IN VIVO STRAIN OF THE TRICEPS SURAES DURING AN ISOMETRIC CONTRACTION

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INTRODUCTION

In both animals (Griffiths, 1991; Lieber et al., 1992; Proske and Morgan, 1984) and humans (Magnaris and Paul, 2000; Ito et al., 1998; Narici, 1999) considerable muscle fiber shortening occurs during isometric contractions while passive connective tissue components are compliant and stretch. These data demonstrate important interactions between the contractile (muscle fiber) and connective tissue elements (e.g., tendon and aponeurosis) during an isometric contraction. The dynamics of the interconnecting active and passive elements interaction and strain on a whole muscle level is still poorly understood, particularly during sub-maximal activations and normal recruitment of muscle. We hypothesize that this interaction results in a marked heterogeneity of tissue strain within the muscle-tendon unit. The purpose of this study is to identify the changes in strain magnitude and distribution within the triceps surae muscle complex of normal subjects during a voluntary submaximal isometric contraction and to identify the dynamic strain properties at specific anatomical sites.

MATERIALS AND METHODS

Six normal subjects were scanned on a 1.5T LX scanner (GE, Milwaukee), using a gated, phase contrast, velocity encoded (Drace and Pelc, 1994), fast segmented sequence, with 4 phase-encoding levels per segment. The subject’s leg was placed in a fiberglass cast immobilizing the knee at full extension (0°), with both legs in the MRI coil. Calibrated strain gauges placed at appropriate points in the cast generated a signal proportional to force exerted which was digitized and recorded for subsequent analysis. The force signal was displayed on an LED display mounted on the scanner and visible by the subject. The subject exerted approximately 50% of maximal force repeatedly through the phase encoding cycles of the MR acquisition, timed to an audio cue generated from a computer and fed through headphones. Velocity was generally encoded only in S/I (superior/inferior) direction with VENC values of 10 cm/sec. Dynamic images were acquired in both the axial and sagittal planes during the muscle contraction. Acquisition matrix was 256x256, FOV 22 cm, TE: 5.3ms, TR: 11.3ms, flip angle 30°, slice thickness 10mm, Avg. 2, bandwidth 32 kHz and total acquisition time of about 1.5 min.

A set of high resolution axial images were initially acquired, volume rendered (using Vitrea, MN), and utilized to identify anatomical locations within the velocity encoded sagittal images (e.g., the soleus, lateral gastrocnemius medial gastrocnemius the aponeurosis and Achilles tendon). Cine PC sagittal images created at every 64 ms during the contraction, were then overlayed with a grid system of markers “tagging” the MR image pixels to represent a small volume of tissue. The motion of these markers was calculated throughout the sequence of cine images. Briefly, the optical density of a pixel of tissue in the MR sagittal images was proportional to its velocity (v). The distance (d) moved by the
pixel of interest is predicted by the expression \( d = t \cdot v \) where \( t \) is the interval between cine images.

**RESULTS AND DISCUSSION**

**Figure 1:** MR image of a sagittal section of the triceps surae showing the location of muscle and connective tissue

![MR Image](image1.png)

**Figure 2:** Example of deformation of grid system superimposed on Cine PC MR image showing tissue strain heterogeneity in triceps surae muscle complex.

The deformation of the grid system at various sites within the triceps surae complex demonstrates considerable heterogeneity of tissue strain (and shortening) both at different times during the isometric contraction and at different locations within the muscle-tendon unit. This is evident by the marked changes in marker location at various sites distributed throughout the entire triceps surae.

During a submaximal isometric contraction only a fraction of the muscle-tendon unit’s population of muscle fibers are active. An uneven distribution of active and passive muscle fibers may contribute to uneven distribution of stress and, therefore, strain. The magnitude of the strain in any region of the muscle will also be a reflection of the density distribution of specific tissues within a region of the muscle and on the mechanical properties of those tissues, i.e. the modulus of elasticity. The amplitude and distribution of strains within a given region of a muscle and within and among motor pools depend not only on structure and distribution of the active and passive tissue components but also on the levels of motor unit recruitment.

**REFERENCES**