Peripheral vascular surgery

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I-1-1 Clinical evaluation and bypass technique of peripheral arterial occlusive diseases

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Introduction

Infrainguinal arterial occlusive diseases are rapidly increasing as the result of increases in longevity. Arterial bypass graftings are more common since Kunlin¹⁾ in 1949 introduced reserved autogenous saphenous veins for routine use in femoro-popliteal bypass. Numerous alternative graft materials have been studied, either as an alternative to the autogenous vein, or as a substitute when the autogenous vein was absent or unsuitable. Bovine graft²⁾, collagen tube grafts³⁾ were found to have poor patency and high rates of aneurysm formation. Allografts⁴⁾ also suffered from poor patency rate.

Dacron grafts^{5,6)} were generally found to be unsatisfactory, although Mosley et al⁷⁾ have recently restudied their use, reporting a 50% patency after 5 years. In 1972 Soyer⁸⁾ reported the use of polytetrafluoroethylene (PTFE) which has been used extensively with varying results. Veith et al⁹⁾ have shown good early patency but disappointing late patency rates for PTFE and conclude it should only be used when no other vein is available, in preference to primary amputation. Dardik et al¹⁰⁾ reported their initial experience with modified human umbilical vein in 1976, which showed good early patency rates. But there are still controversial problems associated with increasing the late patency of bypass graftings.

This study evaluates our infrainguinal arterial bypass graftings and new technique of laser vascular welding.

Patients and methods

At the end of December 31, 1988, 71 patients underwent 76 infrainguinal arterial bypass operations at the department of Thoracic and Cardiovascular Surgery, Nippon Medical School and affiliated hospitals. Sympatotomy, transluminal angioplasty, or amputations without bypass graftings were excluded from this study. Patient ages ranged from 28 to 84 years old with the average age being 68.3 years old. There were 61 men (86%) and 10 women (14%).

Hospital charts were reviewed for medical history, clinical presentation, angiographic results, operative indications and procedures, operative mortality, complications, and graft patency. The

Key words; clinical study, infrainguinal arterial occlusive disease, bypass grafting, laser vascular welding

Table 1 Preoperative Risk Factors

	n	%
Hypertension	29	40.1
Ischemic heart disease	21	29.6
Cerebral infarction	18	25.4
Renal dysfunction	10	14.1
Aortic aneurysm	7	9.9
Diabetes	6	12.7
Smoking	23	32.4

Table 2 Surgical Procedures

	n	%
Aorto-Ilio-Femoral bypass	35	43.2
Ilio-Femoral	24	29.6
Femoro-Femoral		
Axillo-Femoral		
Femoro-Popliteal bypass	14	17.3
Femoro-Tibial bypass	7	8.7
Femoro-Peroneal	1	1.2
Concomitant procedures		
Lumbar sympathectomy	6	7.4
Profundoplasty	8	9.9
Thrombectomy	18	22.2
Balloon angioplasty	11	13.6
Laser angioplasty	8	9.9

Table 3 Cumulative Patency

Table 4 Laser vascular weldings

Femoro-Popliteal bypass (below knee)	5 cases
Femoro-Tibial bypass	1 cases

Table 5 Cumulative Patency

patency was assessed clinically by a staff surgeon with doubtful results being confirmed by Doppler ultrasound or arteriography if indicated.

Follow up was from a minimum of 1 month up to 10 years.

Cumulative graft patency rates and limb salvage rates were calculated by life table analysis with statistical validation.

As for laser vascular welding, an Nd-YAG laser with ER probes (SLT inc.) was used. The laser output was 1 watt per 1 second at each time.

Results

The main stenotic or obstructive lesions of these patients occurred in the femoral artery in 35 cases (43.2%), the popliteal artery above the knee in 24 cases (29.6%), and the popliteal artery below the knee in 14 cases (17%).

Hypertension, ischemic heart disease, cerebral infarction and smoking are popular preoperative risk factors associated with these diseases. Most patients have multiple risk factors and these factors are

common in atherosclerotic diseases (**Table 1**).

Surgical procedures varied according to the lesions. Bypass graftings of the femoral artery as a distal anastomotic site made up 43%, femoro-popliteal above knee bypass ; 30%, femoro-popliteal below knee bypass ; 17% and there were small numbers of bypass graftings to the tibial and peroneal arteries. As concomitant operative procedures, we performed lumbar sympatectomy mainly for poor distal run-off cases, profundoplasty, thrombectomy, balloon and laser angioplasty in about 10 to 20% of the cases (**Table 2**).

Several kinds of vascular grafts were used, but the saphenous vein was the first choice of graft materials which was used in 47% of the cases. Expanded polytetrafluoroethylene was used in 30% as a second choice. Recently biological grafts have also been used.

Ninety-two % of the patients had a rest pain, 72% had intermittent claudication, 38% had ischemic lesions and only 8.5% had pregangrene condition for the surgical indication of bypass graftings.

Hospital mortality was 4%. But the etiology of the death was not related to the bypass procedures. Two patients had acute myocardial infarction and the other one had an acute aortic dissection as the etiology of their deaths.

Over all cumulative patency rate was 76% 6 months after surgery, 69% after 5 years and 59% 10 years later. The patency rate of distal anastomosis of the above knee bypass gave the most satisfactory result with 87% after 5 years and 80% 10 years later. But the patency rate of the below knee bypass decreased to 58% after 6 months, 44% after 5 years and 40% 10 years later (**Table 3**).

To improve the patency rate, especially for the below knee bypass, we used laser vascular welding in 6 cases. Five had femoro-popliteal bypass and one had femoro-tibial bypass (**Table 4**).

The cumulative patency rate of laser vascular welding was excellent up to 3 years after bypass and all bypass grafts were patent (**Table 5**).

Discussion

The patient mortality rate of 4% is acceptable despite the fact that preoperative risk factors were highly accompanied.

Our early graft failure rate was 7.4% one month after surgery. Half of them might be related to technical errors. Operative arteriography was recommended to detect unrecognized technical errors. Dardik et al.¹¹⁾ detected error in 9% of arteriograms which decreased to 3% with experience, Leibman et al.¹²⁾ detected errors in 6% of arteriograms which required correction. This procedure might be useful to detect technical failure.

This study did not demonstrate the change in patency rate due to risk factors such as diabetics, hypertension, smoking et al.

The effect of adding of concurrent sympathectomy to the operative procedure was reported by Culter et al.¹³⁾ who demonstrated a 12% improvement in graft patency after one year when used in patients with poor (0 or 1) vessel run-off. Buda et al.¹⁴⁾ could not demonstrate any improvement in patency or limb salvage rate with the addition of sympathectomy. Our patients, who had concurrent sympathectomy, had a far greater incidence of severe ischemia, poor vessel run-off and diabetes than the non-sympathectomized group. As a result they should have demonstrated inferior patency and limb salvage rates. However, as the patency and limb salvage rates were almost identical in both groups, sympathectomy was probably benefitable. A random prospective study would be required to assess the significance of these results.

As expected, distal anastomosis above the knee achieved better over all results than those below the

knee. The autogenous vein was far superior to other previous graft when anastomosed below the knee, particularly with proximal tibial anastomosis^{15,16)}. But our experience had showed poor late patency rate of those below the knee despite the usage of the autogenous vein graft.

To improve those patency rate, we have demonstrated the new technique of laser vascular welding. From our previous studies^{17,18)}, Nd-YAG laser with contact method could successfully weld vessels and biological vascular grafts, and the anastomotic site was smooth without hyperplasia in the late stage. Although only a small numbers of laser weldings was studied, the cumulative patency rate was 100% up to 3 years after laser vascular anastomosis.

Conclusion

Surgical results of peripheral arterial occlusive diseases were mostly acceptable. In addition, laser vascular anastomosis could be a useful technique to improve the late patency of bypass graftings.

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Peripheral vascular surgery

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I-1-5 A Unique Technique for Improving the Results of Lower Extremity Distal Arterial Bypasses

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Introduction

The patency of tibial arterial bypasses has been reported to be much inferior to that of femoropopliteal bypasses^{1,2)} except in one recent report in which no significant differences were noted³⁾. Before 1979, eight tibial arterial reconstructions were performed at our institution and only one among them achieved long-term patency. We considered the causes of graft failure to be local factors such as scar formation with resultant compliance mismatch and intimal hyperplasia, rather than the so-called outflow status expressed by the numbers of the patent crural vessels demonstrated on angiography. A study of serial postoperative angiograms disclosed that anastomotic stenosis takes place in the recipient artery just distal to the anastomosis⁴⁾. We concluded that the pathological processes around the anastomotic site are caused mainly by circumferential dissection of the recipient artery and vascular clamp injuries. Recently, several reports have been published which support this mechanism⁵⁻⁷⁾. Thus, in 1980, we abandoned the use of vascular clamps in below-the-knee arterial bypasses and adopted Esmarch's bandage method⁸⁾. This report presents the operative technique for tibial and peroneal artery revascularization and the results of the reconstructions obtained.

Operative technique

In cases of atherosclerotic occlusion, the common femoral artery is chosen to be the site of proximal anastomosis, and in Buerger's disease cases, the undiseased superficial femoral artery and sometimes the popliteal artery are chosen. Only the surface of the vascular sheath near the distal anastomotic site is exposed, and the artery is marked with a stitch because it is difficult to point the collapsed artery after exsanguination. The great saphenous vein is harvested, dilated with heparinized autologous blood and used as a reversed graft. In cases where there is no saphenous vein available, arm veins are used. The proximal anastomosis is performed first and the graft is tunneled via anatomical route to the distal anastomotic site. The limb is then exsanguinated using an Esmarch's bandage from the ankle to the middle thigh. Hemostasis is maintained with another bandage. Arteriotomy is done by pulling up on the marker string. When the lumen is entered, the walls of the artery are drawn up by the undissected surrounding tissues

Fig. 1 Schematic presentation of the use of Esmarch's bandage and exposure of distal anastomotic site. The artery is covered by a vascular sheath and marked with a stitch.

Fig. 2 A: The completion angiogram shows muscular branches are patent near the distal anastomosis. B: Six months later, the branches and the recipient artery have grown wide. The configuration of the anastomosis is natural.

and the arteriotomy spontaneously opens wide, allowing the distal anastomosis to be made (**Fig. 1**).

With this technique, there is no need to control or cut the small branches near the anastomotic sites. It can be observed in **Fig. 2** that the muscular branches near the distal anastomosis are patent. The branches and distal arterial tree become wider with the passage of time. There is no entwining of the suture around the clamps, and anastomosis is performed much easier.

Results

From 1980 through May 1989, we performed 26 tibial and peroneal autovein bypass opera-

Fig. 3 Cumulative patency rates of tibial and peroneal arterial bypasses. The primary patency rate is 75.9% and secondary patency rate is 91.7% at the fifth postoperative year.

Fig. 4 Left: This completion angiogram shows a vasospastic change observed in a anterior tibial artery bypass case. Right: The angiogram taken two weeks later shows the disappearance of spasm and natural configuration of the anastomosis.

Fig. 5 Top: Anastomosis to lateral planter artery. Bottom: Anastomosis to dorsalis pedis artery. The recipient arteries are not visible after completion of the anastomoses because they are not dissected.

Fig. 6 Left: Completion angiogram after bypass grafting to the terminal portion of the posterior tibial artery. Severe vasospasm is observed just distal to the anastomosis. Right: Angiogram taken six months later shows a smooth configuration of the anastomosis.

tions. The great saphenous veins were used in 24 cases and arm veins were used in two. There was no bandage-related morbidity and no operative deaths occurred. Two bypass grafts failed in immediate postoperative period (within three months) due to technical errors. Three reoperations were needed during the follow-up period; two due to proximal anastomotic stenosis six and nine months afterwards respectively, and the other due to stenosis between the two combined saphenous vein segments two years after the initial operation. All of them recovered patency later. Thus, the primary patency rate is 75.9% and the secondary patency rate is 91.7% at the fifth postoperative year (**Fig. 3**).

Discussion

The results of lower extremity distal arterial bypasses have been greatly improved with this technique above described, but following the configurational changes of the anastomoses is important for the achievement of long-term patency of bypass grafts. We perform outpatient angiographic examinations at six-month intervals for two to three years even on asymptomatic patients and more often if needed. Completion angiography almost always demonstrates spastic changes of the distal arterial tree. The vasospasm disappears within several days and an angiogram taken at discharge shows a smooth configuration of the anastomosis (**Fig. 4**). In the follow-up period, the distal arterial tree gradually enlarges and the relative configuration of the

graft and the recipient artery becomes more natural. When any significant stenosis is found, immediate revision is required to preserve a functional graft.

We recently adopted this technique to bypass grafts to the ankle-level arteries. The anastomoses to the lateral plantar artery and the dorsalis pedis artery are shown in **Fig. 5**. Note that the recipient arteries are not visible after the completion of the anastomosis, because it is not dissected out. In another case, the completion angiogram after the bypass to the terminal portion of the posterior tibial artery shows spastic change just distal to the anastomosis (**Fig. 6**). In the angiogram taken six months afterwards, however, a smooth configuration of the anastomosis is shown (**Fig. 6**). All of the patients of ankle-level arterial bypasses had ischemic ulcers and/or gangrene and had suffered severe pain at rest. Once blood flow was established to the feet, however, there was immediate relief from the pain and the ulcers healed within weeks. Only minor amputations have been required for the gangrene.

The Esmarch's bandage method obviates circumferential dissection around the arteries, makes anastomoses easier, and contributes to the long-term patency of the bypass grafts.

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Peripheral vascular surgery

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I-1-6 Wound healing on microvascular anastomosis site

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Abstract

Wound healing of the rat femoral artery following end-to-end microvascular anastomosis was studied by using a scanning electron microscope (SEM) and a light microscope (LM). The microvascular wound healing was schematically quantified from the SEM images using a Computerized Graphic Analyzer System. The results revealed that the wound healing process was divided into four successive stages; Stage I (Platelet aggregation phase), Stage II (Fibrin network phase), Stage III (Migratory phase) and Stage IV (Intimal closure phase). The significance of the findings which were obtained at small intervals to understand the process of microvascular wound healing lies in relation to the identification of the time of thrombus formation, knowledge of which allows us to better treat the microsur-gically injured endothelium and to prevent microvascular occlusion.

Introduction

Since the repair process of the inner surface at the microvascular anastomosis site was first demonstrated, many investigators have been agreed on the conception that re-endothelialization began on the third day and was usually completed on the fourteenth day¹⁻⁶. However, Rosenbaum and Sundt⁷ reported complete endothelial coverage on the suture line at day 9. In contrast, O'Brien reported that complete endothelial coverage of the thread entailed 4 weeks' period³. It was, therefore, difficult to clearly define the repair process. The various patho-histochemical and electron microscopic studies have left many points uncertain, particularly the exact temporal serial succession of the stages in the healing process. In this study the author sought to elucidate the precise mechanism of the re-endothelialization repair process.

Methods and Materials

10 week old male Wistar Kyoto rats were used in the study. The surgery was performed under urethane anesthesia intraperitoneally. A standard interrupted suture technique was used to perform end-to-end anastomosis on rat femoral artery. The healing was evaluated through specimen collection at various recovery periods from 1 min. till 7 days after clamp release. The intimal surface was observed with a scanning electron microscope. Details of the method are described elsewhere⁸.

To evaluate the development of the fibrin network and the mode of proliferation for the new

Fig. 1 Site of measurement
Boundary of the exposed media shows clear margin, so this area was used for CGAS measurement. Calibration : 50 μm

endothelial cells at the site of microvascular anastomosis, SEM images were directly analyzed by using the computer graphic analyzer system (CGAS, TVIP 2100, Avionics Co., Ltd., Japan). To accomplish the evaluation of the fibrin network density change by SEM, each small area enclosed by linked fibrin fibers was magnified and measured by using the CGAS at the area of the basal intimal break of the suture which was limited to $100 \mu\text{m}^2$ in each frame. Endothelial continuity was interrupted by microvascular anastomosis, which revealed the underlying internal elastic lamina as well as the media and needle hole. Among these areas, the exposed media showed a clear margin in many of the specimens and considered to be adequate as the site to evaluate the endothelial healing at the base of the suture. The healing rate at the base of the thread was therefore obtained by measuring the area covered with the new-endothelium over the exposed media (**Fig. 1**).

SEM image was then photographed with 4×5 Polaroid Land Film, type 55/Positive-Negative (Polaroid[®], Cambridge, MA, U. S. A.). Then the image was memorized via a television camera and projected into a monitor. A digital analyzer measured the density of the fibrin network and the rate of endothelial healing over the injured media. SEM image of each specimen was measured three times by converting the actual three dimensional structure to the two dimensional image. The date set was used to calculate the mean and the standard deviation. These data were statistically checked by using the t-test to compare the difference between values. Coefficients of the variant ranged between 0.95-1.27%. Therefore, the error due to measurements was estimated to be less than several percent and not considered to be statistically significant.

Results

The SEM study provided detailed information on the repair process initiated by the hemostatic platelet reaction which related to the formation of a fibrin network and to the recovery of the endothelium. The repair process was divided into 4 successive stages at the base of the thread. For simplification minor variations among specimens, including length of each stage, were ignored. Since the different stages are based on gross morphological changes, this 4 stage classification of the repair process at the

Fig. 2 A set of schematic diagrams illustrating the reendothelialization of the vessel
SEM stages of I (Platelet aggregation phase), II (Fibrin network phase), III (Migratory phase) and IV (Intimal closure phase) are in successive order in the healing process.

Fig. 3 Morphological transition in fibrin networks

- A. Fibrin fibers which appeared initially arranged in sparse fibrin networks
 B. Thickening and condensation of fibrin network fibers Spaces between fibrin fibers were decreasing.
 C. Final outcome of the fibrin network maturation process showing thick fibrin fibers in tightly packed structures Calibration : 0.5 um

Fig. 4 Wound healing process

Fig. 5 A statistical analysis of the endothelial healing rate Ordinate shows the logarithm of non-healing coverage values (values of endothelial healing subtracted from 100), while abscissa is for the postoperative day.

K : Reduction rate constant of non-healing rate (day^{-1})

Ti : Initiation time of healing (day)

T₅₀ : Time of 50% healing (day)

base of the thread easily explains the succession of the pathological changes (Fig. 2).

Among these 4 stages, Stage II and Stage III matches well with the period of thrombus formation clinically, which yields necessity for further investigations.

(1) Fibrin networks

The fibrin fibers appeared shortly after the anastomosis and were present for about 3 days, or until the start of the re-endothelialization process of the intimal break at the base of the thread. While the exact onset of visible fibrin formation varied with experimental conditions, the fibrin fibers represented characteristic features of the network structure. The fibrin network was primarily composed of fine

fibers which has much distance between them. As the healing process continued, finer and longer discrete fibrin fibers joined with each other, forming wide, stout and entangled fibrin bands which covered the entire surface of the endothelial lesion. As the three dimensional fibrin network structure changed from a coarse into a dense one, thinning of the mural thrombus in size and thickness provided minute spaces between equally matured fibrin fibers which were crossed strips of linked fibrin. This gave a final configuration in which the individual morphological outlines were indistinct (**Fig. 3**).

Quantitative estimations were obtained by plotting the density change (or the size alteration) of each fibrin network observed postoperatively at 12 hours' intervals against the number of days. As indicated in Figure 4, the fibrin fiber change showed a negative linear relationship, showing $r = -0.886$. The significance of this change is $p < 0.01$. The fibrin network in the early stage, therefore, showed a coarse structure providing wider spaces between cross-linked fibers, while the late stage exhibited shrinkage of the spaces. By the third postoperative day, the turning point of the re-endothelialization process, the value of $0.3 \mu\text{m}^2$ showed a significant reduction from the value at the early stage. The fibrin network gradually became tighter and the change appeared to be a preparation phase for the granulation tissue to provide sufficient blood supply and a firm base for the subsequent re-endothelialization. This transition of fibers is considered a maturation process of the fibrin fibers in the formation of the network.

(2) Re-endothelial coverage

The curve shown in Figure 4 indicates a sigmoid correlation between the endothelial healing at the base of the thread and the postoperative time period. The initiation of re-endothelialization started at the intimal break of the base of the thread between 2nd and 3rd postoperative day. The coverage by the endothelium gradually increased, making a sigmoid growth curve until the 6th postoperative day. These results are summarized to show the precise mechanism of microvascular wound healing in connection with the evaluation by CGAS, by paying attention to the density changes in fibrin networks and the re-endothelialization process at the anastomosis site (**Fig. 4**).

(3) Statistical characteristics

The date on the endothelial healing obtained by the CGAS was statistically analyzed to evaluate the transitional changes in the postoperative re-endothelialization. The values were plotted on a graph with the Y axis representing non-coverage ratio (percent values of endothelial healing subtracted from 100). The change of the non-coverage ratio (Y) after the operation in a logarithmic scale showed an exponential correlation with the time of the postoperative period. The line fitted the negative linear regression gave the ratio of $r = -0.91844$ ($p < 0.01$) for the period of re-endothelialization of the intimal break at the base of the thread. The final assessment of microvascular healing was then achieved by introducing the parameters for the wound healing derived from the curve of exponential regression⁹, $Y = Ae^{-kt}$. These parameters for the healing shown in **Fig. 5** matched well with the SEM observations, indicating the usefulness of these parameters for precisely understanding the microvascular repairing process.

Discussion

It is evident that one can not satisfactorily observe and evaluate the morphology of the microvascular anastomosis repair process by using only the SEM technique. Supporting data are necessary. CGAS analysis provided useful quantitative information on the wound healing process.

Statistical analysis gave further affirmation for these findings, which provided the basis for calculating the indices used in the CGAS statistical evaluations of re-endothelialization: K (endothelial coverage constant), T_i (initiation time of healing), T_{50} (time of 50% healing), and T_{100} (time of 100%

healing). These indices provided a clearer understanding of the sequential events in wound healing at the site of microvascular anastomosis. Depending on the re-endothelialization site, significant differences were found in the endothelial coverage constant for repair (K). Re-endothelialization proceeded smoothly when the K value was large, and likewise for smaller values of T_i , T_{50} , and T_{100} , respectively.

This investigation clarified the finely tuned biological steps involved in wound healing in rat vessels. A comparison between the rat healing process and the human healing process after microvascular surgery will make these findings clinically significant.

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第 14 回学術集会
シンポジウム

平成元年 6 月 20, 21 日 (火, 水)
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Peripheral vascular surgery

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I-1-7 Encephalo-duro-arterio-synangiosis, a new extracranial to intracranial indirect bypass operation to treat moyamoya disease.

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Moyamoya disease is an unusual form of chronic cerebrovascular disease of unknown etiology in which lumens of the distal portion of bilateral intracranial internal carotid arteries and then, the circle of Willis become progressively narrow. To compensate for a decrease in blood supply to the brain due to this arterial stenosis, the collateral systems for the brain are activated and the blood flow per these collaterals progressively increases in inverse proportion to the decrease in blood flow per usual stenotic

Fig. 1 Angiograms of a normal individual and of a moyamoya patient in comparison.

Fig. 3 Schematic illustration of moyamoya disease emphasizing the isolation of the brain from the outside world by the wall (hard closed box of the skull) and the moat (fluid layer of the subarachnoid space).

- A system = Anastomosis intracerebralis
- B system = Basal communications
- C system = Cortical leptomeningeal anastomosis
- D system = Dural networks
- E system = Extracranial networks
- F system = Functional collaterals
- G system = Ground communications

Fig. 2 Collateral systems to the brain.

route. Demonstrable collateral vessels on angiogram called “moyamoya” vessels (overgrown A system shown in Fig. 2) characterize the disease (Fig. 1).

Every failure in the compensation of the blood supply to the brain is expressed as ischemic attacks in the patient and irreversible neurological deficits of the patient become increased in the course of time.

Figure. 2 shows our concept of collaterals to the brain that the brain is surrounded by seven systems of collaterals which we named as A to G systems. The A system is the **Anastomosis intracerebralis** and is the anastomosis between the perforating arterial branches entering into the brain both from the base and from the surface of the brain. They are anastomosed with each other at the external angle of the lateral ventricle. The B system is the **Basal communications** and stands mainly for the circle of Willis. The C system is the **Cortical leptomeningeal anastomoses**. These are end-to-end anastomoses among each principal cerebral artery on the surface of the brain. The D system is the **Dural networks**. The dural arteries are such anastomosed each other as if the brain were covered with a mesh hat of the dural arteries. The E system is the **Extracranial networks**. As known well in case of bleeding from scalp injury, the blood flow of the scalp and pericranial muscle is extremely abundant, and arteries also connect each other and form networks. The F system is the **Functional collaterals** and is non-anatomical ways of increasing cerebral blood flow as hypercarbia and sympathectomy. The G systems are the **Ground networks** and are collateral pathways below the cranial base (i. e. in the neck).

The brain is surrounded by these seven concentric layers of collateral systems. A, B, and C systems are fed by the internal carotid system and vertebrobasilar system. The D and E systems are fed mainly by the external carotid system. Between these two carotid systems, there intervene a solid closed box of the skull and a water layer of the subarachnoid fluid space.

The closed skull and the subarachnoid fluid space isolate the brain from the abundant blood flow of

Fig. 4 Operation of encephalo - duro - arterio - synangiosis (EDAS) and donor scalp arteries.

Fig. 5 A selective external carotid arteriogram (in normal situation, no cerebral arteries are demonstrated by selective external carotid angiography) of a moyamoya patient obtained 8 months after encephalo-duro-arterio-synangiosis. Almost whole a hemisphere is demonstrated through the posterior branch of the superficial temporal artery which is the donor scalp artery.

the external carotid system as if they were the wall and the moat of a castle, and thus hinder the extracranial to intracranial collateral formation (Fig. 2).

In moyamoya disease in which the blood supply per normal route becomes progressively insufficient, the intracranial collateral systems operate first to compensate for the blood flow decrease. The A system becomes so prominent that it becomes very demonstrable on angiograms as seen in Figure 1. Moyamoya, a Japanese word to illustrate this demonstrable vessels on angiogram, became the name of the disease. The external carotid systems, the D and E systems which are abundant in blood supply and patent in moyamoya disease is not utilized as collaterals to the brain at early phase of the disease, as there are such two obstacles as stated above. In the course of time, however, the D and E systems anastomose with the C system forming so called transdural anastomoses, possibly by the enlargement of the minimal arterioles running in such tissues as pachionian granulations, bridging vessels and cranial nerves which physically connect or bridge the dura mater and the brain.

Waiting for the natural increase in blood flow through these spontaneous collaterals from the external carotid systems, however, takes too much time and during this time period irreversible neurological deficits of the patient become increased due to repeated failure in compensation for cerebral blood flow. Thus, it is necessary to surmount the two obstacles stated above, if we were to treat a moyamoya patient before irreversible neurological deficits are produced.

Our new operative methods, encephalo-duro-arterio-synangiosis (abbreviated as EDAS) is an operative procedure which has been developed according to the philosophy stated above, to help the formation of collaterals to supply a sufficient blood to the brain from the external carotid system, by breaking through the wall and by bridging the moat.

The operative procedure is , as shown in **Figure 4**, to push the scalp artery, which is the principal artery of the E system down to the surface of the brain with a strip of galea, to anastomose the D and E systems by suture fixing the galea to the dura mater, and to connect the D system with the C system by bridging the subarachnoid fluid layer with initial spontaneous anastomoses made of capillaries grown in the granulation tissue developed between the dura mater and the brain.

Figure 5 shows an external carotid angiogram of a patient who underwent the EDAS 8 months before. It is found that the whole hemisphere is visualized through the parietal branch of the STA which is the donor scalp artery.

The revascularization of the brain usually occurs proportional to the blood requirement of the brain and symptoms of the patient decrease in proportion to the revascularization of the brain.

We performed this operation on 132 sides of 69 pediatric moyamoya patients and obtained satisfactory results in all of them, proving justification of the above mentioned philosophy which we introduced in the development of our new operative method to treat this interesting chronic cerebrovascular insufficiency.

As shown in this report, our new operative procedure, which should be called as indirect anastomosis is very effective and is now a treatment of first choice⁶ in the management of moyamoya disease in children.

We believe that there are situations in other field of surgery in which an indirect anastomosis surpasses or at least alternates a direct anastomosis. We are happy if our experience can give you encouragement in performing an indirect anastomosis in such circumstances.

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