Stereotactic Technique for Radio-frequency Antenna Implantation for Brain Tumor Treatment — Technical Note and Report of Complications —

HIDEAKI TAKAHASHI*, RYUICHI TANAKA, TAKEO UZUKA, IGOR GRINEV

Department of Neurosurgery, Brain Research Institute, Niigata University 1-757 Asahimachi-dori, Niigata 951-8585, Japan

Abstract: Purpose: Over the past 20 years we have developed techniques and clinical experience of radio frequency (RF) interstitial hyperthermia. This technique is particularly applicable in the treatment of unresectable tumors and in the management of elderly patients with malignant brain tumors. In this report, we introduce stereotactic intratumoral implantation of electrodes (RF antennas) for interstitial hyperthermia and we also present the achievement and complication rate. Our objective was to assess the feasibility of the stereotactic implantation technique for brain hyperthermia.

Methods: A total of 144 procedures (108 for gliomas, 24 for metastatic tumors, 5 for malignant lymphomas, 5 for meningiomas, and 2 for other tumors) have been performed to treat 125 patients with hyperthermia for brain tumor. RF antennas and catheters for thermistor probes were inserted into the tumor using a stereotactic apparatus under local anesthesia. We confirmed the electrode position in the tumor and complications such as hemorrhage in postoperative craniogram and brain computed tomography (CT).

Results: The numbers of RF antenna insertions were one in each of 85 cases, two in 43 cases, three in 2 cases, four in 12 cases, five in 1 case, and six in 1 case. Surgical insertion of RF antennas was achieved successfully in 138 of 144 procedures (95.8%). In six of these patients, intratumoral hemorrhage was observed after surgery in 3 patients, one patient had liquorrhea, and antennas were misimplanted in another 2 patients. Incompletion rate was 4.2%.

Conclusion: Stereotactic implantation of RF antennas was a safe and effective technique for interstitial hyperthermic treatment of brain tumors.

Key Words: complication, interstitial hyperthermia, stereotactic technique

Introduction

Hyperthermia has been reported as an effective experimental treatment modality for cancer therapy. Clinical application has also been trialed in some organs. However, because heating

Received 27 July 2005, Accepted 8 September 2005. *Corresponding author, Phone: +81-25-227-0651; Fax: +81-25-227-0819; E-mail: takahash-nii@umin.ac.jp
methods at tumor sites are so varied, it is difficult to say that an optimal heating method has been established\(^5-11\). Similarly in brain tumors, various heating methods have been used to date\(^5-11\).

We have used radio frequency (RF) interstitial hyperthermia since 1990 at our institution\(^12-14\), and RF capacitive heating methods in the 1980s\(^15\). Interstitial hyperthermia employs needle type electrodes, it is a method for heating the tumor centrifugally, and it is necessary to hold the needle electrode at the center of a tumor for hyperthermic treatment.

Fortunately, using a biopsy technique for brain tumors, it is not difficult to hold electrodes at tumor centers in a predetermined manner by using a stereotactic apparatus\(^16\). At the same time, the biopsy can be accompanied by hyperthermic treatment as an added value.

We discuss the technology and complications associated with the implantation of electrodes for RF interstitial hyperthermia in this report.

**Material and methods**

**Hyperthermia**

A needle-shaped, 130-mm-long applicator (RF antenna) with a diameter of 1 mm was used (Fig. 1). The frequency of RF generator used for hyperthermia was 13.56 MHz. Thermistor probes were positioned in catheters inserted into the tumor. The temperature was recorded at the edge of the tumor or at the border of eloquent areas (internal capsule, motor cortex and speech center). RF antennas and catheters for thermistor probes were inserted into the tumor using a stereotactic apparatus under local anesthesia. RF antenna was placed in the center of tumor which diameter was less than 3 cm because the heating width with one RF antenna is limited to about 3 cm. One to five additional antennas were stereotactically implanted spacing at 1.5-2.0 cm intervals in tumor which diameter was over 3 cm depending on the volume of tumor. Recently, it is possible to calculate adequate tumor coverage for the decision of the number of antenna by preoperative computer simulation. The operation time was ordinarily 40 min. Figure 2-a illustrates typical RF antenna positioning, and parallel and radial catheters for thermistor probes. Figure 2-b is a bone window CT and shows an RF antenna (A), parallel catheter (P) and radial catheter (R). Figure 2-c and 2-d are preheating and post-heating CT. The tumor had necrosis in an enhanced area after hyperthermia.
The head ring of the stereotactic apparatus was secured to the patient using pin fixation under local anesthesia. CT with contrast enhancement was then obtained. The positions of implanted RF antennas and the approach direction of the catheters for thermistor probes were determined using CT scans.

Intraoperative procedure is shown in Fig. 3. Figure 3-a shows skull-drilling with an electric twist drill, 3-b shows the insertion of a stereotactic probe into the target, 3-c shows implantation of an RF antenna along the stereotactic probe, 3-d shows implantation of the radial catheter, 3-e shows fixation of 3 implants and 3-f shows a tumoral biopsy specimen.

CT scans were made to assess the position of antennas and catheters for thermistor probes after operation. Hyperthermic treatment was performed in 3 to 9 sessions with and without radiation. The
treatment time was 40-60 min at 42°C as measured by thermistors at the margin of the tumor lesion.

An RF generator (HEH250 or HEH50, OMRON Co., Kyoto) was used between RF antennas in the brain and external electrode on the anterior chest wall. The catheters and antennas were explanted maximally 2 weeks after placement, when the treatment was completed. Steroids were continued until CT demonstrated reduction of edema.
Patients

A total of 144 procedures (108 for gliomas, 24 for metastatic tumors, 5 for malignant lymphomas, 5 for meningiomas, and 2 for other tumors) in 125 patients with brain tumors to be treated with hyperthermia were preformed and the patients underwent implantation surgery for RF antennas and catheters for thermistor probes.

Results

Numbers of RF antennas

The numbers of RF antenna insertions were one in each of 85 cases, two in 43 cases, three in 2 cases, four in 12 cases, five in 1 case and six in 1 case.

Completion rate

Surgical insertion of RF antennas was achieved successfully in 138 of 144 procedures (95.8%). In six of these patients, 3 patients were observed to have intratumoral hemorrhage after surgery, one patient

Fig. 4.
had liquorhea, and another 2 patients had misimplanted electrodes. Incompletion rate was 4.2%.

Figure 4 shows a representative case. Figure 4-a is a preoperative CT scan and it shows a left frontal glioblastoma with ring enhancement. Figure 4-b and 4-c are postimplantation CT scans. Four RF antennas were implanted into the square of the tumor. Figure 4-d shows posttreatment CT scans and the necrosis of the tumor due to hyperthermia.

Complications

Intratumoral hemorrhage was observed in five patients. Three of these patients had massive hematoma and hyperthermic potentiation was discontinued; the remaining 2 cases had only a small amount of hemorrhage and treatment was continued. Liquorrhea (one case), infection (two cases), and dislocation of RF antennas (two cases) were also noted.

Figure 5 shows a representative case with complication. Figure 5-a is a preoperative CT scan and shows a right thalamic glioma with hydrocephalus. Postoperative CT revealed intratumoral hemorrhage (Fig. 5-b). The patient underwent a craniotomy and evacuation of the hematoma. Then, the patient underwent radiotherapy alone without hyperthermia. Figure 5-c shows posttreatment CT, and the tumor is seen to remain.

The hyperthermic treatments were rather well tolerated.
Discussion

Various hyperthermic treatments have been clinically applied to brain tumors. Methods such as microwave treatment, RF, and ferromagnetic implants have been used, but there is no currently established method. In brain tumors, indication for hyperthermia is malignant glioma. This is because surgical removal of deep-seated malignant gliomas is contraindicated, and surgery tends to be used only for biopsy. Using a stereotaxic instrument, biopsy is performed using a burr-hole method under local anesthesia, and a specimen is obtained from the tumor center. RF antenna implantation is performed after having obtained tissue in a 3-mm probe from a 3.8-mm burr hole made using an electric burr. It is a characteristic of brain hyperthermic treatment that electrode implantation can be performed in a predetermined precise manner using a stereotaxic instrument. In hyperthermic treatment of the brain, two functional points are required to avoid edema: not heating an area beyond 43°C and RF electrode positioning.

Malignant gliomas have a central necrosis, and active tumorous tissue forms their circumference. The tumor shows an area of contrast enhancement on CT or MRI that lies scattered out in the circumference. The reasons that interstitial hyperthermic treatment is chosen for malignant glioma are as follows. Firstly, hyperthermic potentiation is suitable to heat the tumor center because there is little blood flow there. Secondly, the effect of radiotherapy and chemotherapy on the tumor center is inferior. It is thought in particular that interstitial hyperthermia in which temperature distribution acts centrifugally on the tumor is reasonable for the treatment of malignant glioma.

Specific technology is not needed for RF antenna implantation; routine brain stereotactic biopsy techniques are used. We make a small perforation in the skull using an electric burr and insert the RF antenna into the tumor using a specific probe. It is easy to position a catheter for a thermistor probe perpendicular to an electrode inserted in the tumor center with a stereotaxic instrument, and intratumoral temperature distribution can then be known during the nearby heating in real time. There is a tendency to use a template for the electrode implantation at other sites where hyperthermia has been used, but a template is unnecessary where a stereotaxic instrument is available. In addition, a stereotaxic instrument
is advantageous because its accuracy is higher than that of template placement. We can use the tumor border as a reference point for precise placement of the thermistor catheter, and this can then be used to monitor the heating of the tumor to 42-43°C.

There is a report concerning the complications of biopsy by stereotaxic technique based on the experience of 201 cases in our institute. Hemorrhage as a maximal complication of tumor biopsy is found in around 2% of cases. Hemorrhage in a tumor as a complication was present in 5 cases of electrode implantation surgery, and in 3 cases hyperthermic treatment was not possible. In addition, we often found that neurological symptoms worsened after biopsy and electrode implantation in malignant glioma. Brain edema became intense in two cases; hyperosmotic solution and steroid were used after the electrode implantation. Because an electrode is directly inserted through a small skin incision, liquororrhea and infection was experienced in this series. It was important to use a steroid for malignant glioma patients. However, this problem is resolved due to electrode removal 2 weeks after treatment. The mislocation of electrodes is also a major problem, in which case it is impossible to treat the tumor hyperthermically. An error in the use of the stereotaxic instrument, an error in CT planning or a gap in the small burr hole is regarded as elements of mislocation. The single largest cause of placement errors is an electrode fixation gap on the scalp.

The achievement of a 98% yield in correct electrode implantation without many complications rates this as a suitable surgical procedure. However, the future establishment of a noninvasive heating method is desirable.

References
脳腫瘍に対する組織内加温用電極の定位的挿入法について
—テクニックと合併症について—

高橋英明・田中隆一・宇塚岳夫・Grinev Igor

新潟大学脳研究所脳神経外科

要　旨　[目的] これまで我々は摘出術の不可能な脳腫瘍に対して 13.56 MHz RF 組織内温熱療法を試みてきた。今回、組織内加温用の電極 (RF アンテナ) の定位的腫瘍内刺入、留置法についてその達成率、合併症について検討した。

[方法] 脳腫瘍 125 例、144 回の電極設置術施行例を対象とした。内訳は神経膠腫 108 例 (初発 54, 再発 54 例), 転移性脳腫瘍 24 例, 悪性リンパ腫 5 例, 頸部腫瘍 5 例, その他 2 例である。設定手術は、局所麻酔下に定位脳手術装置を用い、直径 1mm の針状電極と温度センサー用のカテーテルを刺入、留置した。術後頭蓋単純写および頭部 CT にて腫瘍内電極位置と出血などの合併症の有無を確認した。

[結果] 電極を 1, 2, 3, 4, 5, 6 本挿入した症例はそれぞれ 85, 43, 2, 12, 1, 1 例であった。144 例中、138 例は適切な位置に電極ならびにカテーテルが設置され、温熱治療を施行し得た (95.8%)。一方、3 例に術後出血を認め、2 例は電極の位置が不適切であり、1 例は髄液漏となり計 6 例 (4.2%) が温熱治療未実施におわった。

[結語] 組織内温熱治療のため、定位的電極およびカテーテル設置術は安全でかつ有効な方法であった。