Magnetic Resonance Imaging of Muscle Electroporation Injury

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Abstract: High resolution MR imaging was performed to evaluate muscle electroporation injury. Three hours following the electric shock *soleus* (SOL), *extensor digitorum longus* (EDL), and *biceps femoris* (BFM) muscles were collected. Identical muscle samples isolated from the non-injured leg of the same rat served as controls. The analysis of T_2-weighted MR images in rat muscles showed a 25-75% increase of the water T_2 relaxation time in the three different muscle samples. The *soleus* muscle showed the largest increase of 75%, from ~40 ms in controls to ~70 ms in injured muscles after electric shock. Increased T2 is consistent with edema and the change in the state of integrity of the cellular components of muscle tissues.

Introduction: Electroporation of muscle cells leads to breakdown of the ionic gradients and release of intracellular contents into the circulation (*1*). These effects trigger edema, which raises the local hydration level over its physiological value. Therefore, the state of water in an injured tissue is changed and the compartmentation and dynamics of the spin populations during magnetic relaxation differ from a healthy tissue. This is the premise for employing magnetic resonance imaging (MRI) to detect and evaluate muscle electroporation injury.

Methods: We measured spin-spin relaxation time (T_2) and spin density (M_0) parameters of water protons in rat muscles using a 4.7-Tesla Bruker scanner. The rats received high-intensity pulses (2 Amp) of few milliseconds duration separated by sufficiently long waiting times (~ 10 s) to reduce thermal contributions to the injury. The rats were sacrificed 3 h post shock and SOL, EDL, and BFM muscles were collected. Identical muscle samples isolated from the non-injured leg of the same rat served as controls. Values of T_2 and M_0 were obtained using a Carr-Purcell-Meiboom-Gill sequence. Following MRI measurements weight of the muscle tissue was measured to determine the water content in the tissue samples. To infer the departure of the characteristic value of T_2 in biological systems from the value corresponding to bulk water we also measured T_2 of lysozyme and ribonuclease A solutions (10 mM phosphate buffer, pH=7.0) as a function of protein concentration.

Results: Values of T_2, as determined by fitting the signal amplitude from the echoes to the decay time, were as follows: deionized distilled water, 614 ± 31 ms; lysozyme (1 mM), 478 ± 25 ms; and ribonuclease A (1 mM), 423 ± 22 ms. The analysis of T_2-weighted MR images (Figure 1) in rat muscles showed a 25-75% increase of the water T_2 relaxation time in the three different muscle samples (Figure 2). The *soleus* muscle showed the largest increase of 75%, from ~40 ms in controls to ~70 ms in injured muscles after electric shock.

Discussion: Electroporation leads to an increase in T_2. This increase may have two components. First, the accumulated water changes the integrity of the cellular components. Second, the dynamics of water molecules may be altered as a result of development of the structural damage due to activation of degradative processes in the tissue. These results suggest that MRI method can provide important insight into molecular alternations resulting from traumatic injury. [Supported by the National Institutes of Health (GM61101)].

References: 1. Lee RC, *et al.* J. Surg. Res. 44:709-719, 1988.

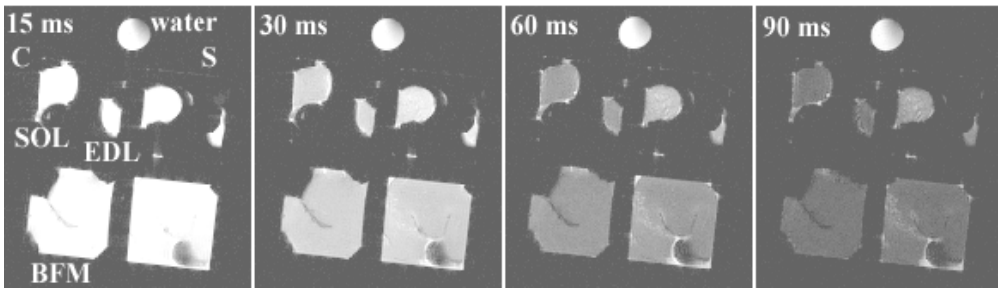

Figure 1. MR images: TE=15, 30, 60, and 90 ms; C, control; S, shocked.

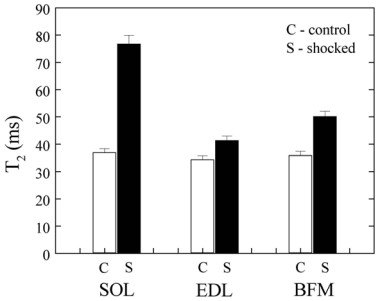

Figure 2. T_2 times of muscles.