Background: Recently, several kinds of lasers have been widely employed in the field of medicine and surgery. However, laser applications are very rare in the field of cardiovascular surgery throughout the world. So, we have experimentally tried to use lasers in the field of cardiovascular surgery. There were three categories: 1) Transmyocardial laser revascularization (TMLR), 2) Laser vascular anastomosis, and 3) Laser angioplasty in the peripheral arterial diseases.

By the way, surgery for ischemic heart disease has been widely performed in Japan. Especially coronary artery bypass grafting (CABG) for these patients has been done as a popular surgical method. Among these patients there are a few cases for whom CABG and percutaneous coronary intervention (PCI) could not be carried out, because of diffuse stenosis and small caliber of coronary arteries.

Materials and methods of TMLR: A new method of transmyocardial revascularization by CO2 laser (output 100 W, irradiation time 0.2 sec) was experimentally performed to save severely ill patients. In this study, a feasibility of transmyocardial laser revascularization from left ventricular cavity through artificially created channels by laser was precisely evaluated. Results: In trials on dogs laser holes 0.2mm in diameter have been shown microscopically to be patent even 3 years after their creation, thus this procedure could be used as a new method of transmyocardial laser revascularization.

Clinical application of TMLR: Subsequently, transmyocardial laser revascularization was employed in a 55-year-old male patient with severe angina pectoris who had undergone pericardectomy 7 years before. He was completely recovered from severe chest pain.

Conclusions of TMLR: This patient was the first successful case in the world with TMLR alone. This method might be done for the patients who percutaneous coronary intervention and coronary artery bypass grafting could be carried out.

Laser vascular anastomosis: At present time, in vascular surgery there are some problems to keep long-term patency after anastomosis of the conventional suture method, especially for small-caliber vessels.

Materials and methods of Laser vascular anastomosis: From these standpoints, a low energy CO2 laser was employed experimentally in vascular anastomosis for small-caliber vessels.

Results of Laser vascular anastomosis: From preliminary experiments it could be concluded that the optimal laser output was 20-40 mW and irradiation time was 6-12 sec/mm for vascular anastomosis of small-caliber vessels in the extremities. And then, histologic findings and intensity of the laser anastomotic sites were investigated thereafter. Subsequently, good enough intensity and good healing of laser anastomotic sites as well as the conventional suture method could be observed. There were no statistic differences between laser and suture methods. A feasibility of laser anastomosis could be considered and clinical application could be recognized.

Clinical applications of Laser vascular anastomosis: On February 21, 1985, arterio-venous laser anastomosis for the patient with renal failure was smoothly done and she could accept...
Introduction:

Much attention has been paid to use lasers in the field of cardiovascular surgery. However, there were no adequate knowledges and its techniques especially in the field of cardiovascular diseases. But, we have tried to apply lasers in the following three main subjects. That is, 1) Transmyocardial laser revascularization for end-stage of ischemic cardiac disease, 2) Laser vascular anastomosis, and 3) Laser endovascular angioplasty.

We have tried to use lasers for experimental and clinical studies. These results are clarified as follows.

1. Transmyocardial laser revascularization for end-stage ischemic heart disease

1) Materials and methods

Adult mongrel dogs were applied in this study. Their chests were opened through the left fifth intercostal space under general anesthesia. Acute myocardial infarction was produced by multiple ligations of the coronary arteries. At the same time, transmyocardial channels were newly created by high energy CO2 laser in the area of the infarcted myocardium with the heart beating, or in temporary ventricular fibrillation. Subsequently, bleeding from the left ventricular cavity was stopped by compression with gauze for about 10 minutes after which further channels could be carried out.

Optimal condition was 60-100 W in output, and irradiation time 0.12-0.25 sec to make transmyocardial laser channels. Thereafter, transmyocardial channels of 0.2 mm in diameter and 10 mm in depth could be safely created by high energy CO2 laser, provided care was taken to keep to the area being lasered, since the CO2 laser emission was obviously absorbed by water and blood. Animal care was in compliance with the “Principle of Laboratory Animal Care” and the “Guide for Care and Use of Laboratory Animals” (NIH Publication NO.80-23, revised 1985).

2) Hemodynamic investigation

Pressure in the septal perforating artery as representative of the intramyocardial pressure and the left ventricular pressure were simultaneously measured. Subsequently, mean value of intramyocardial pressure was 40/30 mmHg and of the left ventricular cavity 95/0 mmHg. The mean pressure gradient between intramyocardial pressure and the left ventricular pressure was 55 mmHg. Therefore, blood flowed from the left ventricular cavity into the ischemic myocardium during systole. On the other hand, blood flowed from the myocardium into the left ventricular cavity as result of 30 mmHg pressure gradient during diastole (Fig. 1).

3) Macroscopic observation

Hemodynamic and ventricular studies were carried out after completion of transmyocardial laser revascularization. Subsequently, newly created laser channels were obviously confirmed on ventriculogram (Fig. 2).
On the other hand, macroscopic findings with or without transmyocardial laser revascularization (TMLR) in the chronic stage after acute myocardial infarction were compared to each other. Subsequently, the left ventricular wall showed almost normal findings in the case with TMLR. On the contrary, a thin and infarcted area in the left ventricular wall was observed in the case without TMLR (Fig. 3). Thus, TMLR revealed excellent microcirculation in the ischemic myocardium.\(^3\)

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**Fig. 1:** Mechanism of transmyocardial laser revascularization (TMLR)
- a) Microcirculation in the myocardium
- b) Hemodynamic study of left ventricular pressure and intramyocardial pressure

**Fig. 2:** Left ventriculogram after TMLR

**Fig. 3:** Macroscopic findings of the left ventricular wall
- a) Acute myocardial infarction group
- b) TMLR group
4) **Histological examination**

Histological findings of newly created transmyocardial channels were as follows. Carbonization of the myocardium was observed in the first layer and coagulation necrosis was also recognized in the second layer of the created laser channels. Histologic findings soon after creation of the myocardial channels are shown in Fig. 4. In histological findings 1 week after TMLR, tissue reaction to laser had disappeared. Patency of the transmyocardial laser channels 3 year after TMLR could be clearly confirmed microscopically (Fig. 5). These findings disclosed the feasibility of the long-term patency of the newly created channels and of clinical application.4-5)

5) **Clinical experience**

On the basis of the satisfactory experimental results the alternative laser method was utilized for a 55 year-old male patient with severe angina attack who had undergone pericardiectomy 7 years ago. The patient was admitted to our Kobe University Hospital because of severe angina pectoris. Marked stenosis (90%) of the left anterior descending artery (LAD) was recognized on the coronary angiogram. An operation was planned to perform coronary artery bypass grafting to the LAD on November 12, 1985. However, the LAD could hardly be exposed, because of severe adhesion of the epicardium due to pericardiectomy. Therefore, six transmyocardial channels were created by laser (85 W, 0.2 sec) in the anterior wall of the left ventricle of the beating heart (Fig. 6). This case was the first successful clinical case by treated TMLR alone in the world.6)

6) **Discussion**

A new method of transmyocardial laser revascularization was carried out by CO2 laser experimentally and clinically. The principle of this procedure is to supply additional arterial blood from the left ventricular cavity into the ischemic area of the myocardium. A minimal tissue reaction was microscopically recognized in the newly created laser channels. In the experimental study, it could be apparently confirmed that laser channels in the myocardium were patent even 3 years after TMLR. Besides, endothelial cells surrounding insides of the laser channels were clearly recognized histologically. It was considered that tissue defects of fine transmyocardial channels in 0.2 mm in diameter were recognized. From these findings the feasibility of long-term patency of laser channels and clinical application was clearly revealed.

Until now, experimental procedure that supply arterial blood from the left ventricular cavity into the ischemic myocardium have been reported.
since 1965. However there were no successful results in this fields.

Mirhoseini created laser channels by CO2 in the akinetic and dyskinetic area of the left ventricle and simultaneously performed CABG in all clinical cases.7) Thus, myocardial revascularization by laser seems to be recommended for the patients for whom CABG alone is inadequate, and also where it could not be carried out at all. Our long-term experimental results and our first one patient treated so far support this statement.

In the 1990’s, clinical TMLR operations have been performed in the United States as well as European countries.7-22) Good results have been reported. These data also have been reported in some scientific papers.

Thereafter, much attention has been paid to TMLR for severely ill patients with ischemic heart disease in Japan. In 1994, Cooley has reported post-operative results of 21 cases treated by TMLR. By Canadian classification, angina attack was decreased from 37±0.4 preoperatively, 1.8±0.6 post-operatively and the blood flow ratio between the endocardium and the epicardium increased from 0.96±0.07 before to 1.10±0.04 after. From these clinical data the availability of TMLR was insisted.8)

There are some excellent advantages in TMLR: a) No requirement of extracorporeal circulation, b) Easy to operate on and short operating time, c) Shorter admission more than CABG, d) Rapid body restoration, and e) Effectively low cost.

At end of March in 2004 over 5100 patients have been treated by TMLR alone or TMLR combined CABG in the world.

It is very important to select the patients with end-stage coronary artery disease, for whom percutaneous coronary intervention (PCI) and CABG can not be carried out, because of diffuse stenosis and small-caliber of the coronary arteries.6)

2. Laser vascular anastomosis

Introduction
Lasers have been widely applied in the field of medicine and surgery, and satisfactory results have been obtained in the several medical fields. However, laser applications are very rare in the field of cardiovascular surgery throughout the world. It has been reported for a long period that it is difficult to keep long-term patency after anastomosis of the conventional fashion with suture materials especially for small-caliber vessels. For 25 years, we have tried to perform CABG in treating patients with ischemic heart disease. There are some problems about obtaining favorable surgical results by the conventional suture method, especially in the case with small-caliber branches of the coronary arteries. From this standpoint, a low energy CO2 laser was applied to perform coronary bypass grafting.23-25)

1) Materials and methods
Adult mongrel dogs were used in this study. The femoral arteries and their veins were gently exposed under general anesthesia. The relationship between output and irradiation time of a CO2 laser was analyzed as well as tissue reaction to the laser in a preliminary experiment. If a laser output of 100 mW was continuously irradiated on the same point more than 10 seconds, swelling, disruption and vaporization of the elastic fibers of the aorta could
be found in proportion to the laser output (Fig. 7).

However, there were no remarkable tissue reactions to a laser output of 40 mW. From these preliminary experiments it could be concluded that the optimal laser output was 20-40 mW and 6-12 sec/mm for vascular anastomosis of small-caliber vessels in the extremities. Side-to-side, end-to-side, and end-to-end anastomosis at the site of the femoral arteries and veins or the carotid arteries and veins were carried out using a low energy CO2 laser (Fig. 8). Diameter of these vessels ranged from 2 to 10 mm with mean of 4 mm. 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 conventional fashion using 5-0 suture materials and sites of anastomosed by laser were microscopically examined as a control. The anterior wall was anastomosis by low energy CO2 (20-40 mW) for 6-12 sec/mm. The focused laser beam was used and moved very slowly along the anastomotic line. The distance between stay sutures was maintained at no more than 5 mm.

Vascular anastomosis has been routinely made by CO2 laser and just four stay stitches on the anas-
tomotic line. After completion of anastomosis intravascular angioscopy was carefully carried out to observe the inside of the anastomotic portion of the vessels of which anastomotic site by laser is wide-open. Vascular anastomosis between the left internal mammary artery and the left anterior descending artery could also be performed by laser under the heart beating. Pressure tolerance test and tensile strength test as well as histological examinations were also studied to evaluate the intensity of the laser anastomotic site of the vessels.

The number of vascular anastomosis (end-to-end, end-to-side, side-to-side anastomosis) reached 75 anastomoses. Bleeding from the anastomotic sites was observed at only 3 points among 75 anastomotic sites. However, it stopped on light compression by gauze on the anastomotic line. Observation periods ranged from 6 hours to 2.5 months. There were no deaths caused by bleeding from vascular anastomosis and operative procedure. Anastomotic sites were picked out for histological examinations which were patent macroscopically at the time of extirpation. Patency was also confirmed by angiogram and pressure tolerance test, or tensile strength test at the anastomotic sites were prudently performed after surgery.  

2) Intensity of the anastomotic sites

a) Pressure tolerance test
Noradrenalin was given intravenously to maintain high pressure after completion of vascular laser anastomosis. However, there were no hemorrhages from the sites of anastomoses were effective enough for the sites to tolerate high pressures without bleeding (Fig. 9).

b) Tensile strength test
Intensity of the vascular anastomosis was examined by weighing. Subsequently, the laser anastomotic sites with only four stay sutures were separated in weights 1,034.2±103.9 g. On the other hand, the sites of anastomoses sutured by 5-0 suture material were also separated into weight 1,103±144.8 g. Thus, there were no significant differences in the intensity of the site of vascular anastomosis in each group (Fig. 10).

3) Histologic findings of anastomotic sites
The sites of vascular anastomosis were microscopi-
cally studied after several times of intervals. A thinned fibrous membrane was found microscopically on the adventitia of the vessels already 6 hours after laser surgery. However, thickened fibrous membrane and marked proliferation of fibroblasts were recognized at the adventitia and the media of the vessels except for the intimal layer, 1 week after laser anastomosis (Fig. 11).

Furthermore, all layers of the artery and its vein were adequately connected by a lot of collagen fibers 2.5 months after laser anastomosis (Fig. 12). Thus, good healings of sites of laser anastomoses were clearly observed histologically. On the contrary, 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 stage and marked granulations in the chronic stage were clearly observed around the suture materials. The technique of laser vascular anastomosis 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 CO2 laser might be recommended in clinical application. 24)

4) Clinical application of the vascular anastomosis

On the basis of excellent experiment results laser vascular anastomosis was employed in 111 patients with angina pectoris, or chronic renal failure and peripheral vascular disorders (Table 1). 24)

![Table 1: Clinical experience of laser vascular anastomosis](https://www.jstage.jst.go.jp/browse/islsm)

<table>
<thead>
<tr>
<th>Site of Anastomosis</th>
<th>No. of Anastomosis</th>
</tr>
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<tbody>
<tr>
<td>Femoral artery (EE)</td>
<td>69</td>
</tr>
<tr>
<td>Femoropopliteal bypass</td>
<td>39</td>
</tr>
<tr>
<td>(E-E Anasto. By SVG)</td>
<td></td>
</tr>
<tr>
<td>Radial artery-ceph. V. (E-S)</td>
<td>4</td>
</tr>
<tr>
<td>Femoral vein (E-E)</td>
<td>3</td>
</tr>
<tr>
<td>Pop.-politeal bypass</td>
<td>3</td>
</tr>
<tr>
<td>(E-E anasto. By SVG)</td>
<td></td>
</tr>
<tr>
<td>Brachial artery (E-E)</td>
<td>1</td>
</tr>
<tr>
<td>r-Renal artery-Ao. Bypass</td>
<td>1</td>
</tr>
<tr>
<td>Tibial artery (S-S, E-S)</td>
<td>3</td>
</tr>
<tr>
<td>SVG-LAD (E-S)</td>
<td>10</td>
</tr>
<tr>
<td>LIMA-LAD (E-S)</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>136</td>
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<thead>
<tr>
<th></th>
<th></th>
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<tbody>
<tr>
<td>E-E</td>
<td>End-to-end anastomosis</td>
</tr>
<tr>
<td>E-S</td>
<td>End-to-side  S-S: Side-to-side</td>
</tr>
</tbody>
</table>
A 44 year-old female patient was admitted to our hospital, because of hypertension and uremia following renal failure (BUN 76 mg/dl, Creatinine 10 mh/dl, K 6.8 mEq/L). A veno-arterial anastomosis at the site of the radial artery was successful carried out using a CO₂ laser hemodialysis on February 21, 1985. The length of anastomosis was 15 mm, and laser output was 30 mW and irradiation time was 120 sec (Fig. 13).

This was the first clinical successful case of vascular anastomosis by CO₂ laser (Okada’s method) in the world.

From these clinical experiences with peripheral vessels, vascular anastomosis by low energy CO₂ laser was employed in CABG for 13 patients with ischemic heart disease (Fig. 14, Fig. 15).

5) Discussion

The diameter of arteries and veins in the extremities were no more than 10 mm and the wall thickness was very thin less than 1 mm. In vascular anastomosis of these vessels optimal laser output was 20-40 mW and irradiation time was 6-12 sec/mm. Laser beams did not reach the intimal layer in these conditions. If the output was over 50 mW, a marked tissue reaction could be observed such as swelling, carbonization and vaporization proportional to the irradiation time. Focused beam was convenient for making fine anastomosis on small-caliber vessels.

There were two important points in carrying out vascular anastomosis. One of them was to close the rim of the vessels tight with some fine stay sutures. The distance between stay stitches must be less than 5 mm. Another one was to focus the beam on the anastomotic line. At this time the beam should be moved very slowly and repeated. Irradiation should be continued until the color along the anastomotic line changes to dark gray, or dark brown. And another laser techniques are also tried to make vascular anastomosis and their favorite conditions are obtained. 26-30)

There is a long-term history of safety in performing vascular anastomosis with sutures. For anastomosis using many suture materials, especially for small-caliber vessels, there are some problems in their patency over the long-term period. From these standpoints a low energy CO₂ laser was employed 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 300 mmHg. On the contrary, laser anastomotic sites were also tested for tensile strength test. However, there were no significant differences between conventional suture method and laser anastomosis. Thus, no intensity problems could be recognized with laser anastomosis.

Based on histological examinations, fibrous membrane, proliferation of fibroblasts and collagen fibers on the anastomotic line were observed by laser, as the time went on. Good healings were obviously confirmed microscopically. The reason for the healing of the anastomotic site is not now clearly recognized. It is supposed that collagen fiber as well as protein components of the tissue may be changed a gel to a sol like a paste by laser thermal energy.

2. Laser angioplasty for cardiovascular disease

Introduction
In recent years, endovascular intervention such as balloon angioplasty, laser angioplasty, atherectomy and the stenting method have been clinically applied for patients with atheromatous plaques of the peripheral arteries. Among them, restenosis after endovascular intervention has been obviously confirmed in 30-40% of the patients who underwent percutaneous coronary intervention (PCI). However, there are some problems in maintaining long-term patency by means of endovascular techniques such as balloon techniques, laser, atherectomy. For these problems, the effects of an Argon laser on vaporization of the atheromatous plaques were experimentally investigated. On the basis of our excellent experimental studies, a laser was utilized for patients with intermittent claudication, angina pectoris, and ischemic ulcer of the lower extremity. Subsequently, the feasibility of laser angioplasty could be confirmed in the field of cardiovascular surgery.

In cardiovascular surgery, Argon, Nd-YAG, Ho-YAG, and Excimer lasers have been widely employed all over the world. An Argon laser (Trimedyne/Laser Ionics, Model 5567, and HGM, Endocoagulator Model 208, USA) was utilized for the vaporizing of atherosclerotic plaques in this study.

1) Materials and methods
First of all, relationship between laser energy and reaction of the aortic walls to the laser was experimentally evaluated using adults mongrel dogs. A metal tip probe (Laser probe PLR-Flex, or Laser probe PLR-Plus, Trime dyne Inc., CA, USA) was mainly used. Subsequently, it could be confirmed

![Fig. 15: Laser anastomosis in the coronary artery bypass grafting](image)

a) Saphenous vein → Left anterior descending artery (LAD)

b) Internal thoracic artery → LAD
that optimal conditions for laser angioplasty were 6 W in output and 3 sec in irradiation time for each shot. On the other hand, a metal tip probe with thermal feedback control system (HGM, Endocoagulator, Model 20S, Laser probe, Salt Lake City, USA) was used, for which the adequate tip temperature for vaporizing the atheromatous plaques was 200°C and the irradiation time was 5 sec for each shot. These conditions were almost the same laser energy for adequacy, that is, in the case with 6 W and 3 sec using the metal tip probe, the intimal layer was vaporized and 8 W and 3 sec the crater reached the media. Then, with 8 W and 3 sec using the bare-ended probe, arterial perforation occurred immediately. On the other hand, in the case with thermal feedback control system the arterial deepened by an increase in the temperature of the metal tip probe. In the case with 100-150°C in the temperature of the metal tip probe, the intima surface was slightly vaporized, with 200-300°C the crater reached deeper intimal layer. In the case with more than 300°C, the media was also vaporized (Fig. 16). Subsequently, it was considered that suitable temperature of the metal tip probe was 200°C.

At the time of laser angioplasty, the use of an angioscope was inevitable for observing the inside of the arteries before and after laser irradiation. At present, laser angioplasty has been performed for 115 patients with atherosclerotic changes of the peripheral arterial diseases. This includes 98 men and 17 women, ranging in age from 43 to 88 year-old with an average of 67. These patients consisted of 109 cases with intermittent claudication, 4 cases with rest pain and 2 cases with a refractory ulcer in the leg.

Laser angioplasty for the patients with peripheral arterial diseases was undertaken in all patients and their operative indications were obviously decided by clinical symptoms and angiographic findings with severe stenosis of more than 75% of the internal diameter and total occlusion of the arteries. The length of occlusive and stenotic lesions in the peripheral arteries ranged from 0.5 cm to 45 cm with a mean of 3.2±5.0 cm in stenotic lesions and 9.8±8.8 cm in the occlusive lesions.38-41)

As a method of laser angioplasty, a sheath catheter was percutaneously inserted proximally for the iliac lesions and distally for the femoral and popliteal lesions under local anesthesia in the inguinal region. After this procedure, an angioscope (0.75 mm, in diameter) was inserted through the sheath catheter and the surface of the atherosclerotic plaques in the artery was observed. At this time, it is very important to wash out the blood with saline for clean observation. Through this procedure, the inside of the artery could be precisely observed. There are several sizes of angioscope, such as 0.75 mm, or 0.45 mm in diameter. From the standpoint of image clarification, an angioscope of 0.75 mm in diameter was the most useful instrument. Thereafter, laser irradiation was carefully initiated to make a laser hole for the occlusive lesion under angioscopic guidance using a bare-ended laser fiber and metal tip probe. In the case with a calcified occlusion at the site of the femoral artery, this artery first exposed and a sheath catheter was directly inserted to the atheromatous plaques under

Fig. 16: Laser energy and its reaction of the aorta
direct vision (Fig. 17).

A guide-wire was then passed through a laser hole which was previously reached using a metal tip probe (2.0-2.5 mm in diameter) inserted over the guide-wire. In this study, 6 W in output and 3 sec in irradiation time, or 200°C and 5 sec using a metal tip probe with thermal feedback control system were utilized as optimal conditions for each laser ablation. Laser ablations were continued to eliminate atherosclerotic plaques under angioscopic and fluoroscopic guidances, until recanalization and a wide opening of the vessel lumen could be observed. Moving the metal tip probe slowly in the artery, it is very important to prevent vasoconstriction and fragmentation of the atherosclerotic plaques during laser ablation. Then, in case where dilatation was inadequate by lasing, percutaneous transluminal angioplasty was additionally undertaken.

All clinical results were expressed as the mean standard deviation. The improved t-test was used to test for differences in variables between the two measurements and a P-value less than 0.05 was accepted as statistically significant.

2) Clinical results of laser angioplasty

At present, 115 patients (141 lesions) have been treated by laser angioplasty. This includes 98 men and 17 women who had intermittent claudication, rest pain and refractory limb ulcers. They consisted of 114 patients with arteriosclerosis obliterans and only one thromboangitis obliterans. 38,41)

Seventy-one among 141 lesions were in the iliac region and 66 lesions existed in the femoropopliteal region. The remaining 4 lesions were thrombogenic stenoses of implanted vascular grafts and the anastomotic site of the saphenous vein

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Table 2: Patients characteristics of laser angioplasty

<table>
<thead>
<tr>
<th>Case</th>
<th>115 (131 legs, 141 lesions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male 98, Female 17</td>
</tr>
<tr>
<td>Age</td>
<td>43 ~ 88 (67.2±9.5)</td>
</tr>
<tr>
<td>Disease</td>
<td>ASO 114, TAO 1</td>
</tr>
<tr>
<td>Symptom</td>
<td>Claudication 109, Rest pain 4, Ischemic ulcer 2</td>
</tr>
<tr>
<td>Site of lesion</td>
<td>Iliac artery 71, Femoropopliteal artery 66, Graft stenosis 4</td>
</tr>
<tr>
<td>Type of lesion</td>
<td>Stenosis 75 (53%), Occlusion 66 (47%)</td>
</tr>
<tr>
<td>Lesion length (mean±SD)</td>
<td>Stenosis 3.2±5.0 cm, Occlusion 9.8±8.8 cm</td>
</tr>
</tbody>
</table>
Table 3: Clinical success rate in the relationship between the location and stenotic changes

<table>
<thead>
<tr>
<th></th>
<th>Stenosis</th>
<th>Occlusion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean length(cm)</td>
<td>N</td>
</tr>
<tr>
<td>Femoropopliteal lesion</td>
<td>5.0±7.6</td>
<td>30</td>
</tr>
<tr>
<td>Iliac lesion</td>
<td>2.0±12</td>
<td>41</td>
</tr>
<tr>
<td>Total</td>
<td>3.3±5.2</td>
<td>71</td>
</tr>
</tbody>
</table>

The criteria of clinical success were evaluated as followed: a) relief of symptom, b) improvement of arterial pulsation, c) increase of ankle pressure index of less than 0.2, and d) residual stenosis of less than 30% in the internal diameter of the lased arteries. On the basis of these examinations, all cases are strictly evaluated. Subsequently, a success rate of 93% could be found in the cases with stenotic lesions. On the contrary, the success rate was 74% in the cases with occlusive lesions (Table 3, Fig.18, Fig. 19). Further, from the length of the lesion, a technical success rate of 98% was observed even in the cases with femoro-popliteal lesions with 10 cm in length (Table 4). However, in the cases in the lesion of more than 10 cm in length, the rate deceased to 71%.

On the other hand, a clinical success rate of 91% was obtained in the cases with iliac lesions of less than 5 cm in length. Thus, there were significant differences in comparison with the success rate and the length of the lesion between both groups. The tortuosity and severe calcification in these regions were considered to be the reason for this significance.

A long-term follow-up study of 120 months was performed on 99 limbs with clinical success by angiography, measurement of ankle pressure index and clinical symptoms except for angioscopy. Subsequently, the cumulative patency rate in the follow-up of 120 months was 85% for the stenotic lesions for the occlusive lesions (Fig. 20).

3) Discussion
Argon, Nd-YAG, Ho-YAG and Excimer lasers have been widely utilized for laser angioplasty. The optimal conditions for laser angioplasty by Argon laser were 6 W in output and 3 sec in irradiation.
time, $200^\circ$C in output and 5 sec in irradiation time in our serial studies.

On the other hand, several laser conditions (6-12 W in output, 3-10 sec in irradiation time) have been reported according to the kinds of laser system and laser fibers. At the time of laser angioplasty, angioscope and intravascular ultrasound guidance were necessary to evaluate the characteristics of the atheromatous plaques and the arterial wall before and after the laser ablation. And sometimes, it was angioscopically recognized that the proximal – and the distal portions were composed of tight atheromatous plaques and the middle portion was not occluded or filled with fresh thrombus. On the basis of our clinical experience, laser angioplasty should be recommended to eliminate, or reduce the stenotic, or occlusive changes of short segments within 10 cm in length for a peripheral artery.

In recent years, laser angioplasty has been widely employed in United States and European countries. The initial success rate by laser angioplasty has been reported to be 65-95% in comparison with 70-85% for percutaneous transluminal angioplasty. In our clinical series, the clinical success rate was 85% in the cases of stenotic lesions in comparison with 75% for occlusive lesions. Thus, satisfactory results by laser angioplasty were clearly confirmed.

On the other hand, the clinical success rate was 98% in cases with femoro-popliteal lesions of less than 10 cm in length. Thus, there were slight differences in the laser effects between stenotic and occlusive lesions as well as in the relationship between initial success and clinical success in the long-term period. Cumberland has reported that 50 of 56 totally occluded arteries were recanalized by laser and that the ankle pressure index increased from 0.53 before to 0.84 after laser irradiation. In addition to this, technical success was 88% and clinical success was 77%.

In Japan, similar results have been reported in recent years. In general, complications in laser angioplasty include hematomas in the inguinal region, the subintimal pathway of the laser fiber, and dissectional change of the artery by additional percutaneous transluminal angioplasty (PTA). We have experienced 11 dissections and 3 subintimal pathway of the arteries by additional PTA, and 4 intimal injuries of laser probe and guide-wire. However, there was no urgent surgical intervention for them.

Thus, there are some differences in the clinical success due to indication, techniques and antithrombogenic management after laser angioplasty. In conclusion, laser angioplasty was effective to significantly open the lumen of occlusive and stenotic lesions of the peripheral artery. At present, excellent results have been revealed within 10 cm in length for femoro-popliteal lesions. On the contrary, satisfactory results were obtained with 5 cm in length for iliac lesions.

References