Lasers in Surgery and Medicine 3: 217–224 (1983)

Hepatic Resection With an Nd:YAG Laser in Pig

G. Godlewski, MD, P. Ginoves, MD, J.M. Chincholles, MD, E. Viel, MD, J.P. Bureau, MD, S. Rouy, DSC, H. Mion, MD, A. Dubois, MD, AND J. Fesquet, DSC

Laboratoire d'Anatomie (G.G., P.G., J.M.C., E.V.), d'Histologie (J.P.B., S.R.), de Biochimie (H.M.), and USTL (J.F.), Faculté Montpellier-Nîmes, Nîmes, France

Eleven hepatic resections were performed by means of a divergent Nd:YAG laser. The beam was transmitted through a fiberoptic delivery system without any handpiece. The shortest resection time and most limited ischemic damage (4 mm) were obtained with 80-W power shoots and a low divergent beam (4°2 for full angle). The hemostatic effects of the Nd:YAG controled bleeding from veins of up to 4.5 mm in diameter, and parenchymatic oozing from the cut edge minimized blood loss. Histological examination revealed the importance of cellular deterioration in the ischemic layer, while electron microscopy showed selective destruction of cell organelles and protein denaturation. Marked elevation of hepatic serum enzymes suggests a high degree of cellular damage. Postoperative examinations confirmed an uncomplicated healing process. Finally, the use of a flexible fiberoptic enables easy surgical manipulation.

Key words: Nd:YAG laser, partial liver resection, cutting efficiency

INTRODUCTION

Partial liver resection is currently used in hepatic surgery for traumatic, parasitic, or carcinogenic disorders. Nevertheless, the risk of massive hemorrage, persistent oozing, and bile leakage after resection, as well as that of infection coming from the cut surface submitted to mass ligation of vessels and ducts, affects the morbidity and mortality rate.

Some authors [3,6,9,13] tried to improve those results using a CO_2 laser in exsanguineous surgery. They emphasized its hemostatic potential in experimental liver resection [3,6]. However, the results on their experimental models are not similar to the conditions encountered in human resection. Indeed, the Co_2 is unable to stop bleeding coming from vessels larger than 1 mm in diameter. Moreover, lack of manueverability of the optic arm and the length of the handpiece make this laser a poor choice for surgery on the liver, where flexibility is required.

On the other hand, some authors reported experimental trials for hemostatic resection in rats, pigs, and dogs [1,7,8,10,12] with an Nd:YAG laser. They used

Address reprint requests to Dr. G. Godlewski, Laboratoire d'Anatomie, Faculte Montpellier-Nîmes, Avenue Kennedy, F-30000, Nîmes, France.

prototypes at high-power energies [1,12], the beam being focused by a system of biconvex or cylindrical optical lenses [12]. Using this method, liver resection was possible and provided good hemostasis of the cutting edge, but subjacent tissue became deeply and severely damaged [10,12]. Moreover, in some cases, the operator had to move the animal beneath the focal point as the direction of the beam is fixed [7,10].

This report evaluates the performance of partial hepatectomy by means of a low divergent Nd:YAG laser beam transmitted by a quartz fiber.

MATERIALS AND METHODS

A multimode Nd:YAG laser (wavelength 1.06 μm), the Medilas 2, produced by M.B.B. and providing 100 W, was used without any focus. The beam was transmitted in two ways, either through a triconical quartz fiber [11], 200 to 300 μm in diameter and 4°2 of divergence for the full angle, or through the usual quartz fiber, 600 μm in diameter and 8° of divergence. In the first case, the impact area was of 1 mm in diameter, while the working distance between the fiber tip and the target was 1 cm. In the second case, the impact area was 2 mm in diameter at the same working distance. A coaxial stream of CO_2 protected the optic system and minimized tissue burning. Special protective goggles were worn by operating room personnel. Surgical instruments were sand-blasted.

Nine young pigs, 2 to 3 months old, and two minipigs, 2 years old, weighing 19 to 35 kg, were anesthetized with intramuscular or intravenous Ketalamine and Diazepam. The liver was exposed through an uppper midline laparotomy performed with sterile surgical technics. Curare was not necessary.

The animals underwent sublobar hepatic resection and half of the quadratus lobe was removed. Resection was performed two times by means of the triconical quartz fiber of NATH and then nine times by the fiberoptic system, 8° of divergence. Operating power output varied from 40 to 100 W with continuous wave and did not lower during all of the resection time. No special supportive treatment (such as intravenous fluids or antibiotics) was given. Pigs were controlled by a second and a third examination on the 3rd, 10th, 15th, 30th, 45th, and 65th day following irradiation. Six animals remained alive.

In each case, sections of the lobectomy site were removed for histological examination. Samples for light microscopy were fixed by Bouin Holland, embedded in paraffin, and stained with hematoxylin eosin (H.E.), periodic acid Schiff (PAS), Masson and Azan stain. Other fragments were fixed in glutaraldehyde for electron microscopy.

Excision time, weight, and volume of the excised tissue, as well as surface of the cut edge were recorded. During the postoperative period, all pigs were monitored every 5 days, with respect to nine laboratory parameters: glucose, total bilirubin, conjugated bilirubin, alkaline phosphatase, νGT, LDH, SGOT, SGPT, and LDH electrophorese.

RESULTS

Gross Pathology

Partial lobectomy was performed by means of a divergent Nd:YAG laser using a fiberoptic delivery system without any focalization. At the beginning of the resec-

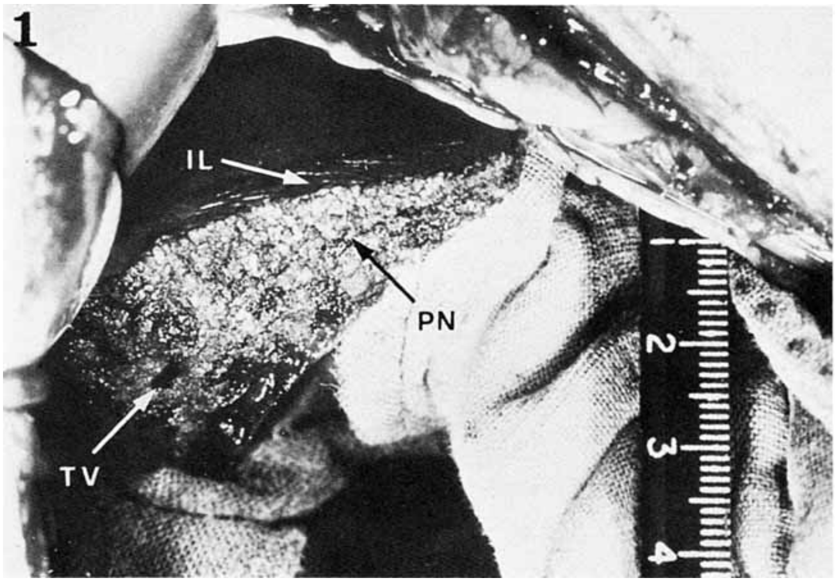

Fig. 1. Cutting edge after liver resection performed by means of a fiberoptic delivery system procuring 8° of divergence and a power output of 80 W. PN= protective necrosis; IL= ischemic layer; TV= transected vessels.

tion, beam penetration through the liver capsule was delayed by beam reflection. Further resection was carried out by moving the laser beam slowly backward and forward across the liver. Smooth traction separating the incision permitted the laser impact to remain at the depth of the cutting valley and vaporize fresh liver parenchyma. This technique left a dry cutting edge with black protective coagulum, at the center of which the transected major vessels were visible. Radiation sealed veins of up to 4.5 mm in internal diameter. Below this protective sealed layer appeared a white dry layer of ischemic parenchyma varying from 3 to 6 mm in thickness, (dependent upon irradiation time, power output, and beam divergence). The higher the beam divergence, the thicker was the ischemic area (Figure 1).

A mean tissue mass of 37 gm (range 21 to 70) was removed and represented 36 cc on an average. The mean surface area of the cutting edge was of 19 cm^2. Excision time was 6.2 min (range 3.8 to 12.3) with a necessary energy output of 22,444 J (16,460 to 32,000). A power output of less than 40 W did not cause resection. The best results, that is, shortest time, most limited ischemic damage, and easiest hemostasis, were obtained by using 80-W shoots. Seven times complete hemostasis of the cutting edge was performed by laser radiation exclusively. Four times 40-W shoots needed supplementary suture of the centrolobular vein to achieve hemostasis. Temporary occlusion of the hepatic pedicle did not improve the quality of the hemostasis, but increased the thickness of the ischemic layer (2 to 3 mm).

All animals submitted to liver resection with a Nd:YAG laser survived and were healthy at controls. Two animals were controlled on the third postoperative day and killed the 15th day, after a second examination. Three others were sacrified the 30th day. Three pigs underwent control the 45th day; there were no signs of secondary hemorrhage, and no bile staining of peritoneum or viscera adjacent to the liver. No

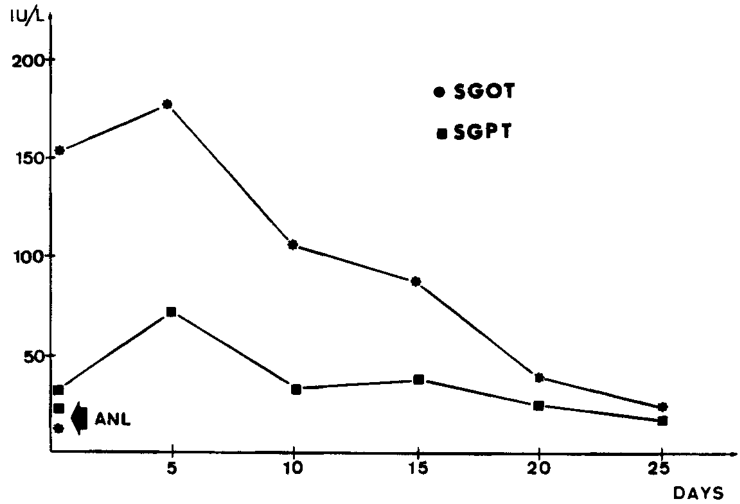

Fig. 2. Laser-induced SGOT and SGPT levels in international units/liter against time in days. ANL = average normal level in pigs.

intraabdominal sepsis occurred. On day 3 the cut liver surface was covered by a layer of white necrotic tissue up to 6 mm deep, which had a superficial slightly charred appearance. At day 10, this layer was soft and easily removed from the underlying parenchyma, which was separated from it by a thin layer of fibrosis. At days 35 and 45, the cutting edge was entirely covered by thick fibrosis and surrounded by omental adherences. The size of the resected area was significantly lessened by hepatic regeneration. A whitish foci of homogeneization were present in three animals. It was embedded between hepatic fibrosis and peritoneal adherences, but caused no clinical inconvenience. Two complications concerning wound closure were noted: one parietal abscess on chronic catgut and one eventration appearing 10 days after reexploration. These extraperitoneal complications did not cause mortality but incited us to close linea alba of the other animals with Ercedex 4. In two animals no complication was observed during a follow-up of 1 year. Four other animals were healthy 3 months after laser irradiation.

All preoperative laboratory parameters were normal. Immediately after resection, LDH and SGOT rose to very high levels and stayed up for 2 to 3 weeks (Figs. 2 and 3). SGPT rose to elevated levels 3 or 5 days after lasering. Moderate elevation of νGT occurred 5 days after irradiation and persisted for 35 to 40 days. Rapid and short elevation of blood glucosee was frequent and attributed to preoperative stress. Biliary parameters were not altered.

Microscopic Pathology

Acute Lesions. Examination of liver tissue incised and removed with a low divergent beam demonstrated four specific histological layers (Figure 4):

(1) Nearest to the thermal source was a first layer of lace-like necrosis covered by charred black cellular fragments with some empty cellular spaces scattered irregularly (150 to 200 μm).

(2) A second layer (1000 to 4000 μm) was severely altered, containing condensed and shrunken cells with eosinophil cytoplasm. Cellular limits were missing and the nuclei were retracted.

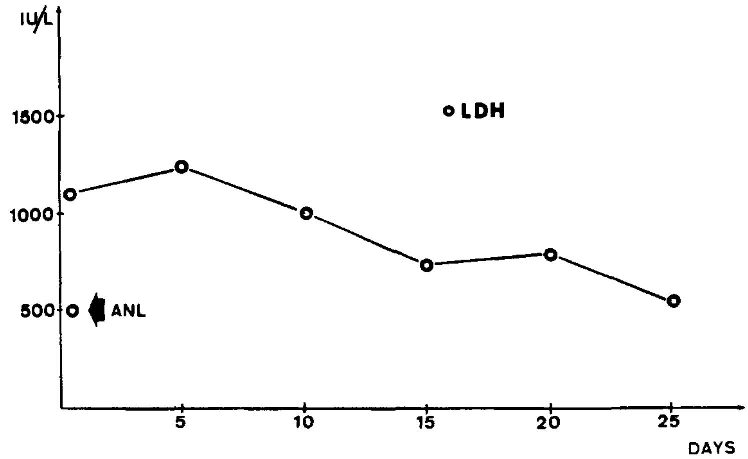

Fig. 3. Laser serum LDH levels in international units/liter against time in days.

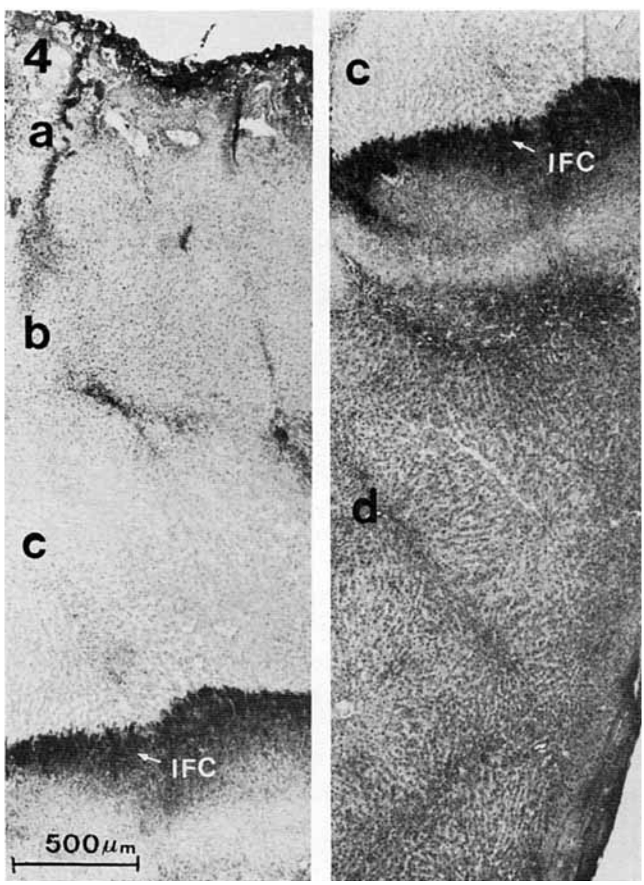

Fig. 4. Tenth day histological examination of incised liver tissue (40 W). From the left to the right: (a) necrosis layer; (b) condensed cells; (c) edematous layer with red cells and a screen of inflammatory and fibrocytic cells (IFC); (d) normal liver tissue. Hematoxylin and eosin, ×33.

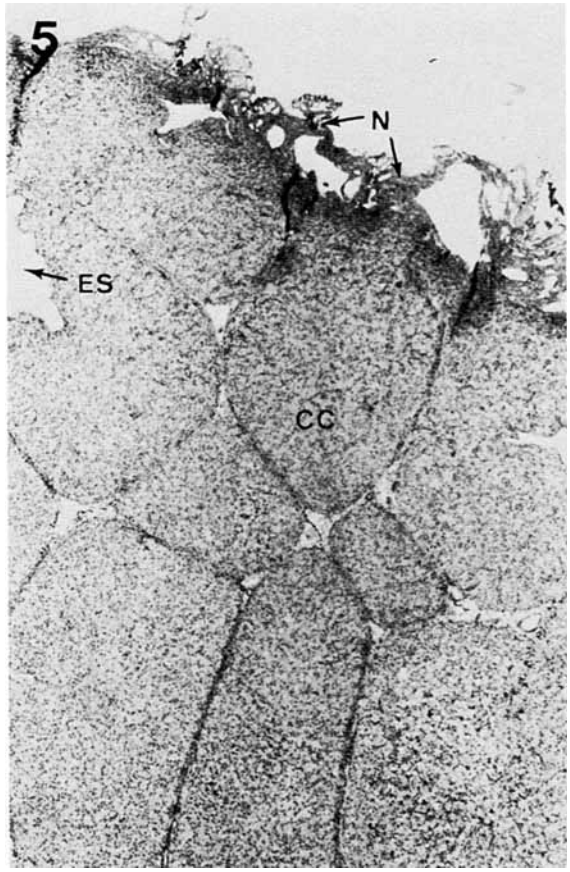

Fig. 5. First day histological examination of incised liver tissue (8° of divergence, 80 W). N= necrosis; ES = empty spaces; CC = condensed cells. Hematoxylin and eosin, ×42.

(3) A third layer with preserved structure (1000 to 2000 μm thick), was composed of cords of liver cells radiating from the central vein but infiltrated by edema and foci of red cells. Some areas recovered their PAS-sensitive tinctorial abilities. Bile canaliculi were not altered.

(4) A fourth layer contained normal liver tissue and peripheric veins presenting thrombosis of their blood content and coagulative necrosis of their wall.

Chronic Lesions. The third day after irradiation, these four layers were well demarcated while a barrier of mononuclear and polymorphonuclear leukocytes and fibrocytes appeared within the edematous layer. Ten days later this barrier (composed of fibrocytes, monocytes, and histiocytes) intensified, embedded between the necrosis layer and viable cellular areas. Important neovascularization and fibrosis were gaining ground. The 30th and 45th day liver edges were protected by a tough fibrosis, while some areas of homogenization wre included in the underlying parenchyma or between hepatic fibrosis and the adjacent peritoneal adherences.

Electron microscopy. Nearest to the cut margin and up to 2000 to 4000 μm of the totality of the ischemic layer, liver cells were severely damaged by coagulative necrosis and protein denaturation of cytoplasmic and nuclear limits (Figure 5). The parenchyma was entirely occupied by faint "shadowy" cells. The edematous layer contained an excessive amount of vacuolization areas and bubbled mitochondria, their cristae being disrupted. Glycogenic granulations decreased in number while lysosomes increased. Bile canaliculi were not altered. Thirty days later important hepatocytic regeneration was installed.

DISCUSSION

Partial lobectomy was possible in pigs by means of Nd:YAG laser coupled to a fiberoptic delivery system without any focalization. We chose the pig experimental model to simulate more closely the cellular and biological response in man. Partial lobectomy was preferred to total lobectomy because of the higher degree of difficulty in obtaining hemostasis.

Since the beam output divergence was 4°2 and 8° for full angle the energy density rate was very condensed while the peripheral diffusion remained rather slight [11]. A focused beam induces a very small impact on the surface of the tissue to be incised, which means a punctual energy density and important diffusion beyond this point will warm hepatic parenchyma before cutting it [4,5], and induce a large section sulcus and important parenchymatic damage [5,10,12]. We found out that the lower the beam divergence the thinner the cellular destruction was.

The immediate hemostatic benefits of the Nd:YAG were controlled bleeding from veins of up to 4.5 μm in diameter [4,5] and the control of parenchymatic oozing from the cutting edges with minimized blood loss. This permitted rapid resection, although major vessels sometimes required ligation. A power output of 40 to 80 W provided good liver section in pig at the cost of a 4- to 6-mm-thick tissue damage. However, the thickness of cellular deterioration has never increased postoperative morbidity and did not alter the satisfactory healing process. Clampage of the hepatic pedicle did not improve the hemostatic results but did increase the thickness of the ischemic cutting edge layer.

A significant increase of hepatic enzymes in serum after laser resection suggested a high degree of cellular damage. The marked elevation of LDH is thought to be due to injury of both the hepatic and red blood cells in the laser's path. A new rise in hepatic enzyme levels in serum after a second biopsy control probably indicates the biological response will occur from the lasering or any liver aggression. Durtschi et al [2] demonstrated much the same thing in that for all laboratory modifications, there was no difference between a liver laserized group and a control group.

Use of a flexible fiberoptic facilitates surgical manipulation and brings within easy reach posterior liver areas inaccessible with a handpiece-transmitted laser. The distance between the fiber tip and the target should not exceed 5–10 mm. because of the distance, an efficient coaxial ventilation is necessary to avoid excessive heating on beam exit and burning effects on the liver parenchyma.

This study tries to show the usefulness of exsanguineous section in solid organ surgery using a divergent Nd:YAG laser on models similar to human liver resection. The laser-induced veinous blocking effects and its hyperthermic features seem of great interest in the palliative removal of multiple hepatic metastases when lobar resections are not justified. It must be considered a complementary safety tool in treatment for liver trauma.

ACKNOWLEDGMENTS

We are grateful to the firm Bernas for their lending us a Medilas 2 (MBB) and for their technical assistance.

REFERENCES

1. Bödecker V, Rudolph M, Grotelüschen B: Messung der intensitäts-verteilung von YAG-laserstrahlung im Gewebe. Biomed Technol (Stutt) 19:160–162, 1974.
2. Durtschi MB, Stothert JC, Ashleman B, Auth DC, Lee MJ, Carrico CJ: Laser scalpel for solid organ surgery. Am J Surg 139:665–668, 1980.
3. Fidler JP, Moeffer RW, Polany TG, Bredemeier MC, Silver VE, Altemeier WA: Laser surgery in exsanguinating liver surgery. Ann Surg 181:74–80, 1975.
4. Godlewski G, Miro L, Chevalier JM, Bureau JP: Experimental comparative study on morphological effects of different lasers on the liver. Res Exp Med (Berl) 180:51–57, 1982.
5. Godlewski G, Miro L, Chevalier JM, Marty-Double C, Bureau JP, Bernard JC, Baumel H: Contribution expérimentale à l'utilisation du laser dans la chirurgie hépatique. Ann Gastro Entérol Hépatol 17:71–77, 1981.
6. Gonzales R, Edlich RF, Bredemeier MC, Polany TG, Goodale RL: Rapid control of massive hepatic hemorrhage by laser radiation. Surg Gynecol Obstet 131:198–200, 1970.
7. Grotelüschen B, Rauner P, Bödecker V, Sepold G: Morphologische Befunde bei Schnittversuchen an der Rattenleber mittels Neodymlaser. Biomed Technol (Stutt) 19:75–78, 1974.
8. Grotelüschen B, Bödecker V: Untersuchungen zur Anwendungsmöglichkeit von Laserstrahlen als Schnittwerkzeug in der Chirurgie. Bruns Beitr Klin Chir 221:409–414, 1974.
9. Hall R, Beach AD, Mill DW: Partial hepatectomy using a carbon dioxide laser. Br J Surg 60:141–144, 1973.
10. Karbe E, Königsmann G, Beck R: Experimentelle Leber- und Nierenchirurgie mit dem CO_2- CO-Holmium-und Neodym-Laser. Schnittwirkung, Hämostase, Histopathologie, Heilung. Langenbecks Arch Chir 351:179–192, 1980.
11. Kiefhaber P, Nath G, Moritz K: Endoscopical control of massive gastro-intestinal hemorrhage by irradiation with a high-power Neodymium YAG laser. Prog Surg 15:140–155, 1977.
12. Meyer HJ, Grotelüschen B, Buchholz J: Schnittcharakteristik beim Schneiden mit Laserstrahlen. Zentralbl Chir 104:30–37, 1979.
13. Mullins F, Jennings B, Clusky L: Liver resection with the continuous wave carbon dioxide laser. Some experimental observations. Am Surg 34:717–722, 1968.
14. Orda R, Wiznitzer T, Goldwasser B, Bubis JJ, Levene S, Kaye RM: Partial hepatectomies with a hand-held laser knife: An experimental study. Br J Surg 64:857–861, 1977.