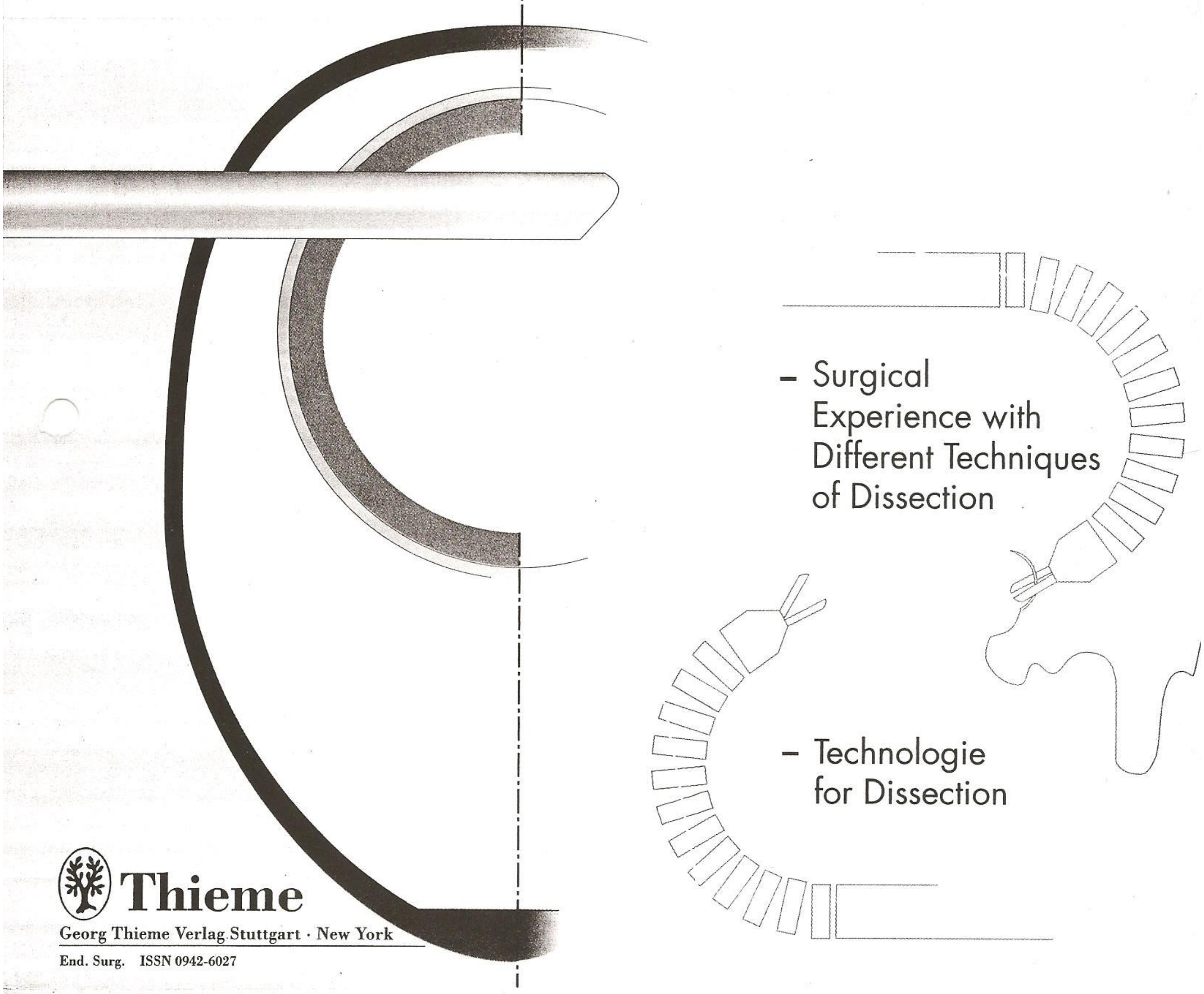
Endoscopic Surgery and Allied Technologies

E 20137 F

3/4 Volume 2
June/August 1994
Page 169 - 236



– Surgical Experience with Different Techniques of Dissection

– Technologie for Dissection

Thieme
Georg Thieme Verlag Stuttgart · New York
End. Surg. ISSN 0942-6027

Histologic Effects of Different Technologies for Dissection in Endoscopic Surgery: Nd: YAG Laser, High Frequency and Water-Jet

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Precise cutting combined with reliable coagulation of the margins of the lesion is an important requirement for dissection techniques in endoscopic surgery. These requirements are met by the two most common ancillary energy sources applied for endoscopic dissection today, electrosurgery and "thermal lasers", mostly the Nd:YAG. For the comparison of the histological effects of monopolar and bipolar high frequency with the Nd:YAG laser an experimental in vitro and in vivo study has been performed. In order to evaluate the advantages of non thermal dissection for endoscopic procedures, a water jet cutting system was included in the in vitro study. In parenchymatous tissue the water jet was found to be the least traumatic technique, followed by bipolar high frequency, laser and monopolar high frequency. The water jet was not applicable for intestinal dissection since uncontrolled bloating of the rectal wall with uncontrolled disruption of the tissue layers occurred. A general disadvantage is that secure haemostasis in the line of incision is hard to achieve. In the microscopic comparison of the shape of the incision, the Nd:YAG laser produced the smoothest lesions with well-defined margins. The monopolar technique was more often associated with irregular and sometimes fissured margins. These results were confirmed in the in vivo part of the study (Transanal Endoscopic Microsurgery).

Key words: Endoscopic Surgery, High Frequency, Nd:YAG Laser, Water Jet

Introduction

Efficient and safe dissection techniques are crucial for successful operative results in endoscopic as well as in open surgery. Besides mechanical dissection techniques the mainly used ancillary energy sources for endoscopic dissection are high frequency (HF) current and thermal lasers. Both methods generate destructive heat in the body which leads to coagulation or separation of the tissue. Typically 10^2 to 10^4 W/cm^2 are applied in HF surgery, the power density of thermal lasers can be higher. Depending on power density and application time a temperature profile, developing out of the spot of application, is generated in the tissue. This temperature profile can be correlated with the consequent thermal damage to cells and tissue, and the effect of thermal energy depends on the temperature generated (Figure 1). The thermal lesions are macroscopically well demarcated from the adjacent unaltered tissue and consist mainly of coagulated protein changed from the colloidal state of tissue into the insoluble gel (1).

On principle, both high frequency and laser produce endothermic heat, i.e. the heat is not directly transferred to the tissue but the result of an energy-tissue interaction. Since this energy-tissue interaction is a dynamic process it causes a change of optical, electrical and thermodynamic parameters of the treated tissue. This explains why depth and lateral extent of thermal lesions are significantly influenced by the application time, which is as important as the power density used. Notwithstanding the way it is generated within the tissue, the denaturation temperature of protein 63°C is the temperature threshold for coagulation (1); safe coagulation of proteins and collagen denaturation is reached at a temperature of about 80° to 100°C. Coagulated regions are subsequently lysed by inflammatory cells and organised to scar tissue.

The mechanism of cutting tissues using destructive heat is mainly related to two phenomena. The rapid internal heating of the cells leads to boiling of the cytoplasm with excessive expansion of intracellular steam and subsequent rupture of the cell at temperatures around 100°C (1). When temperatures of more than 300°C are reached, solid tissue is vapourised and the organ surface is cut.

In contrast to high frequency and laser, a water jet delivers kinetic energy to its target tissue; thermal effects are absent. The potential energy of a pressurised liquid is converted into kinetic energy by means of a small nozzle at the tip of the application device. Dependending on the pressure on the liquid the water jet reaches a speed of several hundred km/h up to supersonic speed. The diameter of the jet, of the nozzle respectively, is usually 0.2 mm down to 0.02 mm (2–5). The water jet transmits its kinetic energy to the tissue surface and shoots particles out of the tissue formation and creates a corridor through the organ surface. By exploiting the differing tensile-strength of various tissues the water jet allows selective dissection. In the dissection of parenchymatous organs the harder vessels can be preserved whereas the soft parenchyma is separated (2–5).

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Temperature range (°C)	Thermal effect
37–42	Heating without irreversible damage
> 42	Enzymes and other sensitive metabolic molecular components become altered
43–45	Conformational change: hyperthermic retraction and shrinkage; cell death
>50	Inactivation of enzyme activity
45–60	Hyperaemia; oedema with loosening of membranes; swelling
>60	Protein denaturation; coagulation and necrosis; white-grey discolouration of the tissue; shrinkage
>80	Collagen denaturation; membrane permeabilisation
>100	Boiling of water in the cells and in the intercellular matrix (more than 1000-fold increase of volume); cell explosion and tissue cavitation
100–300	Dehydration; water evaporisation; carbonisation
>150	Carbonisation
300–400	Smoke generation from carbonisation; blackening of tissue
>300	Vaporisation of the solid tissue matrix
>500	Burning of tissue; pyrolysis in presence of atmospheric oxygen (evaporisation)

According to Reidenbach/Buess (1)

Figure 1: Effects of thermal dissection techniques on tissues (according to Reidenbach HD, Buess G) (1).

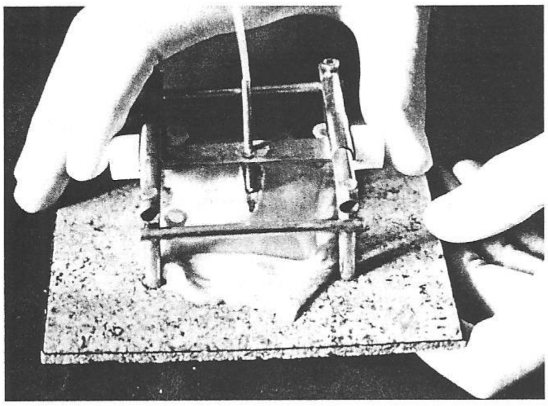


Figure 2: Dummy for the in vitro study with mounted rectal specimen. Direction and distance of the fibre tip to the tissue are kept constant.

In a combined in vitro and in vivo study the histologic effects of dissection using thermal techniques (high frequency monopolar and bipolar, and Nd:YAG laser) as well as the water jet were examined and compared regarding their effectiveness for endoscopic application.

Materials and Methods

In vitro Experiments

All three methods, high frequency (Erbe Elektromedizin, Tuebingen, Germany) (6), Nd:YAG laser (1064 nm, continuous wave, Heraeus Lasersonics, Hanau, Germany) (7) and water jet (Nuclear Research Center, Karlsruhe, Germany) were evaluated in a series of 300 in vitro experiments. We used fresh bovine rectal and porcine liver tissue mounted in a special support to keep the direction and distance of the respective applicator (electrode, light guide, nozzle) to the tissue constant (Figure **2**). A straight cut of 2 cm length was made in each sample over an interval of 5 seconds.

High Frequency

For monopolar cutting we used a 0.2 mm steel electrode at powers of 60 or 90 W, which are usually efficient for cutting with a thin electrode. For quasi-bipolar cutting a newly developed 0.2 mm tungsten electrode (Erbe Elektromedizin) (6, 8) was applied at the same power, 60 or 90 W.

Nd:YAG Laser

The cuts were performed in contact mode. For light transmission we utilised bare fibres (600 μm) and sculptured fibres. Since sapphire tips are not suitable for the application in endoscopic surgery they were not included in this study (7). The power applied was between 10 W and 35 W in steps of 5 W. All experiments were carried out with a cw laser in the interval mode. The interval time as well as the pauses were 0.2 seconds.

Water Jet

We tested a new water jet cutting system developed together with the Nuclear Research Center, Karlsruhe, Germany. The system is designed for experimental evaluation and consists of a pressure generator (200 bar) and different specially developed applicators. At the tip the applicators are provided with sapphire nozzles, the diameter ranged from 0.2 to 0.05 mm. Water was used as liquid for dissection. In addition to liver and rectal tissue, we examined the histologic effects of the water jet on porcine skin.

All the specimens were histologically examined. The tissue was fixed in 4% formalin and routinely embedded in paraffin. 3–5 μm thick serial sections were cut and stained with haematoxylin-eosin and elastica-van Gieson. The maximum extent of the lesion and the alterations in the adjacent tissue were measured in the histological examinations and compared for high frequency, laser and water jet respectively. For these morphometric studies a standard light microscope with a modified digitiser (Summagraphics Co., Munich, Germany) with a light point cursor (MTS Co. Tuebingen, Germany) connected to a personal computer was used.

In vivo Experiments

Monopolar and bipolar high frequency and the Nd:YAG laser were tested in Transanal Endoscopic Microsurgery (TEM) (6, 7, 9, 10). The main interest in the comparison of the two techniques was the extent of the thermal lesions of the rectal tissue and their influence on the healing process and the histology of the scar region.

The animal experiments (sheep) were carried out under general anaesthesia. The bowel was cleaned by irrigation. All the animals were sacrificed 3 weeks after the experiment. The excised

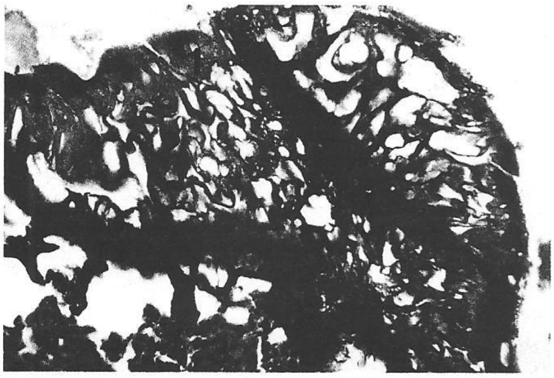


Figure 3: Character of a typical thermal lesion, created by monopolar HF at 90 W. Liver tissue, H.E. × 300. 1: Zone of carbonisation. 2: Coagulated and homogenised tissue with vacuoles as a sign of excessive steam formation in the tissue. 3: Intermediary zone with slightly altered tissue, recovery is possible.

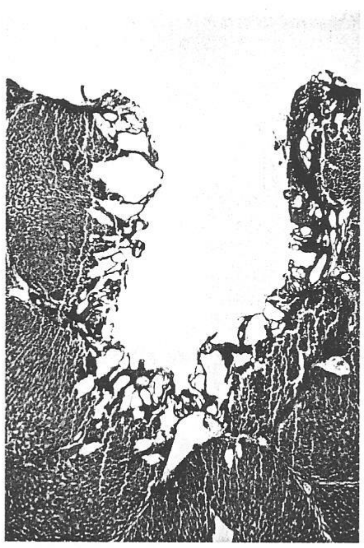


Figure 4: Lesion in liver tissue caused by a monopolar electrode at 60 W. Note the irregular and partly fissural margins. H.E. × 200.

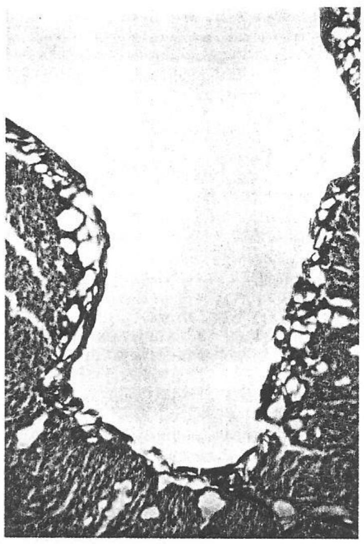


Figure 5: Lesion in liver tissue caused by contact Nd:YAG laser at 45 W. Note the smooth shape of the lesion and the regular margins. H.E. × 200.

tissue as well as the scar regions were histologically and morphometrically examined. Four grades (0–3) of carbonisation, coagulation and vacuolisation were discriminated. On this basis severity scores of the thermal damage were calculated for the laser, monopolar and bipolar high frequency.

High Frequency

11 operations were performed in the conventional technique (9, 10). In each animal two defects were cut into the rectal wall, one using the monopolar and one using the bipolar cutting electrode at 60 W. The location of the intervention varied from 7 cm to 15 cm from the anal verge.

Nd:YAG Laser

12 experiments were carried out. The conventional manner was modified to a two-step procedure. In the first step a ring of coagulation was performed in the non-contact mode at 40 W with lasing intervals of 0.5 seconds and pauses of 0.2–0.3 seconds. In the second step we cut in the coagulated trace in contact mode at 35–40 W with lasing intervals of 0.2 seconds, which were found the best adapted parameters during the in vivo study (7).

Since the application of the water jet proved to be ineffective for the dissection of the rectal wall during the in vitro experiments, it was not incorporated into the in vivo study.

Results

In vitro Experiments

Both thermal dissection techniques, high frequency and laser typically created variable degrees of thermal alterations (Figure 3) (7, 11, 12). The shape of the thermal lesion was similar in all specimens:

- The margins of the lesion showed a small zone of carbonised tissue.
- The adjacent tissue was necrotic with a zone of coagulation and homogenisation.
- Vacuoles with round lacunae could be observed within and adjacent to the necrotic zones as a result of smoke and steam evacuation.

- Next to the zone of irreversible thermal alterations a small zone of discoloured tissue could be observed. In this "intermediary zone" the tissue structures were slightly altered and a partial recovery and restitution is possible. These basic histological effects were on principle identical in both high frequency and laser cutting (Figures 4–7).

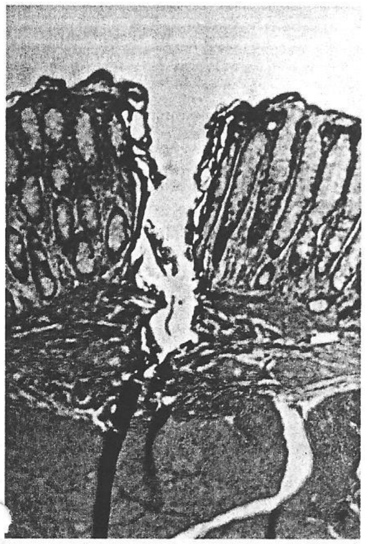


Figure 6: Bipolar HF lesion in the rectal wall at 60 W. H.E. × 200.

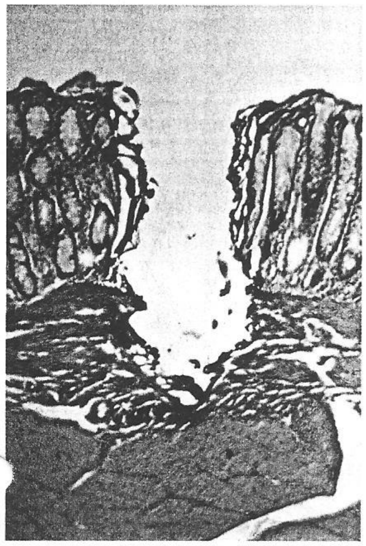


Figure 7: Nd:YAG laser lesion (45 W) cut with the bare fibre. Note the blunt shaped lesion with a small zone of thermal alteration. H.E. × 200.

High Frequency

The extent of the thermal alterations in the adjacent tissue of the cutting lesion caused by monopolar high frequency was regularly larger than those caused by bipolar high frequency current (Figure **6**). In liver tissue, depending to the power used, the thermal alterations ranged between 0.11 mm (60 W) and 0.20 mm (90 W) in bipolar application and between 0.13 and 0.25 mm when the monopolar technique was used. In rectal tissue the lesion ranged from 0.07 to 0.19 mm (bipolar) and 0.12 to 0.26 mm (monopolar). The extent of the thermal damage at the bottom of the lesion was always less than at the side edges of the cutting lesion. In the microsopic examination irregular or fissural margins of the lesion were more often found in specimens treated by monopolar high frequency (almost 38% monopolar, less than 32% bipolar).

Nd:YAG Laser

The zone of maximal thermal damage caused by contact Nd:YAG laser ranged between 0.11 and 0.22 mm in liver tissue and from 0.10 to 0.20 mm in rectal tissue. Between 25 and 45 W no correlation between the extent of the thermal damage and the power or the type of the fibre could be found. Similar to the results of high frequency cutting, the thermal damage at the bottom of the cutting lesion was always smaller than at the lateral margins; there was no sign of a remarkably deep penetration of the laser beam, deeper than the visible ground of the lesion. The lateral margins of the lesions were microscopically irregular in less than 30 of the cases.

Water Jet

Since the water jet delivers kinetic energy to the tissue, thermal lesions were not present in the specimens. The cutting effect results of mechanical fragmentation of the tissue. Since single cells and cell complexes are torn off from the neighbouring tisssue, debris can be found in all water jet lesions.

The character of the lesions depends on the type of target tissue more than in thermal dissection techniques. In the soft parenchymatous liver tissue (Figure **8**) the lesions showed microscopically only slightly irregular margins, in a zone of 5–10 micrometers mechanical disruptions of tissue particles could be found. This disrupted tissue will become necrotic in in vivo applications. The disruption zone is followed by a wider zone of vacuolisation as a result of water injections into the neighbouring tissue.

The disruption of the margins of the lesions with consequent liquid injection increases with the diameter of the nozzle, the water jet respectively. Nozzles with a diameter of more than 0.08 mm at a pressure of 200 bar created great tissue damage at the margins of the lesions and proved unsuitable.

In the rectum the water jet macroscopically led to strong bloating of the tissue, a regular cutting effect could only be observed after a longer application time. Microscopically the layers of the rectal wall were separated from each other over a length of up to 2 mm from the margins of the lesion. This separation effect could be observed especially between the mucosa and the muscularis propria of the rectal wall which differ significantly in tensile strength and firmness. The disruption effects caused by the water jet can be ideally examined in the strong and firm porcine skin. The high tensile strength of the thick corium counteracts a deep penetration of the water jet into the tissue and leads to a collection of water within the cutting lesion. In combination with the continuous water flow into the lesion a strong vortex is created which causes a fountain-like eruption of liquid and tissue particles. In the histology these effects result in a strong debris formation at the entrance and the lateral margins of the lesion (Figure **9**). The mechanical disruptions in the strong skin tissue reach up to 0.4 mm at the lateral margins.

Table 1: Severity scores of the thermal alterations (carbonisation, coagulation and vacuolisation) caused by high frequency and Nd:YAG laser (in vivo).

	Monopolar HF	Bipolar HF	Nd:YAG laser
Carbonisation	2.64 ± 0.46	2.09 ± 0.16	2.31 ± 0.30
Coagulation	2.82 ± 0.30	2.27 ± 0.40	2.44 ± 0.38
Vacuolisation	2.36 ± 0.46	1.36 ± 0.46	1.82 ± 0.24
			(Mean ± SD)

In vivo Experiments

Since the water jet system in the present configuration is not suitable for the dissection of the rectal wall the in vivo experiments were only related to the evaluation of the Nd:YAG laser and high frequency in Transanal Endoscopic Microsurgery.

The histological examination of the excised tissues showed sharply limited margins with just a small zone of thermal damage as described above. Similar to the in vitro study the monopolar high frequency dissection more often caused irregular or fissural lesions in the margins of the rectal excidate than the bipolar technique. The smoothest histological margins of the specimen were produced by the Nd:YAG laser, however the difference between laser and bipolar high-frequency were not significant. The highest severity scores (Table **1**) of the thermal alteration were caused by monopolar, and the lowest by bipolar high frequency, but were little different from those of the laser. The histology of the scar region three weeks after the experiment showed wound healing with only a small zone of granulation tissue. There were no significant differences in the histology of the healing process after application of Nd:YAG laser (Figure **10**), monopolar or bipolar high frequency. The postoperative follow-up of all 23 animals was without complication.

Discussion

Precise cutting and, at the same time, reliable coagulation of the margins of the lesion and of bleeding sources, is the foremost requirement for dissection techniques in endoscopic surgery. These requirements are generally met by common thermal dissection techniques and high frequency and cw lasers, and their application for cutting and haemostasis is efficient and safe in most endoscopic procedures (1, 6, 7, 10). High frequency is well established in different fields of operative medicine, and is easily applicable by virtue of modern computer-controlled devices and a series of matured applicators (8, 13). The Nd:YAG laser also suitably fulfils the requirements for application in endoscopic surgery, however there are some authors reporting contradictory results (12, 14).

Distinct superiority of one of the three thermal dissection techniques examined in this study is difficult to define. However we found characteristic properties of both high frequency (mono- and bipolar) and Nd:YAG laser with regard to the thermal lesions caused. Microscopic examination showed that irregular and fissural lesions were produced by monopolar current more often than with the bipolar technique or the laser. Using the

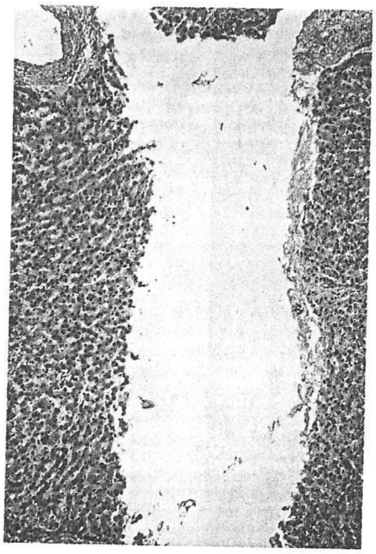
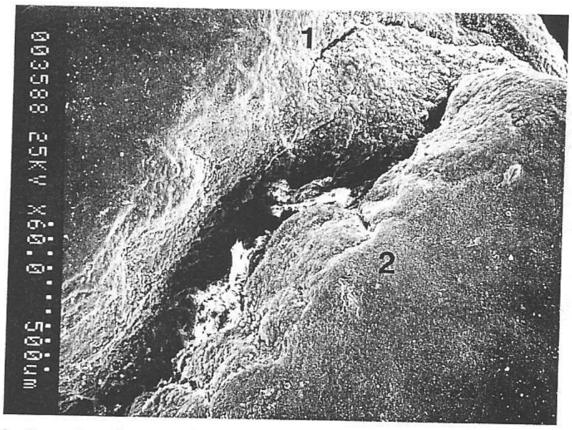


Figure 8: Water jet lesion in liver tissue. Diameter of the nozzle: 0.05 mm.
a H.E. x 200.



b Scanning electron microscopy x 60. **1** The liver capsule is disrupted by the water jet. **2** Intact capsule.

c Scanning electron microscopy x 150. **1** „Naked" hepatocytes at the margin of the lesion as a result of the „washing effect" of the water jet.

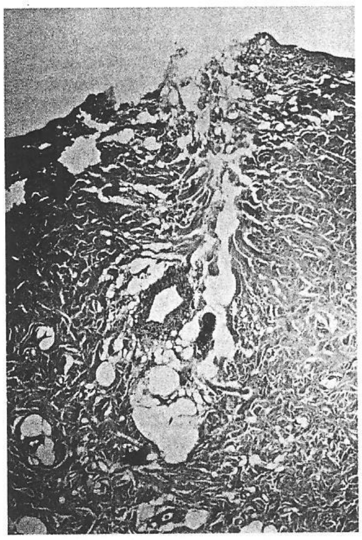


Figure 9: Water jet lesion in porcine skin. Note the disrupted tissue and strong debris formation at the entrance of the lesion as a sign of the fountain-effect of the water jet in firm tissues.

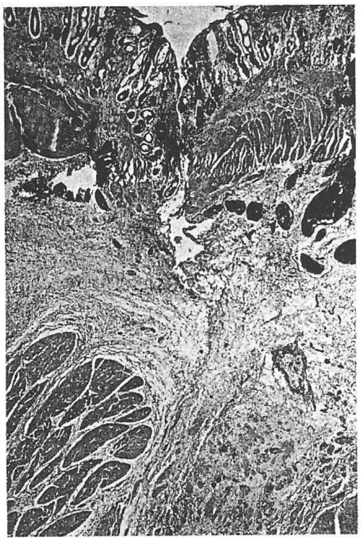


Figure 10: Laser TEM in vivo study: The specimen of the rectal scar after three weeks shows a complication-free healing process with just a small zone of granulation tissue. H.E. × 160.

monopolar electrode the severity of the lateral thermal damage was always higher than with both other methods. The irregularity of the monopolar lesions in comparison to bipolar current could result from a reduced constancy of the electric spark at the tip of the electrode, which is necessary for cutting tissues. The reduced thermal alteration of the incisional margin we found in the in vitro as well as the in vivo part of the study make the bipolar technique highly suited for endoscopic surgery especially when the general safety advantages (vagabonding current is extremely unlikely) are taken into account. Other authors recommend bipolar high frequency for the reduction of the thermal trauma in electrosurgical procedures (15, 16, 17), which is similar to our own experience with in vitro and in vivo applications.

The lesion resulting from the Nd:YAG laser was slight and well demarcated from the adjacent tissue. The extent of the lateral thermal damage at both sides of the incision was not related to the power (between 20 and 45 W) nor to the kind of fibre used. This is because the initial interaction of the fibre tip with the tissue leads to an adhesion of burned tissue products resulting in a glowing coat around the fibre tip as a result of total reflection of the laser light with consequent heating of the tip. This glowing layer vapourises the neighbouring tissue and allows cutting in contact mode. Deep penetration of the laser beam into the tissue, as in non-contact application for coagulation, is avoided. Therefore the necrotic zone at the visible ground of the incision is not wider than at the lateral margins of the Nd:YAG laser lesion. This constantly glowing layer around the fibre tip in contact application also can explain the smoothness of the margins of the laser lesion. Histologically these lesions were less irregular than those of bipolar high frequency, fissured margins were very rare. The lateral thermal damage during Nd:YAG laser cutting was minimal and comparable to the bipolar electrode.

During the in vivo study of TEM using monopolar or bipolar high frequency, the Nd:YAG laser respectively, no significant differences in the histology of the scar region could be found. No local complications such as local peritonitis or abscess formation occured. The post operative follow up of all animals was flawless, irrespective of the dissection technique used.

Notwithstanding the good dissection qualities and the small thermal trauma of bipolar electrosurgery and Nd:YAG laser, the purpose of bringing water jet technology into endoscopic surgery is to use a tool which provides selective dissection properties and at the same time allows a further reduction of the lateral trauma of the incision.. Various authors report promising results of water jet dissection especially in open hepatic surgery (2–5). In order to evaluate the design for a water jet system and applicators dedicated to endoscopic surgery in cooperation with the Nuclear Research Center, Karlsruhe, Germany, a prototype setup was included in the in vitro study. The first experiments showed that suitable cutting results could only be achieved with a jet diameter of 0.08 to 0.05 mm. Larger jets were too traumatic and the incisional depth was uncontrolled. Due to the differences in strength and hardness, cutting of intestinal tissue is not possible with the water jet, leading to spongy inflation and uncoordinated disruption of the bowel wall. The effects on parenchyma however showed a reduced trauma in comparison to the thermal dissection techniques and in our study it was the least traumatic method for the dissection of liver tissue. The zone of kinetic disruption at the margins of the incision, which will become necrotic in in vivo applications, was only 5–10 micrometers wide. In stronger tissues, such as porcine skin, the vortex creation within the incision leads to injection of water into the adjacent structures with considerable disruption and trauma of the margins. A further disadvantage of the water jet is the fountain-effect with catapulting of tissue particles and aerosols out of the treated tissue, which is potentially dangerous in pathologically altered tissue.

In our opinion, the water jet with its remarkably small trauma to the neighbouring tissue holds great promise for the endoscopic dissection of parenchymatous organs in the future. Special applicators and nozzles to control the depth of the incision and to achieve specific dissection effects in endoscopic procedures are currently under development together with the Nuclear Research Center.

Due to the minimal thermal trauma, the electrical safety and especially the advanced computerised electrosurgical devices and multifunctional instruments (6,8) available, bipolar high frequency seems to be the most suitable technology for dissection in endoscopic general surgery at the moment. Furthermore this technique is easy to handle and the necessary equipment is relatively cheap. Good dissection, coagulation and vapourisation qualities in combination with the high degree of safety make "thermal lasers" in principle an ideal tool for endoscopic surgery. However the laser instruments available currently can only partially fulfill the requirements of endoscopic operations. In our opinion, the further progress of laser use in endoscopic surgery is directly related to the development of more sophisticated application devices (7). New multifunctional laser applicators, dedicated to the requirements of endoscopic procedures will increase the effectiveness of laser use and take advantage of the benefits of multimodal application and patient safety.

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