Introduction: High-voltage electrical shock injury causes edema and changes in the histo-architecture of muscle cell membranes altering their accessibility to cellular water and permeability of polar molecules. T2—weighted MRI and contrast enhanced MRI could be useful in the early diagnosis of muscle injury in electrical shock victims non-invasively based on sensitivity to edema, perfusion, and contrast agent distribution volume. We applied both MR imaging techniques to characterize tissue damage in our well-established rat hind limb non-thermal electrical injury model.

Methods: Ketamine/xylazine anesthetized female Holtzman rats (300 ±20 g) were subjected to multiple DC electrical field pulses (2 A, 150 V/cm, 4-milli-seconds duration) tail-to-ankle with 10-seconds pulse separations to minimize any thermal effects.

Proton images of the rat's hind-limb were obtained using a GE 4.7T Omega MR scanner. T2-weighted proton image sets were taken 2 to 2.5 hours after application of the electrical shocks (TR = 3 s, TE = 40 ms, 128x256, multi-slice). T1-weighted images were taken immediately before and 15-20 minutes after intravenous Gd-DTPA injection to detect regional differences in contrast agent uptake kinetics and distribution volume (TR = 400 ms, TE = 5 ms, 128x128, multi-slice).

Images of relative contrast agent distribution volume in the electrically shocked hind limb were obtained by subtracting the pre-injection T1-weighted images sets from the T1-weighted images obtained 10–20 minutes after contrast media injection. MRI scans of non-shocked rat hind limbs served as a control for image interpretation and for threshold determination in post-imaging pixel-by-pixel cross-correlation of contrast enhanced and T2-weighted images using IDL.

Results: T2-weighted images after electrical shock clearly show areas of high MR signal intensity (Fig. 1A) indicating edema. The same areas show an increased Gd-DTPA distribution volume relative to the surrounding tissue (Fig. 1B). No hyper-enhanced zones were seen in T2-weighted or contrast enhanced images of non-shocked rats.

Quantitative analysis of areas with enhanced Gd-DTPA uptake (increased distribution volume) revealed an electric shock dose-dependent trend (see Table 1). Pixel-by-pixel regional correlation showed that about 70% of the enhanced areas in the T1-weighted difference images are identical to the edematous areas indicated by T2-weighted images when significant tissue damage was present.

Discussion: The T2-weighted images indicate the location of edema in the electrically injured muscle tissue. The same areas show an increased Gd-DTPA distribution volume in the T1-weighted images. In this electrical injury model, i.e., electric field induced cell membrane permeability increase, increased contrast agent distribution volume is most likely due to muscle cell membrane damage providing access to the intracellular space.

Conclusion: The results provide evidence that MRI scans are sensitive to the location and degree of muscle necrosis caused by electroporation injury. A similar approach could be applied clinically for the quantitative evaluation of tissue damage after high-voltage electrical injury.

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References

Table 1: Electric Shock Dose Dependent T1/T2 Correlation

<table>
<thead>
<tr>
<th># of shocks applied</th>
<th>0</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>% area w/ Gd-DTPA uptake increase (T1)</td>
<td>13 ±5</td>
<td>31 ±3</td>
<td>23 ±9</td>
<td>27 ±4</td>
<td>25 ±8</td>
</tr>
<tr>
<td>% overlap w/ edema</td>
<td>35</td>
<td>64</td>
<td>46</td>
<td>70</td>
<td>67</td>
</tr>
</tbody>
</table>

Figure 1: Representative T2-weighted image (A) and contrast enhanced (Gd-DTPA) T1-weighted difference image (B, identical slice) of an electrically shocked rat hind limb (nine 2 A current pulses, 4-ms on, 10-s off).