MRI-guided and Monitored Percutaneous Laser Ablation of the Vertebrae (PLAV): A Feasibility and Safety Study

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Synopsis:

We investigated the use of interventional MRI techniques to guide the percutaneous insertion of laser fibers into targeted areas of the vertebrae and to monitor the development of controlled areas of laser-induced osteonecrosis in a porcine animal model as a potential treatment for vertebral metastases in selected patients. We also explored the safety of laser application close to the spinal cord. MRI guidance of PLAV is feasible. The lack of interference between laser application and MR imaging renders online monitoring of the thermal lesion a simple task. MRI-guided and monitored PLAV appears to be safe, even for posterior vertebral body ablations.

Purpose:

Percutaneous image-guided thermal therapy of the spine has gained attention as a possible minimally invasive treatment option in selected patients with recurrent vertebral metastatic disease. CT-guided radiofrequency ablation has sporadically been used for successful treatment of vertebral metastases [1]. The use of MRI to guide and monitor radiofrequency ablation of the vertebrae has been recently reported. [2] In that study, RF ablation away from the neural elements was shown to be safe, whereas ablation of the posterior vertebral bodies was associated with irreversible spinal cord damage. Laser is another form of thermal energy that has been successfully used for percutaneous tumor ablation outside the axial skeleton [3]. Although laser photocoagulation of contained disc herniation has been practiced for more than a decade, the use of laser energy to induce localized areas of osteonecrosis for the purpose of vertebral tumor eradication has not been reported to date.

This work aims to: (1) test the feasibility of in-vivo percutaneous laser ablation of the vertebrae (PLAV) under the sole guidance of MRI; (2) report the acute and chronic MR imaging characteristics of laser-induced thermal lesions of the vertebrae; and (3) assess the safety of PLAV in relation to location within the vertebra.

Material and Methods:

15 MR-guided percutaneous laser ablation procedures were performed in the thoracolumbar spines of 4 pigs under IV anesthesia, using a protocol approved by the Animal Care and Use Committee of our institution. Ablations were randomly distributed over various vertebral levels and locations within each vertebra. In 4 ablation procedures, the laser fiber was positioned within the posterior-most aspect of lower thoracic vertebrae, directly adjacent to the posterior cortex. All procedures were performed on a 0.2 T open interventional MR scanner (Magnetom Open, Siemens Medical Solutions, Germany). Under MR guidance using a FLASH 2D sequence (TR/TE/NSA/FA: 93/12.7/3/30º), an 11G MR-compatible bone biopsy needle (Somatex, Germany) was introduced into the targeted part of the vertebra via a lateral cortical approach. The position was confirmed on subsequently acquired axial and sagittal TSE T1WI (TR/TE/NSA/ETL: 680/24/2/5). The stylet was then replaced by a 600-micron-diameter bare laser fiber. The needle was then partially withdrawn. For laser application, a Nd:YAG laser unit (Trumpf TL80, Umkirch, Germany, wavelength = 1.064 nm) installed outside the MR room was connected to the fiber. Laser energy was applied at each location utilizing 1-3 W of power for 10 minutes. In one session, a cooled laser applicator technique was used in order to achieve the maximum lesion diameter. To monitor PLAV, a T1-weighted gradient echo FLASH sequence (TR/TE/ /NSA/FA: 93/12.7/3/60º) was repeatedly acquired during and after (60s, 180s) laser application. Immediate post-ablation imaging was performed on a 1.5T scanner (Sonata, Siemens Medical Solutions, Germany) and consisted of T2WI, STIR, and CE-T1WI. Thermal lesions were followed up for 1 week (n=6), 5 weeks (n=4), or 6 weeks (n=4). One lesion was harvested immediately after ablation. Follow-up consisted of clinical evaluation for motor neurological deficits and weekly MR scanning utilizing the same pulse sequences and acquisition parameters used for the immediate post-ablation scans. All vertebrae harboring thermal lesions were harvested for histopathological correlation at the end of the follow-up period.

Results:

Successful MR-guided insertion of the bone biopsy needle into the targeted part of the vertebra was achieved in all 15 procedures. The development of the thermal lesion was seen as a hypointense area within the vertebral body on the simultaneously acquired fast T1W GRE images. Laser-induced vertebral thermal lesions demonstrated variable signals on T1WI, hypointense signals surrounded by bright rims on T2WI and STIR images, and marginal enhancement on the CE-T1WI. Chronic lesions (imaged after 3 weeks of ablation, n=8) were generally more distinct than acute lesions (imaged within the first week of ablation, n=7). The mean (+/-SD) thermal lesion diameter (short axis) did not show significant time-dependent changes over the follow-up period. Measured on T2WI, the mean short axis diameter was 1.04 ±0.4 cm on the immediate post-ablation scans, 1.02 ± 0.2 cm on the one-week scans, and 0.97 ± 0.3 cm on the 6-week scans. None of the 15 thermal ablation procedures resulted in motor neurological deficit.

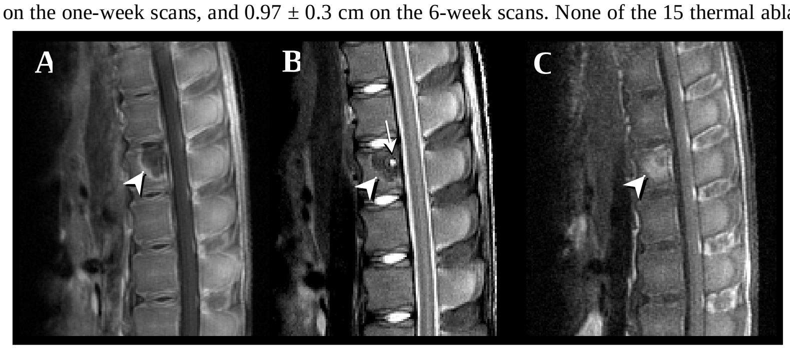

Figure 1: *Sagittal CE-T1WI (A), TSE T2WI (B), and STIR (C) images Acquired on the 4th day after cooled laser ablation of the posterior T11 vertebral body. Encouraged by the safe outcome of non-cooled laser application, we applied the cooled laser technique during this last procedure in our series to maximize the resultant thermal lesion size. Despite placing the laser fiber directly over the posterior cortex, signal changes denoting necrosis (arrowheads) are noticed only anterior to the laser fiber tract (arrow, b), with no abnormal signal detected within the spinal cord. No motor neurological deficit developed in this animal.*

Discussion:

This investigation demonstrates the feasibility of performing percutaneous laser ablation of the vertebrae (PLAV) exclusively under MRI guidance and monitoring. Real-time monitoring of the developing thermal lesion during ablation is a simple task due to the lack of interference between laser application and MR image acquisition. This is in contrast to MRI monitoring of radiofrequency ablation where simultaneous ablation and monitoring, although feasible, is more technically demanding. The MR imaging appearance of acute and chronic laser induced thermal lesions is generally similar to the reported appearance of radiofrequency induced vertebral thermal lesions. Radiofrequency ablation close to the posterior vertebral cortex has been shown to induce spinal cord injury [2]. In contrast to these findings, PLAV is a well-tolerated technique which seems to be a safe alternative to radiofrequency for ablation procedures in the vicinity of neural tissues.

References:

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