Urol Res (1988) 16:127–131

Urological Research
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Laser Welded Vascular Anastomosis*

Comparison of CO_2 and Neodym Yag Laser Techniques

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Accepted: August 24, 1987

Summary. A comparative study was undertaken to investigate the application of a specially adapted microsurgical Neodymium Yag Laser system with a wavelength of 1,319 μm and a CO_2 laser system for laser assisted microvascular end-to-end anastomosis (LAMA) of the rat femoral artery. Conventionally sutured anastomoses served as controls. Postoperative investigations included patency tests, light microscopy and tensile strength measurements. Both laser systems seem to be equally suitable for LAMA: The patency rates do not differ from those of sutured anstomoses and formation of microscopically small aneurysms occurred predominantly in control animals and only once in laser groups. The clamp time needed for LAMA was half the time that was needed for sutured anastomoses. Wound healing in all groups was similar with less fibrotic reactions and less foreign body granulomas in laser groups. At all intervals tensile strength was significantly higher for sutured anastomoses while differences between the CO_2- and the ND: Yag-laser groups were not statistically significant. Potential applications in urology include microvascular anastomoses in erectile dysfunction, pediatric and reconstructive urology.

Key words: Microsurgery – CO_2 laser – Neodymium Yag laser – Vascular anastomosis – Rat – Tensile strength – Histology

Introduction

The application of lasers in urology has gained acceptance but has mostly been restricted to the treatment of bladder and penile cancer [12, 13]. Lasers in stone treatment, and more recently for partial resection of the kidney, has been introduced [6, 7].

The achievements of microsurgery have been rapid and fascinating with vascularized free flap transplantation and anastomosis of 1 mm vessels now being common procedures. Microsurgical techniques can be applied widely in urology: In the vascular repiar of erectile dysfunction, of abdominal testicular retention and for free bowel and omentum grafts [2]. However these techniques are not yet common procedures in the field of urology, probably due to technical difficulties.

Microsurgical laser techniques minimize tissue trauma and facilitate vascular and vasal anastomoses [1, 3, 5, 9].

In this study we compare laser assisted microvascular anastomosis (LAMA) performed with a microsurgical CO_2 laser and also with a specially adjusted Nd:Yag laser unit with conventional microvascular suture anastomosis (CMSA). Postoperative investigations include patency tests, tensile sterngth (t.s.) measurements of the anastomosis and light microscopy.

Material and Methods

Forty-seven male Sprague-Dawley rats weighing 300–350 g were divided into 3 groups (Table 1). The end-to-end anastomosis of the femoral artery was either performed using a conventional suturing technique (gorup 1) or was laser welded with a microsurgical CO_2-laser (group 2) or a Nd: Yag laser (group 3).

Microsurgical Technique

The animals were operated under ketamine general anesthesia. For *CMSA* (group 1) we followed the technique described in detail by Neblett et al. [8]: The right common femoral artery was dissected free and mobilized from the inguinal ligament to the origin of the epigastric vessels. The end to end anastomosis was done with 10/0 nylon interrupted sutures on a BV 6 needle. Approximately 8–10 interrupted sutures were placed and assessed for patency using the occlusive patency test. The anastomosis was then covered with the inguinal fat pad and checked again 30 min postoperatively. The skin incision was closed with skin staples.

* Contains parts of a dissertation

Table 1. Number of anastomoses in treatment and control groups

Group	1	2	3
Technique	CMSA	LAMA CO_2	Lama Nd:Yag
	number of anastomoses		
sacrificed			
3 days p.o.	8	8	8
2 weeks p.o.	10	7	7
4 weeks p.o.	10	7	7
8 weeks p.o.	8	7	7
	36	29	29
Total		94	

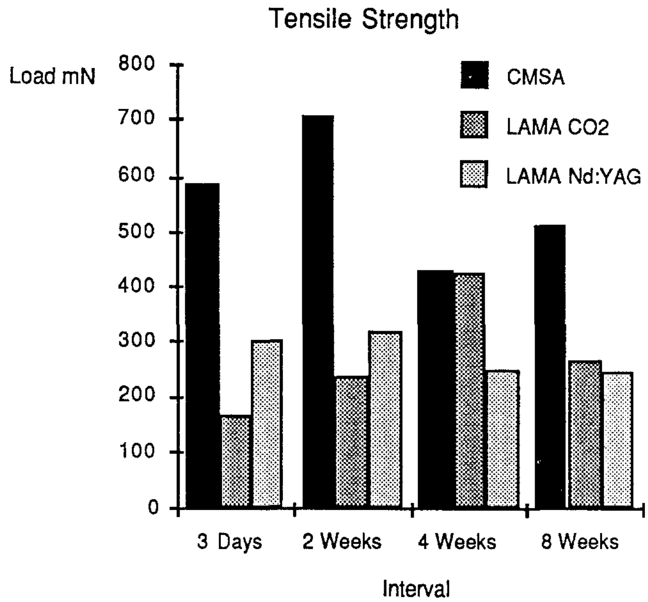


Fig. 1. Mean tensile strength in treatment and control groups at various time intervals

LAMA

Following dissection and preparation of the femoral artery three 10/0 interrupted nylon sutures were placed at 120° intervals using the triangulation technique [8]. Everting sutures were used for Nd:Yag LAMA. CO_2 LAMA (group 2) were performed using a Sharplan 1060[1] laser unit. Short pulses (0.1 s) of laser energy (300–380 mW) with a spot size of 0.5 mm were applied. The completion of the anastomosis was accompanied by a light brown – yellow discoloration of the welded tissue. The same patency tests were done postoperatively as in group 1. The Nd:Yag LAMA were welded with a Nd:Yag laser[2] applying pulses of 0.1 s duration, 0.2 mm spot size and 5.5–7 W.

Postoperative Investigations

The *patency* was assessed immediately postoperatively, 30′ p.o. and at the time of necropsy. *Gross observation* were recorded of the state of the connective tissue around the anastomosis. Specimens for *light microscopy* were resected en bloc, flushed with formalin and fixed in 4% buffered formalin. Sections were then stained with H & E and van Gieson (Elastin). For tensile strength measurements the vesel was dissected free from the inguinal ligament to the superficial epigastric artery. After removal it was stored in saline at 4 °C for 1–2 h. Measurements of the anastomosed artery were done on an Instron material tester[3] (series 6000) at 293 K with a test-speed of 20 mm/min at various time intervals (3 days, 2 weeks, 4 weeks and 8 weeks p.o.).

Statistics. Statistical differences between the 3 groups were assayed utilizing multiple regression analysis and independent linear contrasting.

Results

The time needed for completion of the anastomosis in group 1 (CMSA) was 20–45′ while in groups 2 and 3 (LAMA) it were considerably less. Group 2 required 10–20′ and in Group 3 12–15 min were needed.

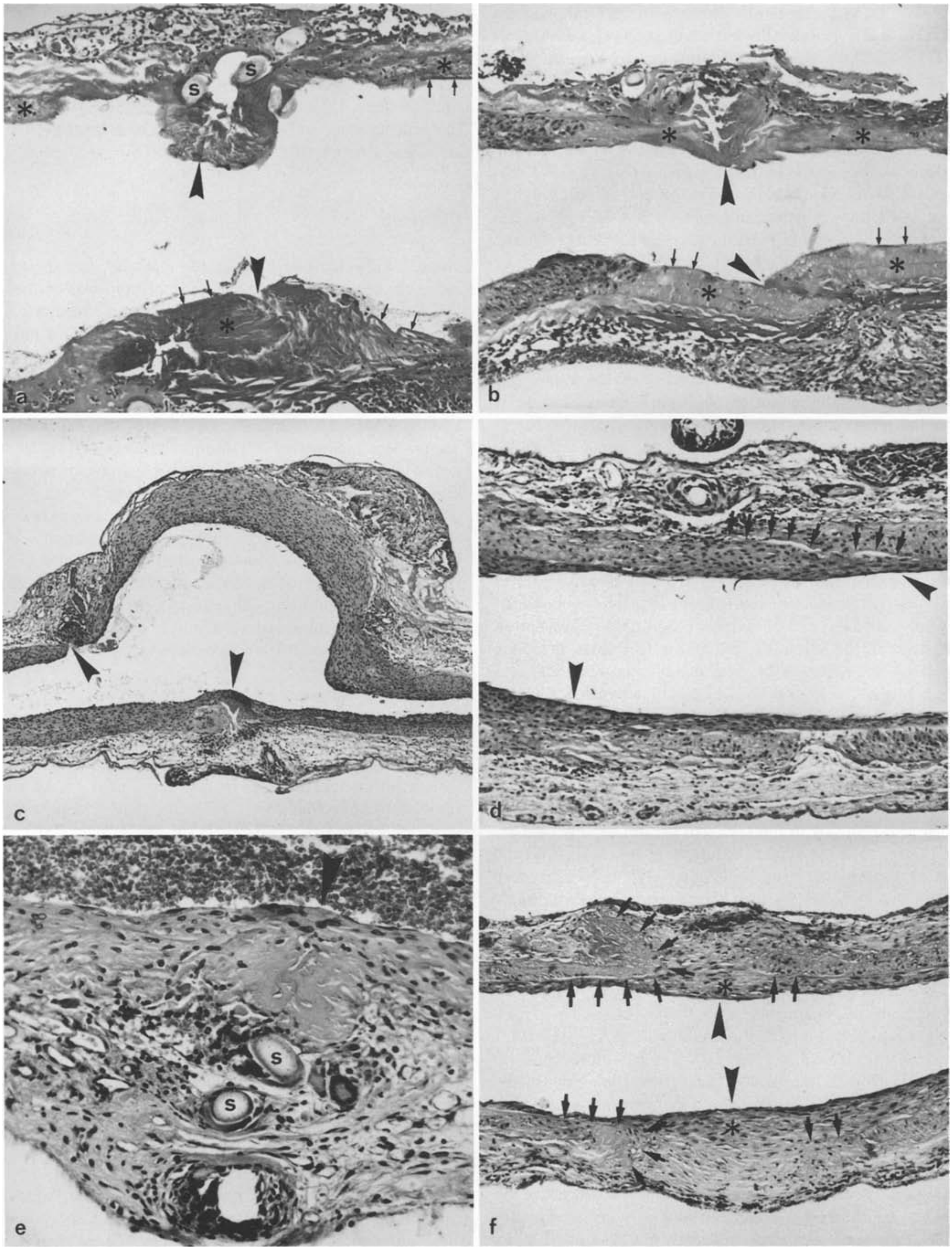
All anastomoses were patent. On gross examination there was no significant difference in the degree of perivascular fibrosis and formation of connective tissue, although LAMA seemed to have less fibrotic reactions at the site of the anastomosis. Only in a pilot study were aneurysms found in 5 animals. With technical experience aneurysm formation did not occur and in treatment animals (LAMA) aneurysm formation was not evident.

Tensile Strength

In each group 3 anastomoses were tested for tensile strength. The mean values are shown in Fig. 1. Three days p.o. the

Fig. 2. **a** Three days after CMSA: the site of the anastomosis *(arrowheads)* shows a denuded lamina elastica interna *(arrows)* and a necrotic media *(stars)*; *s* = sutures. x115. **b** Three days after CO_2 LAMA: the site of the anastomosis *(arrowheads)* with a denuded lamina elastica interna *(arrows)* and a circumscript necrosis of the media *(stars)*. x115. **c** Twenty-eight days after CMSA: the site of the anastomosis *(arrowheads)* with formation of an aneurysm. x46. **d** Twenty-eight days after CO_2 LAMA: the anastomosis *(arrowheads)* shows a dislocation of the lamina elastica interna *(arrows)* on one side of the vessel, which can be hardly discerned on the opposite side. x115. **e** Fifty-six days after CMSA: foreign body reaction around the suture material (s) at the site of the anastomosis *(arrowheads)*. x320. **f** Fifty-six days after Nd:YAG LAMA: The site of the anastomosis *(arrowheads)* with a dislocation of the lamina elastica interna *(arrows)*, bridged by intimal proliferation *(stars)*. x115 ▶

[1] Sharplan 1060, Firma Hoyer GmbH, Bremen, FRG
[2] MBB Medizintechnik, München, FRG
[3] Instron Series 6000, Instron International Limited, Offenbach, FRG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CMSA had a mean tensile strength of 583 mN whereas LAMA had a considerably less t.s. of 165 (CO_2) or 300 mN (Nd:Yag). Two weeks p.o. CMSA showed a mean t.s. of 705 mN and LAMA had a t.s. of 236 (CO_2) and 321 (Nd: YAG). Four weeks p.o. the anastomoses in group 2 and in group 1 had nearly the same t.s. of 432 or 423 mN, whereas Nd :Yag LAMA breaking at 250 mN had less tensile strength. Eight weeks p.o CMSA had a tensile strength of 508 mN; CO_2 LAMA 265 mN and Nd-Yag 248 mN. Statistically the t.s. of CMSA was significantly greater ($F = 26.5$ [df = 1,36; $P < 0.01$]). The difference in t.s. between CO_2 laser and Nd :Yag laser groups was not significant ($F = 0.14$ [df = 1,36]).

Histology

Day 3 (Fig. 2a, b). In CMSA and LAMA the intima was denuded of endothelium up to 2 mm proximal and distal to the anastomosis. Minute deposits of fibrin were occascionally seen adhering to the exposed lamina elastica interna, however, patency was not affected. In CMSA and LAMA a complete necrosis of the media was observed with an extension of up to 2 mm on both sides of the anastomosis. The structural integrity of the lamina elastica interna and externa was preserved except at the site of sutures or vessel transection. Nd:Yag-LAMA produced small gaps at the site of the anastomosis filled with fibrin plugs which were not seen in CMSA and CO_2-LAMA. Coagulation necrosis of the adventitia was evident in LAMA. In CSMA and LAMA sparse infiltration of polymorphonuclear and mononuclear cells was present in the adventitia adjacent to the anastomotic site.

Day 14. The endothelial lining on the intimal surface had been restored and a layer of endothelial cells also covered the anastomosis. The circumferential proliferation of intimal cells resulting in thickening of the intima only moderately decreased the size of the lumen. In Nd: Yag-LAMA the small anastomotic gaps were now filled by proliferating intimal cells. In CMSA the necrotic media had almost completely been reconstructed, whereas in LAMA there were still remnants of medial necrosis, evidenced by a deficit of nuclear staining. Coagulation necrosis of the adventitia was still present in Nd :Yag-LAMA but not in CO_2-LAMA. Predominantly mononuclear cells and foreign body reaction were present around the sutures in CMSA and LAMA.

Day 28 (Fig. 2c, d). Wound healing was complete. On the luminal side the anastomosis was completely covered by a broad proliferation of intimal cells. In CMSA and LAMA the site of the anastomosis could be detected only marked by sutures or the persistent discontinuity of the lamina elastica. The proliferation of the intima did not reduce the lumen significantly. Small aneurysms only detected microscopically were seen more frequently in CMSA ($n = 2$) than in LAMA ($n = 1$). The nonabsorbable suture material in CMSA caused a foreign body reaction.

Day 56 (Fig. e, f). In CMSA and LAMA the thickening of the intima layer did not increase, but the atrophy of the media, already noted occasionally on day 28, was more marked, and most intense in areas with broad intima proliferations. A persistent foreign body reaction with chronic inflammatory infiltrations adjacent to the suture material was seen in CMSA.

Discussion

Using laser welding techniques for microvascular anastomosis can reduce clamp time significantly and anastomoses can be completed much faster. Neblett et al. reported a reduction in clamp time from 15–20′ to 5–10′ in rats, Jain from 15′ to 5′ also in rats and Frazier et al. from 30′ to 20′ in miniature swine [3, 4, 8]. Our own results confirm the data: 20–45′ for CMSA and usually half the time for LAMA. LAMA are technically easy to perform, expecially for the less experienced microsurgical trainee (PK.). This is also nicely illustrated by the smaller number of microscopical pseudoaneurysms in the LAMA groups.

Frazier could describe less fibrotic reactions around laser-anastomoses when compared to conventional anastomoses in minipigs while others found no marked difference [3]. Our results indicate that there are less external fibrotic reactions in LAMA, probably due to less foreign body material. Neither in gross observations nor histologically could we find any significant differences between CO_2 and Nd:Yag laser groups.

There are few reports of tensile strength measurements of LAMA: Neblett et al. found t.s. to be variable with t.s. of CMSA being slightly greater than tensile strength of LAMA [8]. Quigley et al. studied bursting strength of femoral artery anastomoses in rats and found LAMA to consistently burst at lower pressures than CMSA with statistically significant differences on day 1, day 3 and 1 week p.o. [10]. We found the tensile strength of CMSA to be consistently and statisticially significantly higher than t.s. of LAMA. However 4 weeks p.o. CMSA and CO_2 LAMA had nearly the same t.s. CO_2 and Nd:Yag laser groups did not show any statistically significant differences in tensile strengh measurements.

While "... the primary bond produced by LAMA seems to be the 'direct weld' of the tissue of the vascular wall ..." [14], the structural basis for the welding effect seems to be "... a homogenizing change in collagen with interdigitation of altered individual fibrils ..." [11]. Immediately after laser welding no changes whatsoever could be detected by light microscopy. Three days later a slight separation of the wound edges could be seen in Nd :Yag anastomoses, others described this for CO_2-anastomoses too [8, 14]. Wound healing progressed similarly in all groups, which is consistent with other reports [8, 14]. CMSA showed a more pronounced foreign body reaction, whereas the intima proliferation at day 56 p.o. was similar in all groups. Histologically, no differences in wound healing could be detected between CO_2 and Nd:Yag laser groups indicating that tissue bonding in LAMA caused by a common cause: the application of thermal energy. The new Nd:Yag laser system with a spot size of 0.2 mm and a wavelength of 1.319 μm seems to be as useful as a microsurgical CO_2 laser unit.

In urology the potential applications for microsurgical laser systems are numerous: microvascular anastomoses in the treatment of erectile dysfunction, in pediatric urology and for free bowel-, omentum- and composite grafts in reconstructive urology. Furthermore we are currently investigating the use of laser systems for sutureless, watertight anastomosis of the pyelon, ureter and urethra for further pontential applications in pediatric reconstructive urology.

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