Image-guided Percutaneous Thermal Ablation of Bone Tumors[1]

Dietrich H. W. Groenemeyer, MD, Sven Schirp, Athour Gevargez, MD

Bone is the third most common site of metastatic disease. Metastases from carcinomas of the breast, lung, prostate, kidney, and thyroid are most frequent, resulting in lytic, sclerotic, or mixed soft-tissue lesions. In particular, the incidence of bone involvement can exceed 90% in metastatic breast and prostate carcinomas, reflecting both the high incidence and relatively long clinical course of these tumors (1–3). The principle symptoms of bone tumors are pain, sensorimotor disorders, and, in cases of fractures, instability. Patients often experience bone pain, which may be intermittent or constant. In patients with advanced cancer, pain is frequently severe and causes considerable morbidity. Bone loss reduces bone strength and stiffness, increases strain, leads to activity-related symptoms, can result in fracture, and, especially in spinal metastases, can cause neurologic dysfunction. Therefore, clinical priorities must include the optimal management of pain and tumor growth and the prevention of fractures or neural involvement.

Standard therapeutic options include chemotherapy, radiation therapy, hormone therapy, surgery, tumor pain medication, and bisphosphonates (4,5). Reasons for possible failure of these measures include (*a*) ineffective chemotherapy because of poor therapeutic response or toxic effects of the chemotherapeutic agent, which may result in tumor progression; (*b*) insufficient radiation therapy because of radiation insensitivity of the neoplasm or radiation exposure limits; (*c*) a tumor that is not amenable to surgery or a patient who is unable or unwilling to undergo surgery due to poor general health and/or the protracted recovery time; and (*d*) inadequate pain relief and/or side effects of the analgesic, despite maximal opioid or other analgesic administration.

Since the introduction of image-guided percutaneous local tumor therapies, many investigators have used thermal energy sources, such as microwave, radiofrequency (RF), or laser energy, as a minimally invasive option to reduce pain and destroy tumors in patients who do not benefit from conventional therapies. In this article we will review indications and contraindications of, as well as the technical developments and early clinical results obtained with, RF ablation and laser-induced interstitial thermotherapy (LITT) in bone tumors, with a special focus on osteoid osteoma and spinal metastases.

LASER-INDUCED INTERSTITIAL THERMOTHERAPY

Technical Developments

Lasers have been effectively used to treat tumors in various locations. LITT is a minimally invasive technique in which optical fibers are inserted percutaneously (with or without applicators) into the tumors, which are then coagulated and destroyed by direct heating. To our knowledge, computed tomography (CT)–guided clinical laser tumor treatment was first described in 1989 (6). In vitro and experimental animal studies have shown encouraging results, with well-defined coagulative necrosis of predictable size in solid tissue produced by delivering photo energy through thin optical fibers of low-power lasers (7–9). Pilot clinical studies have shown a palliative effect of this treatment in patients with tumors of the liver, pancreas, prostate, brain, breast, lymph nodes, and bone (10–15). LITT is usually performed with Nd:YAG

Acad Radiol 2002; 9:467–477

[1] From the Groenemeyer Institute of MicroTherapy, Universitätsstrasse 142, D-44799 Bochum, Germany (D.H.W.G., S.S., A.G.); the Department of Radiology and Microtherapy, University of Witten/Herdecke, Bochum, Germany (D.H.W.G., S.S., A.G.); and the EFMT Development and Research Center for Microtherapy, Bochum, Germany (D.H.W.G.). Received September 11, 2001; revision requested October 23; revision received and accepted December 11. **Address correspondence to** S.S.

lasers with wavelengths of 1,064 nm or diode lasers with wavelengths of 980 or 805 nm. Laser energy is delivered to the tumor with side- or bare-tip 200–600-μm silica fibers. Diode lasers are frequently used due to their high optical penetration at typical performance of 4–10 W and application times of up to 20 minutes. The Nd:YAG laser is equipped with a special diffusing laser applicator mounted on the silica fiber. The applicator diffuses its light homogeneously and emits laser light to an effective distance of 12–15 mm.

LITT of Osteoid Osteomas

Several investigators have applied laser energy to treat osteoid osteomas. Gangi et al (10) treated three cases of spinal osteoid osteomas with LITT. To destroy niduses of 5 and 7 mm they used a continuous-wave semiconductor portable diode laser (Diomed 25 laser; Diomed, Cambridge, England) with a wavelength of 805 nm. The patients were treated with use of neuroleptanalgesia. After treatment planning with CT, investigators inserted the laser fiber into an 18-gauge spinal needle, previously placed in the nidus with CT guidance to avoid breaking the fiber. With the sterilized, single, freshly cleaved, 400-μm fiber with polymer cladding they delivered 600–800 J to the nidus, depending on its size. The tumor was then ablated with 2 W for 300–400 seconds. There were no complications during or after the procedure. Pain relief was experienced within 24 hours and was still present after 20–60 months. CT follow-up examinations showed replacement of the nidus by normal bone or sclerosis.

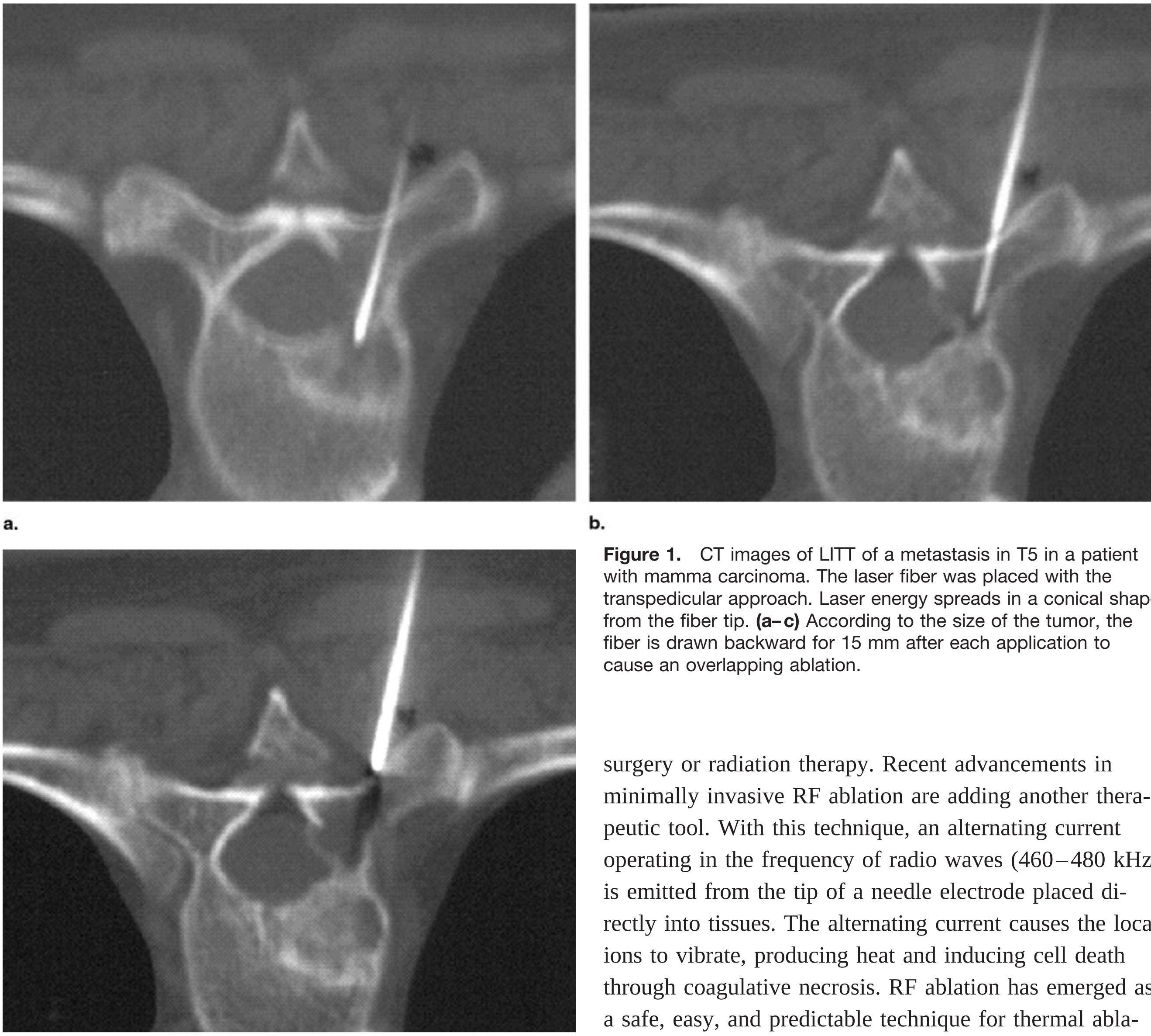
Comparable results were recently reported by Witt et al (16), who used a similar technique to treat 23 patients with osteoid osteoma. All procedures were performed in the CT scanner, with general anesthesia or regional blocks. Niduses 2–12 mm in diameter were coagulated at 1,000–1,500 J. After 15 months, the mean pain score on a visual analogue scale (0 = no pain, 10 = the worst pain imaginable) decreased from 7.5 before operation to 0.95 at the latest follow-up. There were no major complications.

LITT of Spinal Metastases

After encouraging experience with lasers in treating lumbar disk herniations (17) and more than 10 years experience with image-guided local tumor therapies, we used image-guided LITT for the palliative treatment of spinal metastases in 1999. Before interventions in patients, experimental work was done with a 1,064-nm Nd:YAG laser and a bare laser fiber, to evaluate the technique and the relation between laser parameters and the size of tumor necrosis. We worked with soft tissue (porcine liver, kidney, and muscles) and with fixed thoracic and lumbar vertebral bodies from human cadavers. Placement of laser applicators in the vertebral body by means of the transpedicular approach proved effective, but the technique was difficult. We therefore placed the naked fiber in the vertebral body, which was relatively easy with CT guidance. Since fiber tip tracking is difficult with CT guidance, fiber stoppers were used to define length. At magnetic resonance (MR) imaging and macroscopic examination, coagulation necrosis showed inhomogeneous temperature distribution throughout the vertebral body, next to carbonization.

We then treated three patients with spinal metastases by using an Nd:YAG laser with a wavelength of 1,064 nm and a 400-μm fiber. Metastases were completely enclosed in vertebral body structures; no paravertebral or spinal tissue was involved. Metastases were osteolytic in two patients and of a mixed nature with recalcified areas in one patient. All patients had tumor progression after systemic chemotherapy and radiation therapy. Two patients were pain free, and one had local pain in the area of the affected vertebral body. The patients were in good physical condition, with no sensorimotoric disorders related to the spinal metastases.

Before and after LITT, patients were examined with contrast material–enhanced MR imaging. Therapy was performed with CT guidance and local anesthesia, with the patient prone. Immediately before the intervention, patients received a single-shot intravenous antibiotic injection. The procedure began with CT documentation of the tumor and the desired needle position, and then the skin and muscle layers in the area of the puncture were infiltrated with local anesthesia. Next, a coaxial, bent two-needle system with an 18- and 23-gauge, 10–15-cm interventional needle (EFMT Development and Research Center for Microtherapy, Bochum, Germany) was advanced into the tumor by means of a transpedicular approach. A special bone cannula or driller was not necessary. Once the length of the fiber was prepared (5 mm was placed in the tumor), it was placed in the tumor through the interventional needle. Laser energy was applied at a power of 4–10 W and with a pulse length of 0.1–1.0 second at 1-second intervals. Power was slowly increased to 10 W in three steps. A total of 1,400–2,600 J of laser energy was applied. Because the tumors were larger than 7 mm in diameter, the fiber was repositioned before repeated heat application. Two patients reported intolerable local heat sensation during the energy increase. In these cases the procedure was immediately stopped and restarted with



a. b. c.

Figure 1. CT images of LITT of a metastasis in T5 in a patient with mamma carcinoma. The laser fiber was placed with the transpedicular approach. Laser energy spreads in a conical shape from the fiber tip. **(a–c)** According to the size of the tumor, the fiber is drawn backward for 15 mm after each application to cause an overlapping ablation.

lower-energy application after the symptoms had disappeared within a few minutes (Fig 1). The treatment took about 60–90 minutes and was well tolerated. There were no complications. After 3 months, the patients had obtained 45%, 30%, and 35% pain reduction, respectively, on a scale of 0–100. Follow-up MR imaging showed no signs of recurrent tumor growth.

RF ABLATION

Technical Developments

Neoplastic disease has traditionally been approached either systemically with chemotherapy or locally with surgery or radiation therapy. Recent advancements in minimally invasive RF ablation are adding another therapeutic tool. With this technique, an alternating current operating in the frequency of radio waves (460–480 kHz) is emitted from the tip of a needle electrode placed directly into tissues. The alternating current causes the local ions to vibrate, producing heat and inducing cell death through coagulative necrosis. RF ablation has emerged as a safe, easy, and predictable technique for thermal ablation in the liver, kidney, heart, prostate, breast, brain, lymph nodes, nerve ganglia, and bone (18–23). Until recently, however, this method had limited utility because not enough volume of tissue or tumor could be safely heated. Recent technical advances have resulted in larger volumes of tissue ablated, which may enable treatment of larger lesions. This has been accomplished with relatively low complication rates and little collateral damage. To enable treatment of larger tumors, various methods for increasing energy and heat disposition have been developed in experimental and clinical studies (24,25). These include the injection of saline solution before and/or during RF ablation; the use of deployable, hooked and bipolar electrodes; the use of internally cooled RF electrodes;

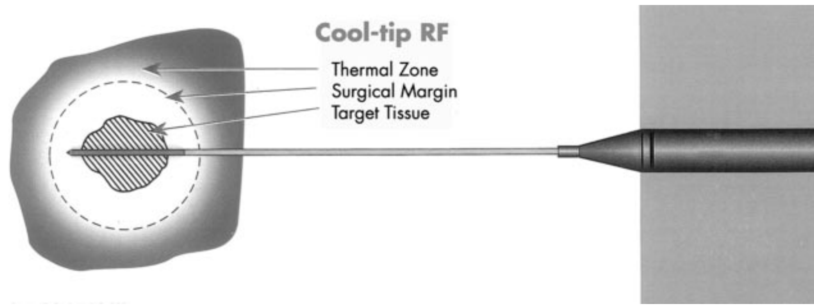


Figure 2. Schematic drawing of tissue ablation with a cool-tip RF electrode.

the production of overlapping lesions; and definitions for RF current application that maximize energy deposition but avoid tissue boiling, charring, or cavitation (Figs 2, 3).

RF systems consist of a generator and a needle electrode with an insulated shaft and a noninsulated distal active tip of variable length that is inserted into the lesion with imaging guidance. The patient is made into an electrical circuit by placing grounding pads on the thighs or back muscles. A generator produces energy of up to 200 W. For the ablation of bone tumors, the RF electrodes currently used are either straight internally cooled electrodes with impedance and temperature monitoring at the tip or deployable electrodes with impedance and thermocouples for temperature monitoring. The active tip may be chosen in different lengths or configurations. RF ablation is generally performed with CT guidance. It may be safely performed on an outpatient basis with local lidocaine (or bupivacaine) anesthesia, sometimes with conscious sedation. For large lesions some investigators prefer general anesthesia and overnight observation. Each treatment session involves up to 15–20 minutes of RF ablation, depending on the device used and the size of the desired lesion. At the end of a single session, the tract may be cauterized on the way out if the lesion is particularly vascular (Fig 4).

RF ABLATION OF OSTEOID OSTEOMAS

Rosenthal et al (26,27) treated osteoid osteomas in 33 patients by using percutaneously placed conventional monopolar RF electrodes (Radionics, Burlington, Mass). A 15-gauge Ackerman needle was used to bore through the surrounding cortical bone with CT guidance. An 18-gauge RF electrode with a 2.3–5.0-mm tip exposure was inserted through the Ackerman needle with a coaxial technique. RF was then applied for approximately 6 minutes, with generator output adjusted to maintain a tip temperature of 80°–90°C. Pain, the primary clinical manifestation of this lesion, was eradicated in 95% of cases; 12 recurrent lesions were successfully retreated with percutaneous techniques. In addition, the mean length of hospital stay decreased from 6.8 to 2.6 days compared with that after surgical excision, previously the therapy of choice.

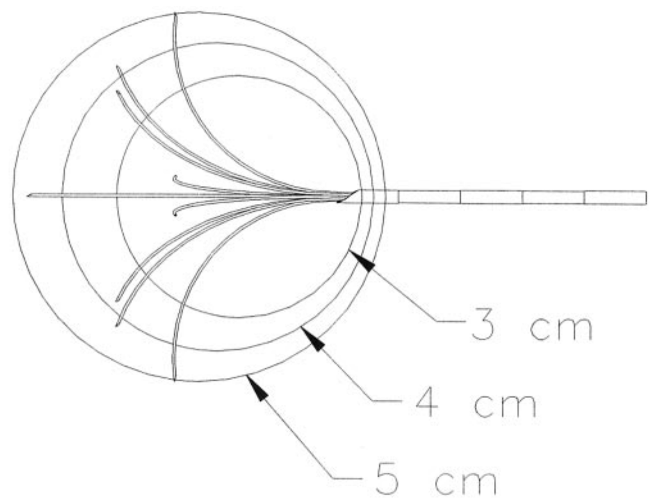


Figure 3. Schematic drawing of a deployable RF electrode illustrates ablation area at three deployment lengths. The last centimeter of the catheter is uninsulated.

In a more recent publication, Barei et al (28) reported findings in 11 patients, who were evaluated and received diagnoses of osteoid osteoma in three different centers, based on typical histories and findings at physical examination and imaging. Patients were treated with CT-guided percutaneous RF ablation after medical treatment failed. The investigators measured pain relief on a pain scale of 0–10. The mean preoperative daytime and nighttime pain scores were 6.1 $\pm$ 2.8 and 8.2 $\pm$ 1.1, respectively. Postoperative scores were reduced to 0.5 $\pm$ 0.64 and 0.82 $\pm$ 1.11, respectively. No complications were reported. Preoperatively, 60% of patients had some interference with employment or school duties, and 90% had interference with desired sporting activities. Postoperatively, all pa-

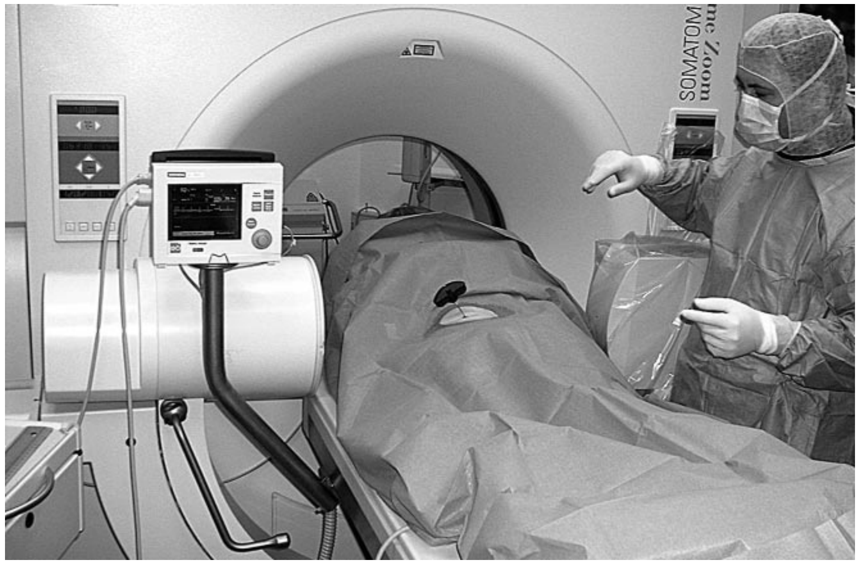


Figure 4. Surgical setup for image-guided hyperthermia of spine tumors. Patient is positioned prone. Bone biopsy cannula has been placed intratumorally with combined CT and C-arm fluoroscopic guidance. Through the cannula, RF electrodes or lasers can be introduced to the tumor to cause the desired ablation.

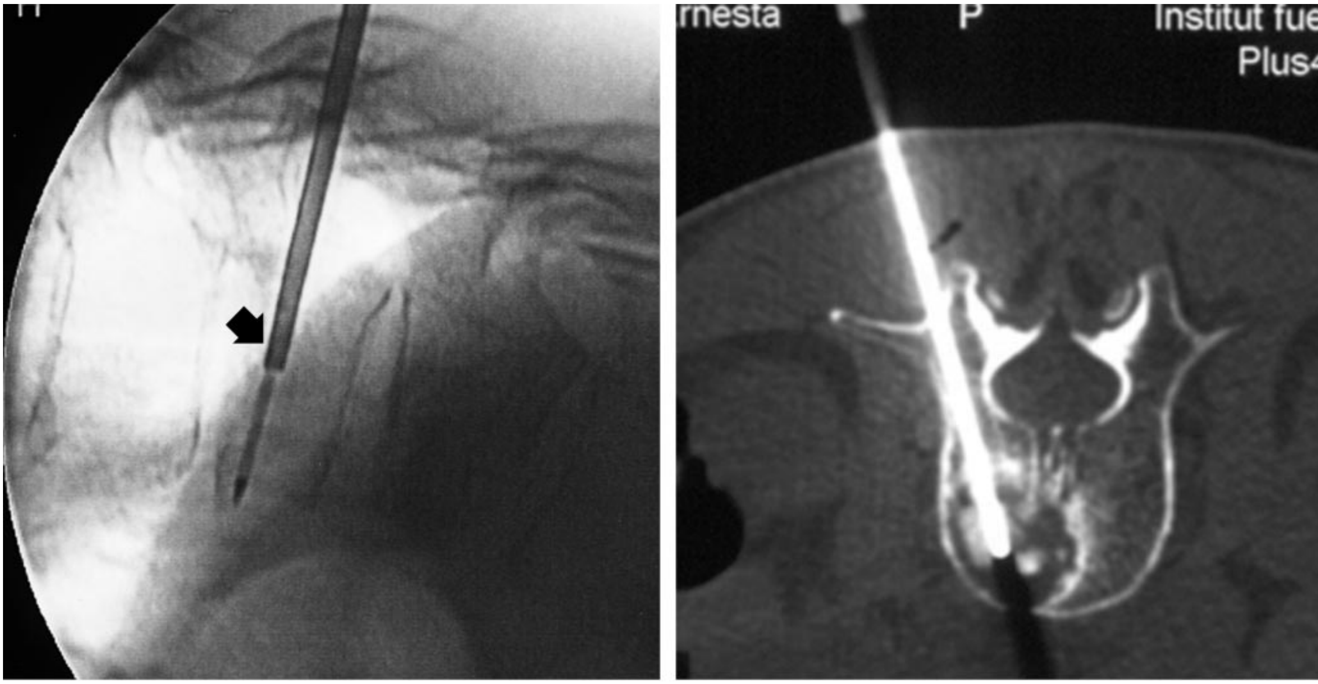
tients were able to perform full-time duties at their school or place of employment, and all were able to resume their desired recreational or sporting activities without residual restrictions. One patient experienced recurrence of a femoral neck lesion despite an initial 7-month period without pain. For osteoid osteomas, usually found in children and young adults, RF ablation has been proved to be as effective as surgery, with similar outcomes and recurrence rates but with shorter hospitalization and fewer complications (26).

RF Ablation of Spinal Metastases

Reports on RF ablation of spinal metastases are rare. In 2000, Dupuy et al (29) described remarkable results in a 54-year-old woman with a focal lesion in vertebral body L2. After the patient was given local anesthesia and conscious sedation, a 14-gauge Ackerman bone biopsy needle was inserted into the tumor under CT guidance. A 3-cm active cool-tip RF electrode (Radionics) was then advanced to the tumor lesion through the Ackermann cannula. Using a Cosman Coagulator RF generator (Radionics) with a maximum output of 1,400 mA, the investigators applied RF heat for 12 minutes. The patient remained asymptomatic 13 months after treatment. Additional RF ablation of metastatic deposits in the sacrum was also performed, but results were not mentioned.

In our institution, RF ablation has been used for metastases of the spine, iliac bone, and sternum after experience with experimental studies (work in progress). In these studies RF ablation was applied to soft tissue (porcine livers, kidneys, and muscles) with a straight, internally cooled electrode system (Radionics). Experiments were performed with CT guidance. We hypothesized that the relevant features of parenchymal tissue are comparable to those of osteolytic or mixed spinal metastases. RF ablation was then applied to fixed human cadaver thoracic and lumbar vertebral bodies. We learned that RF heat can cause thermal necrosis in the vertebral body. These studies also helped define RF ablation parameters. In the CT image, the RF electrode was clearly detectable. Electrode placement was more difficult in bone than in soft tissue. To facilitate placement in the vertebral body, we inserted an 11-gauge trocar bone biopsy needle transpedicularly and then placed the electrode through the needle. Soft-tissue lesions produced at a maximum power of 120 W for 8–20 minutes were 25–35 mm in diameter in all tissues. The carbonization found in LITT experiments was not observed.

Lesions in the vertebral bodies caused with RF ablation at 120 W for 8, 12, 16, and 20 minutes suggest an inhomogeneous temperature spread throughout the vertebral body. Again, no carbonization was observed. In nonvascularized soft and bone tissue, lesions did not increase after 12 minutes of ablation. We therefore chose 15 minutes as the maximum time at the target temperature.



a. b.

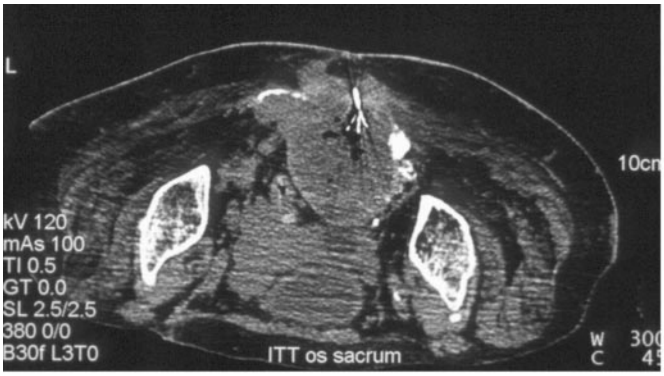
Figure 5. Thermal ablation of a vertebral tumor performed with combined CT and fluoroscopic guidance. **(a)** Lateral fluoroscopic view of the bone biopsy cannula (arrow) and inserted RF electrode. **(b)** Same segment on a CT scan. Lateral real-time fluoroscopic view enables three-dimensional orientation during the procedure.

For RF ablation of spinal metastases we defined indications and contraindications. The indications were as follows: (*a*) unsuccessful or ineffective previous treatment (surgery, radiation therapy, chemotherapy), (*b*) severe pain despite pain medication, (*c*) high risk of neurologic deficits, (*d*) increased risk of fractures, (*e*) risk of immobilization, and (*f*) incompatible side effects of systemic chemotherapy. The contraindications included (*a*) absent or incomplete radiation therapy, (*b*) absent or incomplete chemotherapy or hormone therapy, and (*c*) hemorrhagic diathesis.

Interventions are guided with CT (Somatom Volume Scan Viewer; Siemens, Forchheim, Germany) combined with C-arm fluoroscopy (Siremobil 2000; Siemens). With the C-arm fluoroscope positioned in front of the CT gantry, the position of the instruments can be determined in three dimensions (Fig 5).

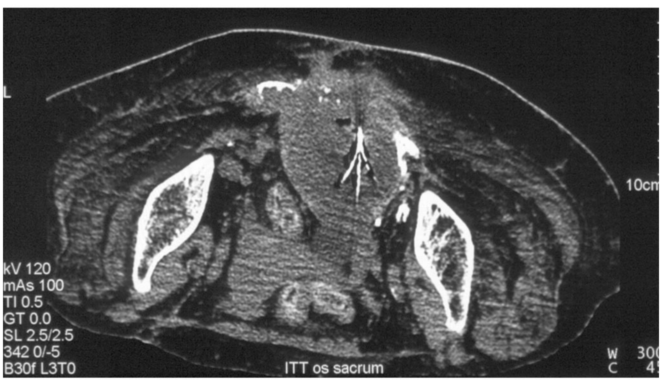
Depending on tumor location, we use either a deployable electrode (50- and 150-W generator; RITA Medical System, Mountain View, Calif) or a straight, cool-tip electrode (200-W generator; Radionics). To update findings, contrast-enhanced MR imaging (Somphonie-1.5 T; Siemens) is performed before the intervention.

As is customary in interventions involving bone tissue, patients received a single-shot intravenous antibiotic injection. Patients are placed on the CT table in a comfortable prone or side position, depending on tumor location. Vital signs, cardiac rhythm, and pulse oximetry are constantly monitored. Axial CT scans of the previously defined therapy plane are used to define the punction coordinates (depth and angle) on the monitor, which are then marked accordingly on the patient's skin. Next, a grounding pad is placed on each thigh. After disinfection and sterile covering, we place an 11-gauge trocar bone biopsy needle transpedicularly into the tumor with CT and fluoroscopic guidance and introduce the electrode with a 3-cm exposed tip through the biopsy needle. For intravertebral interventions we prefer a transpedicular approach to prevent destabilization of the vertebral body. Once the electrode is deemed to be located appropriately for treatment, the RF generator is turned on and a 12–15-minute RF ablation session is performed by gradually increasing the current from 250 mA (25–35 W) to 500 mA (55–65 W) and then to 1,200 mA (110–130 W). For lesions larger than 3 cm in diameter, the electrode is replaced and the tumor repeatedly ablated at the same parameters.



a.

b.



c.

Figure 6. **(a–c)** CT scans show RF ablation of large osteosarcoma in the sacral bone. Deployable-array electrode was used and replaced after 15–20 minutes of ablation to produce a large overlapping lesion. Images show the deployed electrode in different regions of the tumor, which was ablated with 150 W at a maximum temperature of 100°C. Arrays were fully deployed to 5 cm.

Whenever the sound must be repositioned, its position is secured with additional CT control to prevent the involvement of nearby structures (eg, myelon, nerves, and vessels). After the RF probe and trocar are withdrawn, patients rest and are monitored for 2–4 hours. They are then able to leave our institution and return home or to further inpatient care.

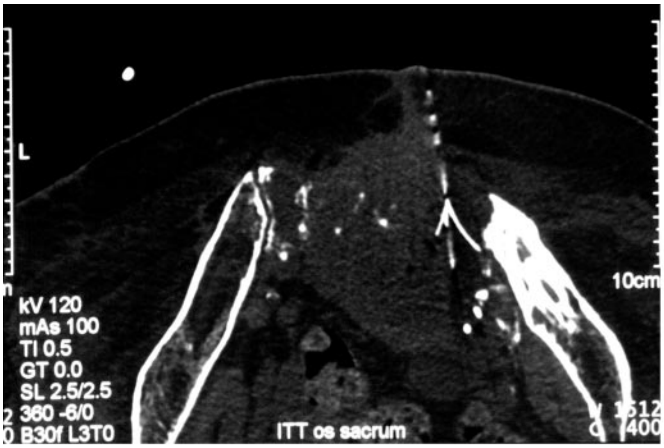
To evaluate the palliative effect of RF ablation for patients with unresectable spine tumors that did not respond to radiation therapy and chemotherapy, we used RF ablation with a deployable-array electrode and a 50-W generator (RITA Medical Systems) in 10 patients in a prospective observational study (30). Of these patients, four underwent vertebroplasty in addition to RF ablation. The purpose of this study was to investigate the feasibility of RF ablation in bone tumors close to the spinal cord and to determine whether this method can reduce back pain and related disability. Tumor growth was documented with pre- and postoperative MR imaging (Figs 6, 7).

After an average of 5.8 months, nine of 10 patients had experienced pain reduction. The average reduction was 74% (range, 30%–100%) in patients who responded to therapy, and pain was completely relieved in three patients, as indicated with a visual analogue scale. Related disability was reduced by an average of 27% (Hannover Functional Ability Questionnaire). Pain relief and decreased pain-related disability were experienced in patients treated with RF ablation alone and RF ablation plus vertebroplasty. One patient reported an increase in pain from 50 to 80 (on a 0–100 scale) and 16.6% increase in back pain related disability, due to a new metastasis in another spine segment.

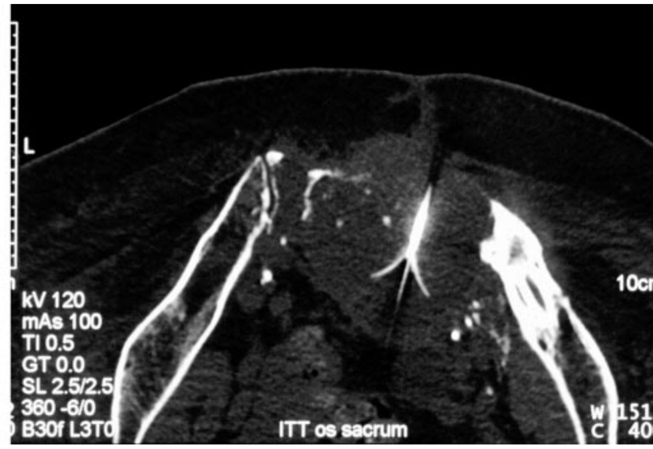
At follow-up, none of the patients had paraplegia. MR imaging showed no intravertebral tumor progression and no fracture in the treated region. Neurologic function (Frankel score) was preserved in nine and improved in one patient. General health (Karnofsky index) was stabilized in six patients, slightly increased (10%–20%) in two, enhanced (50%) in one, and slightly reduced in one. No intra- or postoperative complications were reported for RF ablation or vertebroplasty.

DISCUSSION AND FUTURE OUTLOOK

The primary aim of image-guided percutaneous local thermal ablation of bone metastases is to relieve pain and possibly control tumor growth. In addition, possible fractures and neural damage should be prevented in cases of rapid tumor progression. Recent clinical work has shown that laser-induced interstitial thermotherapy and RF ablation may be effective tools to achieve that aim. Both procedures may present a new treatment alternative, espe-

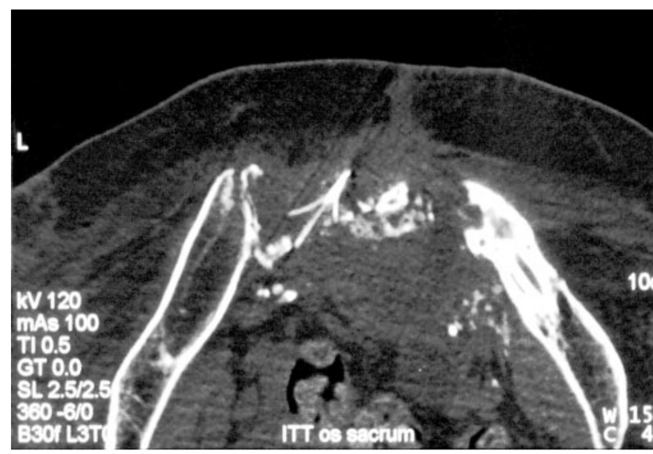


a.



b.

Figure 7. (a–c) CT scan of RF ablation in the same patient with osteosarcoma (Fig 6) in a second treatment session. The tumor was treated at a higher level, again producing an overlapping lesion according to the large tumor size. Deployed electrode arrays (arrows) are clearly visible, which enables precise ablation and a controlled lesion.



c.

cially for patients with limited therapy options due to unsuccessful or ineffective previous treatment (surgery, radiation therapy, or chemotherapy). For osteoid osteoma, for example, open surgery may no longer be indicated because of available percutaneous techniques.

There are multiple techniques for tissue ablation, including percutaneous ethanol injection, in which ethanol is injected directly into the tumor in multiple treatment sessions. This technique has proved clinically effective in the treatment of hepatocellular carcinoma and tumor pain (31–34). Our experience with percutaneous ethanol injection goes back to the late 1980s, when CT-guided percutaneous techniques were introduced, especially for cancer pain and spinal treatments (35,36). Ethanol solution (50%–94%) can effectively cause an irreversible tissue lesion. Since ethanol is a fluid medium with lipophilic affinity, it may cause complications when applied near neural structures. Especially in critical regions close to the spinal cord and in the proximity of large vessels and nerves, a precise and controlled lesion is necessary. Therefore RF ablation and LITT may be preferred to percutaneous ethanol injection, especially in regions where the injection of fluid ethanol cannot be sufficiently controlled or is not advisable.

LITT has been increasingly studied in experimental investigations and has been applied in treating liver tumors (37–42). Only preliminary results are available for extrahepatic applications, and long-term efficacy has yet to be proved with randomized, prospective trials (43). Some therapists choose the amount and duration of delivered laser energy in accordance with experimental work. Experiments in bone have shown that the size of the necrosis around the fiber can be varied from 3.4 mm with 200 J to 9.2 mm with 1,400 J (7). We have produced experimental lesions up to 20 mm in diameter by using a 1,064-nm Nd:YAG laser with side fiber and active 2-cm probe with constant water cooling (work in progress).

Others prefer intraoperative temperature monitoring with thermosensitive T1-weighted MR sequences (38). Patients are then treated in open MR imaging systems after the fiber has been placed in the tumor with CT, MR, or ultrasound (US) guidance. Fast real-time MR imaging monitoring of the extent of thermal damage may be an alternative to overcome the lack of temperature control during LITT, but open MR imaging systems are not yet available to most practitioners.

Local temperature and tissue impedance are factors that affect tissue ablation. Both depend on thermal tissue conductivity, tumor vascularization, and the extent of cortical bone surrounding the tumor (29). The current deployable RF electrode systems have thermocouples on the tip of the electrode to control local temperature throughout the procedure. Internally cooled RF systems monitor tissue impedance and adjust output accordingly. With both systems, predictable lesions can be produced.

RF parameters for the ablation of bone tumors are also based on experimental studies (44), which show that ablations can be consistently created in bone with RF heat without complications. Parameters may vary in the therapy of metastases involving bone, because tumors may be completely surrounded by bone or may involve both bone and surrounding tissue in a single lesion. In deployable RF systems with thermocouples, the maximum temperature output is limited to the area within the array electrodes and the immediate proximity of the electrode tip. In that way a precise and controlled lesion can be produced, which is essential in the direct neighborhood of sensitive structures, such as the spinal cord, nerves, and large vessels or the lung and pleura.

With combined CT and fluoroscopic guidance, the deployable electrodes can be safely placed in osteolytic metastases. In mixed osteolytic-osteoblastic metastases, however, the multiple arrays might not be deployed to their full extent once they touch more solid tissue, such as bone. This may be a limitation of the system, as the size of the lesion is directly related to the length of the electrodes. Straight, internally cooled electrodes can produce controlled lesions in osteoblastic, osteolytic, and mixed tumors. Therapists may pick the most suitable system according to the tumor material, the desired lesion, and the affected region.

Major complications of both LITT and RF ablation in the therapy of bone metastases have not, to our knowledge, been reported, but it is important to recognize that they may occur. Since high temperatures are applied in both techniques, accurate placement of the intervention tools and the creation of a controlled lesion are crucial not only in high-risk areas such as the spine. Experimental studies suggest that a probe placed within bone is very unlikely to cause unintentional thermal lesions to neural tissue (45,46). Although bone tissue seems to have an insulating effect and decreases heat transmission, surrounding tissue, such as muscles, may be burned when too much heat is applied. Possible risks of RF ablation include bleeding, infection, injury to adjacent structures, and abscesses. Skin burn from the electrosurgical return current flow may occur when the grounding pads are not accurately placed equidistant from the ablation site (47). Thorough training before performance of the described techniques is essential to prevent unnecessary damage.

Accurate imaging is essential for successful in situ tumor ablation. Percutaneous tumor ablation is virtually always performed with tomographic imaging guidance. In liver tissue, US is most commonly used for guidance, because of its flexibility, widespread availability, and real-time imaging capabilities. For safety reasons, CT is the standard in spinal interventions (48). With CT, the precision of tip guidance is 1 mm^3 (49), the edges of the instruments are sharply displayed, and the tip can be defined to within ± 0.2 mm. For RF ablation of spinal metastases, we prefer CT combined with C-arm fluoroscopy. The fluoroscopy unit can be installed close to the CT gantry, with sufficient space for the therapist in all directions.

Open MR imaging would be helpful as a second step for controlling the diameter of thermal spreading and necrosis. The advantages of MR imaging guidance with an open system are that there is no radiation and various planes can be acquired. Tip discrimination, however, is still not precise enough in MR imaging, because of artifacts. Especially in high-risk areas like the spine, MR guidance should be avoided to prevent nerve and spinal cord injury (50). The application of new materials such as ceramics and carbon fibers and the use of robotic navigation systems will help make MR imaging a useful tool for imaging guidance in percutaneous tumor therapies. In future, hybrid combinations of imaging systems may be the key to safe interactive and transparent guidance techniques. CT, MR imaging, and electron-beam tomography may be used in combination with US, radiography, or endoscopy. The postprocedural detection of focal areas of untreated or locally recurrent tumor is critical, because an optimal method for postprocedural follow-up has not yet been determined. At present, follow-up imaging is most commonly performed with contrast-enhanced CT. Positron emission tomography or contrast-enhanced MR imaging may provide useful alternatives.

At this point, it seems clear that image-guided percutaneous local thermal ablation can be a secure and effective method to reduce pain in patients with painful tumors involving bone. In particular, metastases close to the spinal cord, which might otherwise be unresectable or not treatable at all, can be effectively coagulated. Pain can be reduced and neural damage prevented, enhancing the quality of life for patients who often have multimorbid conditions and limited life expectancy. It is crucial that physicians performing thermal ablation communicate with oncologists, oncologic surgeons, radiologists, and neurosurgeons. After further experimental research and investigation with larger study groups and longer follow-up, this technique may become an additional or alternative therapeutic option for patients with painful bone tumors.

REFERENCES

1. Tofe AJ, Francis MD, Harvey WJ. Correlation of neoplasms with incidence and localization of skeletal metastases: an analysis of 1,355 diphosphonate bone scans. J Nucl Med 1975; 16:986–989.
2. Powell GJ, Southby J, Danks JA, et al. Localization of parathyroid hormone-related protein in breast cancer metastases: increased incidence in bone compared with other sites. Cancer Res 1991; 51:3059–3061.
3. Carlin BI, Andriole GL. The natural history, skeletal complications, and management of bone metastases in patients with prostate carcinoma. Cancer 2000; 88(suppl 12):2989–2994.
4. Arcangeli G, Giovinazzo G, Saracino B, et al. Radiation therapy in the management of symptomatic bone metastases: the effect of total dose and histology on pain relief and response duration. Int J Radiat Oncol Biol Phys 1998; 42:1119–1126.
5. Bloomfield DJ. Should bisphosphonates be part of the standard therapy of patients with multiple myeloma or bone metastases from other cancers? an evidence-based review. J Clin Oncol 1998; 16:1218–1225.
6. Groenemeyer D, Seibel R. CT-gesteuerte tumortherapie. In: Interventionelle computertomographie. Berlin, Germany: Ueberreuter Wissenschaft, 1989; 212–216.
7. Gangi A, Gasser B, De Unamuno S, et al. New trends in interstitial laser photocoagulation of bones. Semin Musculoskelet Radiol 1997; 1:331–338.
8. Goldhaber D, Deli M, Groenemeyer D, et al. Measurement of tissue temperature by MRI. IEEE Nucl Sci Med Imaging 1993; 3:1702–1705.
9. Bown SG. Phototherapy in tumors. World J Surg 1983; 7:700–709.
10. Gangi A, Dietemann JL, Guth S, et al. Percutaneous laser photocoagulation of spinal osteoid osteomas under CT guidance. AJNR Am J Neuroradiol 1998; 19:1955–1958.
11. Harries SA, Amin Z, Smith ME, et al. Interstitial laser photocoagulation as a treatment for breast cancer. Br J Surg 1994; 81:1617–1619.
12. Kettenbach J, Silverman SG, Hata N, et al. Monitoring and visualization techniques for MR-guided laser ablations in an open MR system. J Magn Reson Imaging 1998; 8:933–943.
13. Mack MG, Straub R, Eichler K, et al. Percutaneous MR imaging-guided laser-induced thermotherapy of hepatic metastases. Abdom Imaging 2001; 26:369–374.
14. Schwabe B, Kahn T, Harth T, et al. Laser-induced thermal lesions in the human brain: short- and long-term appearance on MRI. J Comput Assist Tomogr 1997; 21:818–825.
15. Vogl TJ, Eichler K, Straub R, et al. Laser-induced thermotherapy of malignant liver tumors: general principals, equipment(s), procedure(s)—side effects, complications and results. Eur J Ultrasound 2001; 13:117–127.
16. Witt JD, Hall-Craggs MA, Ripley P, et al. Interstitial laser photocoagulation for the treatment of osteoid osteoma. J Bone Joint Surg Br 2000; 82:1125–1128.
17. Seibel RMM, Groenemeyer DHW, Schmidt AM, et al. Minimally invasive treatment of spinal diseases. Minim Invasive Ther Allied Technol 1996; 5:226–231.
18. Anzai Y, Lufkin R, DeSalles A, et al. Preliminary experience with MR-guided thermal ablation of brain tumors. AJNR Am J Neuroradiol 1995; 16:39–48.
19. Dupuy DE, Zagoria RJ, Akerley W, et al. Percutaneous radiofrequency ablation of malignancies in the lung. AJR Am J Roentgenol 2000; 174:57–59.
20. Gazelle GS, Goldberg SN, Solbiati L, et al. Tumor ablation with radiofrequency energy. Radiology 2000; 217:633–646.
21. Zlotta AR, Wildschutz T, Raviv G, et al. Radiofrequency interstitial tumor ablation (RITA) is a possible new modality for treatment of renal cancer: ex vivo and in vivo experience. J Endourol 1997; 11:251–258.
22. Dupuy DE, Goldberg SN. Image-guided radiofrequency tumor ablation: challenges and opportunities—part II. J Vasc Interv Radiol 2001; 12:1135–1148.
23. Nahum S, Goldberg S, Dupuy DE. Image-guided radiofrequency tumor ablation: challenges and opportunities—part I. J Vasc Interv Radiol 2001; 12:1021–1132.
24. Goldberg SN, Gazelle GS. Radiofrequency tissue ablation: physical principles and techniques for increasing coagulation necrosis. Hepatogastroenterology 2001; 48:359–367.
25. Goldberg SN, Ahmed M, Gazelle GS, et al. Radio-frequency thermal ablation with NaCl solution injection: effect of electrical conductivity on tissue heating and coagulation-phantom and porcine liver study. Radiology 2001; 219:157–165.
26. Rosenthal DI, Hornicek FJ, Wolfe MW, et al. Percutaneous radiofrequency coagulation of osteoid osteoma compared with operative treatment. J Bone Joint Surg Am 1998; 80:815–821.
27. Rosenthal DI, Springfield DS, Gebhardt MC, et al. Osteoid osteoma: percutaneous radio-frequency ablation. Radiology 1995; 197:451–454.
28. Barei DP, Moreau G, Scarborough MT, et al. Percutaneous radiofrequency ablation of osteoid osteoma. Clin Orthop 2000; 115–124.
29. Dupuy DE, Hong R, Oliver B, et al. Radiofrequency ablation of spinal tumors: temperature distribution in the spinal Canal. AJR Am J Roentgenol 2000; 175:1263–1266.
30. Groenemeyer DHW, Gevargez A, Schirp S. Image-guided radiofrequency ablation of spinal tumors: preliminary experience with an expandable array electrode. Cancer J 2002; 8:33–39.
31. Giorgio A, Tarantino L, De Stefano G, et al. Ultrasound-guided percutaneous ethanol injection under general anesthesia for the treatment of hepatocellular carcinoma on cirrhosis: long-term results in 268 patients. Eur J Ultrasound 2000; 12:145–154.
32. Meloni F, Lazzaroni S, Livraghi T. Percutaneous ethanol injection: single session treatment. Eur J Ultrasound 2001; 13:107–115.
33. Sato M, Watanabe Y, Tokui K, et al. CT-guided treatment of ultrasonically invisible hepatocellular carcinoma. Am J Gastroenterol 2000; 95:2102–2106.
34. Yamamoto J, Okada S, Shimada K, et al. Treatment strategy for small hepatocellular carcinoma: comparison of long-term results after percutaneous ethanol injection therapy and surgical resection. Hepatology 2001; 34:707–713.
35. Groenemeyer D, Seibel R. Interventionelle computertomographie. Berlin, Germany: Ueberreuter Wissenschaft, 1989.
36. Groenemeyer DH, Seibel RM. Microinvasive CT-controlled tumor therapy of soft tissue and skeletal metastases. Wien Med Wochenschr 1993; 143:312–321. [German]
37. Eichler K, Mack MG, Straub R, et al. Oligonodular hepatocellular carcinoma (HCC): MR-controlled laser-induced thermotherapy. Radiologe 2001; 41:915–922. [German]
38. Fiedler VU, Schwarzmaier HJ, Eickmeyer F, et al. Laser-induced interstitial thermotherapy of liver metastases in an interventional 0.5 Tesla MRI system: technique and first clinical experiences. J Magn Reson Imaging 2001; 13:729–737.
39. Filler TJ, Bremer C, Peuker E, et al. Pathomorphology of laser-induced interstitial tumor thermotherapy of the liver. Radiologe 2001; 41:181–186. [German]
40. Isbert C, Roggan A, Ritz JP, et al. Laser-induced thermotherapy: intra- and extralesionary recurrence after incomplete destruction of experimental liver metastasis. Surg Endosc 2001; 15:1320–1326.
41. Mack MG, Straub R, Eichler K, et al. MR-guided laser-induced tumor therapy in recurrent extrahepatic abdominal tumors. Eur Radiol 2001; 11:2041–2046.

42. Sturm JW, Keese MA, Bonninghoff RG, et al. Locally ablative therapies of hepatocellular carcinoma. Onkologie 2001; 24(suppl 5):35–45. [German]
43. Eyrich GK, Bruder E, Hilfiker P, et al. Temperature mapping of magnetic resonance–guided laser interstitial thermal therapy (LITT) in lymphangiomas of the head and neck. Lasers Surg Med 2000; 26:467–476.
44. Tillotson CL, Rosenberg AE, Rosenthal DI. Controlled thermal injury of bone: report of a percutaneous technique using radiofrequency electrode and generator. Invest Radiol 1989; 24:888–892.
45. Houpt JC, Conner ES, McFarland EW. Experimental study of temperature distributions and thermal transport during radiofrequency current therapy of the intervertebral disc. Spine 1996; 21:1808–1812.
46. Dupuy DE, Hong R, Oliver B, et al. Radiofrequency ablation of spinal tumors: temperature distribution in the spinal canal. AJR Am J Roentgenol 2000; 175:1263–1266.
47. Goldberg SN, Solbiati L, Halpern EF, et al. Variables affecting proper system grounding for radiofrequency ablation in an animal model. J Vasc Interv Radiol 2000; 11:1069–1075.
48. Groenemeyer D, Seibel R, Erbel R, et al. Equipment configuration and procedures: preferences for interventional microtherapy. J Digit Imaging 1996; 9:81–96.
49. Jerosch J, Groenemeyer D, Deli M, et al. Precision and comparison of CT-, MRI- and x-ray-guided interventions in lumbar facet infiltration: an experimental study. Biomed Technik 2000; 45:228–237. [German]
50. Groenemeyer DH, Seibel RM, Melzer A, et al. Image-guided access techniques. Endosc Surg Allied Technol 1995; 3:69–75.