Ultrashort Echo Time Imaging (UTE) of the Extensor and Flexor Tendons in Bovine Legs

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Target audience

This research is important in MSK imaging and useful for researchers who specialize in quantitative imaging of tendons using ultrashort echo time (UTE) imaging.

Purpose

Bovine leg samples are obtained to investigate the bound water T2* component of the extensor and flexor tendons as a function of age of the animal. From biophysical studies, it has recently been observed that collagen in tendons under stress accumulate sugar by displacing water molecules, leading to an irreversible stiffening of the collagen structure, potentially resulting in degradation of the collagen in tendons. The research indicate that the structure of collagen changes as a function of age, possibly by the accumulation of sugar molecules, which could displace the bound water molecules. In severe cases the loss of bound water molecules could result in tendon inflammation and development of pain over time.

Methods

Imaging: A 3D UTE radial readout pulse sequence was implemented on a 3T Philips Achieva scanner [1]. To achieve minimal echo time using a conventional small extremity 8 coil, the tune delay of the coil was set to 50us, which could not be lowered further due to appearing image artifacts. The achieved minimum echo time was 90us. Dual echo data were collected with the following parameters: 0.78x0.78x5mm^3,TR 46ms, FA 18deg, 2392 radial trajectories, 30 slices, echo times for the first echo ranging from 100us to 10000us in steps of 100us for TE<1000us and in steps of 1000us for 1000us≤TE≤10000us, echo times for the second echo were acquired at the shortest possible in-phase echo times for fat to allow fat subtraction. **Tissues samples:** Bovine legs were obtained from 9 female animals age 27 months (3 animals), 20 months (4 animals), and 2 weeks (2 animals). Bovine leg tissue was wrapped in plastic foil to prevent drying and stored in a freezer. Twenty-four hours before imaging, tissue was brought to room temperature. **Analysis:** To compute the T2* values for the tendons, we determined the multiple exponential components of the extensor and flexor tendons for ten slices immediately above the flexor bifurcation near the hoof using the nonnegative least squares algorithm (NNLQ) to obtain initial estimates of different T2* components [2]. To quantify the bound water fraction, we then modeled the pixel signal intensity (S) at each echo time (TE) by a 2-compartment model with unknown echo times and amplitudes for the short $T2^*_1$ and long $T2^*_2$ component according to $S(TE)=a_1 \exp(-TE_1/T2^*_1)+a_2 \exp(-TE_2/T2^*_2) +n$, where a_1 and a_2 are unknown coefficients. The term n represents a Rician-distributed error term which we determined from a subtraction analysis of equivalent images. To improve the fitting, we extrapolated the signal for TE -> 0, which we used to reduce the 4-parameter fitting ($T2^*_1$, $T2^*_2$, a_1, a_2) to a 3-parameter fitting similar to [3]. Using initial conditions from the NNLQ analysis, we estimated all unknowns using least square fitting. The bound water and free water fractions were calculated by $a_1/(a_1+a_2)$ and $a_2/a_1+a_2)$, respectively. We compared results obtained from the 3-parameter fitting with results from the NNLQ analysis. Furthermore, we relate our results with a recent study on sugar content using Periodic Acid-Schiff Staining (PAS) [4].

Results

Fig.1 and 2 show the location of the extensor tendon and flexor tendon, respectively. Fig.3-5 show PAS sugar content as a function of age of the animal (2 weeks, 18 months, 18 months) from a different study (unpublished). Note that both flexor and extensor tendons have identical low sugar content at age 2 weeks, but sugar accumulation increases rapidly for the flexor tendon with increasing age (compare Fig.4 and 5 (18months) to Fig.3 (2 weeks)). Fig.6 shows the change in the ultrashort T2* value as a function of age. The solid curves correspond to the mean values for a specific age. Note that the T2* of the bound water component increases rapidly for the flexor tendon, but not for the extensor tendon, with increasing age, whereas the T2* of the free water component does not show these opposite tendencies (Fig.7).

Fig.1 Extensor

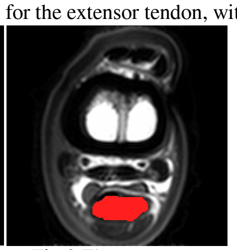

Fig.2 Flexor

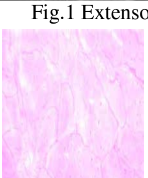

Fig.3. All tendons

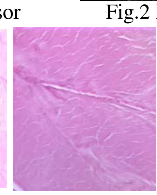

Fig.4. Extensor

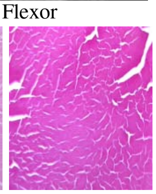

Fig.5. Flexor

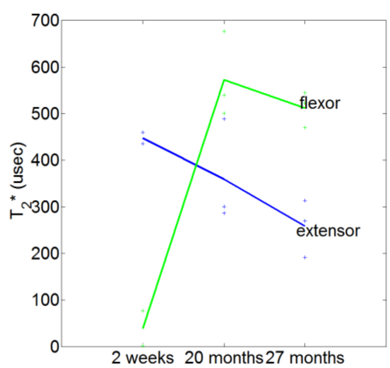

Fig.6 T2* of bound water compartment

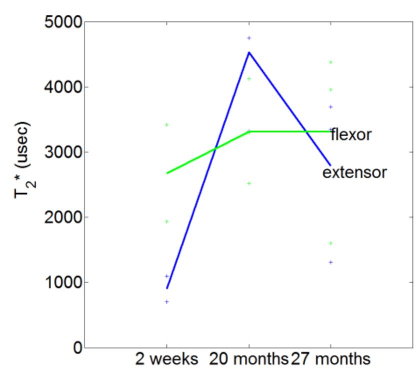

Fig.7 T2* of free water compartment

Discussion and Conclusion

Ultrashort echo time imaging in combination with 2-compartment modeling can determine the T2* value and the fraction of the bound water and free water components. This study has demonstrated changes in the structure of the bound and free water compartments as a function of tendon type and age of the animal. Although the number of tissue samples was low, very different T2* values of the short and long T2* component were obtained for extensor and flexor tendons. Because only the flexor tendon experiences the entire weight of the animal when the animal moves forward, extensor and flexor tendons have very different mechanical properties. Since the stress experienced by flexor tendons is larger than that of extensor tendons, sugar may be absorbed by increased metabolism, leading to a loss of bound water molecules of the tendon's collagen. The T2* values of the bound water component changes with age and may be a biomarker of mechanical stress history or indication of sugar accumulation, indicating displaced bound water.

References

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[4] Fullerton, G.D. Unpublished material.