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Technical Notes and Surgical Techniques

Endoscopic laser ablation of clival chordoma with magnetic resonance-guided laser induced thermal therapy

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ABSTRACT

Background: Chordomas are rare malignant tumors that are difficult to treat and have high recurrence rates despite aggressive therapy.

Objectives: We present the first case of a patient with a clival chordoma in which complete tumor ablation was achieved using Magnetic Resonance guided Laser Induced Thermal Therapy (LITT) delivered via an endoscopic endonasal approach. We analyzed the safety and feasibility of this approach and quantified the response of this pathology to thermal energy. This novel technique is intended to provide chordoma patients with an alternative to surgery and radiotherapy.

Methods: A 54 year-old female with a newly diagnosed clival chordoma elected MRI- guided LITT. She underwent placement of the laser catheter into the chordoma via an endoscopic endonasal approach. With real-time MR thermometry monitoring, laser-generated thermal energy was delivered to the tumor. We defined several parameters to quantify the thermal ablation response: the thermal damage ratio and the thermal ablation constant.

Results: Post procedure contrast-enhanced MRI demonstrated a complete thermal ablation of the mass. The patient tolerated the procedure well and is being followed with serial imaging. The tumor continues to regress beyond 4 months. Additionally, chordoma cells seem to be sensitive to LITT, as indicated by a complete ablation in less than 60 s.

Conclusion: The endoscopic endonasal approach to MRI-guided laser ablation is both technically feasible and safe. As a result, this therapy may be a useful alternative in hard-to-reach chordomas, or in recurrent cases that have failed other conventional treatment modalities.

Introduction

Chordomas are rare, slow-growing, locally-invasive tumors occurring mostly at the sacrococcygeal region and spheno-occipital junction [1]. Treatment typically consists of en bloc surgical resection with adjuvant radiation therapy. Despite such aggressive treatment, the recurrence-free 5-year survival rate in patients with a skull base chordoma is only 60–70% [2]. In recent years, advances in endoscopic endonasal skull base surgery have allowed more complete surgical resections with reduced morbidity.

One such method employs the use of thermal energy in treating intracranial malignancies and has been achieved with radio waves, ultrasound, microwaves, and lasers. Laser thermal ablation has been successfully used in treating a variety of tumors outside the nervous system [3] by destroying tumor cells within a well-defined tissue volume while sparing healthy peripheral tissue.

However, the unpredictability of the ablation size and volume as well as the irregular heating pattern and distribution has largely limited the application of laser thermal ablation for intracranial lesions. The development of magnetic resonance (MR) thermometry has recently made it possible to target abnormal tissue and limit the amount of heat distributed to surrounding tissues by acquiring real-time thermal information during the procedure [4]. By combining these two techniques, MRI-guided Laser Induced Thermal Therapy (LITT) is a minimally-invasive method for delivering thermal energy delivered through a fiber optic laser under stereotactic guidance and real-time thermal feedback. The use of LITT in neurosurgery is gaining popularity due to the ability to apply precise amounts of thermal energy to target lesions that are difficult or impossible to access with standard surgical techniques. We present the first application of MRI- guided LITT to a clival chordoma, report short-term radiographic follow-up, and describe ablation dynamics with respect to chordoma cells.

Patients and methods

The patient is a 54 year-old female with several months of progressive dysphagia and changes in her voice. As part of her

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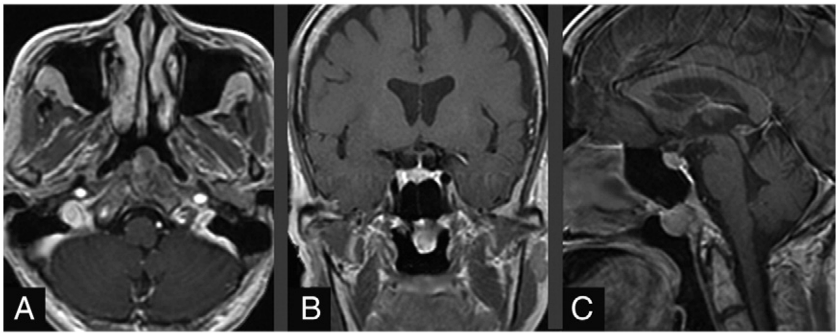

Fig. 1. Pre-treatment MRI. (A) Axial, (B) coronal, and (C) sagittal T1-weighted MRI with contrast showing the clival lesion (white arrows) protruding into the nasopharynx. The lesion measures 1.8 cm × 1.35 cm × 1.3 cm at its widest diameters.

neurologic workup, brain MRI revealed a clival mass. T1-weighted MRI with gadolinium contrast showed a 1.8 × 1.35 × 1.3 cm well-circumscribed, heterogeneously enhancing mass arising from the ventral surface of the clivus and extending anteriorly into the posterior nasopharynx (Fig. 1). There was mild T2 signal hyperintensity within the lesion and no significant FLAIR signal in the surrounding tissue. A CT-guided needle biopsy established the diagnosis of chordoma. She was referred for neurosurgical evaluation and treatment. Further radiographic evaluations revealed that the posterior wall of the clivus was intact with no disruption of the skull base anatomy.

The standard treatment option, en bloc surgical resection with or without adjuvant radiation was offered to the patient. MRI-guided LITT was offered as an alternative treatment option. The family was thoroughly counseled that although this approach may be less disruptive, and require less operative time, the effect of thermal energy on chordoma cells is not known. The patient and her family decided to undergo LITT as part of an institutional IRB-approved study.

Intervention

The patient was placed in the supine position under general anesthesia. The setup was similar to all endoscopic endonasal skull base cases performed at our institution. A single-nare approach was utilized. The cooling catheter was introduced into the nose after passing it through the guidance bolt (Fig. 2A). We achieved excellent visualization of the exophytic endonasal portion of the mass. A 1.65 mm diameter coaxially-cooled diffusing tip laser applicator (VCLAS-400, BioTex, Inc., Houston, TX, USA) was then introduced through the surface of the mass until the bony clivus was felt at the posterior margin of the mass (Fig. 2B). The plastic guidance bolt typically used to anchor the laser to the skull was then advanced down the applicator and seated in the left nostril (Fig. 2C). A 2-0 silk suture was sewn to the nasal septum and tightly tied to the bolt to restrict any migration during transport to MRI (Fig. 2D). The blue cap of the guidance bolt was then screwed tightly over the clear base in order to secure the laser catheter's position within the lumen of the guidance bolt.

The patient was then transferred to the MRI scanner (GE, 1.5 Tesla) to initiate therapy. The laser applicator tip was connected to the Visualase Thermal Therapy System (BioTex Inc., Houston, TX, USA), which provides up to 15 Watts of 980 nm laser energy and software that allows real- time MR thermal monitoring of the selected MR slice. Oblique sagittal sequences in line with the laser catheter were obtained and confirmed optimal laser placement. A reference image in the sagittal plane was selected as the monitoring slice for proton resonance frequency (PRF) based magnetic resonance temperature imaging (MRTI) on the Visualase workstation (Fig. 3A). This allows for temperature information to be superimposed over live treatment images in real-time (Fig. 3B). Target temperature limits were set to 90 °C near the catheter and 50 °C at the posterior and superior borders of the clivus. Based on the temperature and time history, the software predicted cell kill, utilizing the Arrhenius damage model. A test dose was delivered at 3.1 W for 33 s. This confirmed the laser location within the targeted lesion. Once confirmed, a total of 4 ablations were performed at 12 W for a combined total of 311 s.

Post-ablation MR imaging confirmed that the zone of ablation encompassed the entire tumor and therapy was concluded. The laser was removed and post-operative imaging confirmed no hemorrhage within the nasal cavity. The patient was then transferred to recovery where she was extubated in stable condition. She was admitted overnight and discharged the next day without any postoperative complications. After 4 months, her dysphagia has resolved and she reports no further voice changes. The patient is being followed closely with serial imaging.

Results

Radiographic evaluation

Prior to thermal ablation, the lesion heterogeneously enhanced consistent with viable tumor. There was no edema or hematoma seen around or within the lesion. Gadolinium enhanced MRI scans were obtained immediately after ablation, and at various time points after therapy. All post-ablation scans demonstrate a peripherally enhancing lesion with a central focus of low signal that encompasses the entire region of enhancement that was seen on pre-operative MRI. These findings are consistent with complete thermal ablation [5]. An MRI performed at 136 days post-ablation shows a reduction in lesion size.

Volumetric analysis was performed on all images to quantify changes in the size of the tumor mass. The lesion volume was estimated by evaluating it as an ellipsoid structure ($V = 4/3\ \pi^* r_1^* r_2^* r_3$). The tumor lesion diameter was measured in 3 dimensions based on the largest diameter in axial, coronal, and sagittal planes.

The pre-ablation estimate of the lesion volume was 1.65 cm^3. The immediate post-ablation lesion volume was 2.85 cm^3. The lesion volume at 1 day was 2.47 cm^3, at 25 days it was 1.34 cm^3, at 73 days it was 0.59 cm^3, and at 136 days the lesion volume was 0.35 cm^3.

Ablation dynamics

The Visualase software provides a real-time estimate of thermal damage area. This information is routinely used to guide the duration of treatment. The damage estimate is derived from the Arrhenius equation:

$$\Omega(t) = \int_0^t Ae\frac{-Ea}{RT(\tau)}d\tau.$$