 2001). The magnitude of the shear modulus within the muscle was calculated as the mean value for each voxel within a central region of the muscle.

Following MRE scans the biceps was removed and a slack length (SL) was measured. This length was defined as the muscle belly length when the muscle was stretched with a force of 1N. The muscle mass and volume were then measured.

Muscle cross sectional area (CSA) was calculated by dividing muscle volume by SL.

A repeat measures analysis of variance with Tukey post-hoc tests was performed to test for difference between means. The significance was set as 0.05.

RESULTS

The immobilized muscles showed significant atrophy, reduction in muscle SL, and reduced range of motion (Table 1). The shear modulus of the immobilized muscles was significantly higher than the control when scanned at matching angles. The muscle lengths were similar between limbs when measured at the same angle. When comparing modulus at maximum joint angle, the control muscle was much stiffer (Table 2).

	Control	Immobilized
Mass(g)*	31.7 ± 3.9	24.1 ± 2.4
CSA(mm ²)*	234.2 ± 32	190.8 ± 20
SL(mm)*	126.4 ± 3.6	121.2 ± 0.4
Ext Angle(°)*	120 ± 11.5	96.5 ± 16.2

Table 1. Muscle size parameters and maximum elbow extension. *p<0.05

DISCUSSION

When comparing specimens at the same joint angle, the immobilized muscle was far stiffer. While muscle lengths were similar at this joint angle, this was a larger change in length from SL in immobilized muscle. This difference can likely be explained by a loss of muscle sarcomeres as a result of immobilization (Tabary et al 1972) and

length-tension relationship of passive muscle (Ramsey and Street, 1940).

When comparing specimens at maximal joint extension, the control muscle was stiffer. In this position the control muscle had a longer absolute muscle length, but the differences from SL were similar between specimens. This difference is possibly due to a loss of collagen associated with disuse (Takala and Virtanen 2000).

SUMMARY

MRE demonstrated to detect differences between immobilized and control muscle. These differences depend on the joint angle selected for comparison and are likely the result of a combination of loss of sarcomeres and muscle collagen.

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ACKNOWLEDGEMENTS

This study was supported by a grant from the NIBIB R01 EB 00812

	Disuse extended	Control matching disuse	Control extended
Shear modulus (kPa)*	77.3 ± 13.4	30.0 ± 27.7	107.9 ± 20.0
Length (mm)	128.1 ± 4.8	127.4 ± 4.0	132.1 ± 2.8

Table 2. Shear modulus and muscle length for each testing condition. *p<0.05