Laser Coagulation Zones Induced with the Nd-YAG Laser in the Liver

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Abstract. Laser-induced interstitial thermotherapy (LITT) has become a method to treat different types of tumours. To increase the effectiveness of LITT in liver tissue, a new thermo-controlled application system was developed. In in vivo experiments in five pigs, ellipsoidal coagulation regions (3 and 5 cm diameter) were found in the liver within 10 min, which corresponds to a volume of about 20 cm³. In real time, the increasing coagulation zone, which appeared as a hyperechogenic halo, could be observed via ultrasound. The power of the laser source during laser treatment was controlled dynamically via thermosensors. Macroscopically and microscopically, the coagulation zones showed well-demarcated borders of the coagulation lesions, and the surrounding tissue appeared vital. The reparative reaction after irradiation was early fibrosis. For 4 weeks, the surrounding scar capsule, containing fibrocytes, biliary ductules and collagen fibres, enlarged. As a result, the coagulation necrosis became more and more fragmented between collagen fibres, and was largely resorbed. The absence of complications in these pig experiments suggests that this technique of dynamic laser light application is safe and useful for therapy of metastases which are not resectable.

INTRODUCTION

Secondary liver cancer presents an unsolved clinical problem with a poor prognosis, and occurs most frequently (30% of cases) in patients with colorectal cancer. Up to now, resection of the metastasis is the only curative treatment available, with a 5-year survival time of 20–45% depending on the type and extent of the tumour (1, 2). However, only 10–20% of the patients are suitable for surgical resection (3). Surgical complications are bleeding, infection and liver failure. Alternative palliative treatments may have a high morbidity and show no substantial improvement in survival (4, 5). There is still a need for a simple precise technique with a low morbidity for destroying deep tumours of the liver.

The thermal effect is a fundamental property of laser beams in biological tissue. Coagulative and hyperthermic effects due to photon absorption and heat conduction lead to an immediate or delayed tissue destruction (6, 7). Thus, laser light can produce highly predictable localized defective tissue zones. Superficial tumour areas can easily be photoagulated by contact or non-contact light application, which is the best technique for minimal tissue manipulation and reduced chance of tumour spread. Deep tumours or metastases can only be treated by interstitial implanted light delivery fibres into the tissue/tumour.

Laser-induced interstitial thermotherapy (LITT) is an effective and investigative method of tumour therapy. Different types of tumours in the liver, pancreas, lung and brain have been treated in the past (6, 8–11). Additionally, benign hyperplasia (prostate) can also be reduced with interstitial laser coagulation (7, 12, 13).

Mainly, the neodymium-yttrium aluminium garnet (Nd-YAG) laser was used at a wavelength of 1064 nm, because of deep light penetration in biological tissue (14). In addition to laser power, the light application system is also an important factor in producing an effective coagulation zone within a few minutes.
At the beginning of LITT, bare fibres were used to induce interstitial hyperthermia (15). The high power density at the distal end of the fibre restricted the applicable laser power to a few watts in order to avoid carbonization. As a result, only small coagulation zones with diameters of up to 1.5–2 cm could be achieved (16).

To increase the coagulation volume, several (modified) bare fibres were spread out over the tumour volume (17). Open liquid cooling of the fibre tip has been used previously, resulting in a liquid pool with increased interstitial pressure (18, 19). Others have experimented with a frosted sapphire tip to get a wider angle of illumination (20–22). However, the width of the sapphire tip and the compound metal collar limits percutaneous application. The initial use of coaxial gas flow to cool the fibre tip is now obsolete because of air embolism (23).

The development of radially or diffusely emitting fibres increases the affected zone to diameters of up to 2 cm (24). However, there is still the limitation of laser power. Recently, water-cooled laser devices were developed in order to overcome power limitation (25), but these devices do not provide the possibility of monitoring temperature of the surrounding tissue. Furthermore, the applicable power was still limited.

To increase the affected volume and to reduce therapy time, further investigations were made and a new applicator system was created. In the present study, the extent and the pathological change following in vivo interstitial coagulation was investigated in pig livers.

**MATERIALS AND METHODS**

**Animals and laser application**

Five pigs were anaesthetized and treated with LITT (accepted animal experiments, Regierungspräsidium Tübingen, AZ 37-9185.81-3). Pulse, blood pressure, temperature and respiratory rate were monitored continuously during the laser procedure. An upper medial laparotomy was performed to reach the left and right part of the liver. The left part of the liver was punctured with a metal needle. A dilator of outer diameter of 2.5 mm and internal diameter the same as the needle was used for dilatating the applicator channel. The needle was removed and a tube with an inner diameter of 2.5 mm was placed over the dilator. Subsequently, the dilator was removed and the applicator was inserted. After this, the sheath was withdrawn over 5 cm proximal. In this way, the Duran® window of the applicator made contact with the liver tissue at the top of the applicator. Nd-YAG laser light (1064 nm) was used in combination with a thermo-controlled application system. Liver coagulation was performed dynamically over 10 min. After coagulation, the puncture channel was also coagulated by removing the working applicator slowly. The right lobe of the liver was treated in the same way.

The laser procedure was performed using a fibre designed for cylindrical light emission. To protect the tissue from carbonization and water vaporization, thermosensors were used in the backflow of the water-rinsing system (Fig. 1). During the laser process, the coagulation zone was imaged with a 5 MHz ultrasound sector scanner.

The first animal was killed immediately after the coagulation of the two liver zones. The other pigs were left alive for 1, 2, 3 and 4 weeks after the LITT procedure. They were killed with an overdose of anaesthesia, and the LITT-treated liver was examined macroscopically and histologically. The coagulation volumes were calculated via three-dimensional measurements ($V = \frac{4}{3}\pi a^2 b$).

**LITT application system**

The laser device was designed to apply high laser power to deep tissue areas, and to protect the optical fibre. The whole system is shown in Fig. 2. A handpiece comprises an axial channel for fibre deposition and two coaxial ducts for the rinsing circulation. The large distal part of the applicator (20 cm length and 2.5 mm diameter) ends with a Duran® window. A modified laser fibre tip is hermetically sealed against its surroundings by a transparent optical case. The distal end of this 600 mm fibre is modified.