Ultrasound based non-invasive strain and property measurements of ligaments and tendons: An new application of acoustoelasticity to biological tissues

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Introduction

Measurement of *in-vivo* strain in ligaments or tendons has been intensively studied [1]. However, most methods are invasive and require the surgical implantation of a measurement gauge. A theory termed acoustoelasticity (AE) that describes the change of acoustic characteristics in a deformed medium was proposed in 1953 and has been applied to study the deformed standard engineering materials in the past [2]. Recently, AE effect has been observed in biological tissues that are nearly incompressible and can sustain larger nonlinear deformations [3, 4]. These studies did not describe this phenomenon with the framework of AE. We conducted rigorous AE analysis for nearly incompressible materials including biological tissues [5,6]. Based on these studies, we developed ultrasound-based, non-invasive technique to evaluate tissue properties and applied strains in stretched tissues [7]. In this study, this new technique is applied to skin covered stretched porcine digital flexor tendons to successfully evaluate tissue strain.

Method

Skin covered porcine digital flexor tendons were incrementally stretched in saline bath mounted on a test machine. Ultrasound echo were transmitted and received by an external transducer at each increment of strain (Fig. 1). In the recorded echo signal, reflection from skin, front and back surface of tendon are clearly observed (Fig.2). Applied force was also measured. From reflected echo measured at several strain levels, reflection coefficients (ratio of incident wave to reflected wave) from both skin and tendon surface were computed. Wave travel times through both skin and tendon were also measured. From these data, the strain and tissue properties ($\bar{C}_{33}^{skin}(e)$, $\bar{C}_{33}^{tendon}(e)$) were repeatedly via AE. In AE, the transverse stiffness is strain dependent and influences both the reflection coefficient $R(e)$ and wave travel time $T(e)$ in the transverse direction.

Figure 1: Experiment setup.

Results and Discussion

A set of typical wave signals recorded at different stretch levels on are presented in Fig. 2. Strains evaluated from AE analysis are compared with strains recorded in testing machine and strains

evaluated from non-AE method in Fig. 3. If the AE effect is ignored and strains are evaluated from wave travel time only, predicted tissue strain is much less accurate (Fig. 3).

Figure 2: Ultrasound echo reflected from skin covered porcine digital flexor tendon subjected to different stretch.

Figure 3: Evaluated strains compared with recorded strain.

Conclusions

Results of this *ex vivo* study indicate: 1) An AE effect does exist in deformed tissues and can be measured with ultrasound. 2) Strains evaluated using this new technique are very consistent to the strains recorded from testing machine.

References

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