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Laser Welding for Vascular Anastomosis Using Albumin Solder: An Approach for MID-CAB

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Background and Objectives: **To improve minimally invasive direct coronary artery bypass surgery (MID-CAB), new techniques of vascular anastomosis that are faster and more reliable need to be developed.**
Study Design/Materials and Methods: **Common carotids in a canine model were transected and an end-to-end anastomosis was performed by using one of four techniques (1) continuous 6-0 polypropylene closure (suture; n = 6), (2) vascular clip (VCS; n = 6), laser welding using 50% albumin solder with (3) a 1.32-μ laser (1.32las; n = 6), and (4) a 1.9-μ diode laser (1.9las; n = 4). Times for anastomosis (TA) were compared between groups by *t*-test. Pressures at which anastomosis failed (leak point pressure, LPP) were determined and compared by analysis of variance.**
Results: **TA was faster for 1.32las and 1.9las at 8.4 ± 0.7 and 7.8 ± 0.3 min, respectively, when compared with suture at 13.8 ± 1.0 min (*P* = 0.001, confidence interval [CI]–8.1, –2.6 for 1.32las and CI –8.9, –3.1 for 1.9las). There was no statistical difference between VCS (8.3 ± 3.3 min) and any other group (*P* > 0.17). LPPs (mm Hg) were similar for all groups: 350 ± 37 for 1.32las, 280 ± 31 for 1.9las, 347 ± 46 for suture, and 358 ± 53 for VCS, *P* = 0.68.**
Conclusions: **In this study, laser welding using 50% human albumin solder resulted in faster anastomotic times. Anastomoses were equivalent to conventional sutured anastomoses in failing at similar pressures. Laser welding using human albumin solder may be advantageous in improving coronary anastomoses during MID-CAB, but long-term anastomotic strength and histologic evaluation need to be investigated. Lasers Surg. Med. 24:264–268, 1999.** **© 1999 Wiley-Liss, Inc.**

Key words: **carotid; vascular; strength**

INTRODUCTION

The first report on using a laser to perform an anastomosis was by Yahr and Strully in 1966 who performed a side-to-side anastomosis without success [1]. The first successful use of laser was performed by Jain and Gorisch who sealed 0.3–1.0-mm openings with a Nd:YAG laser in 1979 [2].

Laser welding for vascular anastomosis has been shown to produce excellent patency and

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faster anastomotic time in comparison with suturing [3,4]. In addition, histologic studies have shown that laser welding can lead to improved healing and reduce the problems of foreign body reaction, arrest of growth, and intimal hyperplasia, which are often seen in sutured anastomoses [4–6]. Anastomotic strength has been fortified by the development of tissue solder such as human albumin [7]. The tissue solder absorbs the photons preferentially, thereby reducing native tissue damage. The protein solder also undergoes thermal remodeling via denaturation and acts as a bonding agent as it becomes incorporated into the weld [8].

Laser welding has the potential to be particularly advantageous to vascular surgery because anastomoses can be done faster and with less damage to the artery. The effects of laser welding in terms of anastomotic strength and histologic effects over time need to be assessed for vascular anastomoses. Conventional anastomoses for medium-sized vessels (2–6 mm) generally involves a continuous suture with a 6-0 polypropylene suture. These types of suture are difficult to place and result in poor precision, in particular in minimally invasive procedures. To improve minimally invasive direct coronary artery bypass surgery (MID-CAB), laser welding techniques for vascular anastomosis are being developed that are more reliable and can be performed in less time through smaller incisions. Laser welding has the potential to be advantageous in improving coronary anastomoses during MID-CAB by faster anastomotic times with more consistent anastomoses. We hypothesize that laser welding using albumin solder will lead to vascular anastomoses that are as strong as traditional suture but, most importantly, can be performed more precisely and quicker. This study is the first report of using albumin solder to perform laser-welded vascular anastomoses.

MATERIAL AND METHODS

The protocol employed was approved by the Institutional Animal Care and Use Committee. All animals used in this study received humane care in compliance with the Principles of Care and Use of Laboratory Animals prepared by the National Institutes of Health (NIH Publication No. 80-23, revised 1985).

Using a canine model, dogs were sedated with acepromazine (0.1 mg/kg, i.m.). An intravenous line was placed for administration of drugs and fluids. Dogs were then anesthetized with sodium pentobarbital (35 mg/kg, i.v.). Dogs were monitored for spontaneous movements and wakefulness.

All surgery was done by the same surgeons (A.B.M.P., D.P.P.). All dogs had exposure of first the right common carotid artery and then the left common carotid both through an incision lateral and parallel to the trachea over the respective artery. The incision was continued between the heads of the sternocleidomastoid muscle. The carotid sheath was entered, and the jugular vein and vagus nerve were dissected free from the carotid for approximately 5 cm. Proximal and distal control was attained by using vessel loops. The adventitia was dissected from the carotid artery at the site to be transected. Nontraumatic vascular clamps were placed first proximally and then distally. The time was recorded. The artery was transected. An end-to-end anastomosis was performed for the first six carotid arteries with a running 6-0 polypropylene suture (United States Surgical Corp., Norwalk, CT), the second set of six carotids with vascular clip staplers (VCS; United States Surgical Corp.) the third set of six carotids with a Nd:YAG 1.32-μ laser (Premier Laser Systems, Inc., Irvine, CA; 1.5 W, continuous wave, and 400-μ fiber) and 50% albumin solder supplied by Vitex, Inc. (New York, NY), and the last four carotids with a 1.9-μ diode laser (Abiomed R&D, Inc., Danvers, MA; 300 mW, continuous wave, and 400-μ fiber) and 50% albumin solder. For both laser groups, three stay sutures were placed at 120° apart with a 6-0 polypropylene suture. The albumin solder was placed on the wound edges while pulling up on two stay sutures. The laser irradiation was done between the sutures.

The time to complete the anastomosis was recorded. The distal and then the proximal vascular clamps were removed. The anastomosis was observed for bleeding. If bleeding was noted, the clamps were reapplied and the bleeding was controlled with an extra intervention (i.e., another stitch, VCS, or spot weld). The time to complete the extra interventions was recorded. The time to completion was also recorded. After hemostasis was completed, a clamp was placed proximally and the distal artery was tied off. A 22-gauge angiocatheter was placed distal to the anastomosis and secured with a 2-0 silk suture. The proximal clamp was removed, and the baseline pressure was recorded. The proximal clamp was replaced, and normal saline was infused through the angiocatheter into the closed vessel until there was a

TABLE 1. Initial Anastomosis Time to Complete the Anastomosis

Type of anastomosis	Mean ± SE (min)	P*	Confidence interval
Nd:YAG 1.32-μ laser	8.4 ± 0.7 vs. suture	0.001	(−8.1, −2.6)
1.9 μ laser	7.8 ± 0.3 vs. suture	0.001	(−8.9, −3.1)
Vascular clip	8.3 ± 3.3 vs. suture	0.17	(−3.0, 13.9)
Suture	13.8 ± 1.0		

*Student's *t*-test.

visible leak. The pressure at which the leak occurred was recorded (leak point pressure, LPP). The animals were killed with sodium pentobarbital (100 mg/kg).

A similar procedure was performed on five additional animals, except the right carotid had the anastomosis performed by using a running 6-0 polypropylene and the left carotid had the anastomosis performed by using a Nd:YAG 1.32-μ laser (Premier Laser Systems, Inc.; 1.5 W, continuous wave, and 400-μ fiber) and 50% albumin solder supplied by Vitex, Inc. These arteries were removed after the animal was killed with sodium pentobarbital (100 mg/kg). These samples were used to determine tensile strength with an Instron Model Mini-44 tensiometer (Instron, Inc., Canton, MA). The samples were standardized to a length of 30 mm. A portion of distal common carotid was anastomosed by using only the three stay sutures in four arteries and was used to determine tensile strength.

Two samples of the Nd:YAG 1.32-μ laser were submitted for histologic evaluation after the LPP was determined. The histologic sections were formalin fixed, sectioned as longitudinal and cross sections, and stained with hematoxylin–eosin (H&E).

Unpaired Student's *t*-test was employed to determine significant between groups for time data. Analysis of variance was employed to determine the significance between groups for baseline pressure, LPP, and tensile strength parameters. Significance was defined by using the Tukey HSD test. A P value less than 0.05 was considered significant for all statistical tests.

RESULTS

The time to complete the initial anastomosis was more rapid for both laser groups than for the suture group (Table 1). All anastomoses had similar systemic blood pressure distal to the anastomosis and LPP (Table 2). Tensile strength (Table 3) was statistically stronger for sutured anastomosis than were the Nd:YAG 1.32-μ laser with 50% albumin solder and three stay sutures. There was no added strength imparted by the laser welding in terms of tensile strength, except that the anastomosis was able to stretch farther before the anastomsis was disrupted (Table 3).

Histopathologic evaluation of two specimens that had anastomoses using the Nd:YAG 1.32-μ laser showed albumin on the adventitial and intimal surfaces of the carotid arterial wall (Fig. 1, dog 97-D-066). The albumin conforms to the contour of the adventitial surface. There is evidence of thermal injury on the adventitial surface, which extends to approximately one-third of the arterial wall. The anastomosis, which has been disrupted, can be seen to the right of the figure. The etiology of the wall disruption at the anastomosis is unclear.

DISCUSSION

With the advances in laparoscopic surgery and the recent advent of MID-CAB, new techniques that can be used to perform vascular anastomosis through smaller incisions and with more precision than traditional sutured anastomoses must be developed. Lasers have been used to repair arteries successfully since 1979 [2]. However, the use of laser energy has not been successful in performing anastomoses with strength equivalent to that of traditional sutured anastomoses [9]. More importantly, the laser anastomosed arteries have caused thermal injury to the vessel wall, which with time can lead to pseudoaneurysm formation and anastomomatic failure [10]. With the advent of protein solders such as albumin in 1988, laser welding can create better bonded anastomoses because the solder absorbs the laser energy and denatures, thus protecting the tissue from thermal injury [7]. In this study, we evaluated the acute strength of laser welding with both the Nd:YAG 1.32-μ laser and the 1.9-μ diode laser with 50% human albumin solder and VCS vs. traditional 6-0 continuous polypropylene suture.

TABLE 2. Baseline Systemic Blood Pressure (BP; mm Hg) Across the Anastomosis Prior to Determining Leak Point Pressure (LPP)†

	1.32-μ Laser	1.9 μ Laser	Suture	Vascular clamp	*P**
Baseline BP	128 ± 5	123 ± 5	119 ± 6	136 ± 7	0.25
LPP	349 ± 37	280 ± 31	347 ± 46	358 ± 53	0.68

*Analysis of variance.
†Pressure at which the anastomosis is disrupted by infusion of saline into the distal artery through a 22-gauge angiocatheter while the proximal artery is clamped.

TABLE 3. Tensile Strength: Force Required to Disrupt the Anastomosis, With Length Standardized to 30 mm

Type of anastomosis	Mean ± SE	*P** vs. (confidence interval): 1.32-μ Laser	Stay	Suture
Load (N) required to disrupt the anastomosis				
1.32-μ Nd:YAG laser	3.4 ± 0.5		0.995 (−3, 3)	0.000 (−10, −4)
3 Sutures	3.5 ± 0.6	0.995 (−3, −3)		0.000 (4, 10)
Suture	10.4 ± 0.9	0.000 (−10, −4)	0.000 (4, 10)	
Strain (kPa) required to disrupt the anastomosis				
1.32-μ Nd:YAG laser	650 ± 90		0.995 (−500, 600)	0.000 (−1,800, −800)
3 Sutures	590 ± 120	0.995 (−500, −600)		0.000 (−1,800, −800)
Suture	1,080 ± 190	0.000 (−1,800, −800)	0.000 (−1,800, −800)	
Displacement (mm) of the anastomosis before disruption†				
1.32-μ Nd:YAG laser	25.8 ± 4.4		0.037 (1, 25)	0.977 (−12, 10)
3 Sutures	13.0 ± 2.1	0.037 (1, 25)		0.026 (2, 26)
Sutures	26.6 ± 1.5	0.977 (−12, 10)	0.026 (2, 26)	

*Post hoc Tukey HSD test.
†$P = 0.02$, analysis of variance.

In this experiment, we chose an end-to-end anastomosis in a canine carotid model because (1) an end-to-end anastomosis is more difficult to perform than a side-to-end anastomosis and (2) the dog carotid is a medium-sized vessel approximately 2–4 mm in greatest diameter, which represents a size similar to that for an adult coronary artery. We believe laser welding may improve MID-CAB; however, this technique must be developed prior to being used to perform minimally invasive vascular anastomoses. The carotid model is a very simple model that will allow us to establish laser welding with albumin solder to perform vascular anastomoses.

As has been widely reported, laser welding leads to faster anastomoses than traditional suture (the 1.32-μ-laser anastomosis took 8.4 ± 0.7 min, the 1.9-μ-laser anastomosis took 7.8 ± 0.3 min, and suture anastomosis took 13.8 ± 1.0 min).

The acute strength of laser welding in medium-sized vessels is equivalent for laser 1.32, laser 1.9, suture, and VCS groups in terms of LPP (the pressure needed to burst the anastomosis). The tensile strength is significantly lower for the laser 1.32 than for the suture. However, the laser anastomosis can withstand a sufficient load that under physiologic conditions would not become disrupted.

The acute histology suggests entry of albumin into the arterial lumen. The role this has on long-term patency needs to be determined. In Figure 1, the histology shows thermal injury to the outer third of the arterial wall; similarly, the long-term sequel of such an injury must be addressed.

With the advent of MID-CAB, new devices and approaches are currently being developed and evaluated; one such device is the VCS. The VCS can be used to perform a rapid anastomosis, but it is cumbersome to work with, and overall efficacy is limited by wide variability and limited long-term results. In the present study, VCS led to faster anastomoses than did suture but did not reach statistical significance as a result of the large variability in the time to complete the anastomosis. As the technology is further improved, VCS will become easier to use, which will result in significantly faster anastomoses when compared with sutured anastomoses. VCS anastomoses

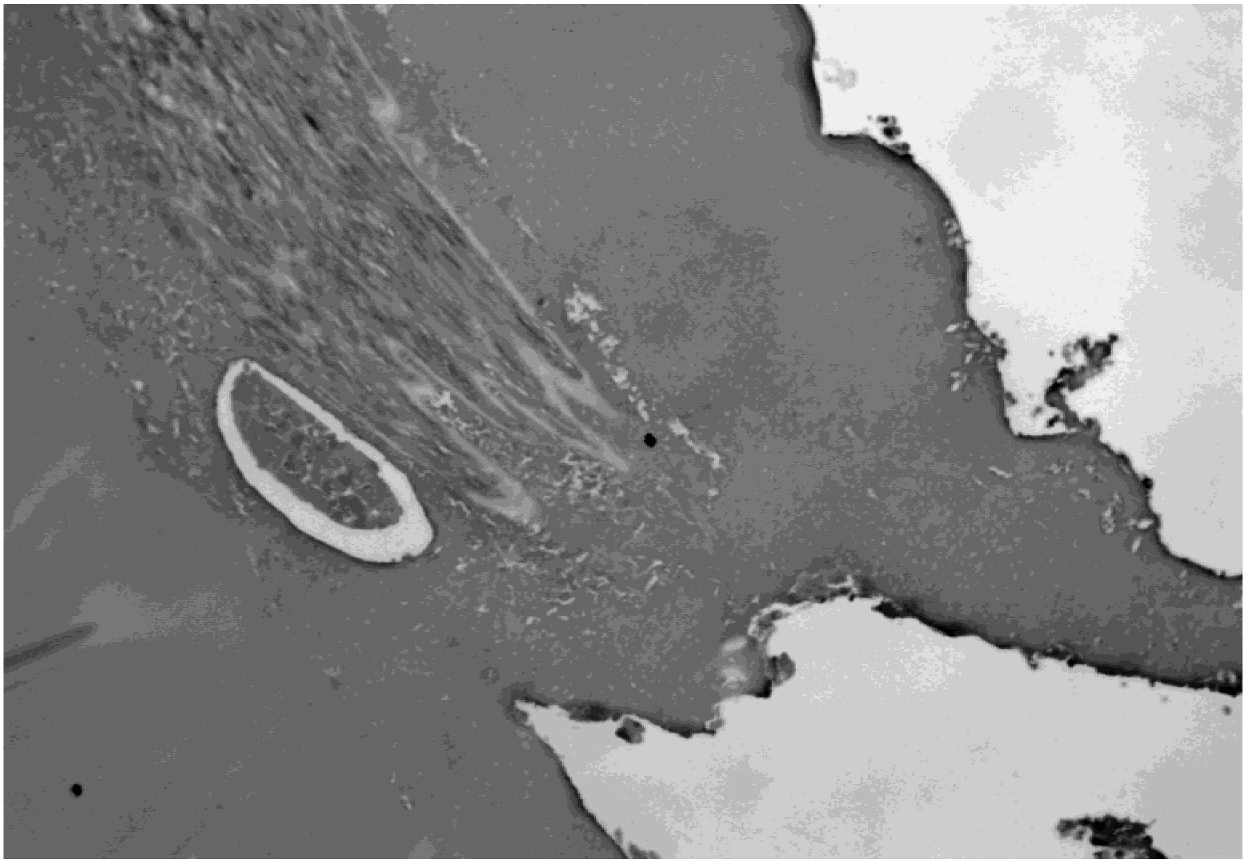

Fig. 1. Cross section of dog carotid artery at the end-to-end anastomosis performed by an Nd:YAG 1.32-μ laser and 50% human albumin. Albumin is seen on the adventitial and intimal surfaces of the arterial wall. The anastomosis is seen on the right lower portion of the figure. The albumin conforms to the contour of the adventitial surface. Wall disruption at the anastomosis is of unclear etiology. Hematoxylin and eosin stain, ×40.

were as strong as both the 1.32-μ-laser and 1.9-μ-laser anastomoses and sutured anastomoses, as defined by the LPP.

Laser welding using albumin solder leads to acute anastomosis that are faster to perform and have similar strength as traditional sutured anastomoses. Laser welding using human albumin solder may be a beneficial means of performing vascular anastomosis and seems to be a promising technology for minimally invasive techniques; however, long-term anastomotic strength, patency, and long-term healing must be addressed.

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