Chapter VI

Laser-induced interstitial thermotherapy (LITT) of liver lesions - technique and application data-clinical data

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Introduction

The liver plays a central role in the human metabolism and so represents one of the organ systems most often affected, especially by tumorous diseases. The group of colorectal carcinomas metastatically almost exclusively attacks this organ, which, according to studies by Weiss et al., can be attributed to the venous drainage of the intestines through the portal vein [1,2]. A large number of primary tumors often cause liver metastases as well as bone, lung and brain metastases. After curative treatment of the primary tumor, the liver infestation has a decisive influence on the survival time of affected patients in many cases. The therapeutic strategy for malignant liver lesions is based on a number of factors such as the underlying primary tumor, localization, the stage the tumor has reached, and general factors, such as age or any existing concomitant disease. Surgical resection is well established in the treatment of liver metastases of colorectal carcinoma, typically yielding 5-year survival rates between 25% and 38%. Two thirds of the patients will experience recurrent metastases, and many patients do not benefit from surgery. Data published from studies investigating the efficacy of surgical resection of liver metastases show 1-year survival rates between 71% and 88%, 3-year survival rates between 21% and 46%, and mean survival rates between 25 and 35 months. Perioperative mortality ranges from 4.4% to 10. In the case of hepatocellular carcinoma [3], when the tumor is at an appropriate stage, liver resection or hemihepatic resection or liver transplant are the essential curative treatment methods [4]. If there are contraindications, transarterial chemoembolization [5-8] combined with a local alcohol injection is used as a palliative therapeutic strategy [9-15]. Interstitial procedures such as laser-induced thermotherapy (LITT) or radio-frequency ablation show a high rate of controlling the site of the tumor and are currently clinically evaluated.

Strategies for liver metastases are considerably more complex. Up to now the liver resection of solitary lesions has been the only potential curative treatment [16-26]. The high incidence of new liver metastases following successful resection of metastases - between 60% and 80% - is the chal-

lenge for therapeutic alternatives, the goal of which should be to achieve survival statistics similar to those achieved through surgery. Ideally such therapeutic alternatives should be less invasive than liver resection; they should have a low complication rate; they should be possible under local anesthesia (for patients with general contraindications for surgery); and they should be less expensive. All these criteria are met by MR-guided laser-induced thermotherapy (LITT), which has been the subject of growing interest in recent years. However, the high rate of intrahepatic relapses and a possible potentising of the intrahepatic growth in metastases as part of the tumor stimulation process by released growth factors is considered problematic. For this reason, over the last years there has been great interest in further developments of interstitial procedures such as laser induced interstitial thermotherapy (LITT) and RF ablation.

The presented data are based on the analysis of a large prospective series of a percutaneous thermal ablation procedure like LITT for treating hepatic malignancies.

Material and method

LITT was performed between June 1993 and May 2002 in 1,115 patients (581 males, 534 females, mean age 59.5 years, range 24 to 89 years) with a total of 3,438 liver metastases and 71 hepatocellular carcinomas. We included patients with different primary tumors like colorectal cancer, breast cancer, hepatocellular carcinoma, pancreatic cancer and a variety of other tumors. A total of 10,963 laser applications were performed with a total of 6,892 laser applicators.

A laser application was defined as laser treatment at one certain position. If the laser applicator was pulled back and another laser treatment was performed to enlarge the coagulative necrosis a second laser application was performed.

We currently treat patients with recurrent liver metastases after partial liver resection, patients with metastases in both liver lobes, patients with locally non-resectable lesions, and patients who have general contraindications for surgery or who refuse surgical resection. The distribution for the different indications is different for different primary tumors (figure 1).

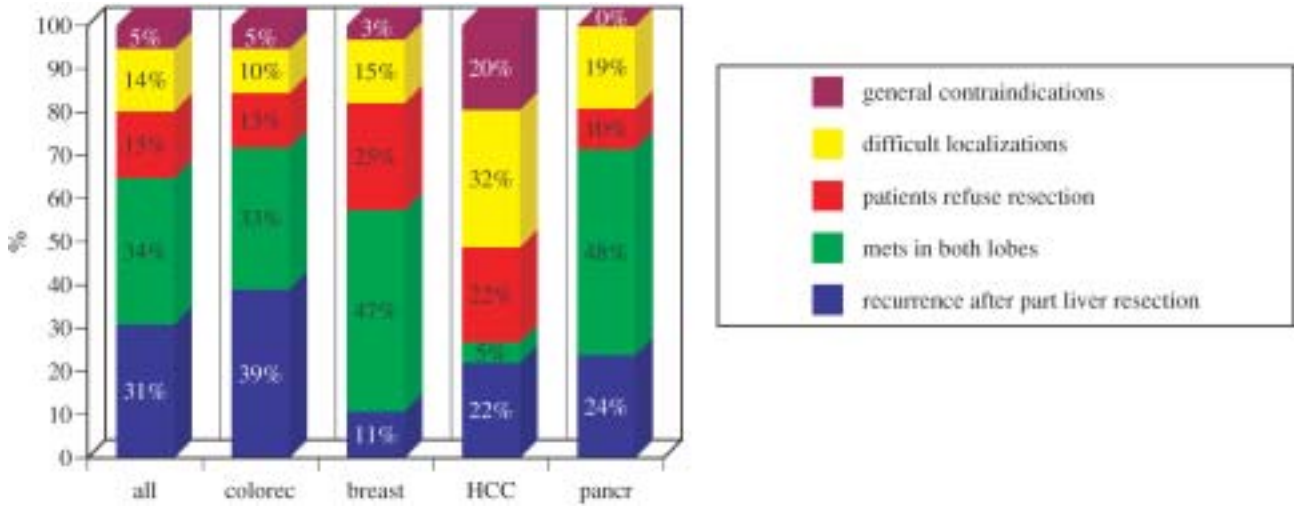

Figure 1
Documentation of the distribution of the indications for LITT treatment for all patients (all), patients with colorectal liver metastases (colorec.), breast cancer liver metastases (breast), hepatocellular carcinoma (HCC), and patients with liver metastases from pancreatic cancer (pancr.).

Laser equipment and application set

Laser coagulation is accomplished using a Neodymium-YAG laser light with a wavelength of 1064 nm (MediLas 5060, MediLas 5100, Dornier Germering, Germany), delivered through optic fibers terminated by a specially developed diffusor. In the beginning a diffusor tip with a glass dome of 0.9 mm in diameter, which is mounted at the end of a 10-meter long silica fiber (diameter 400 µm) was used. Since the year 2000 a flexible diffuser tip has been used with a diameter of 1.0 mm, which makes the laser applications much easier due to the fact that the risk of damage to the diffuser tip has dropped to almost zero. The active length of the diffusor tip ranges between 20 and 40 mm in length. The laser power is adjusted to 12 Watts per cm active length of the laser applicator.

The laser application kit (SOMATEX company, Berlin, Germany) consists of a cannulation needle, a sheath system, and a protective catheter which prevents direct contact of the laser applicator with the treated tissues and allows cooling of the tip of the laser applicator. The closed end of the protective catheter enables complete removal of the applicator even in the unlikely event of damage to the fiber during treatment. This simplifies the procedure and makes it safer for the patient.

The laser itself is installed outside the MR examination room, and the light is transmitted through a 10 m-long optical fiber. All patients are examined using an MR imaging protocol including gradient-echo (GE) T1-weighted plain and contrast-enhanced GD-DTPA 0.1 mmol/kg body weight (b.w). T2- and T1-weighted images are obtained for localizing the target lesion and planning the interventional procedure. The scanners are a conventional 1.5-T system (Siemens, Erlangen, Germany) and a 0.5-T system (Escint).

Imaging during therapy:

After informing patients about potential complications, benefits, and disadvantages of LITT, consent is obtained. The tumor is localized on computed tomographic scans and the injection site is infiltrated with 20 ml of 1% lidocaine. Under CT guidance the laser application system is inserted using the Seldinger technique. After the patient is positioned on the MRI table, the laser catheter is inserted into the protective catheter. MR sequences are performed in three perpendicular orientations before and during LITT.

MR sequences are performed every 30 seconds to assess the progress in heating the lesion and the surrounding tissue. Heating is revealed as signal loss in the T1-weighted gradient-echo images as a result of the heat-induced increase of the T1 relaxation time. Depending on the geometry and intensity of the signal loss and the speed of heat distribution, the position of the laser fibers, the laser power and the cooling rate are readjusted. Treatment is stopped after total coagulation of the lesion, and a safety margin from 5 to 15 mm surrounding the lesion can be visualized in MR images.

After switching off the laser, T1-weighted contrast-enhanced FLASH-2D images are obtained for verifying the induced necrosis. After the procedure the puncture channel is sealed with fibrin glue. Follow-up examinations using plain and contrast-enhanced sequences are performed after 24 to 48 hours, and every 3 months following the LITT procedure. Quantitative and qualitative parameters, including size, morphology, signal behavior, and contrast enhancement are evaluated for deciding whether treatment can be considered successful, or whether subsequent treatment sessions are required.

Qualitative and quantitative evaluation

Laser-induced effects are evaluated by comparing images of lesions and surrounding liver parenchyma obtained before and after laser treatment with each other, and with those obtained at follow-up examinations. Tumor volume and volume of coagulative necrosis are calculated using three-dimensional MR images and measurements of the maximum diameter in three planes (A, B and C). Survival rates are calculated using the Kaplan-Meier method [27].

Results

All treatments are performed under local anesthesia and are well tolerated by the patients. Under some circumstances the use of conscious sedation is initiated. All patients treated between June 1993 and September 1998 were hospitalized from 24 to 48 hours after the intervention. All patients treated from October 1998 up to now have been treated exclusively on an outpatient basis.

Evaluation of the MR thermometry data during MR-guided laser-induced thermotherapy demonstrates that metastatic tissue is very sensitive to heat, showing earlier and more widespread temperature distribution of the delivered thermal energy than does surrounding liver parenchyma. In 90.9% of all cases, the area of obviously decreased signal intensity during LITT treatment is iden-

Table 1
Documentation of the application data for the total patient material including all patients with malignant liver lesions. The number of applicators represents the number of applicators per patient. The number of applications is an indication of how many LITT treatments were performed per patient (LITT treatment with one laser applicator at one certain location is one laser application). If the laser fiber is pulled back in order to enlarge the volume of coagulative necrosis a second laser application will be performed. One LITT session is the LITT treatment performed on one day with 1 to 7 laser applicators simultaneously. One LITT round includes all LITT sessions which are necessary to get all visible metastases treated. If MRI detects new metastases during follow-up control studies 3 months after initial LITT treatment or later and these lesion will be treated again by LITT, this was counted as a second LITT round.

Parameter	Mean	Median	Minimum	Maximum
Age	59,5	60,0	28,4	88,7
Applicators	6,8	5	1	34
Applications	11.4	9	1	56
Metastases	2,8	2	1	21
LITT session	2,4	2	1	13
LITT-round	1,5	1	1	9
Applicator per met.	2,5	2	1	9
session per met.	1,05	1	1	3
energy per met.	104 KJ	82,9 KJ	5,9 KJ	502,4 KJ

tical with the area classified as coagulative necrosis on MR images 24 hours after laser treatment. In 8.6% of the cases the size of the coagulative necrosis obtained 24 hours after LITT treatment is larger compared to MR thermometry images. The difference is 17% in maximum. In 0.6% of the cases the necrosis is smaller on control images obtained after 24 hours compared to MR thermometry images. The difference is 15% in maximum.

The mean number of treated liver tumors per patient is 2.8 (median 2). The evaluation of the application details is presented in Table 1. In 57% of the patients only one or two metastases are treated. In 7% more than 6 metastases are treated in total (figure 2). The localization of the metastases with respect to the different liver segments shows a quite homogenous distribution of the metastases in the different liver segments taking into account the different volumes of the liver segments (figure 3).

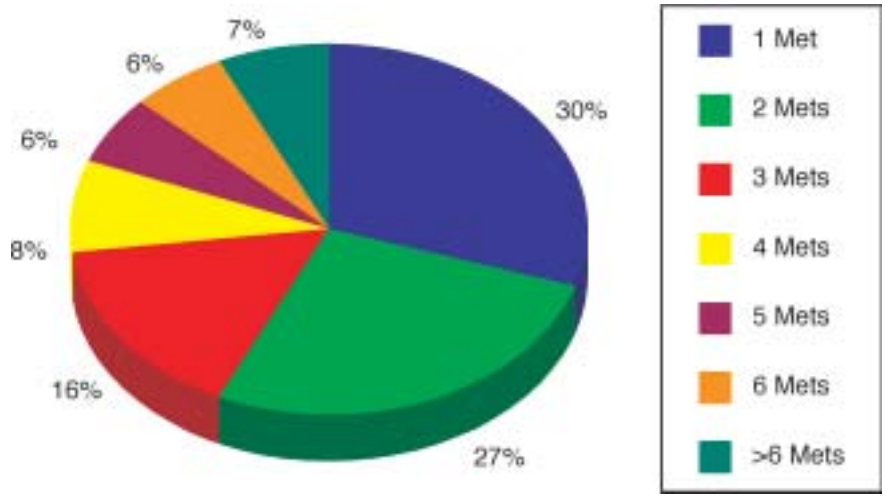

Figure 2
The graph shows the total number of treated metastases per patient, including recurrent metastases during follow-up examinations.

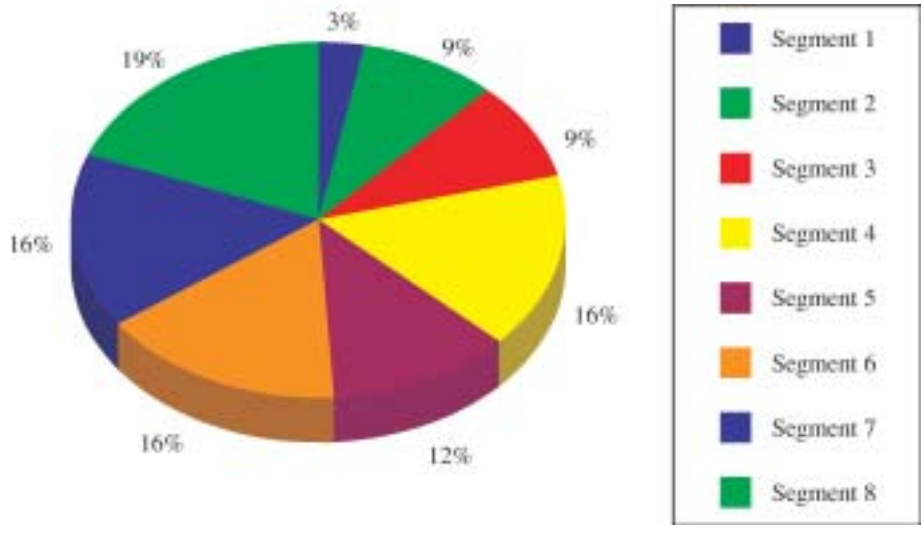

Figure 3
The graph shows the distribution of the treated metastases with respect to the different liver segments.

The evaluation of the distribution of the metastases within the liver is demonstrated in figure 4. 49% of the lesions show a relationship to the liver capsule, 7% present a relationship to the central portal vein structures and only 29% of the metastases are at a location which is classified as easy.

The mean number of inserted laser applicators for the treatment of one metastasis with a reliable safety margin with regard to the size of the metastases is shown in figure 5. In 26.1% of all metastases only one laser applicator was inserted; in 29.8% two laser applicators, in 18.8 % three laser applicators, in 18.4% 4 laser applicators, in 5.3% 5 laser applicators and in 1.7% more than 5 laser applicators were necessary for the treatment of a single metastasis with a reliable safety margin.

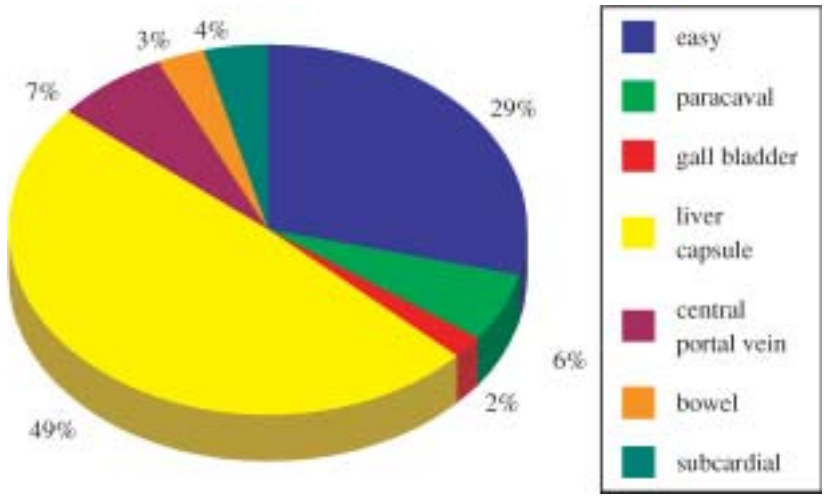

Figure 4
The graph shows the distribution of the liver metastases with respect to the localization of the lesion. A localization was classified as "easy" if the lesion was sufficiently surrounded by normal liver parenchyma without relationship to any of the other listed structures. A lesion was classified as "paracaval" if there was a contact to vena cava inferior. Other important relationships were the liver capsule, the gall bladder, the bowel and the central portal vein structures (including the central bile ducts). A lesion was classified as subcardial, if the lesion was located in liver segment 2 and the distance between the lesion and the pericard was less than 8 mm.

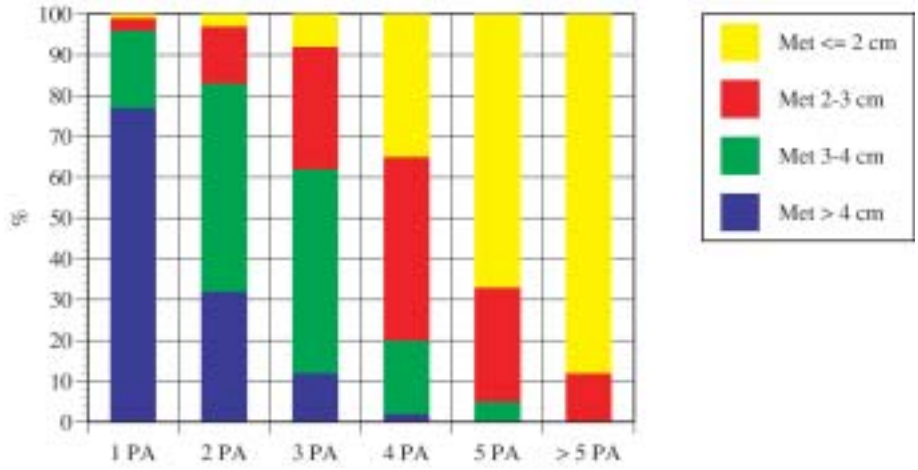

Figure 5
The graph shows the number of laser applicators which were inserted for the treatment of one single metastases with respect to the size of the metastases. PA = power laser applicator.

The approach to the lesion depended on the localization of the lesion (figure 6). Transpleural approaches were avoided in all cases. The most common approach to lesions located in liver segments 7 and 8 was the angulated lateral approach (65.5% and 82.4%, respectively). The most common approach for lesions located in liver segments 2 and 3 was an approach from ventral (50% and 79%, respectively). An approach was classified as dorsal, lateral or ventral if the angulation of the puncture direction was more than 15° from the scan plane. A transpleural approach was avoided in all cases. Therefore the approach to most of the lesions in liver segments 7 or 8 was a lateral angulated approach.

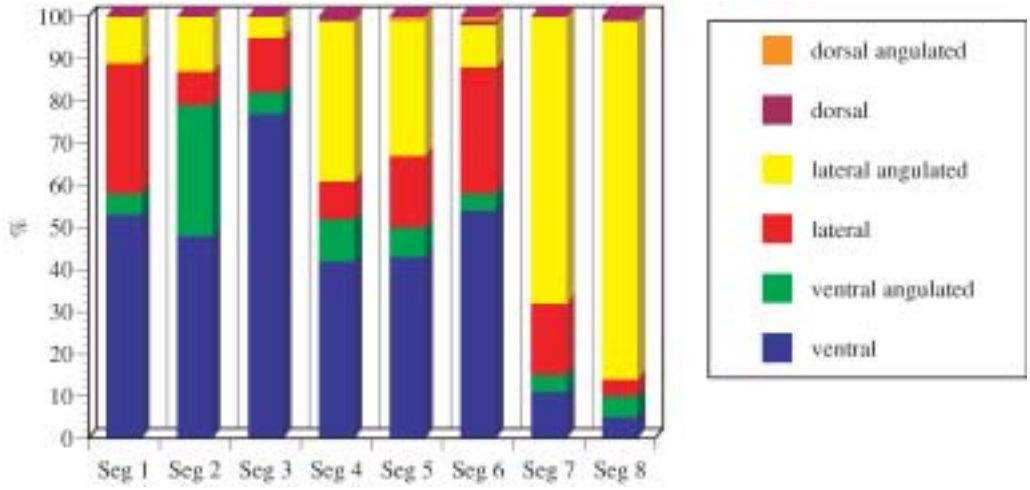

Figure 6
The diagram presents the different approaches to the lesion with respect to the different liver segments. An approach was classified as dorsal, lateral or ventral if the angulation of the puncture direction was more than 15° from the scan plane. A transpleural approach was avoided in all cases, therefore the approach to most of the lesion in liver segment 7 or 8 was a lateral angulated approach.

The applied energy per treated metastasis was documented. The mean energy for metastases with a diameter of 2 cm or smaller was 48 KJ (median 42 KJ, minimum 8 KJ, maximum 189 KJ), the mean energy for metastases between 2 and 3 cm was 89 KJ (median 83 KJ, minimum 12 KJ, maximum 361 KJ), for metastases between 3 and 4 cm the mean energy was 140 KJ (median 129 KJ, minimum 16 KJ, maximum 453 KJ) and for metastases larger than 4 cm in diameter the mean energy was 209 KJ (median 203 KJ, minimum 19 KJ, maximum 502 KJ).

The mean values of the applied energy were statistically significantly higher in liver metastases from colorectal carcinoma versus liver metastases from breast carcinoma and hepatocellular carcinoma (ANOVA test $p<0.01$) (figure 7).

The volume of the induced coagulative necrosis 24 hours after LITT treatment exceeds the volume of the initial tumor significantly ($p<0.001$). During follow-up examinations the volume of the induced necrosis is getting smaller again due to resorption and shrinking of the lesion. In the 3-month control the volume of the coagulative necrosis is already about half of the initial volume of the necrosis, but still larger than the initial tumor volume (figure 8). The volume of coagulative necrosis 24 hours after LITT treatment exceeds the initial tumor volume in average by the factor of 13 (range 12 - 17) for lesions with a diameter of 2 cm or less, by the factor of 8 (range 7.5 - 8.2) for lesions between 2 and 3 cm in diameter, by the factor of 6 (range 5.3 - 6.1) for lesions between 3 and 4 cm in diameter, and by the factor of 2.5 (range 1.8 - 2.7) for lesions larger than 4 cm in diameter (figure 9).

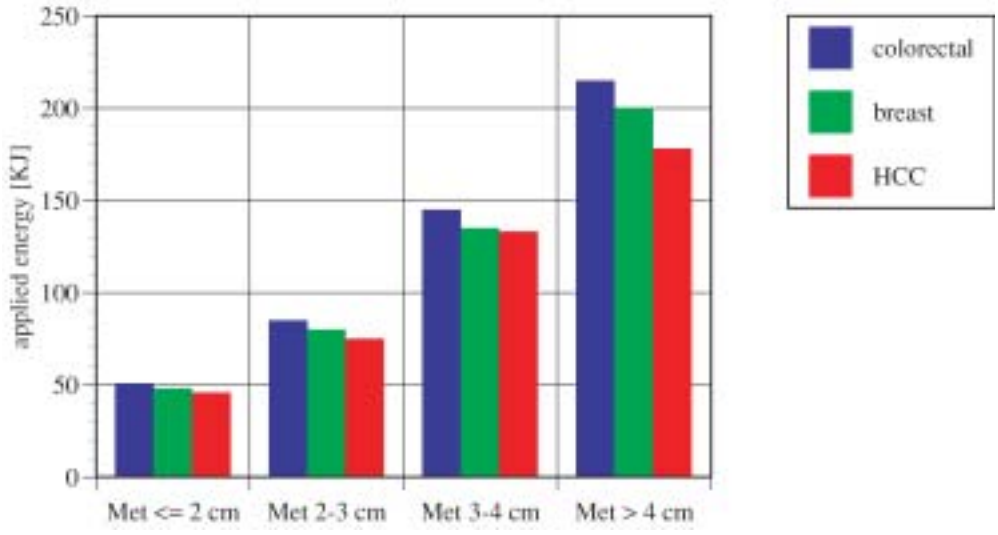

Figure 7
The graph shows the applied energy per metastasis for colorectal cancer liver metastases, breast cancer liver metastases and hepatocellular lesion for metastases 2 cm or less in diameter, metastases between 2 and 3 cm, metastases between 3 and 4 cm and metastases larger than 4 cm in diameter. Values are expressed as mean plus or minus standard error of mean, which is the measure of how much the value of the mean may vary from sample to sample taken from the same distribution. It is the standard deviation of the distribution of all possible means, if samples of the same size were repeatedly taken.

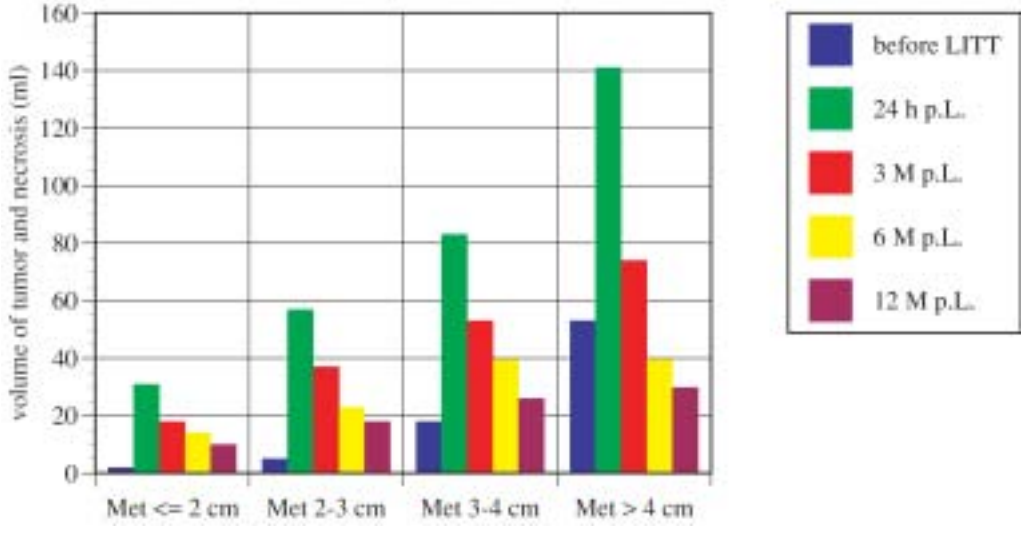

Figure 8
The diagramm shows the mean values for the initial tumor volume (before LITT) as well as the volumes of the obtained coagulative necrosis 24 hours after LITT treatment (24 h p.L), 3 months after LITT (3 M p.L.), 6 months (6 M p.L.) and 12 months after LITT treatment (12 M p.L.). The evaluation included metastases from all primaries.

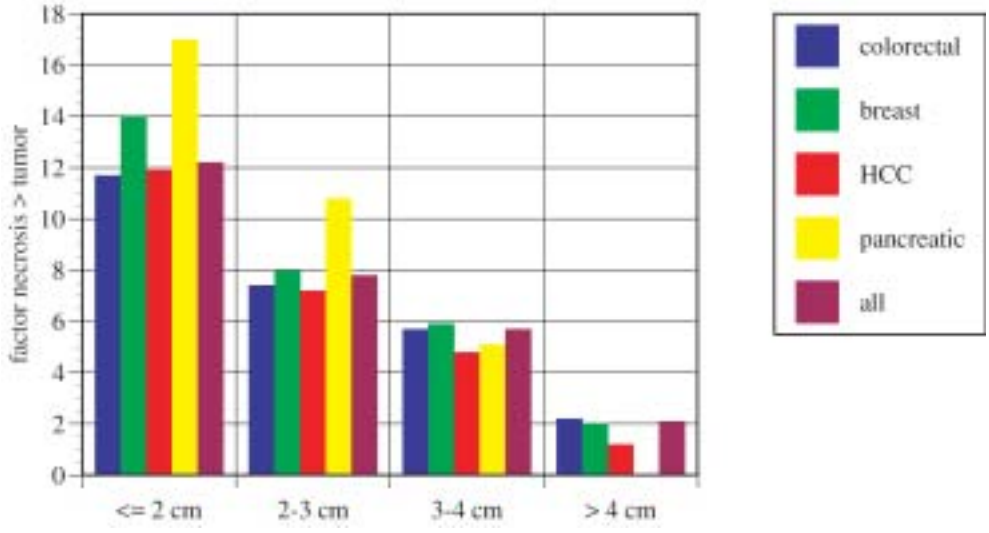

Figure 9
The graph shows the factor by which the necrosis measured on contrast enhanced images 24 hours after LITT treatment exceeds the initial tumor volume. The values are separately given for the different primary tumors as well as the different size of the treated metastases.

Side effects and complications

All patients tolerate the intervention well under local anesthesia. Clinically relevant complications such as bleeding, infection, or pleural effusion are observed at the following rates (based on the number of treatment sessions): pleural effusion, 1.1%; intraabdominal bleeding, 0.1%; liver abscess, 0.4%; 30-day mortality, 0.1%; pneumothorax, 0.1%; injury to bile duct, 0.1%; and bronchial-biliary fistula, 0.07%. The overall complication rate is 1.5%. However, except for the three patient who died within 30 days after the procedure, complications were not severe and could be treated either by drainage or puncture (pleural effusion, abscess) or percutaneous bile duct reconstruction by placing a stent. One patient died 4 weeks after treatment. This patient developed leakage in the jejunum following LITT of a liver metastasis in segment 4a. The patient underwent surgery but succumbed to peritonitis and acute respiratory distress syndrome. The death was considered possibly LITT- related, most likely due to stress ulceration of the jejunum. A second, 72-year-old patient died within 30 days after laser treatment, probably due to sepsis. However, this could not be proven as no autopsy was performed. A third patient died 10 days post LITT due to liver failure. One case of intra-abdominal bleeding was self-limiting and no treatment was necessary.

Imaging during LITT revealed a small, non-symptomatic subcapsular hematoma in 2% of the patients. Local infection at the puncture site was seen after treatment in two patients and treated with intravenous antibiotics. No seeding of metastases was found in our patients.

Local tumor control rate and survival data:

The local tumor control rate is determined using plain and contrast-enhanced MR images obtained 3 and 6 months after LITT treatment. Reflecting the development of the laser application systems and the increased experience of the physicians, the patients were divided into different groups for evaluation of the local tumor control rate. The contrast-enhanced MRI control study 6 months after laser treatment demonstrated a local tumor control rate of 45.1% in group 1, 64% in group 2 and 98% in group 3. This shows that MR-guided LITT results in definitive tumor destruction even in long-term follow-up. During the further follow up period up to 6 years after laser treat-

ment, plain and contrast-enhanced MRI revealed no local recurrence later than 6 months after initial treatment. In the late follow-up period MRI documented only scar tissue without any pathologic contrast enhancement.

Survival curves are evaluated using the Kaplan-Meier method. The mean cumulative survival rate of patients with colorectal liver metastases is 3.8 years (95% confidence interval 3.4 - 4.1 years). The 1-year survival rate is 93%, the 2-year survival rate is 73%, the 3-year survival rate is 50%, and the 5-year survival is 28%. Maximum survival is 83.4 months (Fig. 10a). There is a trend (Fig. 10b) for patients with 1 or 2 initial metastases (mean survival 4.0 years, 95% confidence interval: 3.6 - 4.5 years) to have superior survival to patients with 3 or 4 initial metastases (mean survival 2.8 years, 95% confidence interval: 2.6 - 3.3 years). However, the differences are not statistically significant. Patients with metachronous metastases show a trend to superior survival compared with patients who have synchronous metastases. In our patient collective we have a nearly equal distribution of synchronous and metachronous liver metastases.

The evaluation according to the primary lymph node stage (Fig. 10c) indicates that patients with a N0 or N1 primary lymph node stages have superior survival compared to N2 and N3 patients. The mean survival in patients with N0 and N1 lymph node stage is currently 4.1 years (95% confidence interval: 3.6 - 4.6 years). The mean survival in patients with N2 and N3 lymph node stage is 3.5 years (95% confidence interval: 2.7 - 3.3 years).

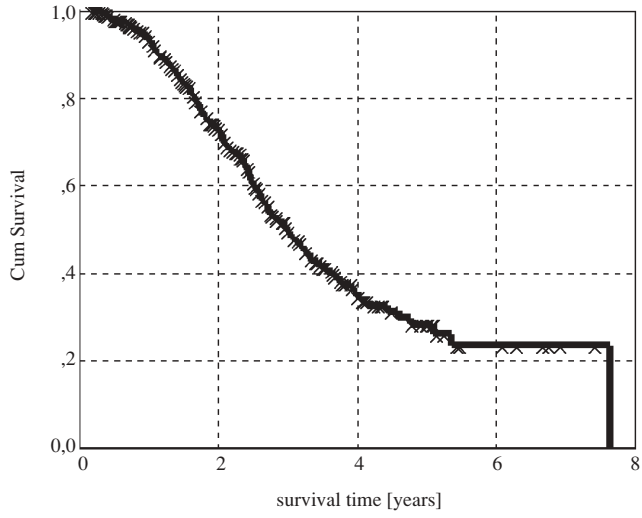

Figure 10a
Survival data of all patients treated with LITT for colorectal liver metastases (n=1556).

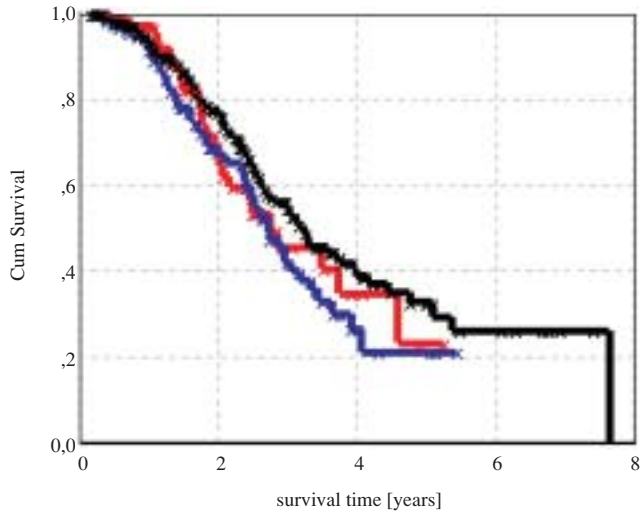

Figure 10b
Comparison of survival of patients with respect to the number of initial metastases (black line = group 1 = 1 or 2 metastases, blue line = 3 or 4 metastases, red line = group 2 = more than 4 metastases).

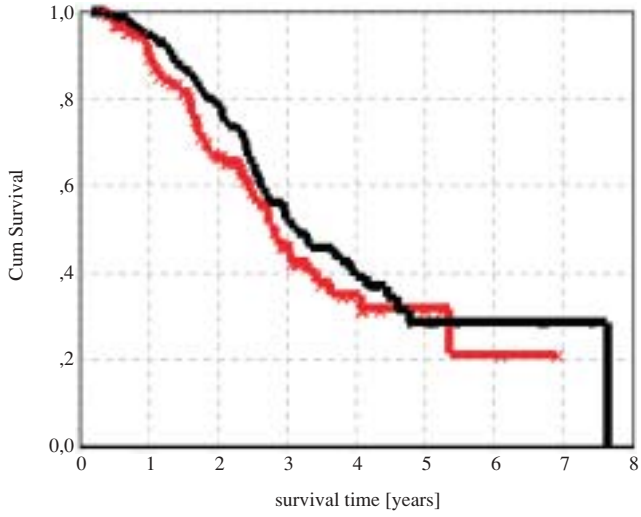

Figure 10c
Comparison of survival of patients with respect to the initial staging of lymph nodes (black line = group 1 = N0 and N1 stage, red line = group 2 = N2 or N3 stage).

Discussion

Liver tumor is one of the most common tumors in Europe and the United States and is twenty times more common in Africa, Japan and the Eastern countries. The liver is the most common site of metastasis. Colorectal cancer is the third leading cause of death in Western communities, outnumbered only by lung and breast cancer. At the time of death, approximately two-thirds of patients with colorectal cancer have liver metastases. Survival in liver disease depends on the extent of liver involvement and the presence of tumors. In several studies, liver metastases from colon carcinoma, which were confined to one lobe and involved an area of less than 25% of the liver, caused death in 6 months when untreated [28]. When 25% to 75% of the liver was involved, survival was 5.5 months; and when more than 75% of the liver was involved, death occurred in 3.4 months.

At this time, liver resection is considered to represent the only potentially curative strategy in the treatment of colorectal liver metastasis. About 40% of the surgically treated patients survive three years, and 25% of them are alive after five year. Repeat liver resections can be performed and still achieve a three-year survival rate of 30%. Clinical conditions, the presence of lesions in a central location, lesions in both hepatic lobes, or poor clinical status preclude surgical treatment. In an analysis of a population of 1,568 patients with metastases confined to the liver which were surgically resected, there was a 5-year survival rate of 28% and a 5-year disease-free survival rate of 15%. Nordlinger et al. demonstrated that factors associated with increased risk of recurrence and death were related to the primary tumor, metastases, and the surgical procedure itself [51]. By contrast there was no correlation with the location of the metastases or the extent of liver resection.

Liver resection can therefore be offered only to a small number of patients with a good chance of success: There is a need for adjunct treatments to improve the success of resection and to diminish the incidence of recurrence after surgery, particularly in patients for whom surgery is not an option.

Therapeutic alternatives in the treatment of liver tumors include surgery, local ablation like LITT, RF ablation, cryotherapy [29-33], microwave ablation [34] and ethanol injection [10,12,13,35] or oncologic strategies such as systemic or locoregional chemotherapy [36-42]. As a high number of tumors grow in damaged liver parenchyma with reduced hepatic functions, it is important for all methods which damage tumor cells to preserve functional reserve capacity, delaying terminal organ failure for as long as possible.

Therefore many local ablation techniques were developed in order to improve the survival of the patients [6]. Nowadays, the most common technique is RF ablation. Radio-frequency waves (RF waves) have been used since the 1960's for treating intracerebral tumors, controlled stereotaxically. For some years RF treatment has also been used for treating soft tissue, focusing on the treatment of malignant liver tumors. As with LITT a coagulation necrosis is caused through a local temperature increase. The necessity for an external second electrode on patients makes an uncontrolled energy flow outside the required target zone theoretically possible, as burns cannot be safely ruled out. Cooling the tip of the applicator in RF treatment was introduced to increase the size of the induced necrosis up to 5 cm in diameter.

Rossi et al. treated 11 patients with 13 metastases in 1996 using mono and bipolar systems and the multi-applicator technique. One year after the operation only one patient was tumor-free and the relapse rate was around 55%. The findings for HCC lesions were better, as there was a relapse rate of only 10% and mean survival times of 44 months [43].

In 1997 Solbiati et al. published a study of 29 patients with 44 liver metastases (size 1.3-5 cm) of colorectal, stomach, breast, and pancreatic carcinomas. Among them were 20 patients with solitary lesions. The operation took place using cooled systems, and a complete tumor ablation was achieved in 91% of cases. At the 3- and 6-month check-up 66% of the treated lesions were still inactive. A survival rate of 100%, 94% and 86% after 6, 12, and 18 months, respectively, was documented [44]. Livraghi tried an approach using conventional systems and simultaneous irrigation with NaCl solution in 14 patients with 24 liver metastases (1.2 to 4.5 cm in size) but only 52% of the lesions were inactive after six months [45].

In 1999 Livraghi et al. presented a direct comparison of RF therapy (42 patients, 52 lesions) with percutaneous alcohol injection - PAI - (44 patients with 60 tumors) in treating hepatocellular carcinomas. This was the first direct comparison of these two different treatment techniques in similarly structured patient populations. 80% of tumors were removed completely using PAI and 90% using RF (no statistical significance). The main advantage of RF therapy proved to be the smaller number of treatment sessions (1.2 versus 4.8). On the other hand a higher complication rate (2% serious, 8% less serious complications versus 0% for PAI) was documented [15]. Side effects with regard to punctures are relevant here, e.g. pneumothorax or haemothorax (2%), injury of the bile ducts and the gall bladder, intraperitoneal bleeding (8%) and also pleural effusions. Depending on the procedure some cases had to be upgraded from local to general anaesthesia due to severe pain during the energy application.

Our data in a large population of patients with liver tumors from different primary tumors, mainly colorectal carcinomas, show a very high local control rate (over 97% in 3- and 6-month control studies) and a very low local recurrence rate. LITT treatment can be performed easily under local anesthesia on an outpatient basis in metastases up to 5 cm in diameter with a 1 cm safety margin, which is very important for a low recurrence rate. Multiple applications can be performed simultaneously.

Our data indicate that there is a high variance in heat distribution. Sometimes a couple of minutes are enough to treat a metastasis with a reliable safety margin and sometimes applications times of 30 minutes and more are necessary to achieve the same necrosis in another metastasis of the same size. Therefore reliable nearly on-line monitoring of treatment is absolutely necessary in order to avoid over or undertreatment of the metastases. Due to the fact that laser ablation is fully compatible with MRI, which is the most reliable method for thermometry, MRI is well suited for monitoring thermal ablation like LITT.

The clinical success of MR-guided LITT depends on many factors. First, optimal positioning of one or more laser application systems in the lesion must be ensured, as determined in three dimensions. The real advantage of MR over CT and ultrasound lies in the heat-sensitivity of the MR sequence and the possibility of visualizing and quantifying the degree of induced necrosis of the malignant and surrounding parenchymal structures. It ensures rapid acquisition of temperature maps, allowing nearly real-time documentation of LITT effects. Monitoring of these effects during ongoing therapy is advantageous for a number of reasons. The technique can be used to assure that the entire lesion has been treated, and if there is residual tissue within the lesion that has not been treated, the applicator can be re-positioned under MR guidance during the same treatment session. This technique allows safe destruction of metastases and well controlled coagulation of a safety margin surrounding the lesion.

Monitoring also minimizes the destruction of healthy tissues, thus enhancing the safety of the procedure, particularly in the vicinity of vital structures such as large vessels or the central bile ducts in the liver. MR provides unparalleled topographic accuracy, due to its excellent soft-tissue contrast and high spatial resolution. This allows early detection of complications.

Several factors may influence the size and morphology of the areas of induced necrosis, including tumor geometry and adjacent structures such as arteries, portal and hepatic veins, and the biliary tree. The relationship of the tumor with the liver capsule is an essential factor in planning treatment of the lesion.

The survival rates achieved, which represent the most relevant success criterion for a treatment, are slightly superior in patients with metastases from a colorectal carcinoma or a carcinoma of the breast to those in surgically resected patients. It must be considered, however, that a surgical resection was not or was no longer an option for most of the patients being treated due to metastatic relapse after surgical resection or a bilobibular pattern of infestation. In spite of that it was possible to achieve survival rates comparable to surgical resection among these patients, who are actually in a group with a worse prognosis. Compared with the extensively published historic survival data after surgical metastatic resection, LITT offers a very good further treatment option. Due to the survival data and local tumor control rates achieved so far, in our opinion randomised studies comparing LITT with chemotherapy solely in the case of patients who fulfil the inclusion criteria for LITT are no longer ethically tenable.

Above all, however, intensive chemotherapy, systemic or regional, with marked toxic side effects severely affects the quality of life in the majority of cases. Looking at it from this background all the more attention must be paid to the treatment concepts described here, because minimally invasive techniques are applied which adversely affect patients less and short-term.

Consequently, the prerequisites are given to integrate these new procedures into oncological treatment programs which have been carried out up to now. LITT, which has been used for the past eight years in the clinical routine, can play a great part in modern oncological treatment concepts.

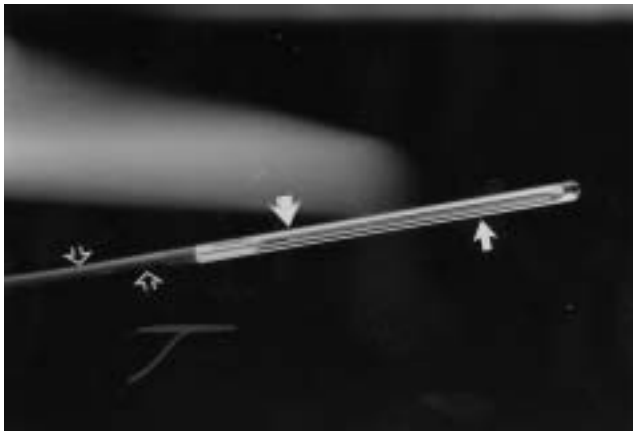

Figure 11a
Macroscopic visualization of the laser-induced catheter set. Small white arrow heads for the sheath. White arrows: thermostable application catheter.

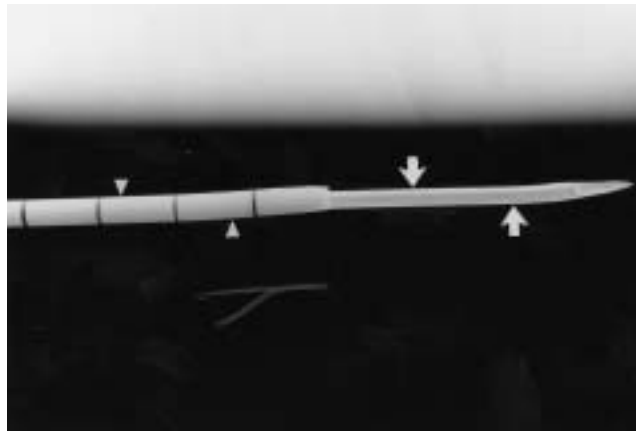

Figure 11b
Macroscopic visualization of the laser fiber (glass dome: white arrow; flexible catheter: open arrows).

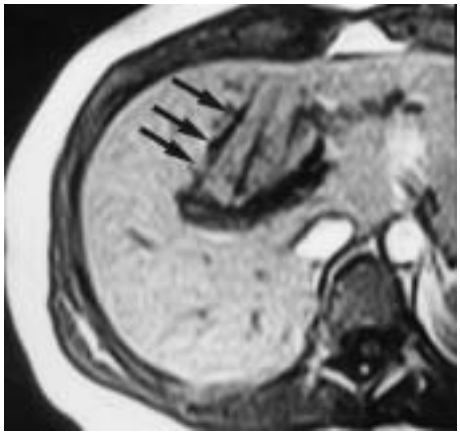

Figure 12a
Metastasis of 4 cm in size in the right liver lobe, segment 4. Percutaneous insertion of three laser fibers (black arrows) in the center and the periphery of the metastasis. Note the portal vein posterior to the metastasis.

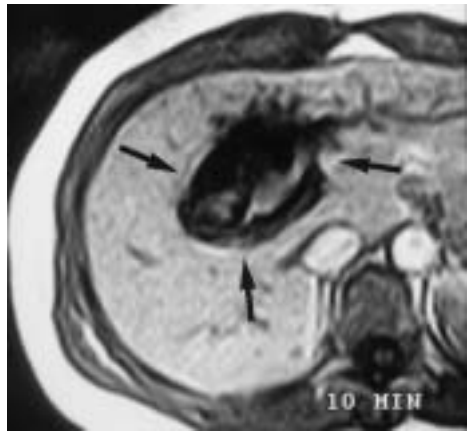

Figure 12b
10 minutes after percutaneous laser-induced thermotherapy. Note the enormous signal loss within the lesion covering the whole area of segment 4 (black arrows).

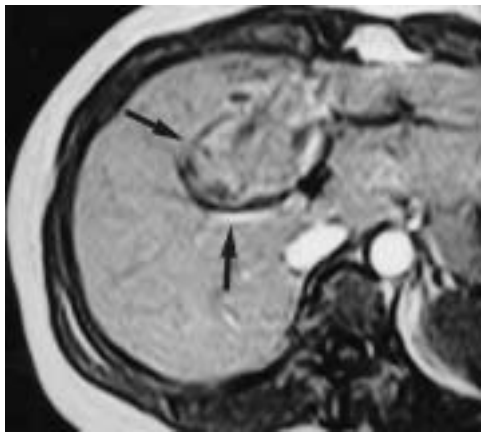

Figure 12c
Contrast-enhanced MR image before start of the laser application with high signal intensity of the lesion.

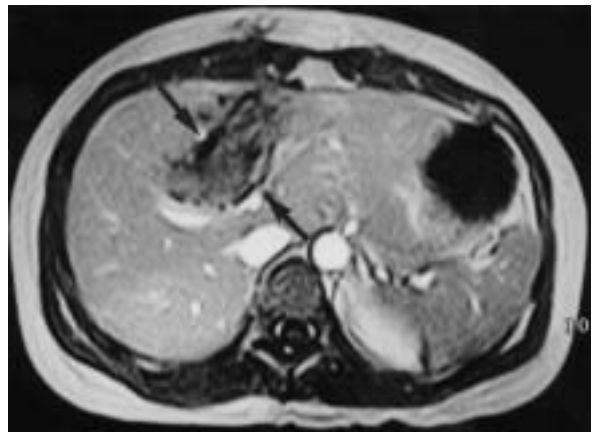

Figure 12d
Gradient-echo-sequence Gadolinium-enhanced post laser application, note the devascularisation of the lesion with coagulated material (black arrows)

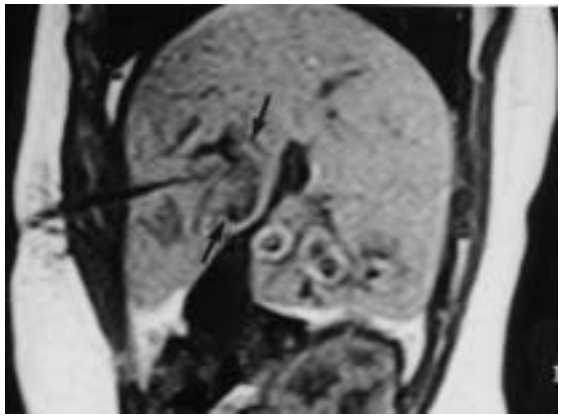

Figure 12e
Demonstration of the laser effect. Sagittal slice orientation inserted laser as straight line, lesion itself (black arrows).

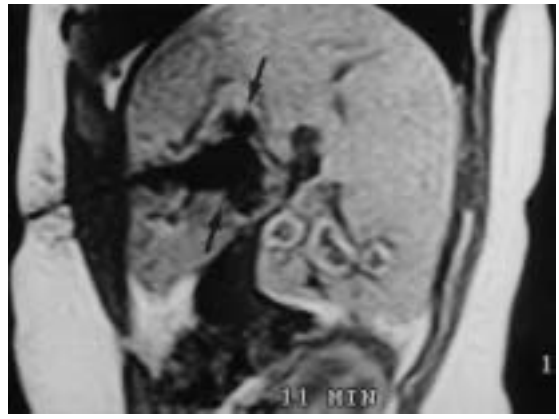

Figure 12f
11 minutes post laser application. MRI demonstrates a signal loss within the lesion in the adjacent structures.

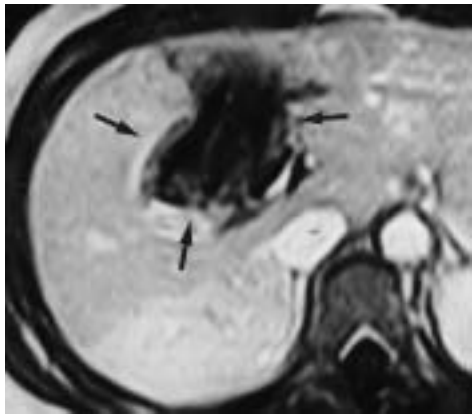

Figure 12g
T1-weighted gradient-echo-sequence post Gadolinium DTPE. Final control at the end of the laser treatment with enormous signal loss of the total metastasis and a safety margin of 1 cm surrounding the lesion.

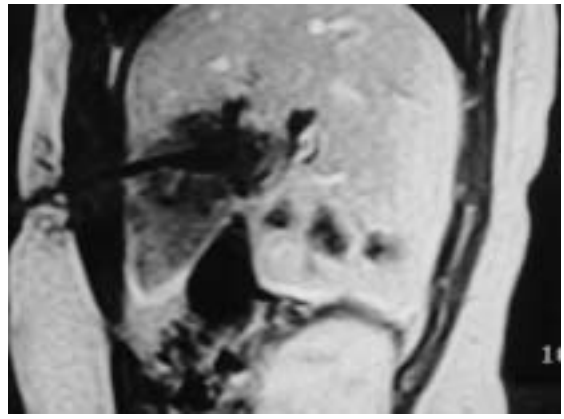

Figure 12h
Demonstration of sagittal T1-weighted sequence, Gadolinium-enhanced. The sagittal orientation demonstates the complete signal loss and an enormous degree of necrosis and coagulation within the metastasis and adjacent structures.

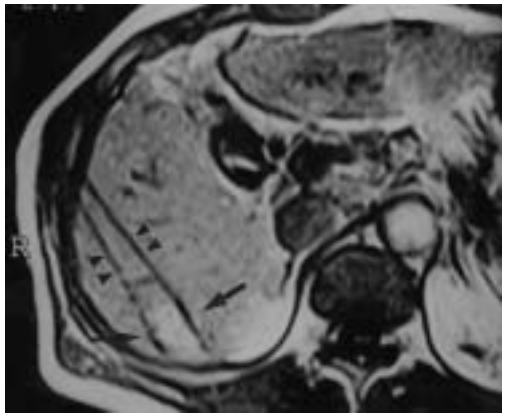

Figure 13a
Hepatocellular carcinoma in segment 7. Percutaneous laser application via insertion of three laser fibers. Gradient-echo-sequence plain before laser treatment. Demonstration of the lesion with high signal intensity due to fatty tissue (black arrows). Note the black linear structures all along the laser fibers (arrow heads).

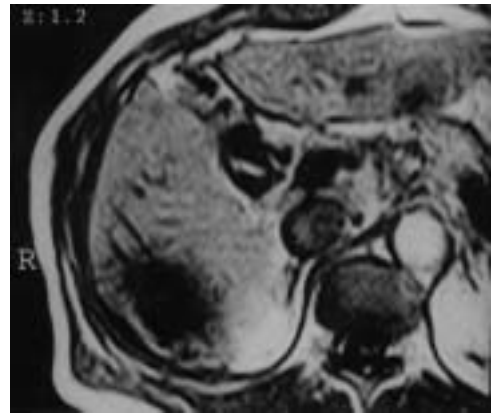

Figure 13b
15 minutes post laser treatment MR thermometry. In the MRI huge area of signal loss with a diameter of 5 cm achieved via the application of the laser energy.

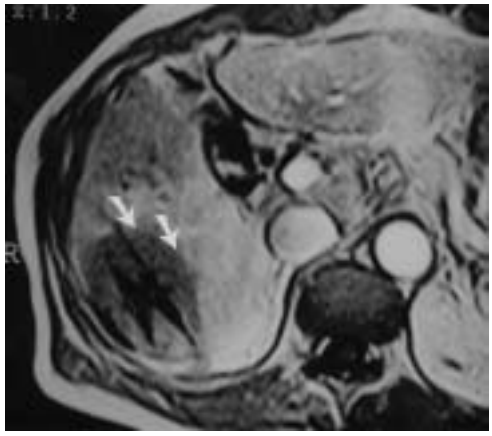

Figure 13c
Gadolinium-enhanced gradient-echo-sequence post laser application as final control. Demonstration of the complete coagulation of the hepatocellular carcinoma. Safety margin of 10 mm (white arrows). Thus, a complete tumor destruction was achieved.

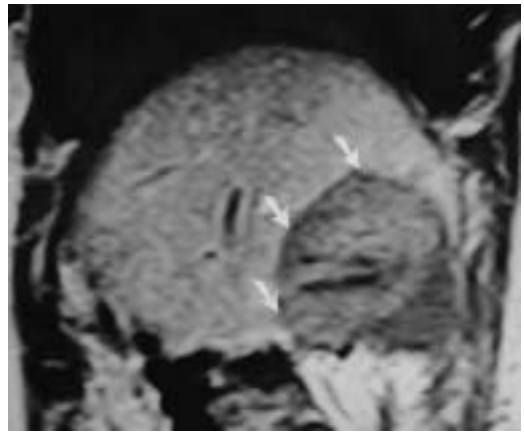

Figure 13d
Sagittal orientation gradient-echo-sequence, Gadolinium-enhanced. In the sagittal orientation the sharp delineated necrosis is visualized allowing a very clear distinct margin.

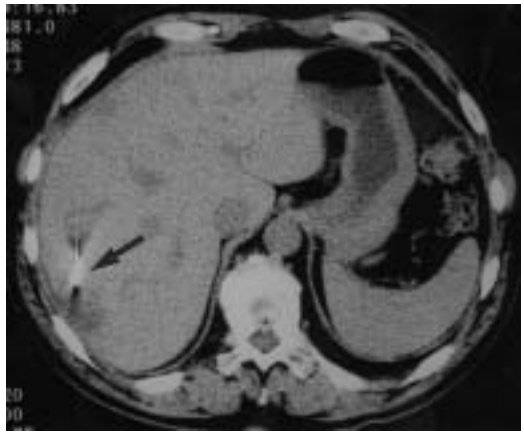

Figure 14a
CT-guided application of a laser catheter . Note: needle anterior to the lesion itself (black arrows).

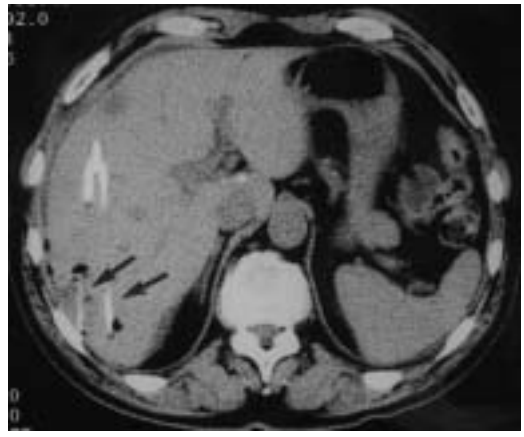

Figure 14b
CT demonstration of the two inserted thermostable laser catheters (white arrows).

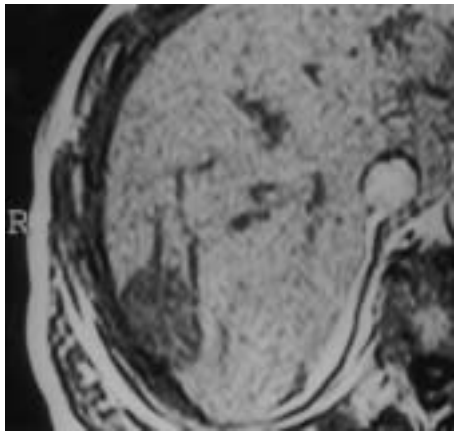

Figure 14c
MR control gradient-echo-sequence demonstration of the laser fibers in the lesion with low signal intensity. Note the low signal intensity of the lesion and the linear structures.

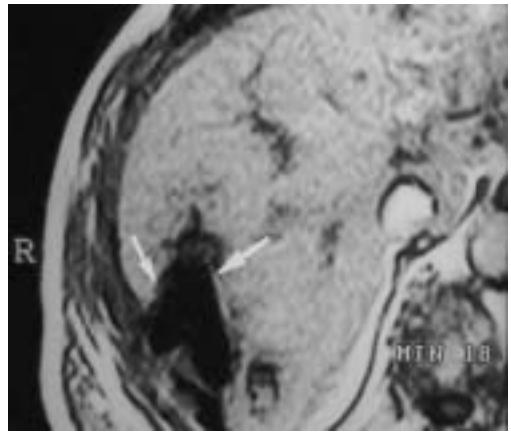

Figure 14d
MR thermometry 18 minutes post laser application. Asymmetric signal loss according to and adapted to the geometry of the lesion (white arrows).

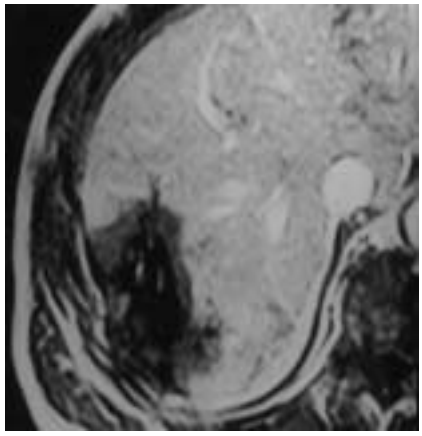

Figure 14e
Gradient-echo-sequence, Gadolinium-enhanced, axial orientation, final control in the T1-weighted sequence. Note: coagulated area with low signal intensity and no enhancement.

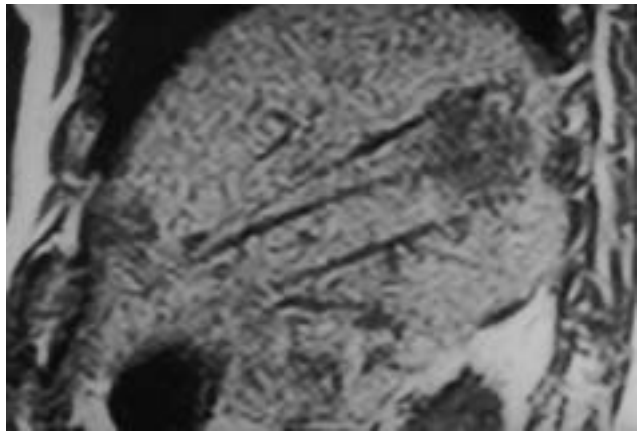

Figure 14f
Visualization of the pretreatment situation in sagittal orientation. Low signal intensity of the lesion. Note: the inserted structures of low signal intensity.

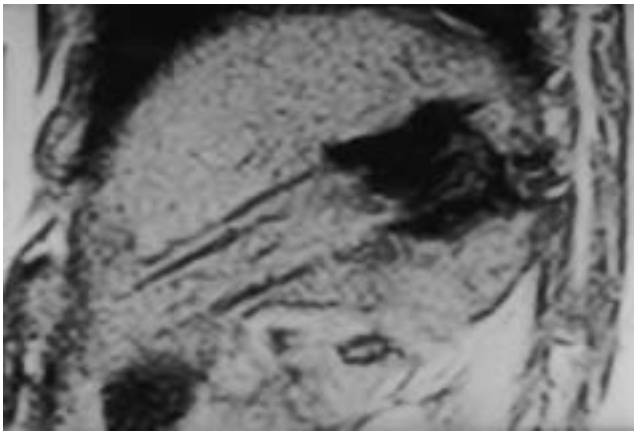

Figure 14g
Signal loss of the metastasis according to the geometry of the lesion.

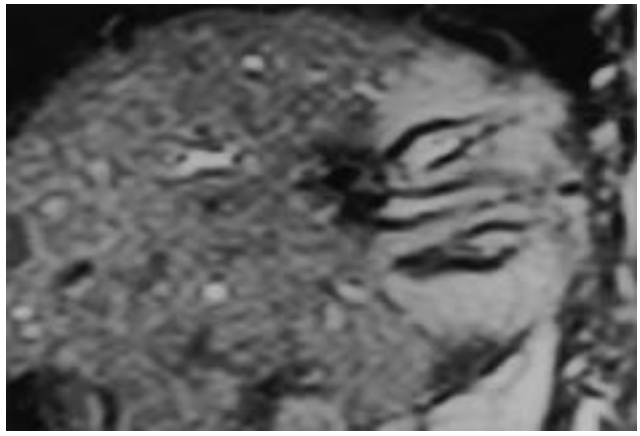

Figure 14h
Final control T1-weighted sequence, post Gadolinium enhancement. In the final control there is an increase in the signal intensity of the total lesion according to some intralesional haemorrhage.

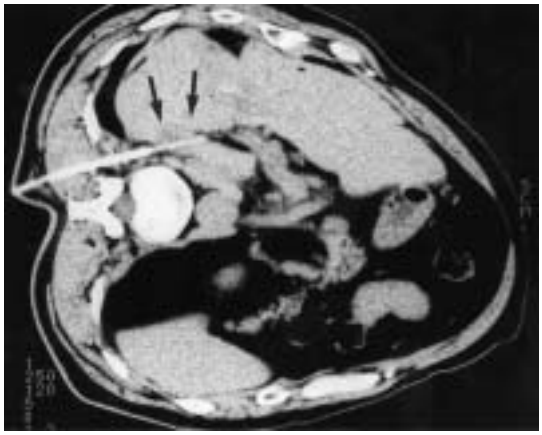

Figure 15a
Demonstration of laser ablation of a complex topographic relationship with a metastasis near the vertebral column. Note: the lesion itself has low density (white arrows in the inserted laser catheter).

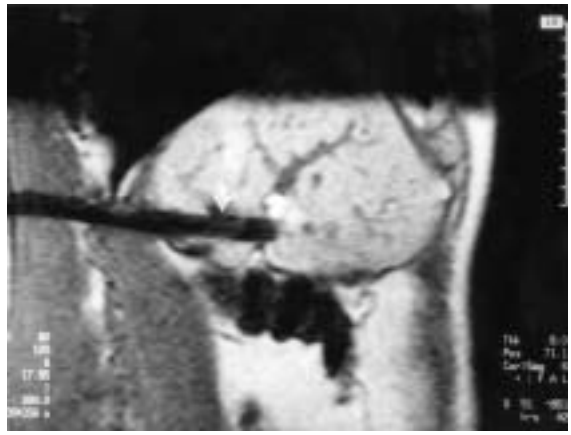

Figure 15b
In sagittal orientation demonstration of the course of the inserted laser fiber (white arrow) in relationship to the liver with medium signal intensity.

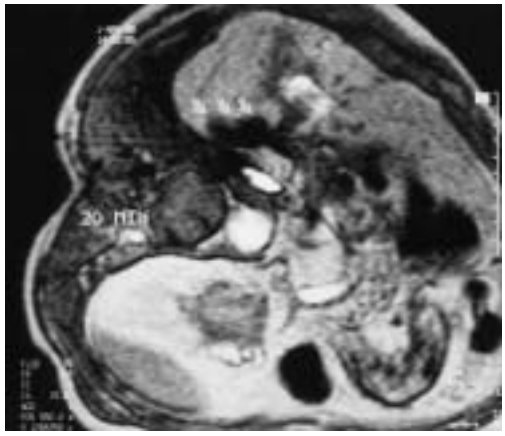

Figure 15c
MR thermometry 20 minutes post laser ablation. Note the loss of the signal intensity (curved white arrows).

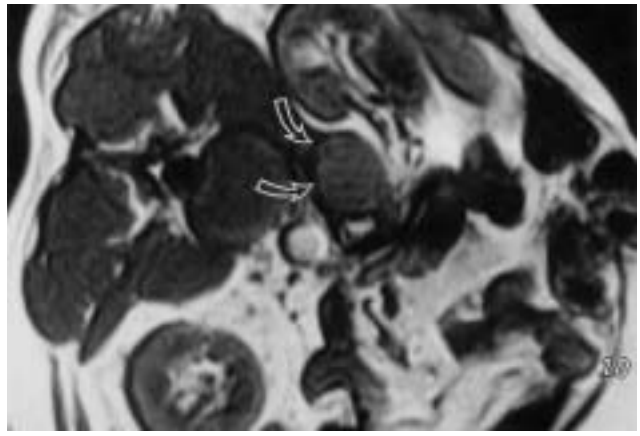

Figure 16a
Lymph node metastasis in the paraaortal lesion on the right hand side. The lesion itself has medium signal intensity (curved white arrows).

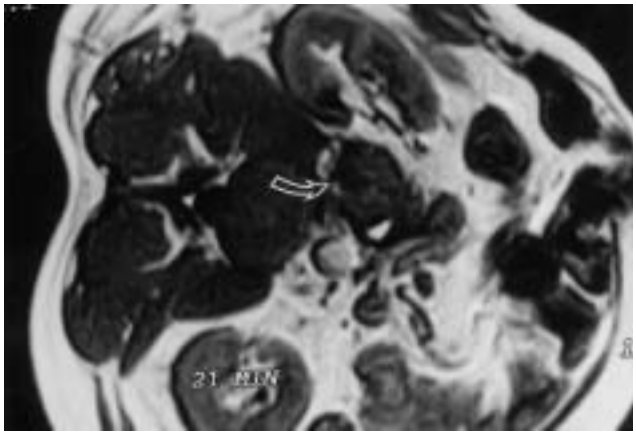

Figure 16b
21 minutes post laser ablation via 2 inserted laser catheters demonstrates a signal loss of the complete lesion. Note the course of the cavae medially in the aorta.

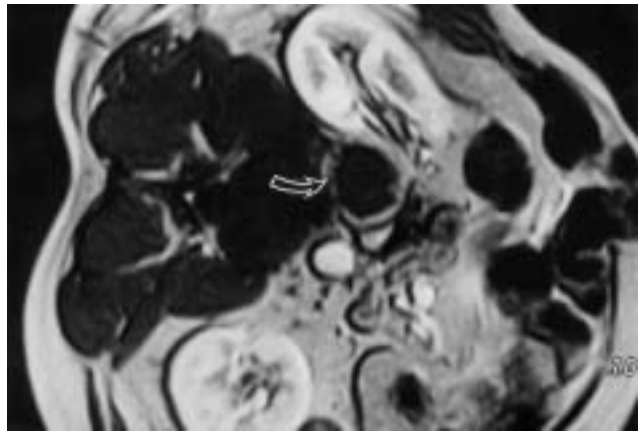

Figure 16c
Gadolinium-enhanced T1-weighted final control study. The sequence demonstrates a complete devascularization of the lymph node metastasis with a small peripheral rim of high signal intensity (curved white arrow).

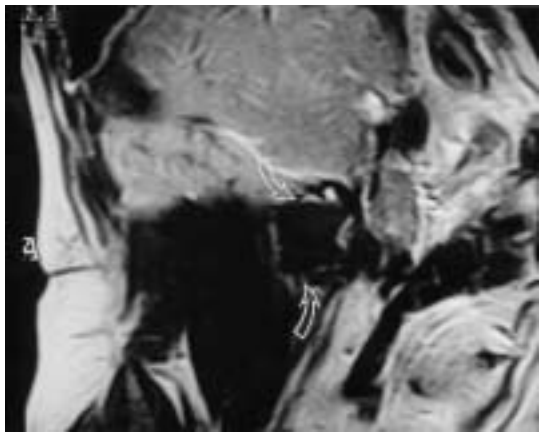

Figure 16d
Sagittal orientation. Verification of the lymph node metastasis (curved white arrows) in relationship with the bowel. Adjacent kidney structures.

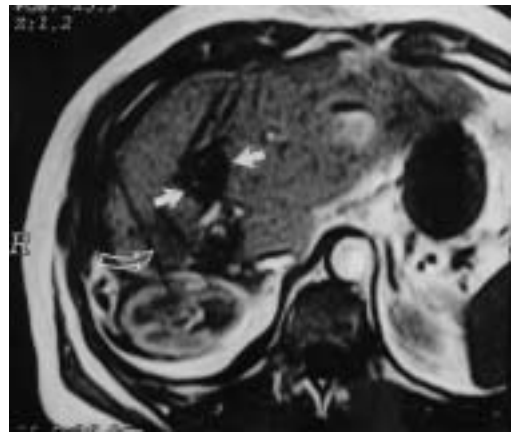

Figure 17a
Patient with complex situation post hemihepatectomy, two recurrent metastases with direct relationship to the biliary tract. Simultaneous ablation of two lesions via 4 laser fibers.

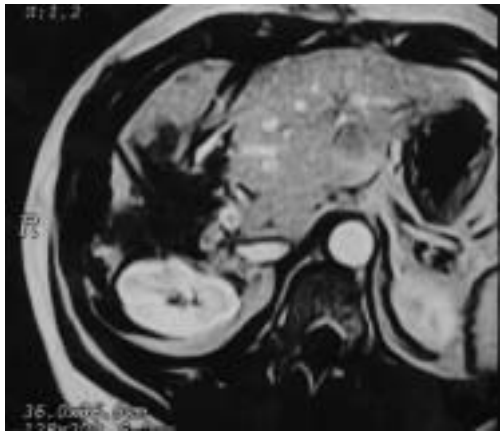

Figure 17b
Post MR control, contrast-enhanced final control, post interventional final control. Note the huge degree of devascularized areas interhepatically. The biliary tract has been completely ablated. CT control see Figure 7c

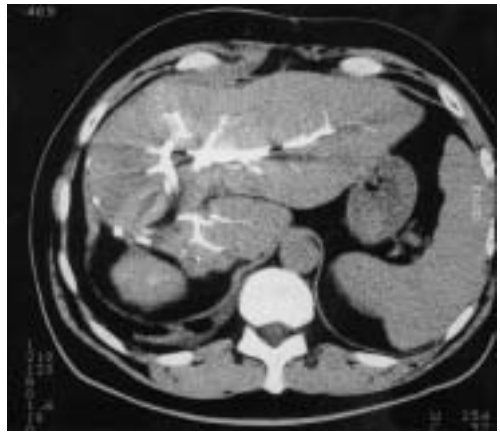

Figure 17c
CT-guided PTC demonstrates the course of the interhepatic bile ducts.

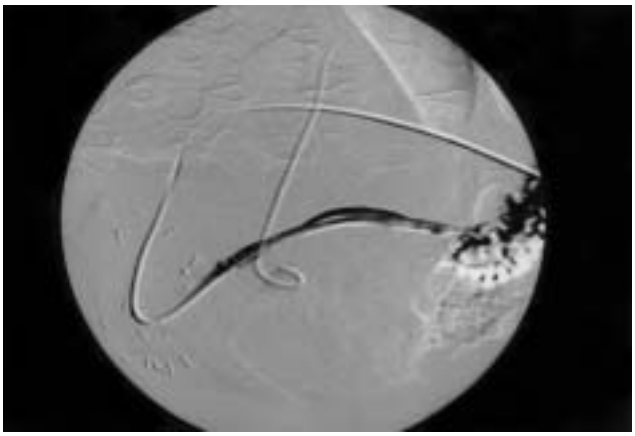

Figure 17d
CT-guided placement of an interhepatic drainage (see Figure 7b, e) for temporay biliary access. A complete local tumor control could be achieved by laser ablation.

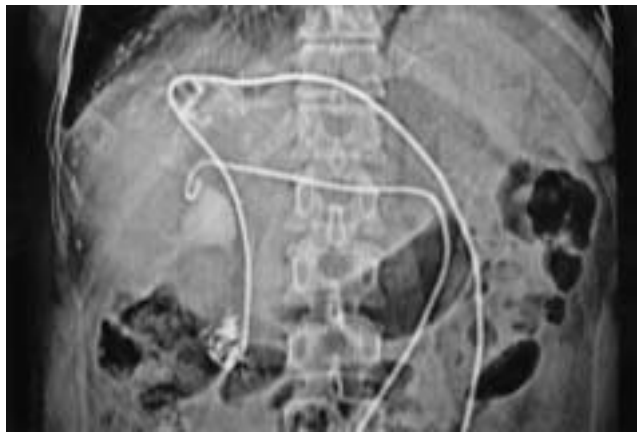

Figure 17e
Demonstration of the inserted catheters.

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