INTRODUCTION: There is no current diagnostic method that can quantify the healing process of injured tendons. If we could non-invasively evaluate the strength of the healing tendon, it would be quite beneficial for the patients in planning rehabilitation program or in deciding when to resume sports activities.

A normal tendon contains abundant collagen fibers which are highly oriented longitudinally to resist the tensile stress. We have already shown that the proton NMR T2 relaxation time of water in the normal tendon demonstrates a strong anisotropy (1, 2, 3). This anisotropy is caused by the dipolar interaction between the water molecules which are bound and aligned longitudinally along the collagen fibers. We have also shown that an increase in the number and longitudinal orientation of the collagen fibers in the regenerating tendon after injury is accompanied by an increase in the amount of bound water which can be demonstrated through NMR T2 relaxation anisotropy (4). Our results suggest that an examination of the bound and aligned water in the regenerating tendon using MR imaging can quantify its structural regeneration. Hence, our present study is focused on how the T2 relaxation time of the regenerating tendon correlates to the mechanical properties of the tendon.

MATERIALS AND METHODS: Data were obtained using Japanese white rabbits (mature males). We made a partial incision transversely on the Achilles tendon under intravenous pentobarbital anesthesia. At 3, 6, 12 and 18 weeks after the tenotomy, these rabbits were euthanized and the regenerating sections of the Achilles tendons at the site of tenotomy were dissected for the following measurements. Intact Achilles tendons served as controls. Magnetic resonance measurements were carried out using an MR spectrometer (MSL-100, Bruker) operating at 2.34 Tesla. Each tendon was measured with the long axis oriented at 0º (parallel), 35º, 54.7º (magic angle), 75º and 90º (vertical) to the static magnetic field. The T2 relaxation time of water in the tendon was measured using a spin-echo pulse sequence with a repetition time of 3.0 sec at 25ºC. For biomechanical evaluation, Achilles tendons with the calcanea (Bone-Tendon Complex: BTC) were harvested at 3, 6, 12 and 18 weeks after the tenotomy. The cross-sectional area of each specimen was measured with a digital caliper. After preconditioning, the BTC was tensile tested to failure at a rate of 20 mm/min.

RESULTS AND DISCUSSION: Exponential analysis of the T2 decay curves resulted in a distinction between a long and a short T2 relaxation component in the regenerating tendons harvested 6 weeks or later after the tenotomy. We assume the short and long T2 relaxation times of water in the regenerating tendon are derived from bound and free water fractions in the tissue, respectively. The short T2 relaxation time of the regenerating tendon 12 weeks after the tenotomy demonstrated anisotropy, which became more pronounced at 18 weeks (Figure 1). The anisotropy is caused by the dipolar interaction which is one of the most effective determinants of the proton-NMR T2 relaxation time of bound and ordered water in the tissue. The dipolar interaction between the water molecules in the tendon is dependent on the angle between the tendon and the static magnetic field. The interaction becomes weakest when the tendon is directed parallel to the static magnetic field (Figure 2).

CONCLUSION: The effect of the dipolar interaction between water molecules in the regenerating tendon becomes strongest when the tendon is directed parallel to the static magnetic field. Measurement of the short T2 relaxation time of the water under this condition can, therefore, estimate structural recovery of the regenerating tendon, which correlates well with its biomechanical strength. Application of this idea to MR imaging will allow us to optimize the treatment of patients with tendon injuries.

REFERENCES: