Mechanisms associated with deep pressure ulcers; a multi-parametric MRI study.

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Introduction

Pressure ulcers represent a serious health and financial problem. Prevalence figures are very high: 20% in general hospitals up to 29% in nursing homes [1]. Pressure ulcers can initiate either at the skin layer or within deeper tissues. The latter are termed deep pressure ulcers and often initiate in the muscle layer near bony prominences. Spinal cord injury (SCI) subjects are one of the populations especially susceptible to the development of deep pressure ulcers. Deep pressure ulcers inevitably involve deep tissue injury which was recently defined by the NPUAP (US National Pressure Ulcer Advisory Panel) as "A pressure-related injury to subcutaneous tissue under intact skin". This definition instantly reveals one of the major problems associated with their early detection. In addition, the underlying mechanisms leading to deep tissue injury following compressive loading are not well understood. Hypotheses associated with the pathogenesis involve localized ischemia, reperfusion injury, impaired interstitial fluid flow and sustained deformation of cells [2]. In this study three MRI techniques and a finite element model were applied to a rat model in order to distinguish between the different factors that contribute to muscle damage after compressive loading.

Materials&Methods

A novel experimental set-up was designed and built to mechanically load the tibialis anterior (TA) of anesthetized Brown Norway rats while the animal resides inside a MR scanner with a 6.3 Tesla magnet. The procedure was approved by the animal care committee of Maastricht University. The TA was loaded with a plastic indenter (diameter 3 mm) for 2 hours (indenter-experiments, n=9). A multi-echo spin echo sequence (TE=12-96 ms, 8 echoes, TR=4.5 ms, FOV 30x30 mm^2, matrix 128x128) was used to detect damage. An index of tissue perfusion (PI) was obtained by injection of Gd-DTPA (0.2 mmol/kg) (n=6). A gradient echo sequence (TE=2.5 ms, TR=35 ms, α=30°, FOV=30x30mm^2, matrix 128x64) was used to measure signal increase after injection, which is a measure for perfusion [3]. To separate the effects of ischemia and deformation, T2-values were evaluated in different ROIs, which were chosen on the basis of the T2-maps and PI-maps during loading. As a control, experiments were performed using an inflatable tourniquet, which was positioned above the knee, to induce pure ischemic loading (tourniquet-experiments, n=3). To further examine the influence of deformation on tissue damage, tagging MRI (n=4) and a dedicated finite element (FE) model were used to correlate local strain fields to damage location. Tag lines were applied in two orthogonal directions, using two C-SPAMM acquisitions for each direction [4]. A gradient-spoiled fast field echo sequence (TE=2.5 ms, TR=10 ms, α=30°) was used to image the tagging grid before and after application of the indenter. Quantification of the tag displacements was done using the HARmonic Phase (HARP) analysis [5].

Results

Figure 1a-c shows typical T2-weighted images before and during loading and 60 minutes after unloading. After a loading period of 2 hours, higher signal intensity (arrow) was visible in the loaded region of the TA compared to images taken during loading. In figure 1d-f, the PI-maps indicate a large ischemic region (dark region) during loading and high PI values in the loaded region shortly after unloading. T2-values were evaluated in three ROIs (indicated in figure 1a). The normalized T2-values are indicated in figure 2a. The T2-values from the tourniquet-experiments were evaluated in ROI 1, to allow comparison between ischemia and compression in the same region. In the compressed region T2-values were significantly increased after unloading. In the pure ischemic region, however, T2-values were elevated during loading but returned to pre-loading values within 40 minutes after unloading. This demonstrated that only compression led to irreversible changes. This was confirmed by histological analysis (figure 2b-d), which showed necrotic fibers after compression and only minor changes after ischemic loading. The tagging measurements showed a localized region with high shear strains during loading (figure 1i). This was calculated in an experiment with similar indentation as in figure 1b. The region with high shear strain agreed well with the location of increased signal intensity on T2-weighted images (figure 1c).

Discussion&Conclusions

For the first time, the temporal and spatial development of *in-vivo* muscle damage after compressive loading was measured using an MR-compatible loading device. By combining different MR techniques in one model, the importance of deformation in the onset of deep tissue injury could be demonstrated by the difference in response to ischemic versus compressive loading, and by the close correlation between location of damage and max shear strain. The relevance of deformation in damage initiation is an important finding, both in defining objective damage thresholds, which should not be solely based on the threshold for skeletal muscle to ischemia, and in design criteria for supporting surfaces. In addition, the relevance of deformation might, at least in part, explain the increased susceptibility of SCI subject for deep tissue injury since their muscle properties deteriorate in time. The proposed positive effect of electrical stimulation in reducing the risk of pressure ulcers [6] might also be related to the importance of deformation. The MR techniques used in the present study can also be applied in clinical practice for early detection of deep pressure ulcers, which is extremely important. By the time a deep pressure ulcer becomes visible at the skin surface, effective clinical intervention may prove problematic and prognosis is variable.

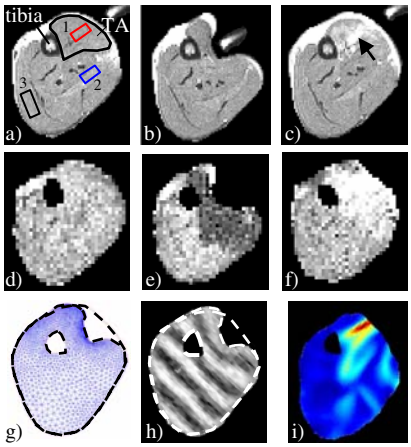

Figure 1 *T2-weighted MR images a) before and b) during loading and c) 60 minutes after unloading. Perfusion index maps measured d) before and e) during loading and f) 5 minutes after unloading. g) Dedicated FE model and h) tagging MRI to determine i) local strain fields during loading*

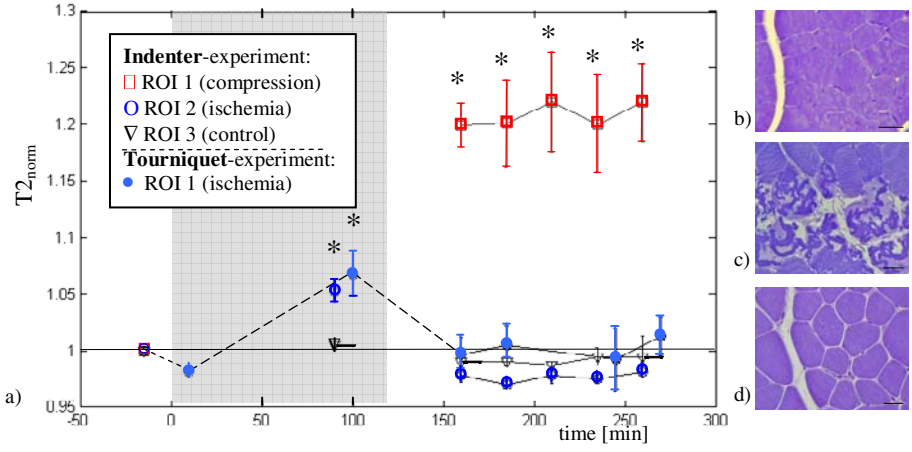

Figure 2 a) *Time course of normalized T2 for ischemic (closed symbols) and compressive loading (open symbols). ROIs are indicated in figure 1a. Shaded rectangle represents intervention period. * indicates significant difference ($p<0.05$) relative to initial value. Histological slices b) control, c) 2 hours of compression, and d) 2 hours of ischemia. Muscle fixated 24 hours after load removal. Bar represents 50 µm.*

References:

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