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Bipolar Radiofrequency Ablation of Spinal Neoplasms: Average Power to be the Most Predictive Value in Respect of Induced Extent of Ablation Volume

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Abstract

Objective: To obtain an equation for the prediction of radiofrequency induced ablation volumes.

Summary of Background Data: Radiofrequency ablation of tumor masses is an established procedure and is increasingly used as pain therapy of unresectable spine tumors. The bipolar radiofrequency ablation potentially minimizes the risk of injury to adjacent structures. Predictability of the extent of the induced ablation zosne has been hown on an ex-vivo model. There has been no investigation examining the parameters of radiofrequency ablation in an in-vivo model.

Methods: 38 lesions of the spine in 36 patients were treated using bipolar radiofrequency ablation. Extent of ablated tissue, amount of administered energy, average power and total duration of ablation were recorded.

Results: Induced Volume of Necrosis (VN) correlates with Average Power (AP) following the equation VN=-3.579+0.998*AP.

Conclusion: Average power can be used as the most predictive parameter for calculation of the induced necrosis volume in an in-vivo model too.

Keywords: Bipolar radiofrequency ablation; Spine; Neoplasms; Prediction

Introduction

Bone metastases are often the source for tumor-associated pain causing reduction of the patient´s quality of life. After lung and liver metastases, bones are the third most common localization for metastases [1]. Patients in an advanced tumor stage, who develop symptoms of paraplegia or massive local pain due to a local spinal process, often cannot be treated surgically due to their impaired general condition and considering the grim prognosis of the underlying disease. In these cases a local, minimally-invasive therapy as a palliative approach may be a useful option for reducing patient symptoms and preserving mobility. Radiofrequency Ablation (RFA) of tumor masses is an established procedure proven in numerous studies to be an effective therapeutical option for neoplasms of the liver, kidney, lung and bone [2-7]. It is also increasingly used as pain therapy for unresectable spine tumors either alone or in combination with vertebroplasty [6,8,9]. A potential complication of this pain therapy is the accidental injury of nerves adjacent to tumorous masses due to the inability to visualize the exact spreading of heat generation before and during the treatment. Stopping the ablation when the patient mentions pain during the therapy, it still often is too late to avoid nerve damage, especially if the tumor has already invaded the dorsal rim of the vertebral body and the spinal canal [8]. In many studies analgesic therapy was performed using monopolar electrodes [8,10-14]. Often the result of the necrosis induced by monopolar electrodes deviated a lot from the preinterventionally planned and are shown in plenty experiments on liver tissue [15-17] because current flow is incalculable. The bipolar technique was used in the therapy of liver tumors in 2003 [18,19] and was first described as a therapeutic method for vertebral tumors in three cases by Xavier Buy in 2005 [20]. During bipolar RFA two electrodes are inserted into the tumor. After activation of the system current flows are controlled between the pins. The pins can be integrated either in a singular or between multiple pins, so that heating of unwanted regions can be reduced. A Korean publication on animal livers showed that hypertonic saline-enhanced bipolar RFA more efficiently created larger areas of thermal ablation and higher tissue temperatures than monopolar RFA [19]. In contrast to the more commonly used monopolar approach in which current flows from the electrode in the target zone and the grounding pads placed on the body surface, the bipolar technique utilizes current flowing solely in the area the two pins are placed [21,22]. This fact gives concern for additional precaution for patients with pacemakers or surgical clips as pacemaker dysfunction may occur, especially if the pacemaker is located between the probe and grounding pad [23]. Skin burn secondary to inadequate ground pad positioning was observed during monopolar radiofrequency ablation [24]; this should not occur in the bipolar or multipolar approach as grounding pads are not necessary in the closed electrical circuit inside the target tissue. Comparisons between bipolar and monopolar RF systems have shown that bipolar systems achieve greater energy efficiency with considerably larger zones of coagulation and higher tissue temperatures [19,25].

The aim of this observation is to determine if perinterventionally obtained parameters can predict the extent of the emerging zone of induced necrosis.

Materials and Methods

Subjects

After obtaining written informed consent, 36 patients (23 men, 13 women; age range, 34-84 years; mean age 65.8 years) with primary or secondary tumor involvement of the spine were treated on overall 38 lesions at our institution between February 2006 and May 2009.

This retrospective analysis included patients with disease progression despite previous surgery, maximal chemotherapy, maximal radiation and hormone therapy; lack of highly-invasive surgical option; severe local tumor pain insufficiently responsive to opiates and other analgesics; intervertebral tumor spread; risk of paraplegia or fracture in case of tumor progression; locomotor disability due to a local tumor process; and osteolytic and mixed metastases with mostly palliative intention (in one case an osteoid-osteoma was treated with curative intention).

Patients were excluded in cases of intradural and intramedullary tumors; risk of bleeding (acetylsalicylic acid, anticoagulants); acute, general infection; local infection in the target zone; or allergy against one of the peri-interventionally applied drugs.

Synopsis of Tumor entities can be seen in Table 1 along with tumor location Table 2. Involvement of the dorsal rim or the pedicles of the vertebral body indicate the lesion to be adjacent to vulnerable structures and underlie a higher therapy-risk. In overall 30 lesions (78.95%) the dorsal rim; in 25 lesions (65.79%) the pedicles and in 23 (60.53%) the dorsal rim and the pedicles were both infiltrated by the tumor. In 6 cases (15.79%) none of these structures were involved by the tumor spread.

Tumor entity	Number of patients	Number of treated lesions	% of total patients
Renal cell carcinoma	9	11	25
Breast carcinoma	8	8	22,23
Prostate carcinoma	5	5	13,89
Colon carcinoma	3	3	8,34
Bronchial carcinoma	3	3	8,34
Urothelium carcinoma	2	2	5,56
Esophageal carcinoma	1	1	2,78
Gall bladder carcinoma	1	1	2,78
Hypopharyngeal carcinoma	1	1	2,78
Larynx carcinoma	1	1	2,78
Osteoid-Osteoma	1	1	2,78
Pancreas carcinoma	1	1	2,78

Table 1: Entities of primary tumors

Spine level	quantity
Lumbar spine	23
Thoracic spine	12
Sacrum	1
Cervical spine	2

Table 2: Level of tumor manifestation

Pre- and post-interventional Imaging

MR-Imaging with 1.5 T MRI was performed pre-interventionally (on Magnetom Vision; Siemens HealthCare, Erlangen, Germany or Intera; Philips HealthCare, Eindhoven, Netherlands). The lesions were illustrated in transverse and sagittal slices in T1- and T2-weighted images before and after application of contrast media (0.1 mL/Kg body weight of Gadovist; Bayer Schering HealthCare, Berlin, Germany). On the first or second post-interventional day, follow-up MRI with the same parameters was performed to measure the extent of necrosis (Figure 1).

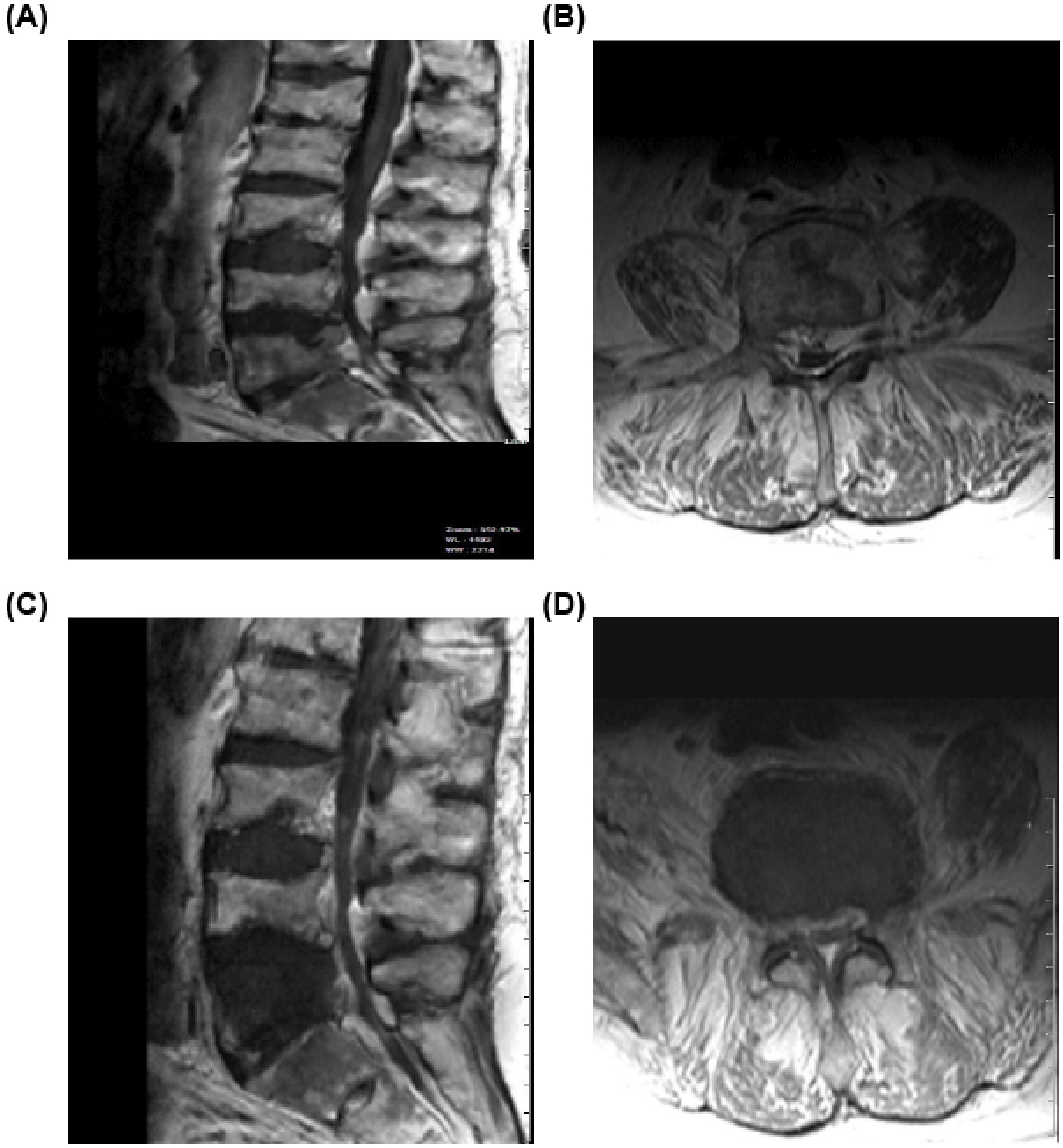


Figure: 1. Pre- (a, b) and post-interventional (c, d) contrast enhanced T1- weighted imaging of spinal tumorous lesion.

For calculation of the elliptoid volumes half-axis of the necrosis zones was obtained from the contrast enhanced sequences and inserted into the formula for the calculation of an elliptoid volume (4/3 π abc). In case of irregular boundaries definition of the extent of the induced necrosis was not distinct. For this reason the maximal possible extent of each axis was chosen in every case so that comparable data could be acquired.

Radiofrequency ablation

Impedance-controlled radiofrequency ablation was performed by three experienced neuroradiologists. The radiofrequency power was limited to 50 W. All ablations were perfomed using a power generator and cooling pump (CelonLab Power and Celon Aquaflow III; Celon AG medical instruments, Teltow, Germany) that can supply up to three liquid-cooled RFA probes. Peri-interventional prophylactic antibiotics (2,0 g Spizef; Grünenthal, Wien, Austria) was administered.

The lesion was treated controlled fluoroscopically and via DynaCT using a posterior approach with the patient prone under general anesthesia utilizing up to two bipolar RFA probes with active tips of 20 or 30 mm measuring 1.8 mm in diameter (Celon ProSurge 250-T20 or Celon ProSurge 250-T30; Celon AG medical instruments Teltow, Germany) (Figures 2a and b).

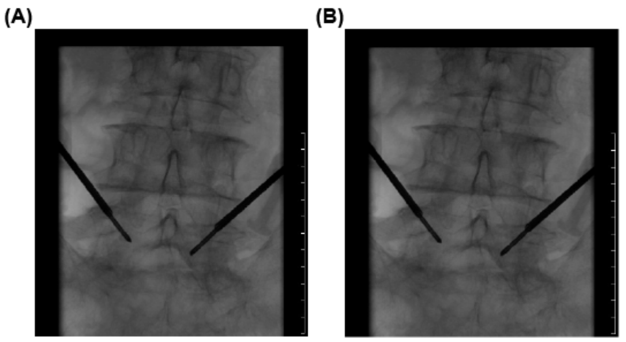


Figure 2: Periinterventional fluoroscopic and Dyna CT-imaging and assessment of probe position.

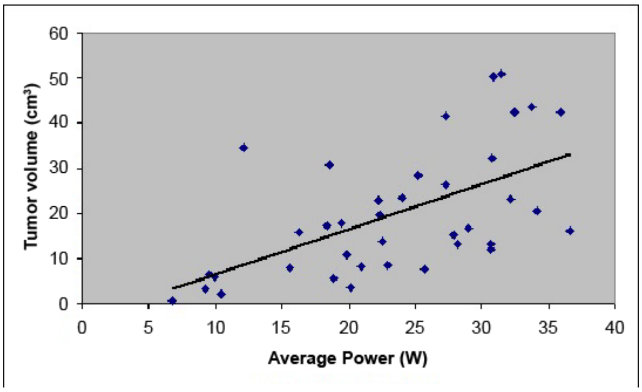
Average power in Watts, energy in kJ, duration of energy application in min and resistance in ohms were transferred to a personal computer connected to the RF generator and were recorded by using a software program (Celon Power Monitor, Version 2.8; Celon Medical instruments, Teltow, Germany).

Statistical methods

The model equations describing the relationship between the volume of coagulation, duration of energy application, amount of applied energy and average power will be described in the context of the results to be reported. The linear regressions were performed with the statistical Package SPSS version 15.

Results

No procedural-related complications were observed. The induced necrosis volumes varied between 0.5 and 50.9 cm^3 (mean 19.7 cm^3). Average power of 6.8 to 36.6 W (mean 21.6 W), energy of 1.5 to 85 kJ (mean 31.2 kJ) was needed. Duration of the ablation varied between 3.7 and 43 min (mean 19.7 min). The relationship between the factors “volume of necrosis” (VN), “average power” (AP), “energy” (E) and “time” (t) an equation can be established: VN= -22.474-0.553*E +1.565*AP+1.051*t. The residual error amounts 11.2 cm^3. This equation is most influenced by AP ($p=0.003$) and only tendentially by t ($p=0.077$). The Influence of E is not significant ($p=0.167$). Deleting E from the equation following formula can be obtained: VN=-8.614+0.944*AP+0.29*t. Here the Influence of AP is even higher ($p<0.001$) and the influence of t lower ($p=0.175$). Residual error amounts 11.4 cm^3. Deleting t from the equation following formula emerges: VN=-3.579+0.998*AP (Graph 1). Residual error amounts 11.6 cm^3.



Graph 1: Graph showing induced tumor volume and average power

Discussion

Radiofrequency ablation of primary or secondary therapy-refractory, unresectable spine lesions is described in several publications since 2000 [6,26-28]. The main aim of the radiofrequency ablation is complete coverage of the lesion with an adequate security margin [29]. Often spinal tumors are adjacent to vulnerable structures that have to be saved during ablation. For instance, Nakatsuka et al. observed damage of neuronal structures in 4 of 17 cases (~24%) after spinal tumor ablation. This count particularly in cases tumorous masses invades the dorsal rim or the pedicles of the vertebra [8]. In a subsequent publication Nakatsuka et al. report that such damage may be avoided by placing a thermocouple in the spinal canal in the subarachnoid or the epidural space with ablation ceased when spinal canal temperature reached 45°C. Temperature rose to 48°C in one case (10%) and despite immediate discontinuation of ablation therapy, transient neural damage occurred [13]. These examples show that an exact planning of the extent of induced necrosis is inevitable for a safe performance of radiofrequency ablation of the spine.

In the monopolar approach the heat produced spreads in all directions from the probes in contrast to bipolar radiofrequency ablation in which one electrode is thermally shielded by the second electrode [19,25]. This advantage can be utilized in cases where tumor tissue is neighboring vulnerable structures whose safety is mandatory as shown in some case reports [20,30]. Another method to avoid unwanted damage is the real-time visualization of ablation zones during the procedure utilizing sonographic or MR-tomographic methods. Nouso K et al. showed in 2005 in a study on ablation of tumors of the liver sonographical visualization of microbubbles that emerge during thermoablation. The extent of this sonographically observed region correlated with the extent of the ablation zone as confirmed by MR-imaging [31]. Methodically such a monitoring during the intervention on the spine is not possible. There is no literature about observation of the ablation zone using MR-thermometry to date. This might be a new approach in thermoablative therapy of spinal lesions.

There are limitations of this approach. In case, the tumor mass shows contact to vulnerable structures a security margin of vivid tumor has to be left. In these cases the aim of the treatment is reduction of tumor mass. Additionally this treatment cannot be performed if there is an infection in the target zone.

Predictable zones of coagulation and a precise control of energy application are requirements for a safe and effective therapy. To improve radiofrequency ablation several techniques have been tested on liver tissue including internally cooled electrodes [32], perfusion electrodes [33], multiprobe arrays such as cluster [34] or multitined expandable electrodes [15] and modification in algorithm of energy deposition [35] or additional reduction of blood flow [36] or pharmacological influence [37,38].

In our study a bipolar RF system using internally cooled electrodes was investigated in respect of ablation parameters and their influence on the emerging extent of ablation volume. Even though it was not aim of this study different tumor entities had an influence on the collected technical data. Hypervascular tumors like renal cell carcinoma seem to need more energy to be completely ablated probably due to cooling effects of the vascularisation. Future studies could focus on the influence of the different entities. We were able to show a correlation between administered average power and the volume of the ablated area. Clasen et al. also determined in an ex-vivo-investigation of necrosis areas after bipolar radiofrequency ablation of bovine livers a correlation between appliqued power and emerging volume of necrosis. His equation was VN=0.9*AP [39]. Studies with monopolar RFA-probes have shown that bigger volumes of necrosis can be achieved in ex-vivo livers than in in-vivo livers [32]. Additionally Bitsch et al. was able to show that despite higher effort of Energy and time smaller volumes of ablation were achieved in perfused livers than in non-perfused livers [40].

Conclusion

Our calculations indicate that average power was the most influencing factor for the volume of the necrosis. The restrictions mentioned in Clasen et al's experimental results on ex-vivo bovine livers in respect to in-vivo spinal tumors may account for the slight variation between our equations. On the other hand, our findings implicate that the conclusions of Clasen et al. are largely applicable to in vivo models.

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