Journal of Bone Oncology 12 (2018) 69–77

Contents lists available at ScienceDirect

Journal of Bone Oncology

journal homepage: www.elsevier.com/locate/jbo

Research Paper

Thermal effect of percutaneous radiofrequency ablation with a clustered electrode for vertebral tumors: In vitro and vivo experiments and clinical application

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ARTICLE INFO

Keywords:
Radiofrequency ablation
Spinal tumor
Spinal cord
Adjacent nerves
Clustered electrode

ABSTRACT

Purpose: To investigate effects and heat distribution of radiofrequency ablation (RFA) on vertebral tumors in vitro and in vivo swine experiments and its clinical application.

Materials and methods: RFA was performed on the swine spine in vitro and in vivo for 20 min at 90 °C at the electrode tip, and the temperature at the electrode tip and surrounding tissues were recorded. Clinical application of ablation combined with vertebroplasty was subsequently performed in 4 patients with spinal tumors.

Results: In the in vitro study, the mean temperature at the front and ventral wall of the spinal canal was 50.8 °C and 43.6 °C, respectively, at 20 mm significantly greater than 37.7 °C and 33.7 ± 1.7 °C, respectively, at 10 mm ablation depth. The coagulative necrosis area was significantly ($P < 0.0001$) greater at 20 mm depth than at 10 mm depth (mean 17.0 × 20.7 mm^2 vs. 14.2 × 16.6 mm^2). In the in vivo experiment, the local temperature increased significantly ($P < 0.05$) from around 36 °C before ablation to over 41 °C at 20 min after ablation, with the temperature at the electrode tip (90.4 °C) and within the vertebral body (67.0 °C) significantly ($P < 0.05$) greater than at the posterior (41.9 °C) and lateral wall (41.8 °C). From 2 to 5 weeks, bone remodeling began. Clinically, all four patients had successful RFA and vertebroplasty, with no neurological deficits. The pain scores were significanlty ($P < 0.05$) improved before (4.5–10, mean 8.0) compared with at four weeks (0–1.8, mean 1.8).

Conclusion: The clustered electrode can be efficiently and safely applied in the treatment of spinal tumors without damaging the spinal cord and adjacent nerves by heat distribution.

1. Introduction

Radiofrequency ablation (RFA) was initially developed in the past few decades for treatment of soft tissue tumors and has been proved to be a safe and effective therapeutic option for patients with liver, lung, kidney and bone neoplasms and has been increasingly performed in clinical settings [1–10]. Ever since the first application of RFA in the bone tissue for treating osteoid osteoma was reported in 1992 [11], this technique has been employed for more bone tumors including chondroblastoma [12], chondromas [13], and osteolytic metastasis [14]. However, when tumors are adjacent to nerves, risk of nerve injury may exist in RFA, especially because the current intraprocedural imaging monitoring methods could not clearly detect the gross margin of RFA necrosis. This limits the application of RFA. Neural damage by RFA is one of the most serious complications of the ablation procedure and has been recorded in patients with spinal tumors adjacent to nerves [15–17]. RFA produces ionic oscillation and subsequent friction heat to destroy tissues through thermal coagulative necrosis, and the heat delivered to the tumor tissue is responsible for neural injury. The temperature in the tumor may reach 100 °C during RFA, and this heat may be transferred to adjacent nerves. Nerve injury takes place when the spinal canal temperature achieves 45 °C, and it is considered unsuitable for RFA if the spinal tumors were located within 1 cm to the spinal cord [18]. The major concern with thermal ablation for spinal tumors is injury to the spinal cord and nerves if ablation is applied adjacent to the posterior vertebral body wall or in epidural tissues. Moreover, in bone and in the spine in particular, RFA is more difficult than in soft tissues due to unpredictable bone environment surrounding the targeted lesion. Even though some RFA studies have been carried out for patients with primary or metastatic spinal tumors [19–22], no detailed animal

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https://doi.org/10.1016/j.jbo.2018.07.001
Received 26 April 2018; Received in revised form 2 July 2018; Accepted 5 July 2018

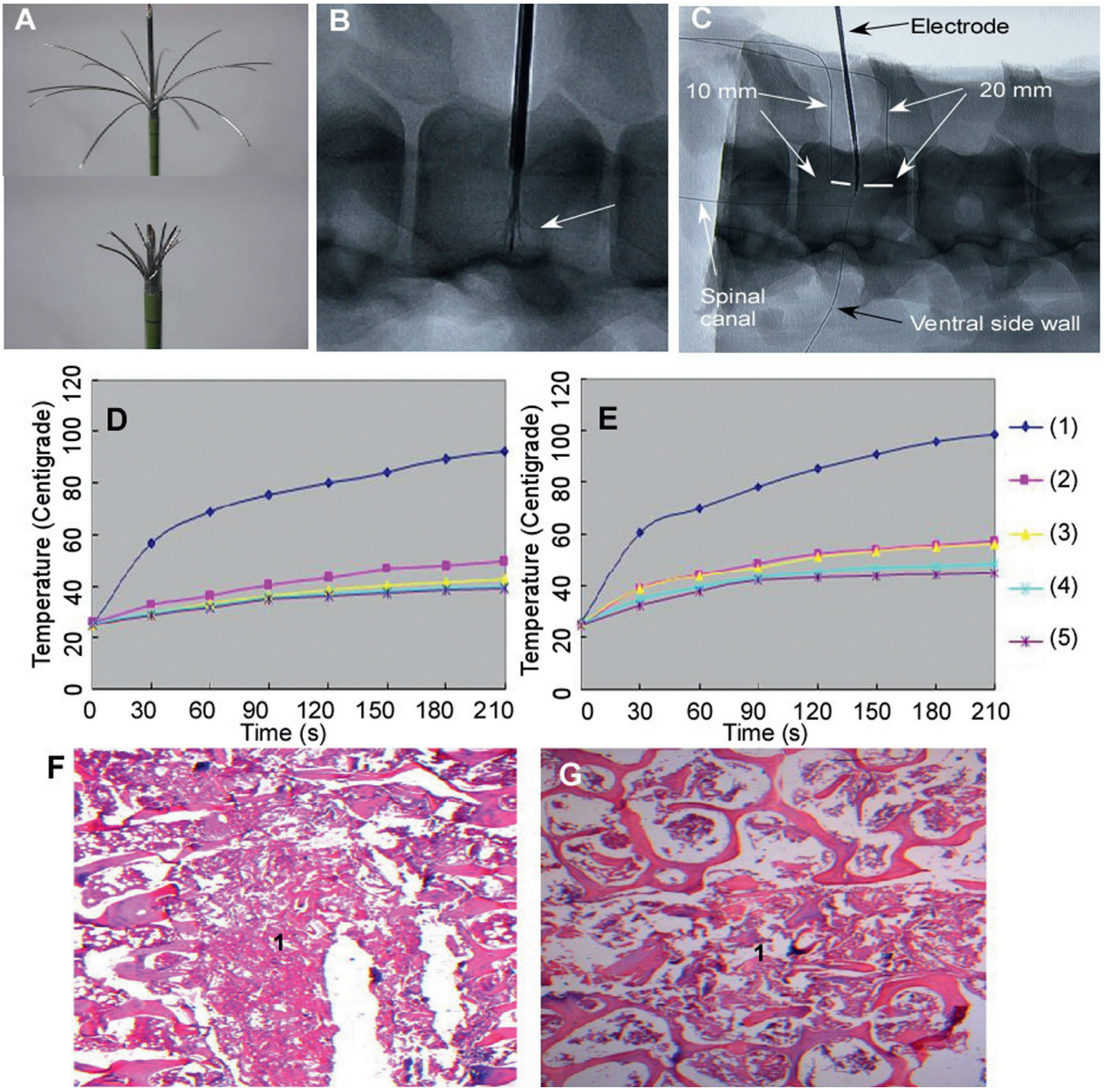

Fig. 1. In vitro study. (A) The hooked array electrode for radiofrequency ablation has 13 hooks. (B) The electrode was sent into a vertebral body with the array electrode partially opened (arrow). (C) The distribution of ablation and temperature sensors. Two temperature sensors were located 10 and 20 mm away from the electrode needle, respectively, the third (indicated by spinal canal) on the front wall of the spinal canal, and the last one on the ventral side wall of the vertebral body. 10 mm indicates the temperature senor is located 10 mm from the electrode tip while 20 mm the senor 20 mm from the electrod tip. Ventral side wall indicates the sensor is on the ventral side of the vertebral body while spinal canal indicates the sensor is on the spinal canal front wall or the posteiror wall of the vertebral body. (C, D) Temperature changes were detected during the initial 210 s when the electrode needle was inserted 10 mm (C) and 20 mm (D) inside the vertebral body. Line 1 indicates a temperature sensor at the center of electrode, line 2 indicates a sensor at 10 mm away from the eletrode tip within the vertebral body, line 3 indicates a sensor at the front wall of the spinal canal, line 4 indicates a sensor at the ventral side wall of the vertebral body, and line 5 indicates a sensor at 20 mm away from the elctrode within the vertebral body. (E, F). Histopathology revealed coagulation necrosis (1) of the bone trabecula structure with no osteocytes at the center of the electrode (E) and 1.5 cm away from the electrode tip (F). The trabecula was destroyed much more in the center than 1.5 cm away.

experiments have been performed to investigate heat distribution in targeted spinal lesions and surrounding tissues of spinal cord and nerves especially in RFA with a clustered electrode. We hypothesized that because of lack of animal experiments investigating heat distribution in the spinal canal and surrounding tissues in RFA for spinal tumors, no generally accepted protocols for RFA in spinal tumors exist especially regarding a clustered electrode for RFA. This study was consequently designed to investigate the effect of RFA and heat distribution in spinal canal and around the vertebral bodies in swine experiments in vitro and vivo, and based on these experiments, we subsequently treated some patients with spinal tumors.