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Microwave Ablation for Bone Tumors

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Abstract

Microwave ablation is a technique which achieves tumor ablation by turning the ultrahigh frequency microwave energy into heat in the center of target tissue where the antenna was located. Microwave ablation can produce fast and well-distributed heat and causes necrosis in the tumor tissue. It is a micro invasive surgical method which can be applied in the treatment of a variety of tumors. It has several advantages comparing with other complementary methods for the treatment of tumor. For example, microwave ablation requires little cost, effectively prevents the metastasis of tumor cells, requires shorter time for hospital stay and helps keeping the integrity of the structure of the bone with tumor, which is essential for preserving the function of the limb after the surgery. However, it may also increase the incidence of pathologic fracture, cause nerve injury and poor wound healing. Appropriate output of energy and frequency of microwave, appropriate temperature in the center and surface of tumor as well as well manipulation of several antennas on large tumors can effectively eliminate the treatment related complications and achieve more satisfying results after the surgery.

Microwave ablation is a minimally invasive technique, which causes coagulation necrosis by rising the temperature with deposition of electromagnetic energy to a critical level of around 60. Microwave ablation can be applied as a complementary method for the treatment of tumors. It has already been used for the treatment of liver, gastrointestinal, cerebral, renal, lung and musculoskeletal tumors. In this paper, we made a review on the mechanisms, advantages, applications, and challenges for the microwave ablation in musculoskeletal tumor therapy.

Keywords: Microwave ablation; Bone tumors

The Mechanism of Microwave Ablation

The mechanism of microwave ablation is that microwave energy produced by the microwave emitter is transferred through the antenna to the target tissue. Ultrahigh frequency electromagnetic field in the tissue can induce rapid orientation rotation (2×109 to~5×109 times/sec) on polar molecules, especially the water molecules and produce heat energy by the clash of molecules under rapid rotation [1,2]. Because of its mechanism that the heat produced is the result of dielectric loss, the production of this magnetic field does not require integrated current loop or direct contact with the target tissue. Thus microwave ablation can produce fast and well-distributed heat in a tissue of a certain radius. Generally, there is more blood supply in the tumor tissue, which results in faster heat generation under the same microwave energy [3,4].

Because of the high polarity of water molecules, only a small amount of energy is needed for the treatment of remnant cavity and cause little damage to the normal tissues around. After the ablation of tumor, 0.9% sodium can be used to reach every remnant cavity and transfer heat energy [5]. Heat energy generated by ultrahigh frequency microwave not only inactivates tumor tissue, but also causes necrosis and clogging on the blood vessels in the tumor tissue, decreasing the blood loss during the surgery and possibility of tumor metastases through blood.

Except from in situ inactivation of tumors, microwave ablation can also be applied to handle the remnant cavity after tumor ablation and satellite tumor lesions. Studies have confirmed that tumor cells can be inactivated by treating with 60℃ for 5minutes [6] or under 43℃ for 30minutes [5].

Advantages of Microwave Ablation in Musculoskeletal Tumors

Clinical appilication of microwave ablation has several advantages, which makes it a perfect candidate as a complimentary method for the treatment of tumor.

1. As a microinvasive surgery method, microwave ablation causes little trauma on the patient and thus is easily acceptable by patients.

2. Microwave ablation has a wide range of indications, even a patient who can’t tolerate open surgery, radiotherapy or chemotherapy can still be treated by microwave ablation

3. Microwave ablation is a convenient method that requires little time for hospital stay.

4. Microwave ablation can decrease the complexity of surgical procedure. In situ microwave ablation makes it possible to excide the bone tissue with tumor intrusion by segments and lessen the surgery time and the blood loss during the surgery.

5. Microwave ablation can keep the integrity of the tumor infected bone structure and avoid the difficulty and complications caused by reconstruction procedure on the site of bone defect.

6. Microwave ablation on the bone tissue intruded with tumors or microwave ablation on the bone tissue after the procedure of removing

the tumor can prevent the metastasis of tumor cells and reduce recurrence rate.

7. With patients limb salvation is a goal, in situ isolation and microwave ablation can keep the structure of bone and joints, which avoids large bone defects, which helps save the function of the limb.

8. Studies have confirmed that microwave ablation can preserve the activity of growth factors at the lesion site, and promote the recovery of bone tissue and functional reconstruction. [7-10] microwave ablation induces the production of heat shock protein and increase the function of T-cells, natural killer cells, macrophage which strengthens the immunity system and inhibit the spreading of tumor cells [11]

9. Low expense: the heat produced by microwave destroys the blood vessels of tumor and decreases the blood loss during the surgery [7]. As a result, complexity and complications of surgery and the time needed for the operation will be decreased.

10. Microwave ablation can heat tissues faster with larger ablation zones, a characteristic that may contribute to less recurrence rate [12,13].

Comparing with another similar method of heat ablation-radiofrequency ablation, microwave has several advantages such as faster heating, larger volume of necrosis as well as less susceptibility to heat sinks or local perfusion [14]. Moreover, the low electrical conductivities of lung and bone will likely hamper RF current flow but permit better microwave propagation.

Complications of Microwave Ablation

Despite the unique qualities of microwave ablation, there are several possible complications that should be recognized and efforts should be paid to avoid.

1. If the heat energy is not controlled adequately, it may cause damage on the tissues around the tumor [11,15,16]. When the temperature reaches a threshold, synthesis of DNA, RNA and protein of the affected cells will be hampered, which changes the plasmalemmal permeability and function of biomembranous, increases the activity of cyrolysosome, which causes coagulation necrosis and cell death [17]. So it is necessary to keep the heat temperature steady and under certain level to protect surrounding normal tissues safe. From our experience, placing a gauze in between the tumor and normal tissue along with continuous perfusion of cold sodium may effectively reduce the damage of heat to the surrounding normal tissues. However, it should be kept in mind that normal saline within 2 cm from the antenna tip actually propagates the energy rather than protects the surroundings. If the lesion is near a joint, the join cavity should also be irrigated with cold sodium to prevent cartilage, ligament, vessels and nerves from thermal injury.

2. Pathological fracture: although in-situ microwave ablation preserves the anatomical structure of the lesion, but there is often a defect caused by ablation: loss of calcium phosphorus of bone tissue during the ablation process decreases the biomechanical properties of the bone, which makes the bone liable to pathologic fracture. New bone can be generated by filling the defect with bone allografts and composite materials. In weight bearing areas, further structural support is necessary; augmented osteoplasty with metallic material and polymethyl methacrylate (PMMA) can be viable option for such purposes.

3. Nerve lesion and poor wound healing: although there are not many reports of microwave ablation's effect on nerves, but we found it is a complication with rather high incidence rate. We assume there can be several reasons for the occurrence of nerve lesion with microwave ablation. For example, nerves can be injured by the radiation heat if the isolation and protection of surrounding normal tissues from the tumor under microwave ablation therapy. In the course of isolating the surrounding tissues, nerves can be over compressed or dragged, causing stenosis or spasm of nerve vessels.

Incision, especially ones near proximal tibia may not be easily healed since the microwave ablation can destroy the soft tissues and blood supply around the incision. Shifting of medial gastrocnemius muscle to cover the anterior tibia is an effective method to promote healing of incision in this region.

Clinical Application of Microwave Ablation

Microwave ablation has been widely applied in the clinical treatment of bone and soft tissue tumors in the last a few years. From the published records in English and Chinese language literature (Table1) [18-34], microwave ablation had been used as a complimentary method for the treatment of different variety of musculoskeletal tumors and in most cases gained satisfactory results.

Challenges and Prospective for Microwave Ablation

To use microwave ablation more safely for broader spectrum of musculoskeletal tumors, there are still several challenges to overcome.

1. The amount of energy that needed for the microwave ablation still needed to be explored. Heat should be decided considering the character, size and shape of the tumor, a formula to calculate the approximate amount of energy output can be developed to provide individualized form of treatment for each patient.

2 The temperature and time of microwave ablation: currently it is believed that 5-10 min of microwave ablation treatment with the temperature of 50℃ can effectively cause necrosis to the targeted tumor. However, normal tissues can be affected under the heat of high temperature over a long time. Lower temperature and shorter time for specific tumors can be studied and applied to avoid complications of microwave ablation on normal cells.

3 Protection of normal tissues during microwave ablation procedure: so far there are not many studies concerning the protection of normal tissues around targeted tumors. New techniques to restrain the microwave energy within a targeted region should be developed to use microwave ablation safer in the future.

4. How to restore and keep the strength of the structure of bone after the microwave ablation procedure is still a main concern since there was considerable number of patients who suffered from pathological fracture soon after they underwent microwave ablation. Techniques involving autografts, allografts as well as artificial implants may provide us possibilities to avoid pathologic fractures after microwave ablation.

5. Frequency of microwave: Currently the main frequency used in microwave ablation technique 2450MHz or 915MHz. Pereira et al [31] have proven that microwave systems at 2450MHz provide better and more predictable results. Using 915- MHz and 2450-MHz microwave ablation for porcine livers, Sun et al found that under the same power output (50,60,70,80W), peak temperature with the 915 MHz cooled-

shaft antenna was significantly higher than that with the 2450 MHz cooled-shaft antenna ($p<0.05$) and the short- and long-axis diameters for the 915 MHz cooled-shaft antenna were significantly larger than those for the 2450 MHz cooled-shaft antenna ($p< 0.05$) [35]. It is still necessary to find more appropriate and specified microwave length for the nature and diameter of tumors.

6. Effective and safe combined application of multiple antennas: One needle insertion has relatively inadequate ablation area while multiple needle insertions require long operation time and result in increasing radiation exposure for the patient. Single and double-slot coaxial antennas have been compared by several authors, and it was shown that double-slot antennas create a more localized heating [36,37].

Author, year	Patient no	Frequency:MHz	Power (W)	Temperature (ºC)		Time (min)	Pain (VAS)	Function	Complications	Comments
				Center	Surface					
Guo 2009 (23)	31	2450	20-80			30-May	Pain disappeared:6; alleviated:7	Excellent:9; fine:18; fair: 4		
Zhang2012 (24)	9	2450	800	108-120	50- 60	30- 40		Fine7 fare :2		
Fan 2009 (25)	152	2450		70-80		30		Fine:129;fare: 15	Recurrence:17; infection: 6;frature 2; cartilage lesion4	
Zhu 2008 (26)	12	2450		50-85		30	preop: 5.5;postop:3.5	Fine 7; fair: 5		Spinal tumors
Wei 2008 (27)	18	2450		100	50	20-30		Excellent:14;fine:2;fair:1; worse:1		Knee lesions
Wang 2012 (28)	32	2450		80				Fine: 28;fare: 4		GCT
Hu 2011(14)	17	2450			50	20		Fine: 9; fare:1; worse: 7		
Zhang 2012(29)	5	2450	80-120					Excellent: 2;fine:1		
Yang 2012 (30)	73	2450	80-100		50	20-30			Fracture 4; deep infection:2; necrosis in edge of skin8	
Zhang 2011(31)		2450	80-120	>50	50	20-30		Excellent:5;fine:4same 1		
Ren 2013 (32)	11	2450	800	80		20		Excellent8; fine3	Recurrence1	GCT
Zhou 2002 (33)	46	2450	800						Recurrence2;infection2	GCT
Fan 2009 (34)	309	2450		70-80		30			Recurrence:37;fracture: 25;infection:9	
Basile 2013(35)	7	2450	20			2	Preop2-6;Postop 1			Osteoosteoma
Kastler2013(36)	15	2450	30-1800			16	Preop: 7.2±0.97;Postop: 1.64±1.87			

Table1: Studies on the application of microwave ablation on bone tumors

Conclusion

In bone tumors treatments, microwave ablation has the advantage of penetrating deeper and being more effective than RFA, due to the bone's low conductivity and relative permittivity [15,38]. Our model predicts, indeed, relatively large ablation zones, which continue to rise with longer application times, due to bones' low perfusion rate, as previously explained. Currently, most of the treatments are limited to pelvis; however research is done for potential applications of microwave ablation in osteoid osteomas. As smaller and case-specific zones could be needed for such treatments, the "disk-shaped" heating of square array configurations could be preferred. We have not found any experimental or clinical studies with arrays in bone tissues to compare and validate our results.

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