MR Thermometry for Predicting Thermal Damage: Interstitial Laser Coagulation in an In Vivo Canine Prostate

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Introduction: MR image-guidance for interstitial thermal-coagulation therapy has proven to be a valuable tool for three primary roles (i) device localization, (ii) thermal monitoring, and (iii) post-treatment lesion assessment. However, a quantitative understanding of how temperature-time exposure relates to thermal damage is crucial if the predictive value of real-time MR thermal-mapping is to be fully realized [1]. In this study, results are presented on interstitial laser coagulation (ILC) of an in vivo canine prostate model which are used to evaluate three models of thermal damage. The models were analyzed for their ability to classify an isoeffect along the lesion margin as derived from post-treatment MR images as well as direct histological evaluation of the excised canine prostate. Histological evaluation shows that the thermal-injury boundary can be predicted from a threshold-critical temperature of approximately 51°C or an equivalent 43°C period of 200 minutes. The methods described in this study are expected to have direct implications for the treatment of benign prostatic hyperplasia and prostate cancer with ILC, which will be the focus of future human studies.

Methods and Materials:
In this study a diode laser was used (Indigo 830e, Indigo Medical Inc., Cincinnati OH) for applying ILC in the prostate glands of two male Labrador dogs [2]. At surgical laparotomy, two laser fibres and four Luxtron fibre-optic thermal probes (Luxtron Corp., Santa Clara CA) were inserted into the right and left sides of the prostate gland.

The PRF-shift method of MR thermometry was used where temperature-induced phase shifts were obtained from a gradient-echo acquisition [3]. All imaging was performed on a 1.5 T MRI system (GE SIGNA) using a 5-inch surface coil placed on the dog’s abdomen. An SPGR sequence, two ILC applications were made in each prostate with left sides of the prostate gland.

Upon localization of the laser fibres with a 3D-SPGR sequence, two ILC applications were made in each prostate with simultaneous MR thermal mapping. A typical ILC application consisted of maintaining a target temperature of 85°C (as measured by a thermal sensor in the laser fibre) for 3 minutes. MR thermal mapping was terminated once the entire prostate returned to uniform body temperature.

Post-treatment images were used to assess the thermal-coagulation volume and consisted of T1-weighted (TE=20ms, TR=50ms, FOV=160mm, 256 x 128 matrix). The laser fibres were oriented parallel with the main-magnetic field to eliminate magnetic susceptibility-related crosstalk in PRF-shift thermometry.

Lesion max. T

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>t43 (min.)</th>
<th>TTP (min.°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50 ± 2</td>
<td>1.6 ± 0.2</td>
</tr>
<tr>
<td>2</td>
<td>49 ± 3</td>
<td>1.0 ± 0.2</td>
</tr>
<tr>
<td>3</td>
<td>66 ± 6</td>
<td>1.0 ± 0.2</td>
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<tr>
<td>4</td>
<td>49 ± 2</td>
<td>1.8 ± 0.2</td>
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Conclusion: Thermal-mapping modalities, such as MRI, must supply more than simple temperature measurements within tissue to ultimately realize their clinical importance or necessity. A better understanding of how temperature exposure relates to actual thermal damage is necessary in order to properly establish the predictive value of real-time MR-thermal mapping. Post-treatment MR images may provide conspicuous margins that don’t necessarily reflect the true extent of thermal coagulation, and often require a delay period for a host response which places a severe limitation on their prognostic value during thermal treatment.