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1.9 µm diode laser assisted anastomoses in reconstructive microsurgery: preliminary results in 12 patients

Serge Mordon, Michel Schoffs, Véronique Martinot, Bruno Buys,
Philippe Patenotre, Jean Claude Lesage, Guy Dhelin

INSERM (French National Institute of Health and Medical Research), Pavillon Vancostenobel, University Hospital, F-59037 Lille Cedex, France (SM,BB,JCL,GD)
Department of Plastic Surgery, Hôpital R. Salengro, University Hospital, F-59037 Lille Cedex, France (MS, VM, PP)

Correspondence : Serge Mordon, INSERM, Pavillon Vancostenobel, CH&U, 59037 LILLE Cedex , FRANCE
tel/fax : +33 (0) 320 446 708 Email: mordon@lille.inserm.fr

ABSTRACT

The authors reported an original 1.9 µm diode laser assisted microvascular anastomosis (LAMA) in human. This technique has been applied in 12 patients during reconstructive surgery for digital replantations (n=2), for digital revascularisations (n=3) and for free flap transfers (n=7). Fourteen end-to-end anastomoses (10 arteries, 4 veins) were performed. LAMA were always performed on vessel which did not impede the chance of success of the surgical procedure in case of thrombosis. LAMA was performed with a 1.9µm diode laser after placement of 2 equidistant stitches. The diode spot was obtained by mean of an optic fiber transmitted to the vessel wall via a pencil size hand piece. The used parameters were as followed: spot size = 400µm, power = 70 to 220 mW, time = 0.7 to 2 seconds, mean fluence = 115 J/cm². The mechanism involved is a thermal effect on the collagen of the adventitia and media leading to a phenomena which the authors have termed "heliofusion". This preliminary trial has permitted to define the modalities of its use in human. The technique is simple, rapid and easily learned. The equipment is not cumbersome, sterilisable and very ergonomic. LAMA does not replace sutures but is complementary, thanks to a reduction in the number of stitches used and to an access to surgical areas which are not easily accessible. This study must be completed by a larger scale study to confirm this technique and its reliability. Others uses could be performed on different tissues such as biliary and urinary track, specially under laparoscopic conditions.

Keywords : diode laser, extinction coefficient, thermal weld, collagen, anastomosis,

INTRODUCTION

Microsurgical transfer of free flaps has been a significant advance in plastic and reconstructive surgery. Microsurgical vessel anastomoses are necessary to restore blood circulation. These anastomoses are performed on vessels whose diameter is less than 0.5 centimeter. Conventional anastomoses use very fine suture (22 µm). Patency of anastomoses is highly dependent on the surgeon's skill.
In order to reduce the surgical trauma associated with the presence of stay sutures and, to shorten the operative times as well as to simplify the procedure, other experimental methods have been proposed. Since 1979, laser assisted microvascular anastomoses (LAMA) have been performed [1]. LAMA offers several advantages: the

procedure is performed more quickly than conventional anastomoses [2-4]; the induced vessel damage is limited [5]; reduced inflammatory reaction is observed [2,4-8].

Since 1979, LAMA has been evaluated using a wide range of laser wavelengths, including CO2 lasers [9-12], Nd:YAG laser [13,14], Argon laser [3,8,15-17] and diode lasers [18-20]. In a previous experimental study, we suggest that a low-energy 1.9 µm diode laser has potential clinical application for anastomosis of small vessels [20]. End-to-end anastomoses have been obtained easily, safely and quickly in Wistar rats with this 1.9 µm diode laser.
Arterial laser assisted anastomoses have been extensively studied. However, studies on venous anastomoses are scare and present with different technical problems. Indeed, perfusion pressure is lower in venous than in arteries leading to an easier seal. However, the vessel wall is thinner and the risk of intimal damage is higher. These venous anastomoses have been performed with CO_2 laser, Argon laser and diode lasers. In the development of theses laser assisted anastomoses, diode lasers represent a significant advance. Indeed, the cumbersomness of these previous equipment disappeared
Thus, since several years, the feasibility of microvascular anastomoses using a diode laser have been proved, with an excellent patency rate [18, 21, 22]. But, the majority of authors have usually combined the use of 805nm low-power diode laser and a previous staining of the vessel wall in order to enhance the optical absorption of diode laser energy into the tissue. This staining is usually obtained using an exogenous chromophores like ICG (Indocyanin Green) [23,24]. This chromophore is used alone or combined with different molecules (albumin, growth factors, hyaluronate,...)[25,26].
In contrast to these studies, the 1.9 µm diode laser thanks to its wavelength well adapted for small vessel anastomoses permits welding of the vessels without the use of a chromophore alone or solder preparation.
This study reports preliminary clinical microvascular results in 12 patients, using a 1.9 µm diode laser without additional staining or solder.

MATERIALS AND METHODS

Diode laser
The laser used in this study was a diode laser model 6432-P2 (SDL, San Jose). Energy supply was provided by a box where size was similar to that a diathermy. The light was transmitted through a 300 µm optic fiber. Laser energy was delivered in a noncontact mode using a pencil size handpiece. The handpiece was held approximately 1mm from the target, resulting in a tissue spot size of 400µm. This diameter was chosen for its suitability to the average diameter of the vessels (1 to 2 mm). LAMA was achieved using the following parameters: (λ=1.9µm, $\varnothing$= 400µm, P= 70mW-220mw, t= 0.7-2s, F=115J/cm²). Using these parameters, a slight blanching of the vessel adventitia was observed. .

Patients
Twelve patients have benefited from a laser assisted microvascular anastomoses during their surgical procedure, for digital replantation (n=2), digital revascularisation (n=3), or free flaps transfer (n=7). Fourteen end to end arterial (n = 10) or venous (n = 4) anastomoses have been performed. (table 1). Microvascular anastomoses using a diode laser did not impede with the favorable outcome of surgery. It has been performed in cases where one accessory vessel could also be anastomosed (second artery or second vein). All patients were operated on by trained operators and with informed consent of the patients and ethical committee approval.

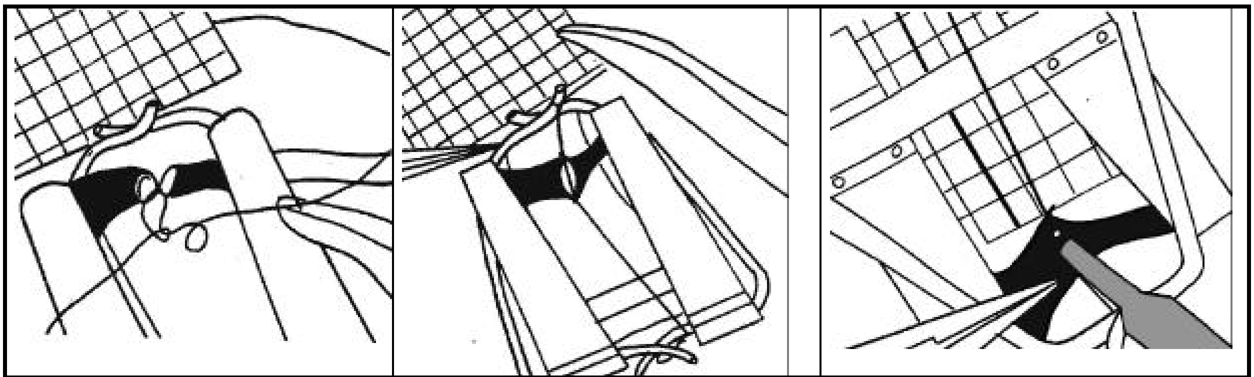
Surgical procedure (12 patients)	vessels (14)	n (14)
Digital reimplantation (n=2)	veins arteries	2 0
Digital revascularisation (n=3)	veins arteries	1 3
Free flap transfer (n=7)	veins arteries	1 7

Table 1: surgical procedure

Methods

Two nylon stay sutures were positioned on the vessel wall in order to obtain good coaptation of the edges (fig1). The anastomoses was completed by 6 to 8 spots laser on each faces. The technique consists in juxtaposing several 400 µm spots on well aligned edges of the vessel. A 30 seconds delay period was respected before unclamping the vessel, so as to obtain cooling of the fused area. The type of the vascular connections and the setting of the parameters of the diode are reported in table 2.

For each anastomosis, immediate patency with the so-called patency test of O'Brian and watertighness after removal of the clamp were studied. In cases of residual leakage, complementary sutures were inserted. Finally, for each patient, the results (failure or success) of the surgical procedure have been analyzed, taking into account that, in this preliminary study, LAMA were always associated with a conventional anastomosis using sutures.



A clamp interrupts blood flow during anastomose Two sutures are inserted on the vessel to be anastomosed.	By tensing the sutures, the edges are straightened and juxtaposed. The sutures are tensed on the edges of the vascular clamp.	Anastomosis is completed by several continuous spots obtained with the diode laser on both face of the vessel successively exposed.

Figure 1: Differents steps of the LAMA technique using the diode laser. (λ=1.9µm, ∅= 400µm, P= 70mW-220mw, t= 0.7-2s, F=115J/cm²).

RESULTS

The results of the surgical procedure appear in table 2. All the anastomoses were patent. Two anastomoses (patients 3 and 4), at the beginning of our experience, presented a leak with bleeding after the removal of the vascular clamp.

In patient 4, two supplementary stitches resulted in watertightness of the anastomoses. In patient 3, welding of the vessel by diode laser as a failure and anastomosis was performed again classically using sutures. Through this parameter has not been measured systematically, all the operators observed that diode laser welding was very quickly performed in less than ten minutes.

n°	Surgical procedure	anastomosed vessels	diameter (mm)	power (mW)	time (s)	patency
1	temporalis fascial flap on ankle	Anterior tibial art. - superficial temporal artery	2	140	0.7	good
2	temporalis fascial flap on ankle	posterior tibial art.- superficial temporal artery	2	140	0.9	good
3	Latissimus dorsi flap on ankle	Thoraco-dorsal artery- anterior tibial artery	1.5	70	1	Bleeding
4	Thumb replantation	Dorsal vein	1	70	1	Bleeding
5	digital (V) revascularisation	Collateral radial artery	1.2	140	2	good
6	Ring finger (IV) revascularisation	dorsal vein	1.8	100	2	good
7*	Ring finger (IV) revascularisation	Collateral radial artery Collateral ulnar artery	1.6 1.6	80 80	1 1	good good
8	Thenarien free flap on the III digit	Radiopalmar artery Collateral radial artery	1,5	220	2	good
9	Digital replantation (P2, III)	dorsal digital vein	1.5	220	1	good
10	articular free flap (2 toe) on IPP (IV)	digital artery- toe collateral artery	1	140	1	good
11	toe free flap (P3 on III)	digital artery- toe collateral artery	1	140	0.7	good
12*	Osteocutaneous antebrachial free flap on thumb	digital artery-radial artery Dorsal vein- superficial antebrachial vein	1.5 1.8	100 100	0.7 0.7	good good

Table 2 : Summary of the results obtained with the 1.9µm diode laser. For each LAMA, vessel size and laser parameters are specified. * means that two vessels were sutured in patient #7 and patient #12.

Calculation shows that for these 14 cases, the average vessel diameter was 1.5mm ± 0.3mm. The average power was 126mW ± 45mW; the average pulse duration was 1.1 and the standard deviation ±0.4s. The average fluence was 110J/cm².

DISCUSSION

The use of 1.9 µm diode laser has permitted to perform successfully vascular microsurgical anastomoses in human. The procedure was rapidly performed with a 100% patency rate. The two partial (case 3) and total (case 4) failure presented a leakage and bleeding after vascular unclamping, but without less of patency. Initially, we have attempted to obtain water-tightness again using the diode laser after unclamping. Subsequently, the anastomose was completed with supplementary stitches. These two cases occurred at the beginning of our study and can be attributed to lack of experience. Furthermore, the parameters used, particularly the power (70 mW) was probably insufficient for the thickness of the vessels being welded. For subsequent patients, we used a higher power supply. However, it is interesting to precise that further laser welding do not lead to thrombosis due to overtreatment on the vessel wall.

These clinical results confirm that the parameters, previously determined in our experimental study, are efficient for vessel welding [20]. These parameters are also agreement with those reported by Kung et al. using a 1.9 µm Nd:YAG laser [27]. Vessel welding was performed with fluence ranging from 55 J/cm² to 110 J/cm= . Considering that the thermal damage is dependent on the fluence, it is interesting to compare this value for different wavelengths. With a 805 nm diode laser, Tang et al. used 3150 J/cm= to perform carotid anastomoses [22] and Ulrich et al. used a fluence of 3980 J/cm= with a 1.32 µm Nd:YAG Laser [14].

Based on our observation, and previous reported data, the 1.9 µm seems to be a nearly ideal wavelength suitable for small vessel anastomoses. Since, the maximum acute strength is obtained when the extinction depth of a laser is equal to that of the tissue thickness, the extinction depth of the laser wavelength must be similar to the thickness of the adventitia and the media in the case of LAMA. Since for wavelengths above 1.4 µm, water is the dominant chromophore of most biological tissues, it is possible to compare the H2O extinction length of different wavelengths. In the case of the CO2 laser, the H2O extinction is 0.05 mm.. For 1.9 µm, the H2O extinction is 0.15 mm which is similar to the media thickness. In that later case, the welded thickness is comparable to the extinction length of the wavelength giving consequently a weld strength of $4x10^6$ dynes/cm= comparable to the strength of suture repairs ($5\text{-}6x10^6$ dynes/cm=) [27]. This calculation is similar to that proposed by Steward [28]. He considered that the 1.9µm absorption coefficient at 1.9µm was $100cm^{-1}$, giving a tissue penetration depth (1/e fold depth) for this wavelength of 0.1mm. At last, this observation is confirmed by the measurement of the weld strength for the CO2 laser by Nakata [29]: 1-2 x 10^6dynes/cm². This value lower than this observed for the 1.9µm wavelength confirms that the welded thickness is reduced with the CO_2 laser compared to the 1.9µm laser:

As stated by Murray et al [30], the mechanism of welding of tissues by laser may involve crosslinking of proteins. The formation of covalent crosslinks between proteins is the main mechanism of this tissue fusion. Among the different proteins, the collagen plays the major role. Histologic and electronic microscopic examinations of successful tissue fusion have demonstrated alignment and apparent bonding of collagen fibers for temperature around 75°C. The collagen bonding theory is supported by several authors, who observed a homogenizing change in periodically banded collagen with interdigitation of altered individual lasers that appeared to be the structural basis of the welding effect in microvessels [31]. However this phenomenon resulting in the formation of an “ internal glue ” displays maximal strength after a delay of at least 24 hours. Consequently, the welding remains fragile in the immediate period following its realization, specially when there is excessive tension and when the blood pressure of the artery is relatively strong. This immediate lake of resistance explains leakage after unclampling.
Since the term welding means an almost immediate mechanical resistance, the term fusion seems appropriate. We proposed the term "heliofusion" since it refers to the use of light to obtain this tissue fusion.

CONCLUSION

Laser procedure was not aimed at replacing sutures which will always be useful at least for straightening the edges. Indeed contact between the two edges is mandatory in order to obtain a welding effect of the vessel wall. Thus, with the vessel welding obtained with the diode laser, we reduce the number of stay sutures in the vessel lumen, which induces a constant foreign-body reaction.

There are numerous advantages with this technique: gain of surgical time, easier performance of vascular anastomosis with difficult access, easier learning curve, reduced parietal vascular damage confined to the adventitia and media. The hand piece is easily sterilized and the power supply box is not more cumbersome than a diathermy. Finally, it does not required specific maintenance and no associated cooling device. Furthermore, the low cost of diode laser, should lead to disposable hand pieces, thus reducing sterilization problems associated with the material.

Preliminary results of the clinical use of diode laser to perform vascular microanastomosis in human appear encouraging. Other clinical evaluation must be achieved in order to precisely evaluate the gain in surgical time, and to precisely determine the parameters setting to that of the vessel wall variable thickness and diameter. Finally, other uses seem possible, particularly concerning urethra, urethers and bilary tree which deserve to be investigated.

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