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CO_2 and Nd:YAG laser systems in microsurgical venous anastomoses

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Summary. A comparative study was undertaken in 81 rats to investigate a CO_2 and Nd:YAG laser system for laser-welded anastomosis of the femoral vein. Conventionally sutured anastomoses (CMSA) served as controls. Laser-welded anastomosis (LAMA) was easier and could be performed 30% faster than CMSA. Postoperative investigations included patency tests, postmortem examinations and light and electron microscopy. Aneurysms were not seen. Foreign-body reaction was more pronounced in CMSA. Patency rates for CO_2-LAMA and CMSA were equal, whereas Nd:YAG-LAMA resulted in significantly higher rate of early postoperative thrombosis ($P < 0.01$). Because of its physical properties, the CO_2-laser system seems to be better suited for laser welding of delicate structures such as the rat femoral vein.

Key words: Microsurgery – CO_2 laser – Nd:YAG laser – Rat – Vascular anastomosis

Microsurgery has gained rapid acceptance and a wide field of applications in urology. As conventional microsurgical techniques require thorough training and are often difficult to perform, laser welding has been proposed for vasovasostomy, vascular anastomoses and urethral reconstruction so as to save surgical time and facilitate the procedure [2-4, 8, 10, 12, 13]. Whereas most studies on vascular repair have been devoted to arteries [1, 11, 15], little work has been done to investigate laser-assisted anastomosis of veins [5]. In conventional microsurgery, veins are far more difficult to anastomose, as the walls are delicate and likely to cling together. In the present study we investigated CO_2 and Nd:YAG systems for laser welding of end-to-end anastomoses of femoral veins of the rat.

Materials and methods

A total of 81 Sprague-Dawley rats weighing 300-350 g were randomly divided into 3 groups. End-to-end-anastomosis of the right femoral vein was accomplished either by a conventional suturing technique (CMSA, group 1) or by laser welding (LAMA, groups 2 and 3).

Microsurgical technique

The rats underwent surgery while under ketamine general anaesthesia (100 mg/kg body weight). Apart from the use of four rather than three stay sutures in group 3, techniques described elsewhere [3, 11] were adhered to. In group 2, a CO_2 laser system (Medilas-Sharplan 1040; MBB Medizintechnik, München, FRG: pulse duration, 0.1 s; spot size, 0.5 mm; power setting, 300 mW) was used and in group 3 we employed an Nd:YAG laser system (MBB Medizintechnik, München, FRG: pulse duration, 0.1 s; spot size, 0.2 mm; power setting, 6 W; wave length, 1.32 µm).

Postoperative investigations

Patency was assessed immediately after completion of the anastomosis and at 1 h after the operation. The animals were killed and postmortem examinations were done at 3 days, 2 weeks and 1, 2 and 6 months postoperatively. Patency was again tested and specimens were excised, fixed in 4% buffered formalin and stained with H&E and van Gieson's solution for light microscopy. Specimens for scanning electron microscopy were taken at 1 h, 3 days and 2 weeks postoperatively and were fixed in 2.5% buffered glutaraldehyde.

Statistics

Statistical differences between the three groups were assayed using multiple regression analysis and independent linear contrasting.

Results

As the femoral vein of the rat is a delicate structure as compared with arteries, the thin walls required that special care be taken to avoid stitching of the back wall in group 1. Similarly, in groups 2 and 3, laser energy had to be applied cautiously. The laser welding spots had to be

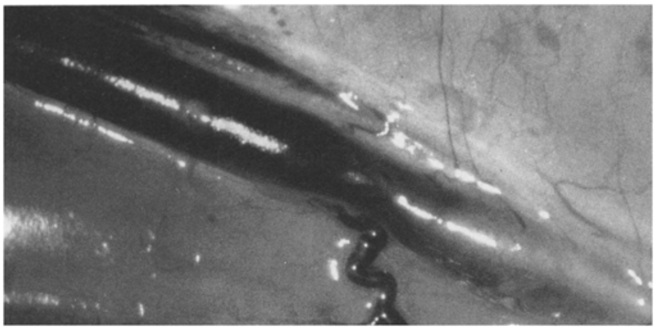

Fig. 1. CO_2 laser-welded venous anastomosis 2 weeks postsurgery, showing characteristic narrowing of the vessel around the anastomosis

deposited precisely, as overlapping easily resulted in thermal damage to the vessel wall. After completion of laser-assisted anastomosis, the veins in groups 2 and 3 showed characteristic narrowing, with an extension of 1 mm occurring on each side of the anastomosis (Fig. 1). The stenosis was more pronounced in Nd:YAG-welded vessels. The grade and rate of stenosis decreased with time: it was seen in all lasered anastomoses at 1 h postsurgery, in 5/10 vessels on day 3, in 2/10 rats at 2 weeks and in 3/8 animals at 4 weeks following the operation. It was not observed 2 or 6 months postoperatively.

In contrast to laser-welded arterial anastomoses, the venous procedure did not result in the formation of

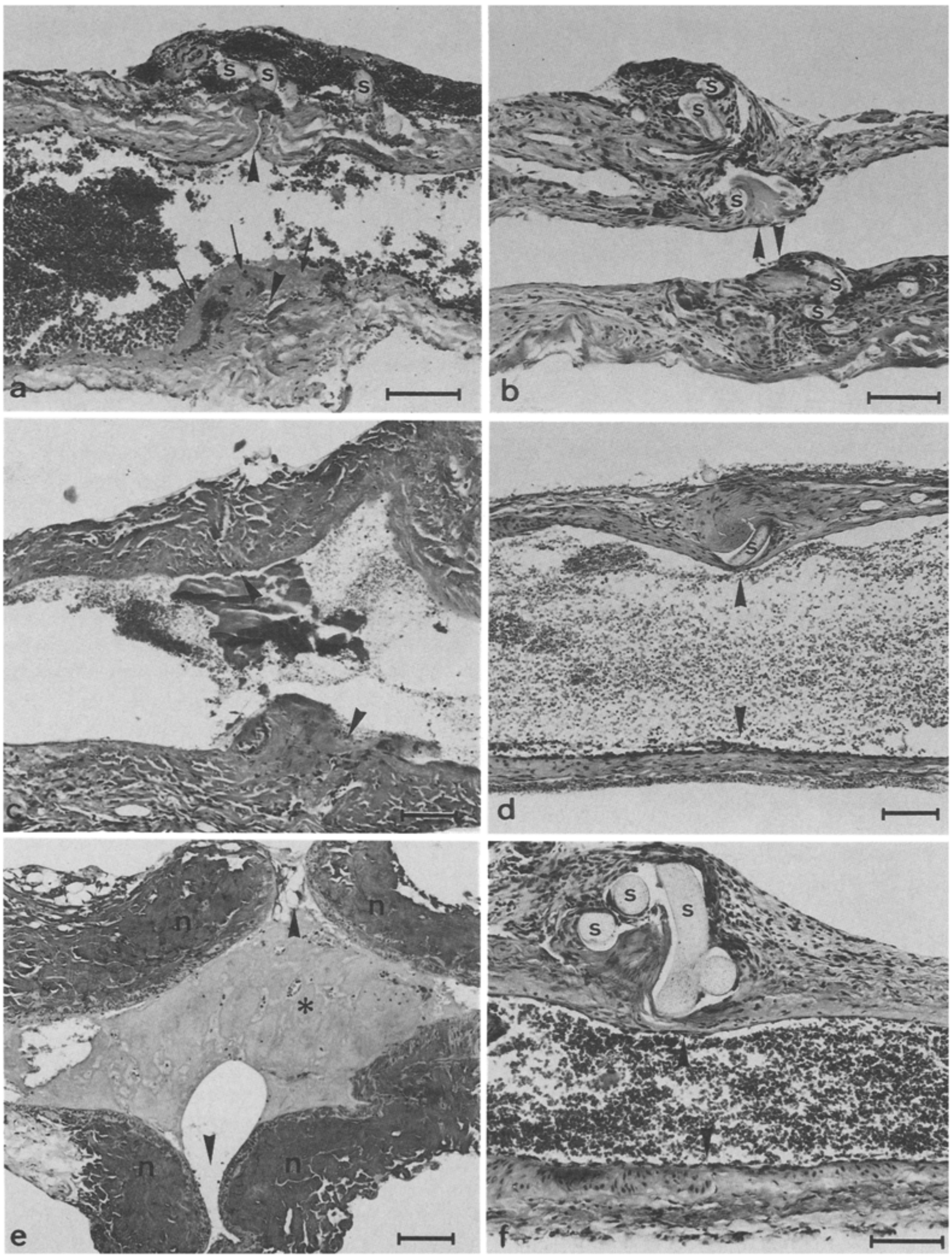

Fig. 2a–f. Morphological studies using light microscopy. Bars = 100 μm. **a** At 1 h after CMSA, the site of anastomosis (*arrowheads*) is marked by sutures (*s*) and covered with small deposits of fibrin (*arrows*). **b** On day 14 after CMSA, the site of anastomosis (*arrowheads*) is covered with monolayer of endothelial cells; note the marked foreign-body reaction around the sutures (*s*). **c** At 1 h after CO_2-LAMA, the site of anastomosis (*arrowheads*) shows no considerable gaps. **d** On day 14 after CO_2-LAMA, the site of anastomosis (*arrowheads*) is marked by sutures (*s*) on one side. **e** At 1 h after Nd:YAG-LAMA, the site of anastomosis (*arrowheads*) exhibits small gaps occluded by thrombosis (*asterix*); note the extensive coagulation necrosis (*n*) of the vascular wall. **f** On day 14 after Nd:YAG-LAMA, the site of anastomosis (*arrowheads*) is marked by sutures (*s*) on one side

Table 1. Patency rates in treatment and control groups

Group	Type of anastomosis	Postoperative patency (n)							Overall patency rate
		Immediate	1 h	3 days	2 weeks	1 month	2 months	6 months	
1	CMSA	27/27 (100%)	5/5	5/5	5/5	4/4	4/4	4/4	100%
2	CO_2-LAMA	23/27 (85%)	5/5	4/5	5/5	4/4	4/4	4/4	96%
3	Nd:YAG-LAMA	19/27 (70%)	4/5	4/5	5/5	4/4	4/4	4/4	92%

aneurysms. Laser-welding reduced surgical time by 30%: whereas 18 min were required for anastomosis in group 1, 11 and 13 min were needed in groups 2 and 3, respectively. The time difference between groups 2 and 3 is explained by the fourth stay suture used in group 3, the necessity of which had been determined in pilot studies and is consistent with the findings of others.

Patency

Patency rates are listed in Table 1. Between 2 and 5 min after completion of the laser anastomosis, a thrombus formed in 4/27 rats in group 2 and in 8/27 animals in group 3. This thrombus caused complete occlusion of the vessel and had to be flushed out by the removal of one stay

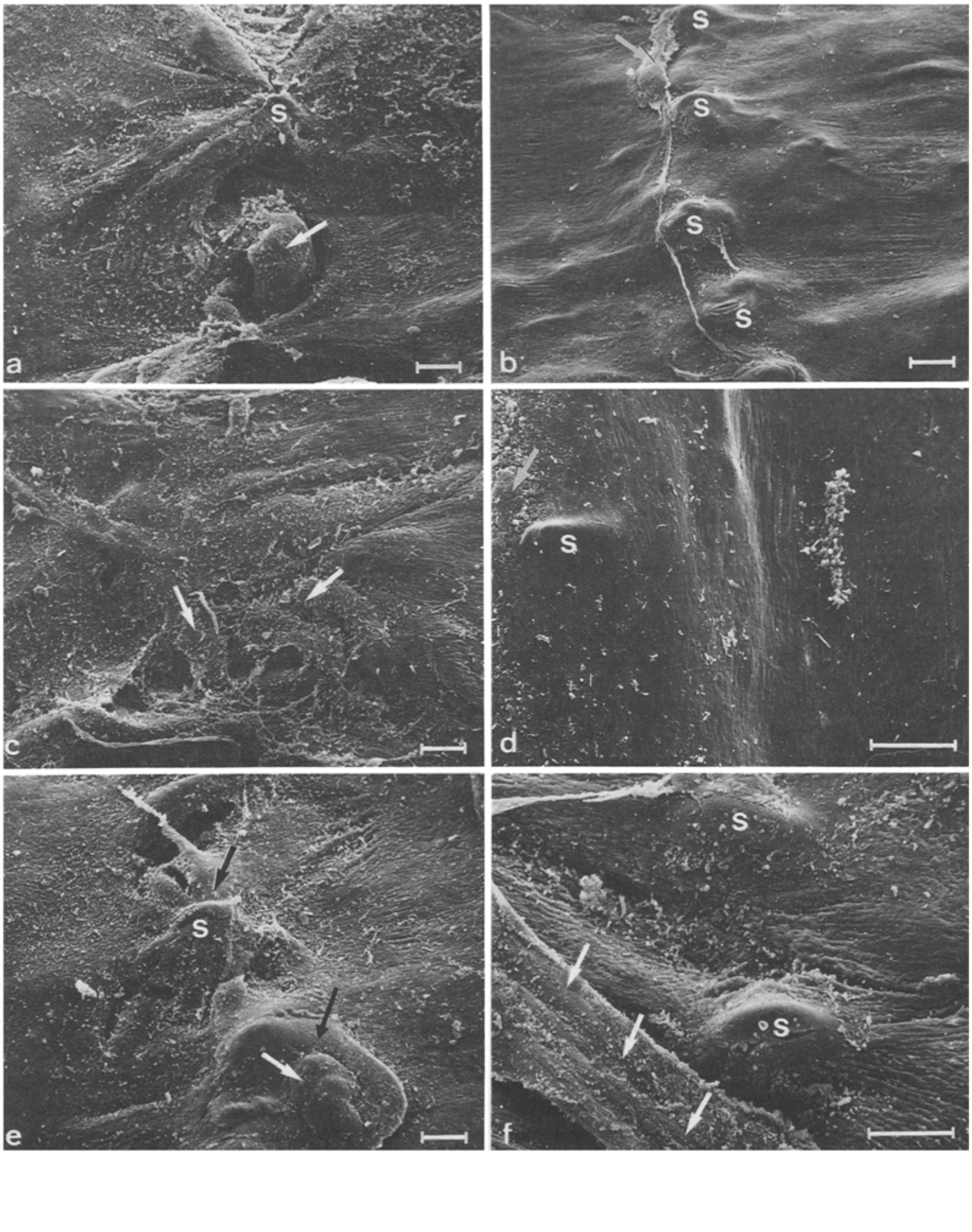

Fig. 3a–f. Scanning electron photomicrographs of luminal surfaces after CMSA and LAMA, showing the anastomotic site both on day 3 after **a** CMSA **c** CO_2-LAMA and **e** Nd:YAG-LAMA, with small deposits of fibrin (*arrows*) sometimes covering the sutures (*s*), and on day 14 after **b** CMSA **d** CO_2-LAMA and **f** Nd:YAG-LAMA, as marked by prominent sutures (*s*) and covered with an intact layer of endothelial cells; minute deposits of fibrin (*arrows*) are visible adjacent to the sutures. Bars = 100 µm

suture and injection of heparinized saline. In all cases the anastomosis could be reconstituted by spot welding and remained patent thereafter. The difference in immediate postoperative patency rates was statistically significant between all groups ($P < 0.01$). The differences that were observed during the follow-up period were not statistically significant.

Light microscopy

At 1 h and on 3 day (Fig. 2a, c, e) after CSMA and LAMA, both ends of the dissected vessel were closely aligned; however, minute gaps filled with fibrin plugs were occasionally seen at the anastomotic site in group 3. The intima was denuded of endothelium on both sides of the anastomotic site. Small deposits of fibrin were seen adhering to the exposed lamina elastica interna; however, vessel patency was not affected. Coagulation necrosis of the media and adventitia was evident in LAMA, being more pronounced in group 3. In the adventitia adjacent to the anastomotic site, a sparse infiltration of polymorphonuclear cells was evident after 3 days.

By day 14 (Fig. 2b, d, f) after CMSA and LAMA, the endothelial lining on the intimal surface had been restored and a monolayer of endothelial cells covered the anastomotic site. In all groups the site of anastomosis was marked by nonabsorable sutures, which were surrounded by a foreign-body reaction. At 1, 2 and 6 months after CMSA and LAMA, the site of anastomosis remained marked by a persistent foreign-body reaction around the nonabsorbable sutures. At no time did aneurysms or a circumferential thickening of the intima due to proliferating intimal cells occur.

Scanning electron microscopy

At 3 days after CMSA (Fig. 3a) and LAMA (Fig. 3c, e), both ends of the dissected vessel were closely aligned, the anastomotic site and sutures being covered with minute deposits of fibrin. On day 14 after CMSA (Fig. 3b) and LAMA (Fig. 3d, f), the site of anastomosis was marked by the slightly prominent sutures, which were covered with a restored layer of endothelial cells. Minute deposits of fibrin were occasionally seen adjacent to the sutures. Following LAMA the welded spaces could hardly be identified except by the prominent stay sutures (Fig. 3d).

Discussion

Studies on microsurgical laser-welding of veins are scarce. McCarthy and co-workers [9] successfully anastomosed rabbit vena cavae with a diameter of 4–6 mm using a CO_2 laser, and Gomes et al. [6] laser-welded saphenous veins in dogs by means of an argon laser. Longitudinal jugular and femoral venotomies were laser-welded in canines with an Nd:YAG CO_2 or argon laser by White and co-workers [17, 18]. In these comparatively large vessels, patency rates were 95%–100%; they did not differ from those obtained using conventionally sutured anastomoses, and the formation of aneurysms did not pose a problem.

Fried and Moll [5] performed laser-welded end-to-end anastomoses on femoral veins in rats using a CO_2 laser. They had to apply four stay sutures in veins, whereas three were sufficient in femoral arteries. The energy setting was 200 mW; the spot size, 0.3 mm; and the pulse duration, 0.1–0.4 s. Their overall patency rate of 86% in the laser group was superior to that found for the control group (81%). Consistent with our findings, these authors reported a lack of intimal hyperplasia in venous anastomoses, did not observe aneurysms and concluded that although laser-assisted anastomosis "... is far simpler and faster than the conventional method ... a failed anastomosis can preclude further laser attempts ...". Laser welding reduces foreign-body reaction, but in nondamaged vessels this is not necessarily reflected by an improvement in patency rates. In traumatized vessels, however, a recent study indicated the superiority of laser welding: especially in the early postoperative period, LAMA resulted in significantly better patency rates than did CMSA [14].

What kind of laser system is best suited for microvascular repair? Although numerous authors have proven the feasibility of microsurgical laser welding and have investigated CO_2-, Nd:YAG- and argon-laser systems, comparative studies are lacking. In anastomosing rat femoral arteries, we could not find a difference between CO_2 and Nd:YAG laser systems [3]. The only other comparative study we could find in the literature had investigated the use of Nd:YAG and CO_2 lasers for closure of venotomies in canines [17]. In these comparatively large vessels, both lasers offer an alternative to conventional suturing; a difference between the two systems was not found.

The results presented herein indicate that for small laser-welded venous anastomoses, higher patency rates can be obtained with a CO_2 laser system. This might be caused by the differing physical properties of the lasers used. The wall of the rat femoral vein is very thin and the Nd:YAG laser beam, with its wavelength of 1.32 μm, can penetrate the entire wall, leading to transmural necrosis and endothelial damage. The beam is strongly scattered and, hence, causes more diffuse tissue heating with consecutive edema [7, 16]. This might explain the higher rate of postoperative thrombosis and the lower patency rate obtained in group 3. On the other hand, the CO_2 beam, with its wavelength of 10.6 μm, is easily absorbed by tissue water, and the resulting coagulation necrosis is circumscript and superficial. Based on our findings, we believe that for laser welding of small, delicate structures such as the vas deferens or vessels with a diameter of up to 2 mm, a CO_2-laser system seems to be better suited.

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