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Workshop

Open-Configuration MR-Guided Microwave Thermocoagulation Therapy for Metastatic Liver Tumors from Breast Cancer

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Background: Liver metastases from breast cancer are associated with a poor prognosis, however, local control with microwave thermocoagulation therapy has been used in certain subgroups of these patients in the past decade. In this study, open-configuration magnetic resonance (MR) -guided microwave thermocoagulation therapy was used for metastatic liver tumors from breast cancer, and the efficacy of this treatment was assessed.

Methods: Between June 2000 and April 2004, we used MR-guided microwave thermocoagulation therapy on 11 nodules in 8 patients with metastatic liver tumors from breast cancer. The procedure was carried out under general anesthesia. A 0.5 T open-configuration MR system and a microwave coagulator were used. Near-real-time MR images and real-time temperature images were collected and displayed on the monitor. The MR-compatible thoracoscope was used and combined with MR imaging guidance. Navigation software, a 3D Slicer, was installed and customized.

Results: The customized navigation software displayed near-real-time MR images. The percutaneous puncture into the tumors was successful in all cases. No mortality or major complications occurred as a result of the procedures. Five of the 8 patients are alive with new metastatic foci with a mean observation period of 25.9 months.

Conclusions: We developed several devices to allow safe, easy, and accurate MR-guided microwave thermocoagulation therapy of liver tumors. Open-configuration MR-guided microwave thermocoagulation therapy appears to be a feasible method for tumor ablation of metastatic liver tumors from breast cancer.

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Key words: Breast Cancer, Liver metastasis, Magnetic resonance (MR) guidance, Microwave ablation

Metastatic liver tumors from breast cancer are a common clinical problem associated with a poor prognosis that is due to disseminated disease requiring systemic, rather than local, therapy, even if metastasis appears to be limited to a single organ. However, it has been reported that in 5 to 12% of patients metastases can be confined to the liver[1, 2]. There have been recent reports of improved survival in patients undergoing surgical resection of limited liver metastases from breast cancer[3, 4].

In recent years, minimally invasive surgical procedures for the treatment of cancer such as percutaneous ethanol injection therapy[5], cryotherapy[6], laser therapy[7], radio-frequency (RF) interstitial thermal ablation therapy[8], and microwave thermocoagulation therapy[9] have been rapidly developing. Various clinically available imaging modalities have been used for guidance. Among them, magnetic resonance (MR) imaging possesses many advantages, because it is free of ionizing radiation, produces good soft-tissue contrast, is useful even with bone and air spaces, and has multiplanar multisection capabilities. An open-configuration MR system, which was specially designed for intraoperative use, enabled us to employ new minimally invasive surgical techniques with MR imaging guidance[10]. We began our clinical studies of MR-guided microwave thermocoagulation therapy of liver tumors in 2000[11].

In this study, open-configuration MR-guided

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Abbreviations:
MR, Magnetic resonance; RF, Radio-frequency

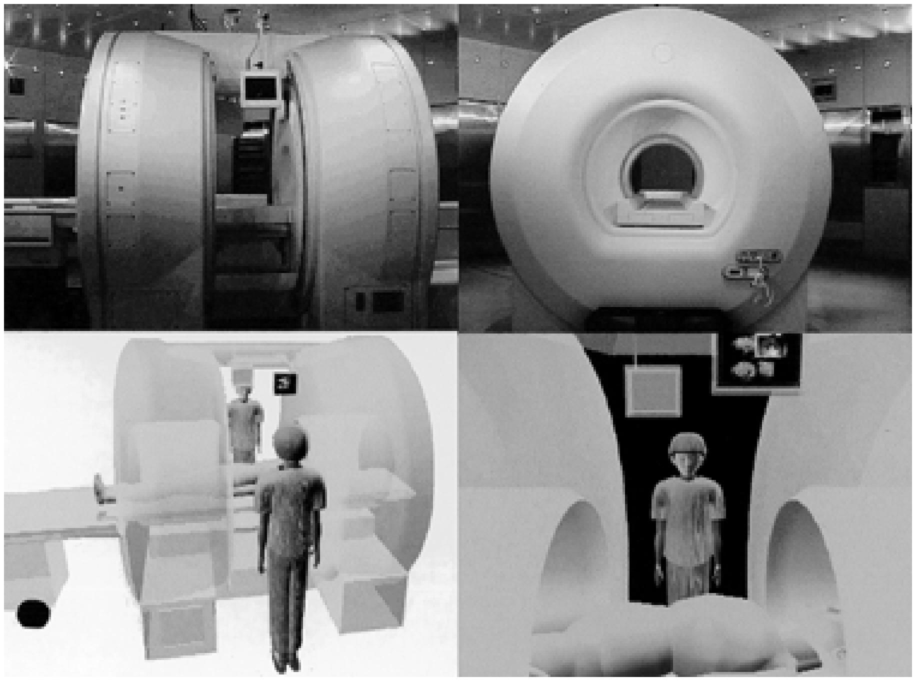

Fig 1. Open-configuration 0.5 T superconducting MR imaging system (SIGNA SP/i).

microwave thermocoagulation therapy was used for metastatic liver tumors from breast cancer, and the efficacy of this treatment was assessed.

Patients and Methods

Patients

To evaluate the efficacy of microwave thermocoagulation therapy for local control of liver metastases from breast cancer, the inclusion and exclusion criteria for entry into the study were established as follows: 1) the object of treatment was limited to 5 lesions in each patients; 2) the size of the lesion was $<$ 3.0 cm in diameter, and patients having a 3.0 cm or greater lesion underwent transcatheter arterial embolization; and 3) the patients were free of major coagulation disorders and hepatic failure.

Between June 2000 and April 2004, we used MR-guided microwave thermocoagulation therapy at our hospital on 11 individual metastatic liver tumors from breast cancer, measuring 10-55 mm (mean, 22.4 mm), in 8 consecutive patients who had previously undergone resection of their primary tumors. All patients were women with a mean age of 49.0 years (range, 41-69 years). At presentation, 4 of the 8 patients had metastases confined to the liver, whereas the other 4 patients also had metastases to the other sites (lung metastases in 2 patients, bone and lung metastases in 1 patient, and bone metastases in 1 patient). The ethics committee of Shiga University of Medical Science approved this study. The procedure and any possible complications related to this type of therapy were explained to each patient, and signed informed consent was obtained from the subjects.

Methods

All MR imaging was performed with a 0.5 T superconducting system (SIGNA SP/i; GE Medical Systems, Milwaukee, WI) (Fig 1). Near-real-time MR images were obtained with a spoiled gradient-echo sequence. The acquisition time for one image was less than 2 seconds. An interactive image plane control system, FlashPoint model 5000 (Image Guided Technologies, Boulder, CO) was integrated with this MR system. The image plane could be controlled by the surgeon with a hand-piece having a needle guide at the center and three light-emitting diodes on the three pedicles (Fig 2). Two liquid crystal displays were prepared between the two magnets to show the surgeons the MR images for navigation. A microwave coagulator (Microtaze, OT-110M; Azwell, Osaka, Japan), operating at 2.45 GHz, was used as a heating device. MR-compatible needle-type electrodes

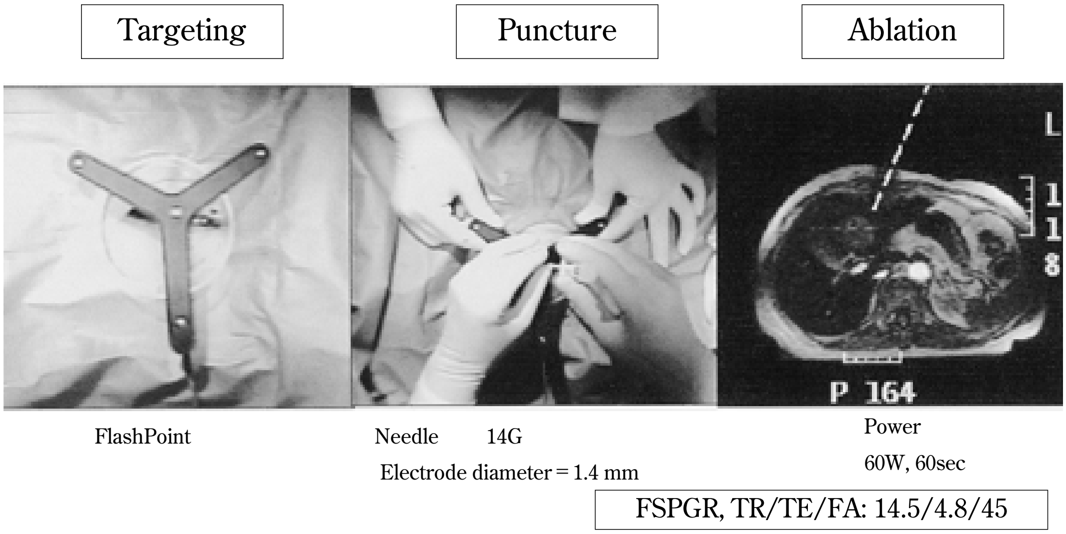

Fig 2. Procedure of MR-guided microwave thermocoagulation therapy: targeting, puncture, and ablation.

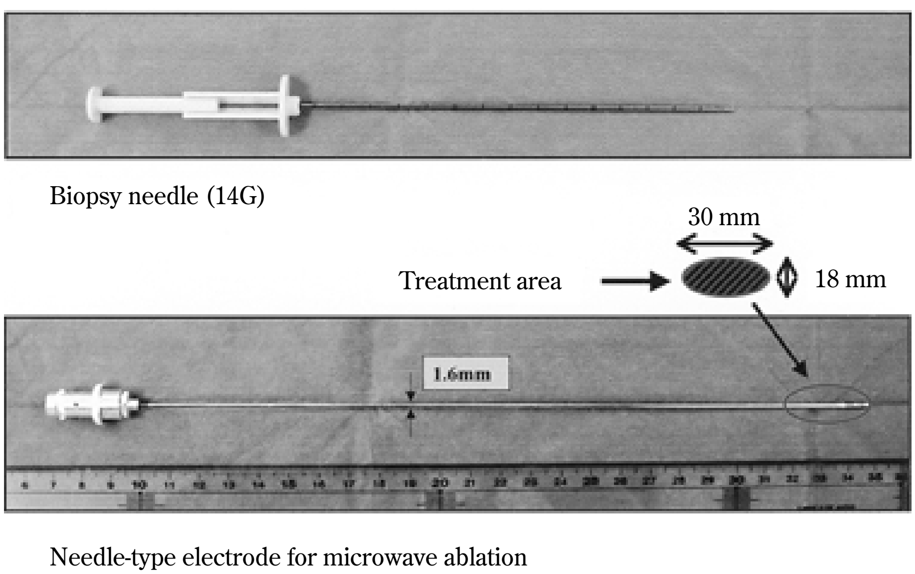

Fig 3. MR-compatible needle and electrode for microwave thermocoagulation therapy.

(250 mm long, 1.6 mm in diameter) were made of brass coated with silver and gold (Fig 3).

After the patient underwent general anesthesia, the MR-compatible biopsy needle (Daum, Schwerin, Germany) under the guidance of near-real-time MR imaging was used to insert an electrode into the tumor through the outer sheath of the needle. Microwave ablation was carried out at 60 W for 60 seconds. Usually, three ablations were repeated at the same points. Preliminary studies during laparotomy revealed such ablations caused an oval-shaped coagulated area 20 mm in diameter and 30 mm in length along the axis of the electrode. Ablation and puncture were repeated depending on the size and number of tumors.

Temperature changes in individual pixels were calculated by the proton resonance frequency method[12] using a Real Time Image Processing application in the SIGNA SP/i system, which was modified to display temperature increase values. Real-time temperature images during ablation were displayed on the surgeon's monitor with a color scale (Fig 4). For the treatment of tumors located just below the diaphragm, the MR-compatible thoracoscope was used and combined with MR imaging guidance.

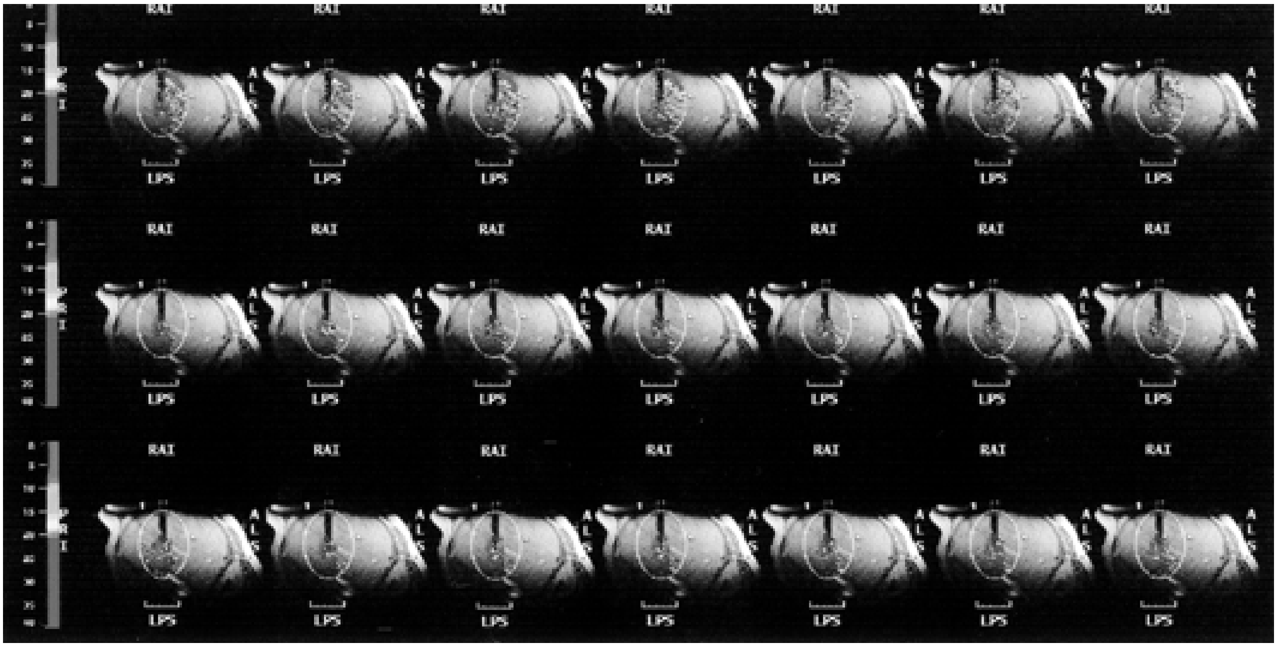

Fig 4. Thermal mapping during microwave thermocoagulation therapy. Around the electrode tip, temperature increase was clearly observed.

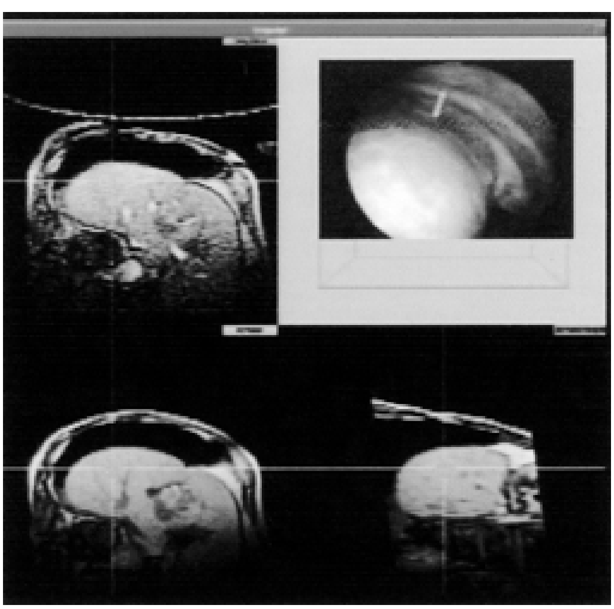

Fig 5. Display of the navigation software (3D Slicer) during near-real-time imaging navigation for thoracoscope- assisted microwave thermocoagulation therapy. The upper left is a near-real-time MR image, thoracoscopic image shows a needle through the diaphragm, and below it are two reformatted images from the three-dimensional data.

Navigation software, a 3D Slicer[13, 14], was installed in an independent SUN Ultra 60 workstation (Sun Microsystems, Santa Clara, CA) and connected with the MR scanner by a network cable. The 3D Slicer could display a fluoroscopic MR image in combination with two reformatted images (same and perpendicular planes to the fluoroscopic MR image) from preoperative high resolution three-dimensional volume data (Fig 5). Recently, a new function, footprinting, which recorded and displayed football shaped coagulated areas (footprints) 20 mm in diameter and 30 mm in length along the electrode in the 3D space, was introduced to the 3D Slicer. The direction of the electrode was obtained from the information of the FlashPoint system. The footprint was placed along the direction of the electrode and its position was manually adjusted along the axis of the coordinates determined by the electrode, while the fluoroscopic MR images showed the electrode tip[15].

Results

Imaging Findings

The percutaneous puncture into the tumors was successful in all cases. Even if ablations were repeated, the visibility of the tumor by MR imaging was not disturbed throughout the procedure. The thoracoscope was used to ensure that the lung was not injured by the puncture process and to detect any bleeding from the diaphragm or chest wall, which was easily stopped by the microwave coagulator. The 3D Slicer was customized to pro-

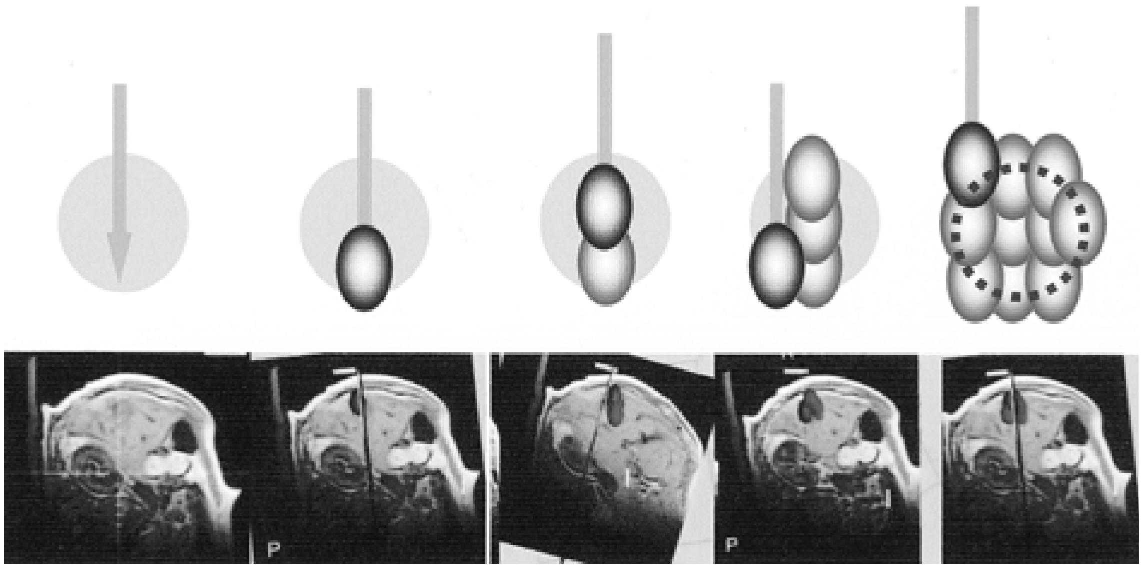

Fig 6. Footprinting of the coagulated areas by microwave ablation. Football-shaped footprints were placed at the locations of the heating center along the axis of the electrode.

vide safe, easy, and accurate near-real-time image-guided navigation. The combined display of the tumor area and the footprints clearly demonstrated already treated and nontreated areas, and specifically indicated to the surgeons which part should be treated next (Fig 6).

Treatment Efficacy

Of the 11 metastatic tumors, 10 showed complete necrosis, not only of the tumor area but also of the neighboring noncancerous tissue after microwave thermocoagulation had been repeated 3-10 times for each tumor. In one other tumor, microwave ablation was found to be incomplete. In this case, complete ablation was not possible because of multiple and large tumors. To date, 5 of the 8 patients are alive with new metastatic foci with a mean observation period of 25.9 months (1-43 months).

Side Effects and Complications

Serum aspartate and alanine aminotransferase levels generally increased up to two to three times the baseline values transiently after each treatment but they normalized by one to two weeks postoperatively. No changes were observed in other serum levels.

No mortality or major complications occurred as a result of the procedures. Only one patient developed a high fever, which resolved after 1 week.

Discussion

Metastatic breast cancer generally is managed with systemic, rather than local, therapies. Recently, minimally invasive surgical procedures for the treatment of cancer such as ethanol injection therapy, cryotherapy, laser therapy, RF therapy, and microwave thermocoagulation therapy have been rapidly developing. For patients with metastatic breast cancer, percutaneous local treatment should satisfy most of the following requirements in addition to destroying the lesion: safety, expense, ease of operation, and effectiveness. These are all factors that should be considered in determining the optimal treatment for liver metastases from breast cancer.

MR imaging possesses good soft tissue contrast and is applicable even if either bone or an air space lies between the puncture point and the target. In addition, MRI can monitor tissue temperature changes during the procedure. Laser beams do not generate RF noise in MR images, but control of transmission is not necessarily easy because it is affected by tissue color or carbonization. An RF generator can be a source of electromagnetic noise in MR images. Various types of RF generator have been applied to reduce the electromagnetic interference in MR images. Some investigators have reported on the feasibility of microwave thermocoagulation under the MR imaging guidance[16]. Recently, microwave thermocoagulation therapy has been established as a useful treatment of liver tumors[17].

In the present study, open-configuration MR-guided microwave thermocoagulation therapy showed satisfactory therapeutic efficacy for local cancer control. For near-real-time MR imaging, T1-weighted imaging with a spoiled gradient-echo sequence was used because of its short acquisition time. The customized 3D Slicer navigation software was useful in overcoming these limitations of near-real-time MR imaging navigation. The high-resolution three-dimensional data clearly depicted not only the target but also the surrounding vascular structures. The display of reformatted images in the two perpendicular planes was also useful for navigation in three-dimensional space, because two-dimensional near-real-time images did not include such information. As a result, surgical navigation was accomplished more accurately and safely with the customized navigation software. Near-real-time MR images showed not only the needle position but also any tissue movement or shape change.

In conclusion, we developed several devices to allow safe, easy, and accurate MR-guided microwave thermocoagulation therapy of liver tumors. Although this method requires refinement and further assessment, open-configuration MR-guided microwave thermocoagulation therapy appears to be a feasible method with several advantages to ablate tumors from metastatic breast cancer.

References

1) Zinser JW, Hortobagyi GN, Buzdar AU, Smith TL, Fraschini G: Clinical course of breast cancer patients with liver metastasis. *J Clin Oncol* 5:773-782, 1987.
2) Hoe AL, Royle GT, Taylor I: Breast liver metastases: incidence, diagnosis and outcome. *J R Soc Med* 84:714-716, 1991.
3) Elias D, Lasser PH, Montrucolli D, Bonvallot S, Spielmann M: Hepatectomy for liver metastases from breast cancer. *Eur J Surg Oncol* 21:510-513, 1995.
4) Yoshimoto M, Sugitani I, Iwase T, Watanabe S, Kasumi F: Therapeutic efficacy of hepatectomy in the treatment of hepatic metastases from breast cancer. *J Jpn Surg Soc* 96:174-179, 1995 (in Japanese with English abstract).
5) Livraghi T, Vettori C, Lazzaroni S: Liver metastases: Result of percutaneous ethanol injection in 14 patients. *Radiology* 179:709-712, 1991.
6) Ravikumar TS, Kane R, Cady B, Jenkins RL, McDermott W, Onik G, Clouse M, Steele G Jr: Hepatic cryosurgery with intraoperative ultrasound monitoring for metastatic colon carcinoma. *Arch Surg* 122:403-409, 1987.
7) Nolsoe CP, Torp-Pedersen S, Burcharth F, Horn T, Pedersen S, Christensen NE, Olldag ES, Andersen PH, Karstrup S, Lorentzen T: Interstitial hyperthermia of colorectal liver metastases with a US-guided Nd- YAG laser with a diffuser tip: a pilot clinical study. *Radiology* 187:333-337, 1993.
8) Rossi S, Di Stasi M, Buscarini E, Quaretti P, Garbagnati F, Squassante L, Paties CT, Silverman DE, Buscarini L: Percutaneous RF interstitial thermal ablation in the treatment of hepatic cancer. *A J R* 167:759-768, 1996.
9) Tabuse K: A new operative procedure of hepatic surgery using a microwave tissue coagulator. *Arch Jpn Chir* 48:160-172, 1979.
10) Schenck JF, Jolesz FA, Roemer PB, Cline HE, Lorensen WE, Kikinis R, Silverman SG, Hardy CJ, Barber WD, Laskaris: Superconducting open-configuration MR imaging system for image-guided therapy. *Radiology* 195:805-814, 1995.
11) Morikawa S, Inubushi T, Kurumi Y, Naka S, Sato K, Tani T, Yamamoto I, Fujimura M: MR-guided microwave thermocoagulation therapy of liver tumors: initial clinical experiences using a 0.5 T open MR system. *J Magn Reson Imaging* 16:576-583, 2002.
12) De Poorter J, De Wagner C, De Deene Y, Thomsen C, Stahlberg F, Achten E: Noninvasive MRI thermometry in human muscle. *Magn Reson Med* 33:74-81, 1995.
13) Jolesz FA, Nabavi A, Kikinis R: Integration of interventional MRI with computer-assisted surgery. *J Magn Reson Imaging* 13:69-77, 2001.
14) Gering DT, Nabavi A, Kikinis R, Hata N, O'Donnell LJ, Grimson WE, Jolesz FA, Black PM, Wells WM 3rd: An integrated visualization system for surgical planning and guidance using image fusion and an open MR. *J Magn Reson Imaging* 13:967-975, 2001.
15) Morikawa S, Inubushi T, Kurumi Y, NakaS, Sato K, Demura K, Tani T, Haque HA, Tokuda J, Hata N: Advanced computer assistance for magnetic resonance-guided microwave thermocoagulation of liver tumors. *Acad Radiol* 10:1442-1449, 2003.
16) Moriarty JA, Chen JC, Purcell CM, Ang LC, Hinks RS, Peters RD, Henkelman RM, Plewes DB, Bronskill MJ, Kucharczyk W: MR monitoring of interstitial microwave-induced heating and thermal lesions in rabbit brain in vivo. *J Magn Reson Imaging* 8:128-135, 1998.
17) Seki T, Wakabayashi M, Nakagawa T, Itoh T, Shiro T, Kunieda K, Sato M, Uchiyama S, Inoue K: Ultrasonically guided percutaneous microwave coagulation therapy for small hepatocellular carcinoma. *Cancer* 74:817-825, 1994.