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OKADA, MASAYOSHI

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A NEW METHOD OF VASCULAR ANASTOMOSIS BY LOW ENERGY CO_2 LASER : EXPERIMENTAL AND CLINICAL STUDY

MASAYOSHI OKADA, KAZUTA SHIMIZU, HIROSHI IKUTA, HIROYUKI HORII, AND KAZUO NAKAMURA

Second Division, Department of Surgery
Kobe University School of Medicine

INDEXING WORDS

low energy CO_2 laser; vascular anastomosis; output and irradiation time; pressure tolerance test; clinical application

SYNOPSIS

Nowadays, in vascular surgery there are some problems in maintaining the long-term patency after a conventional anastomosis especially for the small caliber vessels. So low energy CO_2 laser which indicated minimized tissue reaction in preliminary experiments was employed to make vascular anastomosis with only a few stay sutures for the purpose of aortocoronary bypass. Fifty four mongrel dogs were used in this study. Side-to-side, end-to-side and end-to-end anastomoses in the femoral arteries and their veins, the carotid arteries and their veins were prudently performed by CO_2 laser. A-C bypass was also successfully done between the left internal mammary artery and the left anterior descending artery under the beating heart. Outputs of 20-40mW and irradiation times of 6-12sec/mm were optimal conditions for anastomosis of small caliber vessels. Satisfactory intensity and good healing of the anastomotic sites were recognized by pressure tolerance test or tensile strength test and pathological examinations in comparison with the conventional suture method. On the basis of the excellent results of our experiment, a low energy CO_2 laser

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Authors' names in Japanese : 岡田昌義、清水一太、生田　博
堀井弘幸、中村和夫

was utilized clinically in 4 patients with anginal attack or renal failure. All patients are doing well without any complications through the vascular anastomosis by laser. This method may be recommended in performing vascular anastomosis for small caliber vessels such as aorto-coronary bypass in the near future.

INTRODUCTION

Recently, lasers have been widely used in the field of medicine and surgery, and favorable results have been recognized.[1, 2, 3, 7, 18, 19] But, laser applications are rare in the field of cardiovascular surgery throughout the world.[8, 9, 11, 12, 13] Nowadays, it is difficult to keep long-term patency after anastomosis of the conventional fashion with suture materials especially for small caliber vessels. For 15 years, we have tried to perform aorto-coronary bypasses in treating in the patients with ischemic heart disease. There are some problems about obtaining favorable surgical results by the conventional suture method, especially in the cases with small caliber branches of the coronary arteries.[13, 15]

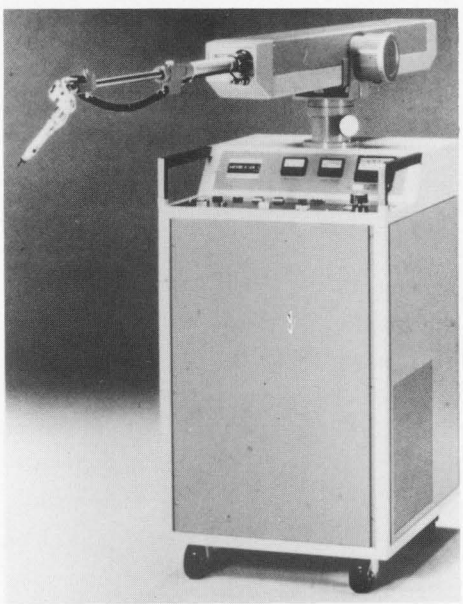


Fig. 1 CO_2 laser apparatus (Medi-laser).

From this standpoint, a low energy CO_2 laser (Fig. 1) was experimentally applied in vascular anastomosis for the purpose of making possible A-C bypasses in the near future.[14]

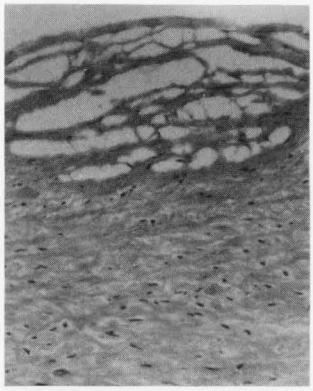
MATERIALS AND METHODS

Fifty four mongrel dogs weighing 8-15kg were used in this study. The femoral arteries and veins were gently exposed under general anesthesia. The relationship between output and irradiation time of a CO_2 laser was analyzed as well as tissue reaction to the laser in a preliminary experiment. If a laser output of 100mW was continuously irradiated on the same point more than 10sec. Swelling, disruption and vaporization of the elastic fibers of the aorta could be observed in proportion to the laser output (Fig. 2).[14]

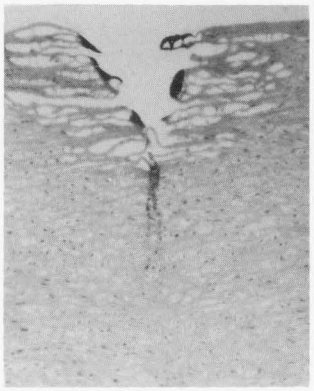
But there were no remarkable tissue reactions to a laser output of 40mW. From these preliminary experiments it could be concluded that the optimal laser output was 20-40mW and irradiation time 6-12sec/mm for vascular anastomosis of small caliber vessels in the extremities. Side-to-side, end-to-side and end-to-end anastomoses at the site of the femoral arteries and veins or the carotid arteries and veins were performed using a low energy CO_2 laser (Fig. 3, Fig. 4). Diameter of these vessels ranged from 2 to 10mm with a mean of 4mm. Stay sutures of 5-0 monofilamentous suture material were anchored at the incised ends of the vessels and were located to hold tightly the rim of the vessels. The posterior wall of the femoral artery and its vein was sutured in the usual fashion using 5-0 suture materials and the sites of anastomoses were microscopically examined as a control. The anterior wall was anastomosed by low energy CO_2 laser (20-40mW) for 60-120 sec. The focused laser beam was utilized and moved very slowly along the suture line. The distance between stay sutures was maintained at no more than 5mm (Fig. 5).

Recently, vascular anastomosis has been routinely made by CO_2 laser and just four stay sutures on the suture line (Fig. 6). After completion of anastomosis intravascular angioscopy was carefully carried out to observe the inside of the anastomotic site of the vessels.

Vascular anastomosis between the left internal mammary artery



a) Output 50mW., irradiation time 10 sec (swelling of the elastic fibers was observed).



b) Output 100mW., irradiation time 10 sec (carbonization and tissue defect could be seen).

Fig. 2 Tissue reaction to laser energy.

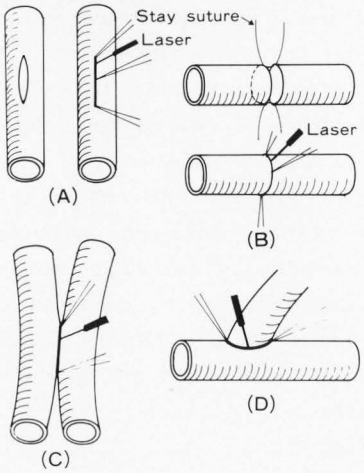


Fig. 3
Types of vascular anastomosis by CO_2 laser.

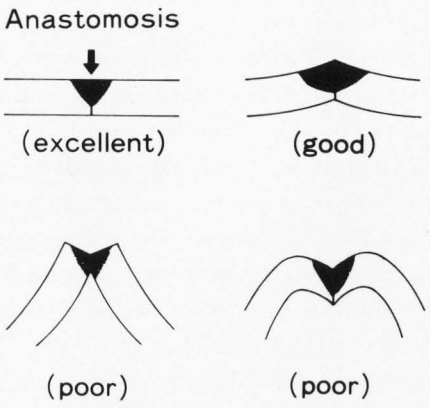
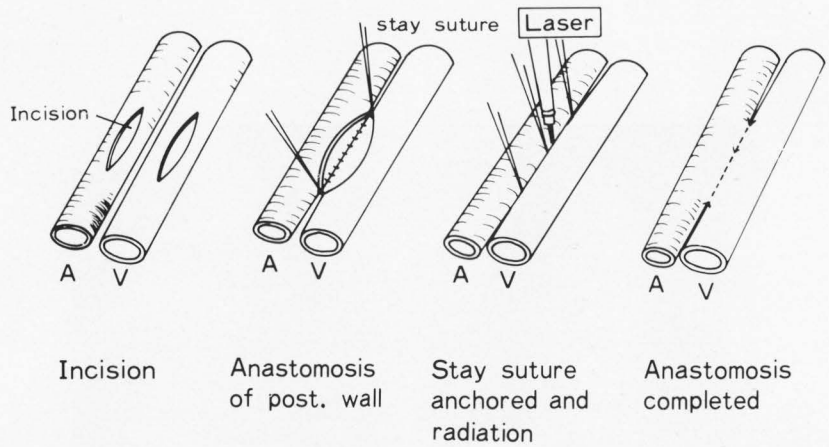
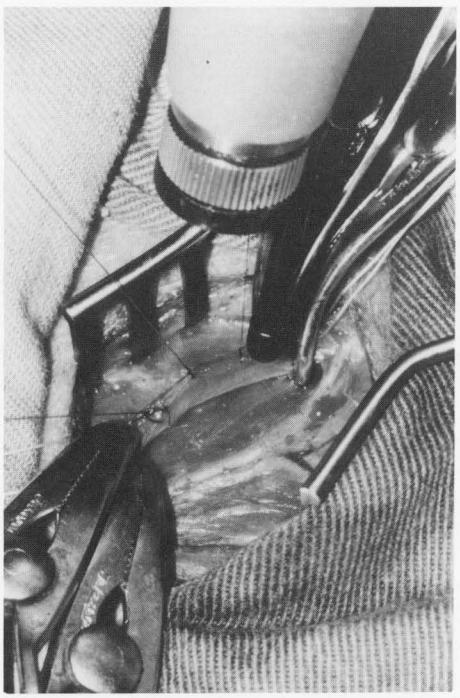


Fig. 4
Techniques for vascular anastomosis by laser.



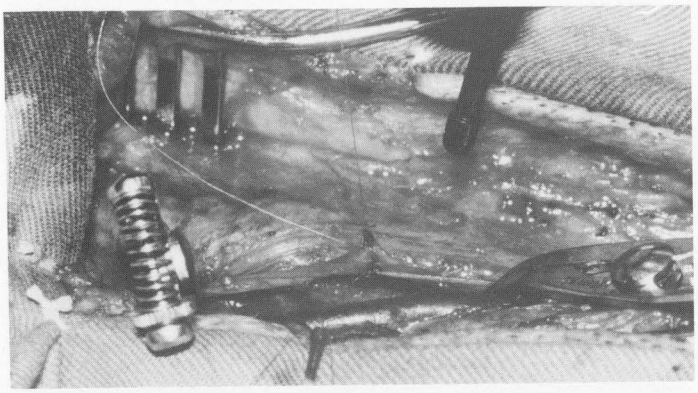
a) Side-to-side anastomosis by CO_2 laser.



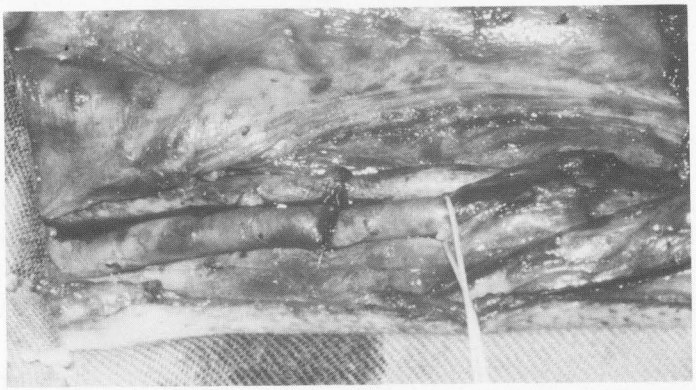
b) During laser irradiation.

c) Completion of side-to-side anastomosis between the femoral artery and its vein.

Fig. 5 Schema and practice of vascular anastomosis.



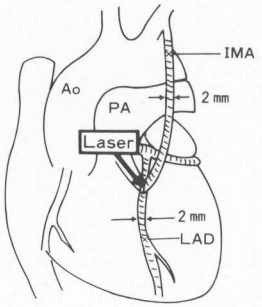
a) During laser irradiation.

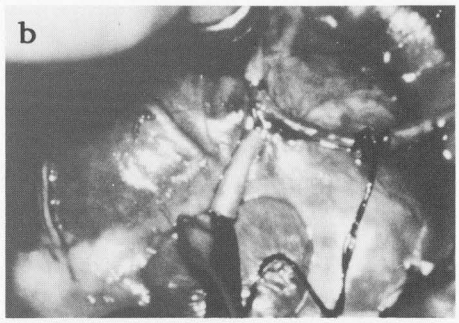


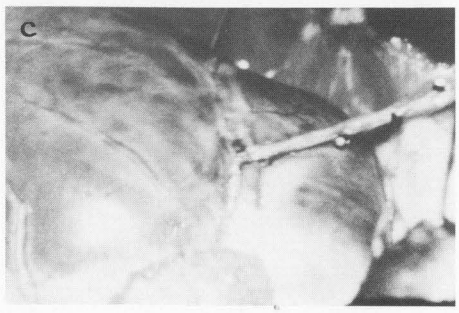
b) Completion of end-to-end anastomoses in the femoral artery and its vein.

Fig. 6 End-to-end anastomosis by laser.

and the left anterior descending coronary artery could also be carried out by laser with the heart beating (Fig. 7).[16] Pressure tolerance test and tensile strength test as well as pathological examinations were also performed to evaluate the intensity of the anastomotic sites of the vessels by laser.







a) Schema of A-C bypass (LIMA-LAD).

b) During laser irradiation.

c) Completion of A-C bypass.

Fig. 7 Coronary artery bypass surgery by CO_2 laser.

RESULTS

The number of vascular anastomoses (end-to-end, end-to-side, side-to-side anastomosis) is shown in Table 1.[17] Bleeding from the anastomotic sites was found at only 3 points among 71 anastomoses. But it stopped on light compression by gauze on the suture line. Observation periods ranged from 6 hr to 2.5 months (average 2 weeks after laser surgery). During this period five of the initial 18 dogs died of respiratory failure, or body weakness. However, there were no deaths caused by bleeding from vascular anastomosis and operative procedure. The remaining 36 dogs were sacrificed soon after surgery and at 1 week intervals, and anastomotic sites were picked out for microscopic examinations which were patent macroscopically at the time of exstirpation. Patency was also confirmed by angiogram (Fig. 8) and then a pressure tolerance test or tensile strength test as well as histological

examinations at the anastomosis site were prudently performed after surgery in each animal.

Table 1 Number of Vascular Anastomosis

A) Experimental studies

Anastomosis	Number
1) End-to-end anastomosis	38
(artery 14 / vein 24)	
2) Side-to-side anastomosis (arterio-venous)	23
3) End-to-side anastomosis	6
Total	67

B) Clinical cases

Anastomosis	Number
1) End-to-side anastomosis (veno-arterial)	2
2) End-to-end anastomosis (artery-artery)	2
Total	4
Grand total	71

Pressure tolerance test

Noradrenaline was given intravenously to maintain high pressure after completing vascular anastomosis by laser. However, there were no hemorrhages from the site of anastomosis even with a pressure of 300mmHg (Fig. 9). From this excellent finding, it could be recognized that vascular anastomosis by laser was effective enough for the site to tolerate high pressures without bleeding.

Tensile strength test

Intensity of the site of laser or suture vascular anastomosis was examined by weighing. Consequently, the anastomotic sites by laser with only four stay sutures were separated in weights from 950 to 1100g. On the other hand, the sites of anastomoses sutured by 5-0 suture materials were also separated in to weights from

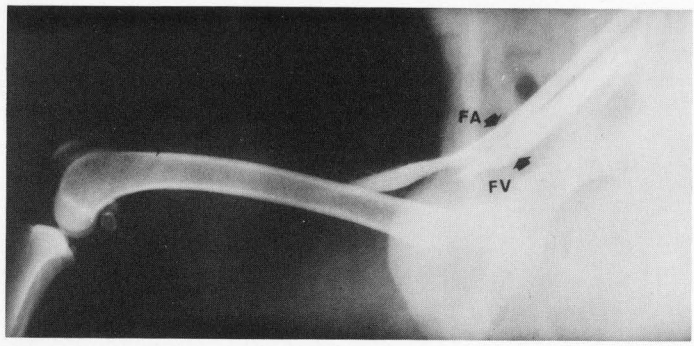


Fig. 8 Postoperative angiogram (side-to-side anastomosis).

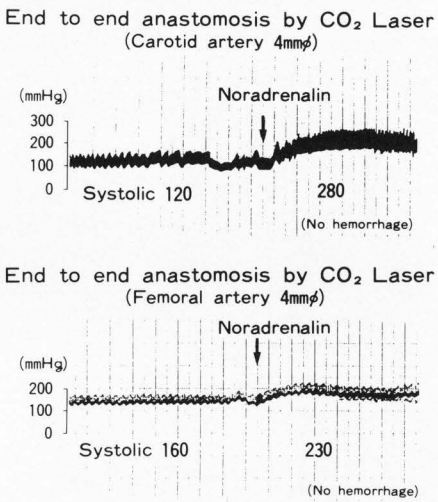


Fig. 9 Pressure tolerance test.

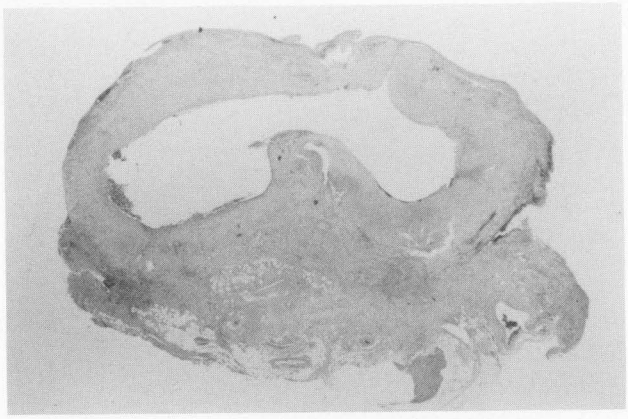
1100 to 1300g. Thus, there were no significant differences in the intensity of the site of vascular anastomosis in either group.

Pathological findings

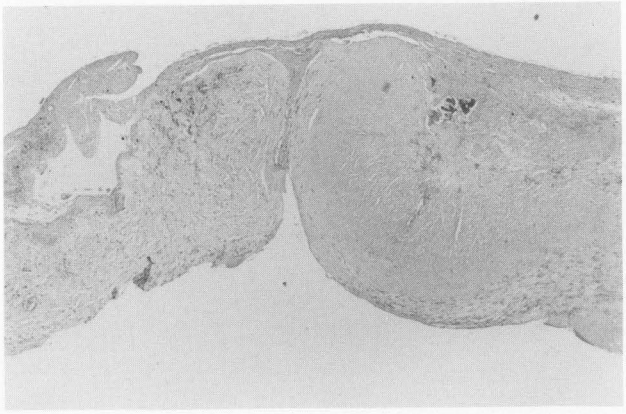
The sites of vascular anastomoses were microscopically investigated after several time intervals. A thinned fibrous membrane was observed microscopically on the adventitia of the vesseles already 6 hr after laser surgery. However, thickened fibrous

membrane and marked proliferation of the fibroblasts were recognized at the adventitia and the media of the vessels except for the intimal layer, 1 week after laser anastomosis (Fig. 10). Furthermore, all layers of the artery and its vein were sufficiently connected by a lot of collagen fibers 2.5 months after laser anastomosis (Fig. 11). Thus, good healing of the site of laser anastomosis was clearly recognized histologically.[14]

On the other hand, the suture anastomotic sites were also examined microscopically in detail. Subsequently, many giant cells as well as the infiltration of several types of cells in their early stages and remarkable granulations in the chronic stage were clearly observed around the suture materials.



a) Anastomotic sites 1 week after laser surgery (upper) and suture surgery (lower).



b) Anastomotic portion by laser (magnified figure).

Fig. 10 Pathological findings.

The technique of vascular anastomosis by laser was very easy and good results could be obtained in hemodynamic and histological findings in comparison with conventional anastomosis using suture materials.

From these favorable findings it was considered that vascular anastomosis by low energy CO_2 laser might be applicated in clinical case.[16, 17]

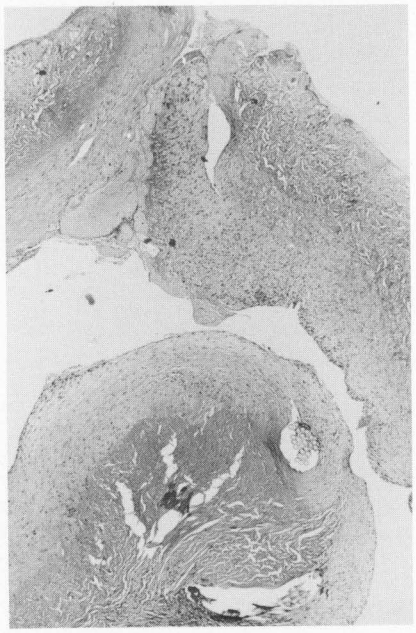


Fig. 11 Pathological findings (2.5 months later, upper: Laser, lower: suture surgery).

Clinical applications

On the basis of these excellent experimental results vascular anastomosis was employed in four patients with anginal attack or chronic renal failure (Table 2).[17]

Case 1 : A 44 year-old female patient was admitted because of hypertension and uremia following renal failure (BUN 76mg/dl, Creatinine 10mg/dl, K6.8mEq/L). A veno-arterial anastomosis at the site of the radial artery was successfully performed using a CO_2 laser for hemodialysis on February 21, 1985. The length of anastomosis was 15mm, and laser output was 30mW and irradiation time was 120 sec (Fig. 12). This is a first successful case of

vascular anastomosis by CO_2 laser in the world. She is now doing well without any complications.

Clinical cases of vascular anastomosis by CO_2 Laser

Table 2

Case		Age	Sex	OP. method	Length of Anastomosis (mm)	CO_2 Laser		Remarks
						Output (mW)	Irradiation time (sec)	
1	K.F.	44	F	End-to side (ceph.v.-RA)	15	30	120	excellent
2	S.Y.	51	F	End-to end (I-FA)	10	40	60	excellent
3	M.F.	32	F	End-to side (ceph.v.-RA)	8	40	100	good
4	H.K.	53	M	End-to end (I-FA)	11	40	50	excellent

I-FA : left femoral artery, Ceph.V. : cephalic vein, RA : radial artery

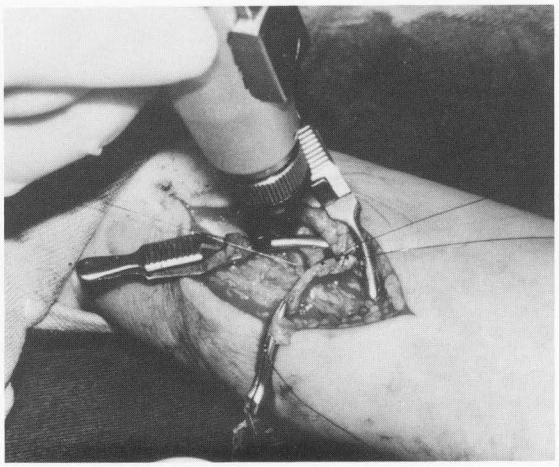
Case 2 : A 51 year-old female patient was admitted to our clinic because of severe anginal pain caused by double vessel disease. So, double A-C bypass to the circumflex artery and the right coronary artery was smoothly performed in the usual fashion. At the time of operation incision site (10mm in diameter) of the femoral artery used for cardiopulmonary bypass was successfully anastomosed by CO_2 laser (output 40mW) for 60 sec on April 9, 1985 (Fig. 13). The postoperative course was uneventful without any complications.

Case 3 : A 32 year-old female patient was admitted because of severe renal insufficiency (BUN 72mg/dl, Creatinine 13mg/dl, K5.4mEq/L). A veno-arterial anastomosis 8mm in length was made by laser without any difficulties on April 25 this year (Fig. 14). She is doing well after hemodialysis.

Case 4 : A 53 year-old male patient was admitted to our clinic because of angina pectoris due to double vessel disease. The incision site (11mm) of the femoral artery used for cardio-pulmonary bypass was satisfactorily anastomosed by CO_2 laser for less than 50 sec on June 18 this year (Fig. 15). He is also doing well without any complications.

From these clinical experiences, vascular anastomosis by low

energy CO_2 laser may be safely recommended for small caliber vessels such as in A-C bypasses in the near future.



a) During veno-arterial, end-to-side anastomosis by laser.

b) Completion of vascular anastomosis between the cephalic vein and the radial artery.

Fig. 12 Clinical case of vascular anastomosis by CO_2 laser (case 1, 44Y.F.).

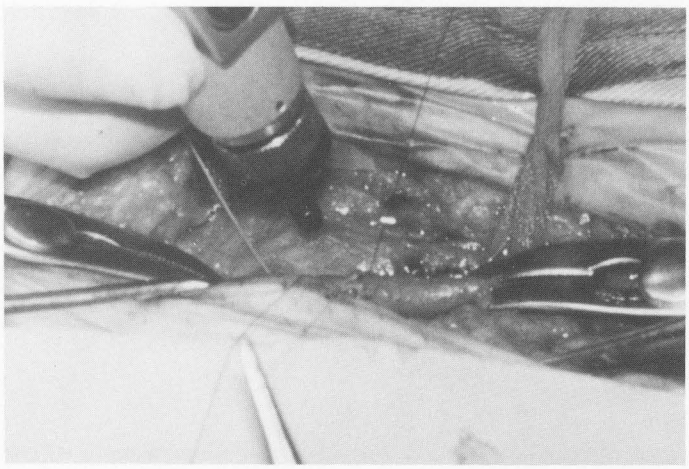


Fig. 13 End-to-end anastomosis of the femoral artery by laser (case 2, 51Y.F.).

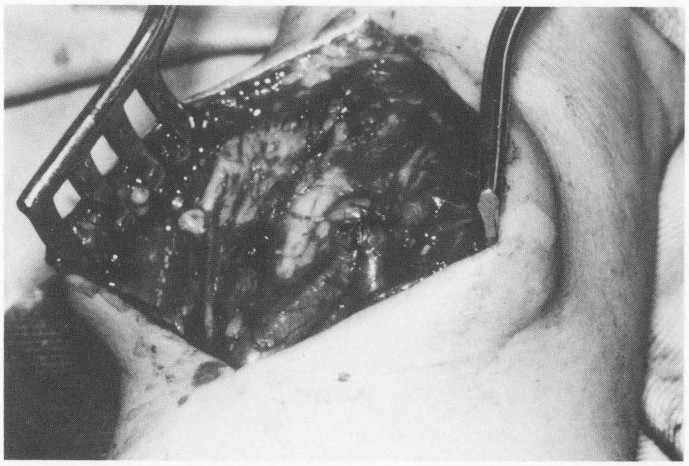


Fig. 14 Veno-arterial anastomosis by laser (case 3, 32Y.F.).

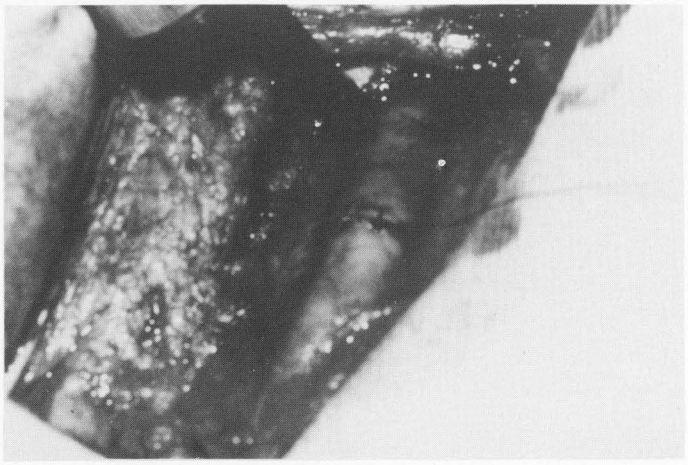


Fig. 15 End-to-end anastomosis of the femoral artery by laser (case 4, 53Y.M.).

DISCUSSION

Tissue reaction of low energy CO_2 laser

The diameters of arteries and veins in the extremities were no more than 10mm and the wall thickness was very thin less than 1mm. In vascular anastomosis of these vessels optimal laser output was 20-40mW and irradiation time was 60-120 sec. Laser beams did not reach the intimal layer in these conditions. If the output was over 50mW, a marked tissue reaction could be seen such as swelling, carbonization and vaporization proportional to the irradiation time. Focused beam was convenient for making fine anastomosis on small caliber vessels.[4, 5, 6, 10]

Important factors in vascular anastomosis by laser

There were two important points in carrying out vascular anastomosis. One of them was to close the rim of the vessels tightly with some fine stay sutures. The distance between stay sutures must be less than 5mm. Another one was to focus the beam on the suture line.[5] At this time the beam should be moved very slowly and repeated. Irradiation should be continued until the color along the suture line changes to dark gray or dark brown.

Intensity of the site of anastomosis

There is a long-term history of safety in performing vascular anastomosis with sutures. To anastomosis using many suture materials, especially for small caliber vessels, there are some problems in their patency over the long term. From this standpoint a low energy CO_2 laser was utilized for vascular anastomosis. Pressure tolerance was carefully tested to evaluate intensity at the site of laser anastomosis. However, no hemorrhage was observed even at the high pressure of 300mmHg. On the other hand, laser anastomotic sites were also tested for tensile strength test. But, there were no significant differences between conventional suture method and laser anastomosis. Thus, no intensity problems could be seen with laser anastomosis.

Mechanism of vascular anastomosis by laser

On the basis of pathological examinations, fibrous membrane, proliferation of fibroblasts and collagen fibers on the suture line were observed by laser, as the time went on. Good healing was clearly recognized microscopically.[5, 6, 14] The reason for the healing of the anastomotic site is not now clearly known. But it is supposed that collagen fibers as well as protein components of the tissues may be changed from a gel to a sol like a paste by laser heating.

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