MUSCLE-TENDON ULTRASOUND: QUANTITATIVE CONSIDERATIONS

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INTRODUCTION

In the last ten years ultrasound has been used as a non-invasive tool for characterizing muscle-tendon structure and behavior in vivo. Ultrasonography is an exciting tool, but it has limitations that have not been adequately considered by many using it to quantify muscle-tendon structure and deformation. Ultrasound images of biological structures are based on an assumed speed of sound (SOS) through these structures and the signal attenuation. However, biological tissues transmit and attenuate sound waves differently. Therefore ultrasound images may be distorted in the direction perpendicular to the ultrasound probe surface if the SOS in the biological structures varies from the value used in the ultrasound algorithms. This distortion would directly affect structure thickness and cross-sectional area measurements, important biomechanical quantities that appear to have been reported in the past without consideration for this distortion (Gillis et al 1993, 1995; Kawakami et al 1995; Kubo 2003[1], 2003[2]; Ito et al 1998; Sipila et al 1996). The purpose of this study was to investigate the error associated with tendon, fat and muscle thickness measurements obtained using a commercial ultrasound system.

METHODS

Experiments were conducted to quantify the speed of sound in tendon, fat and muscle for the purpose of determining thickness errors that could result when using a commercial ultrasound system. Sutures were tied to the ends of bovine tendon and fat, and chicken muscle samples. Samples were tested sequentially. The free ends of the suture were secured to a suspension device located in a tank and the sample was slightly loaded in tension (Figure 1). The sample's thickness was measured six times with calipers. The tank was filled with water and a Hitachi EUP L53 ultrasound probe was positioned over the sample. Ultrasound images were collected and the thickness of the sample was measured six times from digital images created from the Hitachi EUB 6500 Ultrasound System (this system assumes an average speed of sound in body tissues of 1540 m/s). Thickness measurements were repeated with the calipers to check for any hydration changes. Average caliper and ultrasound image thickness measurements were compared.

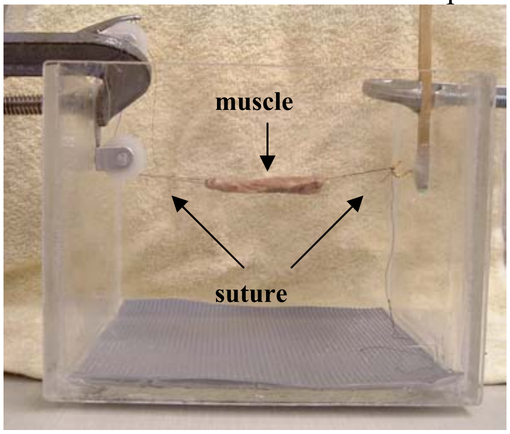

Figure 1: Suspended muscle in test chamber.

The SOS within each sample was determined from

$$SOS = \frac{Tc \bullet 1540}{Tu}$$

where Tc and Tu are the sample thickness measured using calipers and from the ultrasound images, respectively, and 1540 m/s is the SOS used to create the ultrasound image.

Speed of sound measurements were compared to literature values. The percent errors between the thickness measured using calipers and from the ultrasound images were determined.

RESULTS AND DISCUSSION

The calculated SOS values, percent difference from the thickness calculated for the ultrasound system (1540 m/s), and the percent difference from the thickness estimated with literature SOS values appear in Table 1 for tendon, fat, and muscle. The SOS values calculated using the caliper measured thickness matched well with literature values. Small SOS variations can be attributed to species, temperature and tissue density variations.

SUMMARY

In order to determine tendon material properties such as stress, it is necessary to measure both force and cross-sectional area. As stated previously studies have used tendon cross-sectional area values from ultrasound measurements without considering the differences between the SOS in body structures and the SOS used by the ultrasound system to create the images. These experiments show that ultrasound underestimates the thickness, and therefore area of a tendon by about 5 %, overestimates these dimensions for fat by about 7 %, and underestimates the thickness for muscle by about 1 %.

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Table 1: Tendon, Fat, and Muscle SOS Results and % Difference in Thickness.

Tissue	Reference	SOS m/s	% Diff. to 1540 m/s	% Diff to Literature
Tendon	Coughlin	1618	-5.09 %	1.92 % (1)
Tendon	Garcia (1)	1650	-7.14 %	N/A
Fat	Coughlin	1432	7.00 %	1.23 % (2)
Fat	Canals (2)	1450	5.84 %	N/A
Muscle	Coughlin	1572	-1.21 %	0.454 % (3)
Muscle	Canals (3)	1580	-2.6 %	N/A