

ARTERIOVENOUS FISTULA FOR DISCREPANCY IN LENGTH OF LOWER EXTREMITIES

By

T. HIERTONN

The surgical construction of an arteriovenous fistula between the femoral artery and vein has been used for the purpose of equalizing leg length differences in 5 cases of poliomyelitis. The local and general effects in these cases have been studied for 10 years.

BACKGROUND AND DEVELOPMENT

Knowing the growth stimulating effect often produced in cases of congenital vessel abnormalities with arteriovenous communications, it was an easy step to the surgical imitation of such a condition by creating an arteriovenous fistula near the actual growth zones in the extremities with retarded length. *Janes & Musgrave* (1949, 1950) showed in experimental studies the growth stimulating effect of a surgically produced fistula between the femoral artery and vein in puppy dogs. The method was applied clinically in the Mayo Clinic, Dec. 5, 1950. According to *Janes* (1958), 44 children have been operated there. The method is also under clinical trial in Toronto (*Mustard* 1957). At the orthopaedic clinic of Karolinska Institutet the method was first clinically applied in the autumn of 1950, on a suggestion from *Ph. Sandblom*. At the same time, in collaboration with *N. Obel*, a study was made of the arterial and venous pressures and skin temperatures adjacent to 3 and 4 armed arteriovenous anastomoses in dogs.

PATHOPHYSIOLOGY

A direct communication between the high pressure arterial system and the low pressure venous system brings about an increased blood volume passing through this region. The total blood volume and the

heart's minute volume are increased and the involved artery, vein and fistula can be dilated. The situation and size of the fistula, and to a certain extent the duration of patency, are of considerable importance in the local and general symptoms. According to *Holman* (1937, 1955) a fistula of 1–1½ cm. in diameter, between the aorta and the inferior vena cava invariably causes fatal cardiac insufficiency, whereas a fistula of the same size between the femoral vessels is never immediately deleterious. A strikingly rich local collateral circulation is obtained in the neighbourhood of an arteriovenous fistula because of the hemodynamic changes. In the tissues far distal to an arteriovenous fistula, on the contrary, the arterial circulation can become fundamentally reduced depending on how much arterial blood is shunted passed the area. This in combination with the impeded venous return explains the peripheral ischemia and stasis, which can occur in both congenital and acquired arteriovenous fistulae.

TABLE I

Case number	Sex	Polio at the age of	Paralytic distribution	Discrepancy in length of lower extremities at operation. Tape measure	Age at operation years
1	M	2 years	Left hip, knee, and foot	7 cm	12
2	F	1 year	Right hip, knee, and foot	9 cm	11
3	M	3 months	Left hip, knee, and foot	4 cm	9
4	M	3 months	Left hip, knee, and foot	5 cm	6
5	M	1 month	Right hip, knee, and foot	5.5 cm	6

MATERIAL

During the time 23/8 1950 until 8/2 1951, an arteriovenous anastomosis between the femoral artery and vein has been performed on 5 children with retarded growth in one lower extremity following polio.

The ages, sexes, distribution of the pareses, and the differences in the leg lengths are shown in Table I. The leg lengths were measured partly with X-ray, partly with a tape measure, and partly evaluating the discrepancy by placing wooden blocks under the short leg when standing, until levelling of the pelvis is obtained. Orthoroentgenography was first introduced in the clinic in 1953, and before this, leg length was measured from a simple survey film of the thigh and foreleg respectively. If not otherwise stated, the figures for leg length in this

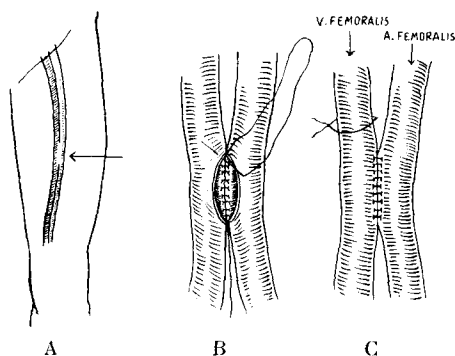


Fig. 1.

A. The site of the fistula between a. and v. femoralis.—B. The posterior line sutured with adventitia to adventitia.—C. The anterior line sutured with intima to intima. Black silk around vein proximal to the fistula as guide to next stage.

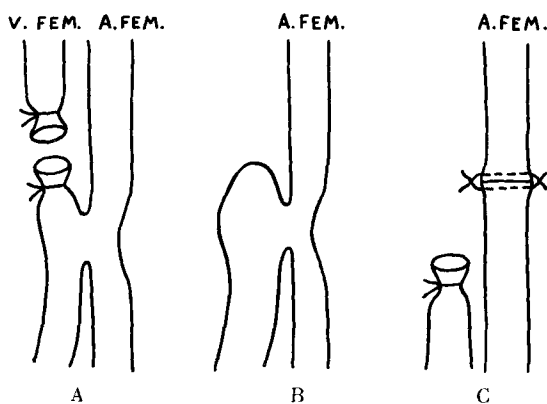


Fig. 2.

A, Stage 2. Ligation and transection of vena femoralis proximal to the fistula after 3 weeks. —B. The 3-limbed a-v-fistula. Note the dilatation of the vein. —C. Operative closure of the fistula and arterial reconstruction.

article were obtained by clinical measurement. All cases were followed before operation regarding leg length and they showed a progressive increase of the discrepancy.

OPERATION TECHNIQUE

Stage 1. The femoral artery and vein were dissected free, just above the middle of the thigh. (See Fig. 1). After clamping with soft vascular clamps, adjacent longitudinal incisions, about 10 mm. long, were made

in the artery and vein. The posterior artery and vein walls were sutured with 5-0 Deknatel silk, bringing adventitia to adventitia in the simplest way from the lumen side. The anterior suture line was made from the outside, bringing intima to intima. A black silk thread around the femoral vein proximal to the fistula and brought out into the subcutaneous tissue, was used as a direction marker for the second stage.

Stage 2. Three weeks later, when the arterial-venous anastomosis was endothelialized, and the femoral vein was more adapted to the increased pressure, the femoral vein was ligated and divided above the anastomosis. Transformation of a 4-limbed to 3-limbed anastomosis is designed to diminish the shunting of arterial blood to the heart, and direct it distally in the femoral vein. (Figs. 2A, B and Fig. 7).

Effect of the Arteriovenous fistula.

After the construction of the arteriovenous fistula, all the cyanotic, atrophic and cold extremities showed a more normal skin colour and some swelling of the thigh and foreleg which partly masked the severe muscular atrophy. Furthermore there was a marked increase in the temperature of the thigh, knee, and greater part of the lower leg on the operated side. The veins over the thigh and leg became tense and pulsating. Blood from these pulsating veins had a lighter red colour and a higher O₂ measurement than venous blood from the other side. Subjectively the feeling of peripheral coldness disappeared. To some degree the bulk of the thigh and calf became greater and this was interpreted by the patients and the parents as a reduction of the muscle atrophy. The improvement of the muscle function which was taking place according to the parents, could not be verified objectively with certainty.

Skin temperature measurements¹.

The temperature of the thigh, knee and upper parts of the foreleg was 1-3° higher than on the non-operated side.

Distally, however, in only one case (no. 1) and only on one occasion was there any significant difference in the temperature of the toes between the operated and non-operated side, when examined after vasodilatation (by bodywarming) and after subsequent cooling for 60 minutes at room temperature.

¹ Performed in the Physiotherapy Department of the Karolinska sjukhuset.

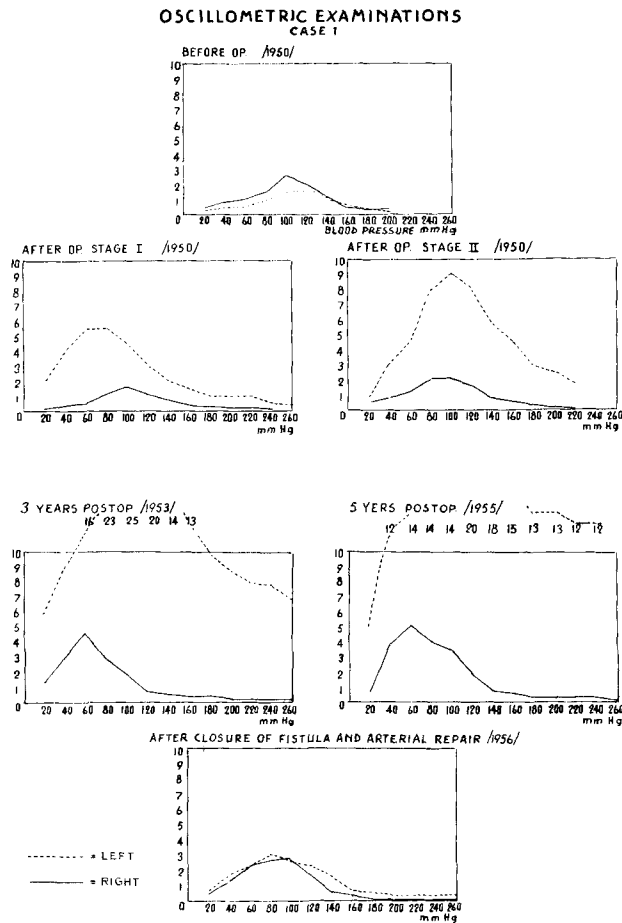


Fig. 3.

Oscillographic examinations. After construction of a v fistula in the left thigh, strikingly increased oscillographic readings are obtained. Note normalization after closure of fistula.

*Oscillographic studies*¹.

Before operation there were somewhat lesser readings on the paralysed short side as compared to the unaffected side, both over the thigh and foreleg. After the first stage of the operation an essential increase of the pulsations was detected over the thigh but those over the foreleg continued to be small, and indeed were less than preoperatively. After stage 2 the pulsations over the thigh became greater than normal but

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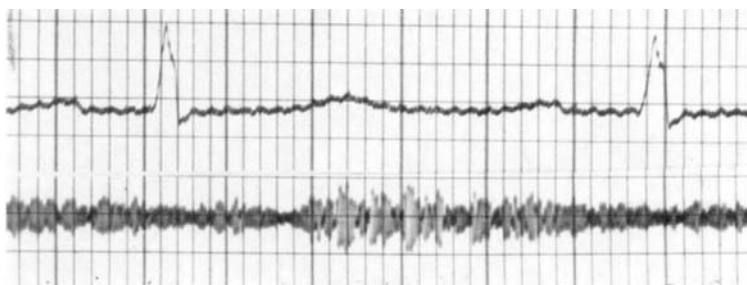


Fig. 4.

Phonoarteriogram with microphone placed over arteriovenous fistula. Note the continuous character of the murmur. Upper tracing ECG. Lower tracing phonoarteriogram. (Case 2 three months postoperatively).

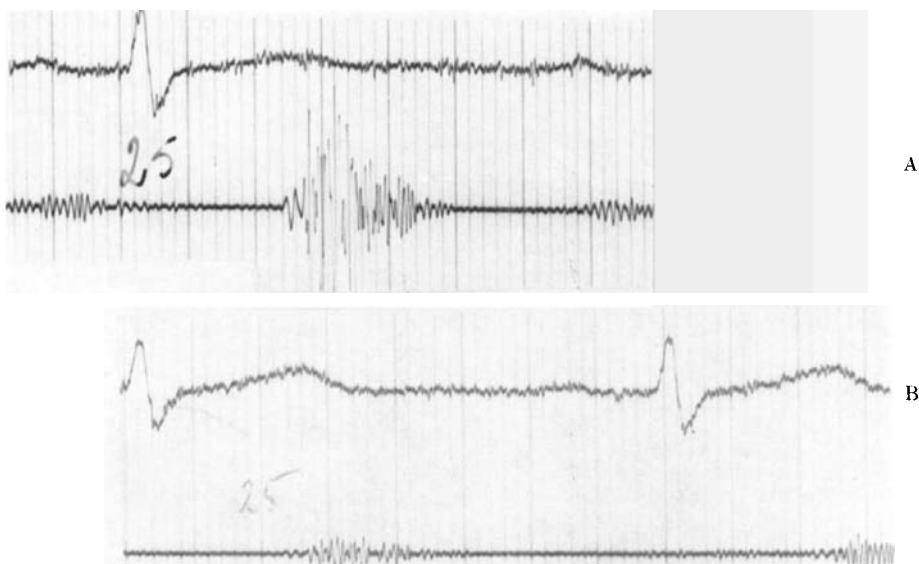


Fig. 5.

Phonoarteriograms over the fistula (A) in 1955. (B) in 1956 (Case 4).

- A. There is a loud high frequent murmur beginning just under the middle of T Wave of ECG and ending in protodiastole. Another murmur of much less frequency and intensity begins with P wave and goes on into the first murmur.
- B. There is only one late systolic murmur. The amplitude is lower than before. These changes correspond to partial thrombosis of vena femoralis.

over the foreleg they remained small for a time. Later the readings were greater than normal even over the foreleg. The curves shown in Fig. 3 (case 1) are characteristic. After closure of the fistula and repair of the artery, the oscillometric readings became normal and equal on both limbs.

Thrill, murmur, pulse rate and "Branham's sign".

A palpable thrill, and a clearly audible murmur almost of machinery type, were present over the arteriovenous connection in the thigh. These signs result from the turbulence in the blood streaming through the relatively small fistula into the dilated vein. The systolic accentuation of the murmur is due to variation in the speed of flow with every pulse beat. This could be studied during synchronous phonoarteriograms and ECG determinations. Fig. 4 shows a phonoarteriogram over a fistula (case 2) with a strong continuous murmur. In another case (case 4) the phonoarteriogram showed that the murmur was not fully continuous and instead was diphasic (Fig. 5). In this case a strong high frequency murmur began late in systole, then there was a clear pause before another murmur began in diastole. The changes in the phonoarteriogram corresponded well with other methods recording changes in the circulation. With calibrated phonoarteriography, it is possible to register, classify and compare the murmurs—even for purposes of teaching. The murmur was propagated proximally and distally, to the groin and to the knee.

In two cases after the arteriovenous fistula, the pulse rate was regularly somewhat higher than before operation. No definite difference was established between the pulse rates after stage 1 and stage 2. There were insufficient observations in the other cases for an assessment of the pulse rates associated with 4-branched and 3 branched arteriovenous fistulae. After the first half-year a certain adaptation probably occurred. With repeated examinations during the first few years after operation, normal electrocardiograms and pulse rates were found.

A definite reduction of the pulse rate by 6–10 beats per min. was regularly obtained with compression of the fistula either manually or with a blood-pressure cuff. This sign which is usually called "*Branham's sign*" in the textbooks, is explained by reflex reduction of the heart rate with increasing of the peripheral resistance in the circulatory system.

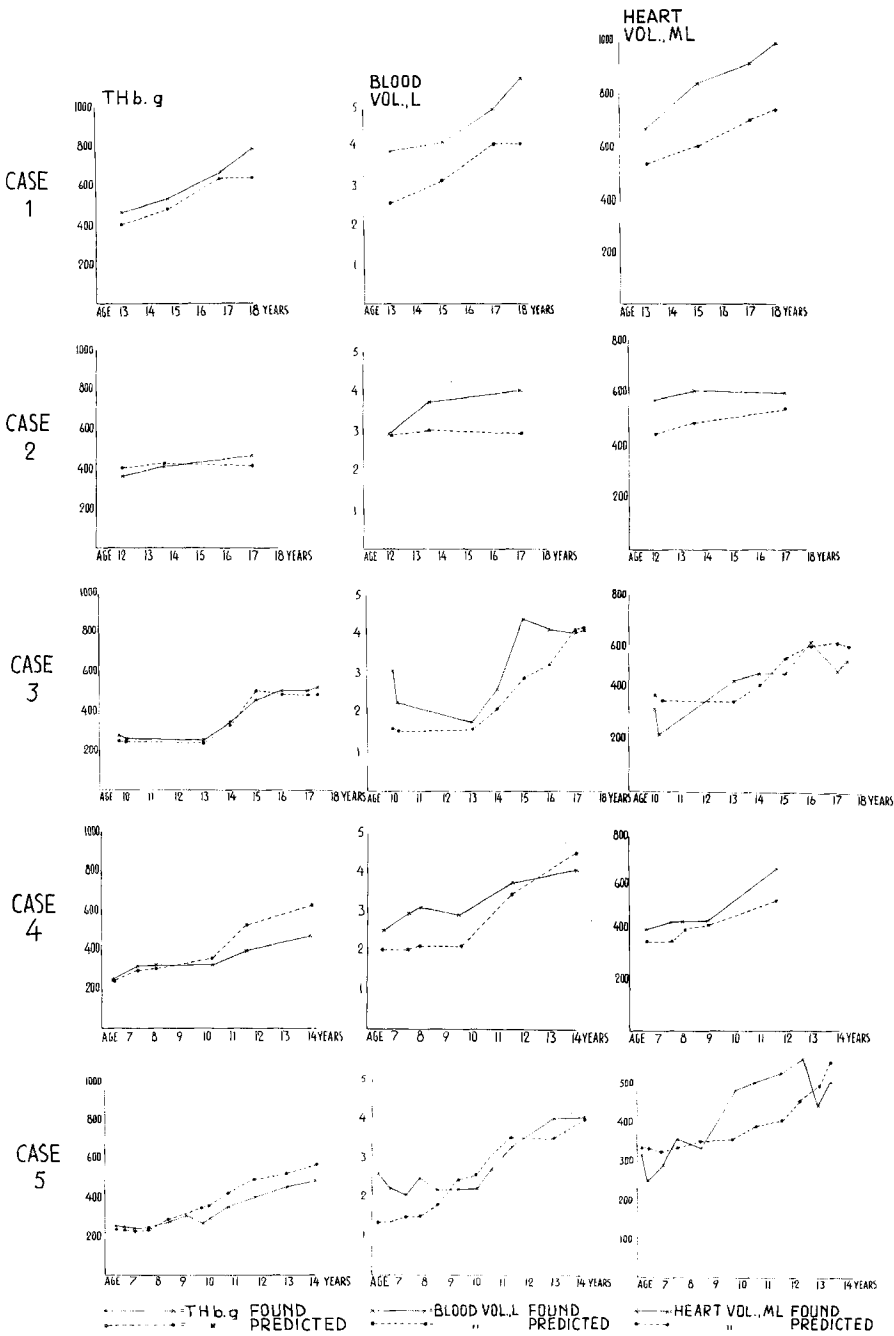


Fig. 6.

Survey of determinations of total amount of haemoglobin (THb), blood and heart volume after creation of an A-v fistula.

CARDIAC SIZE, BLOOD VOLUME AND TOTAL HEMOGLOBIN

During the years following the creation of an arteriovenous fistula these patients had many examinations of their hearts, blood volumes and total hemoglobin. These were performed at the clinical physiology laboratory of the Karolinska sjukhuset.

Total amount of hemoglobin (THb). The THb was determined by the alveolar CO method, reported in 1948 by *Sjöstrand* (and with some minor modifications by *Carlsten et al.* 1954 and *Wiklander* 1956).

Blood volume. The total blood volume was calculated from the values for THb and the hemoglobinconcentration (Hb) determined from finger blood, disregarding the slight underestimation thus obtained due to the assumption that the hemoglobin concentration is constant in the whole blood volume. The normal value was calculated from the predicted THb/15,4.

The heart volume. The heart volume was determined in the prone position with two plane roentgenograms according to the method described by *Larsson & Kjellberg* 1948, and *Kjellberg et al.* 1951.

As shown by the curves in Fig. 6 the THb values in two patients (case 4 and 5) were somewhat lower than estimated. In the remaining three cases the values found were at the same level as expected. The blood volumes of all patients with the exception of case 5, lay at all times somewhat above the normal values. The same tendency was found in case 5 during the first years after the performed fistula. The hearts were slightly enlarged in four cases (case 1, 2, 4, 5). In case 3, the cardiac volume was judged as normal on every examination. Neither exceptionally high values nor any signs of progressive cardiac damage, were found in any of the cases.

THE CONDITION OF THE VENOUS VALVES

Angiography studies were performed in all the cases.

In 4 patients this was done in conjunction with stage 2 of the operation by injecting contrast material distally in the femoral vein.

The problems were 1) did the valves nearest the operation area constitute an absolute barrier to a distal flow in the femoral vein?

2) were there large venous branches near the fistula which too quickly directed the shunted arterial blood in a centripetal direction before it reached the growth zones in the knee region?

Even by arteriograms undertaken later¹ could these questions be

¹ These were performed in the Karolinska sjukhuset, Radiology Department, in some occasions with stereo-technique.

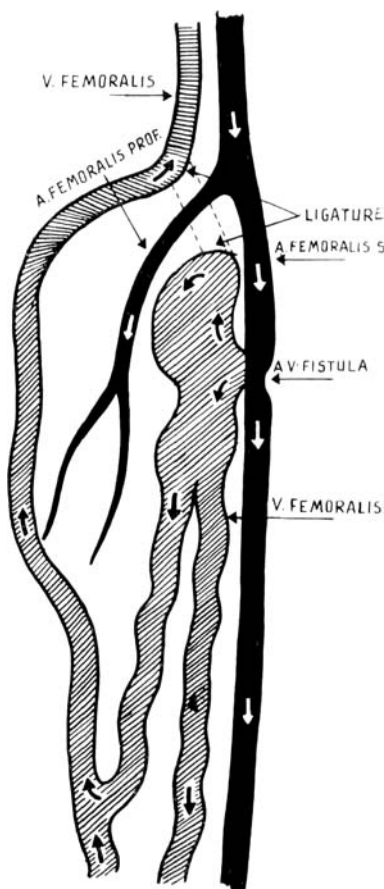
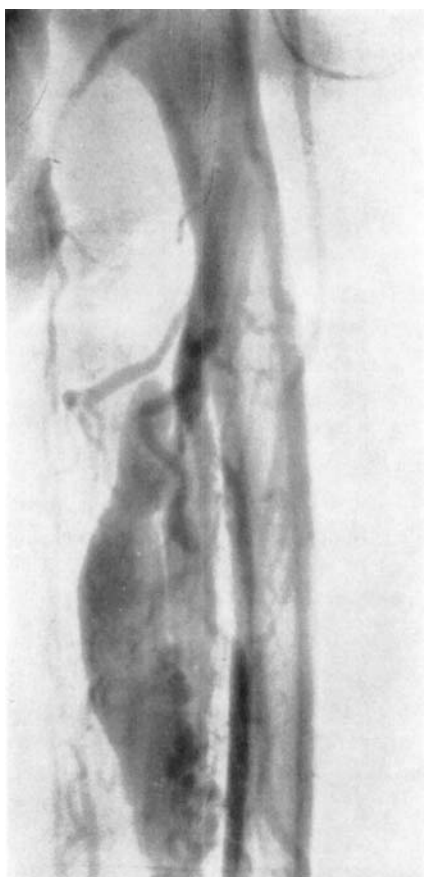


Fig. 7.

Arteriogram 5½ years after creation of arterio-venous three-limbed fistula between the femoral artery and vein. (Case 1). There is a large dilatation of the femoral vein.

For explanation see the schematic drawing compiled from several projections.

answered in the negative, and therefore an additional operative attack on the valves and the collateral veins was not required.

Fig. 7 shows a typical picture of the anastomoses area with the contrast medium filling the whole femoral artery and into the grossly dilated femoral vein distal to the ligature. Some of the contrast rapidly passed proximally via superficial veins but a large part travelled in the distal direction.

As shown in Fig. 8, neither the venous valves nor the profuse collateral veins were able to divert the blood stream from the lower thigh

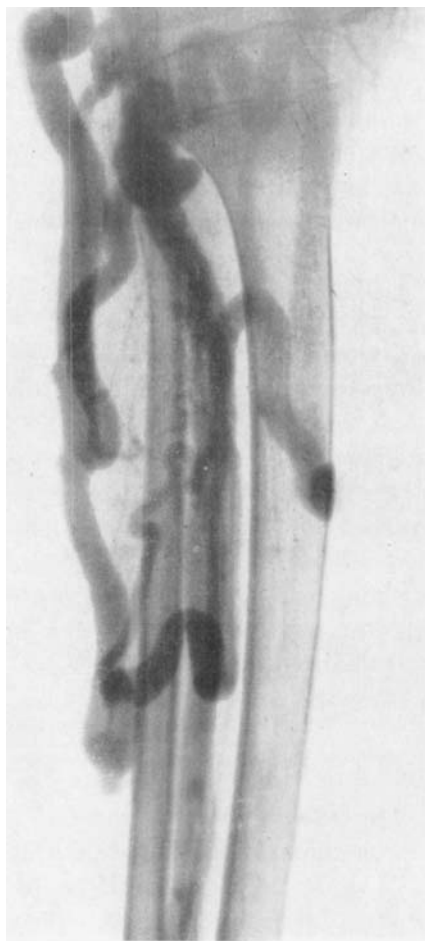


Fig. 8.

Arteriogram 7 years after creation of arteriovenous fistula (Case 5). There is a marked dilatation of the veins of the leg and increased vascularity around the knee.

TABLE II
Complications.

Case	Fistula created	Nature, severity and duration of the complications
3	1950	Chronic ulcer 20×20 mm above the medial malleolus 1956-1958.
4	1951	Chronic ulcer 20×20 mm of the calf, 2 months 1955. Pulsating hemorrhage on one occasion. Spontaneous thrombosis of the vein distal to the fistula, 1959 (beginning 1956?) Local tenderness 2 months.
5	1951	Chronic ulcer 25×25 mm above lateral malleolus.

and upper part of the foreleg. A fairly large proportion of the contrast in this way reached the foreleg before the direction of the stream became centripetal. The arteriograms showed in a convincing way the extremely rich vascularization in the neighbourhood of the growth zones in the knee region. In the region of the fistula the femoral artery was somewhat narrowed but any significant pre- or post-stenotic dilatation of the artery was not seen.

COMPLICATIONS

Chronic ulceration of the lower leg on the operated side appeared on three cases (see Table II). These were preceded by induration and tenderness and became fairly superficial sores of the type usually seen in chronic stasis. They healed with rest, applications of Burow's solution and elastic bandages, but had a tendency to recur. In one patient (case 4) a pulsating hemorrhage occurred on one occasion from the ulcer 2 cm. in diameter, situated above the medial malleolus. The bleeding was arrested by compression. The same patient later had a spontaneous venous thrombosis into the fistula.

Dorsalis pedis and posterior tibial pulses could be demonstrated in all cases.

THE GROWTH STIMULATING EFFECT

The clinical measurements with a tape-measure, and by wooden blocks under the short leg until the pelvic obliquity was abolished, both showed a clear reduction of the leg length discrepancy during the observation time in all cases (see Figs. 9-10 and Table III).

TABLE III

Case	Discrepancy in length of lower extremities in cm according to tape measurements		Duration of fistula	
	at creation of fistula	at closure of fistula	Years	Age of patient
1	7	2	5.3	12-18
2	9	2.5*	6	11-17
3	5	2	7.5	9-17
4	5	2	6 or 7	6-13 (14)
5	5.5	1.5	7	6-13

* Last follow-up 1956. Unsuccessful tracing for follow-up study 1960.

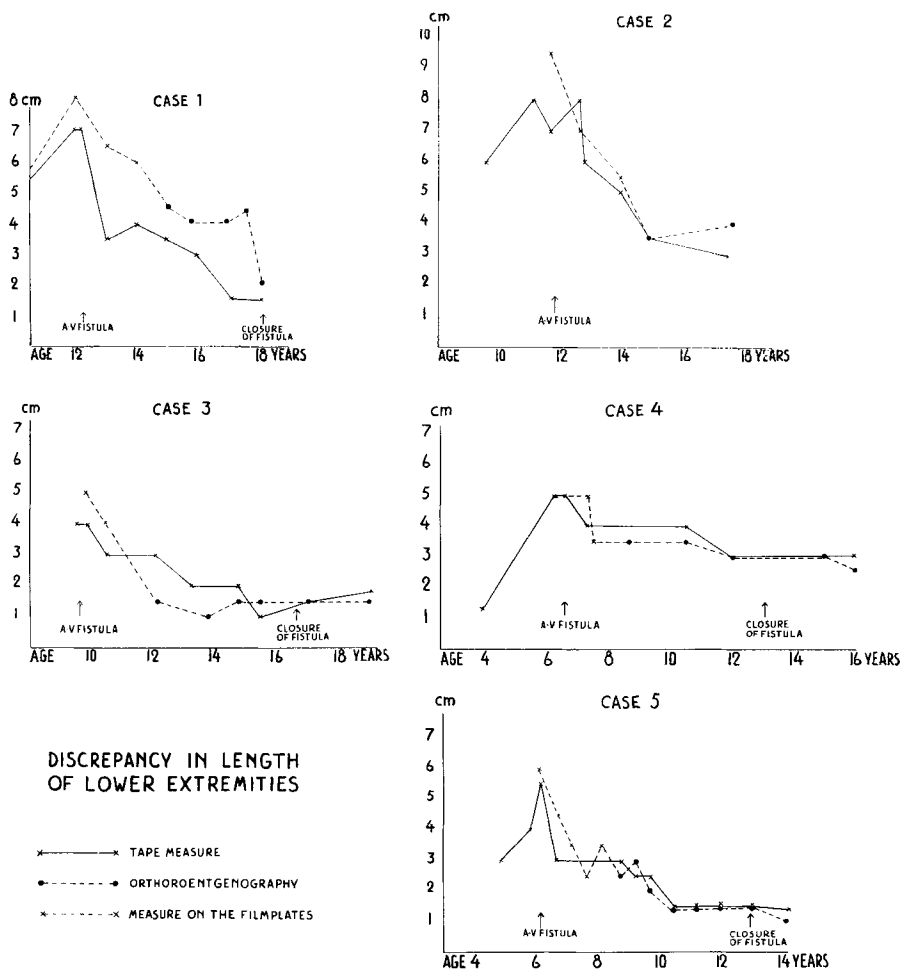


Fig. 9.

Results of growth stimulation by A-v fistula.

The orthoroentgenographical method which has been used routinely in this clinic since 1953, and is described by *Sandaa* (1953), gives more exact values. The figures from these later examinations ought not to be directly compared with those obtained by another roentgen measuring method which was used prior to 1953. This means that a completely satisfactory objective roentgen measurement of the growth stimulating effects produced by the arteriovenous fistulae is lacking in this study.

If the effect is judged only by orthoroentgenography (since 1953) it is seen (Fig. 9) that the leg length difference has been reduced in two

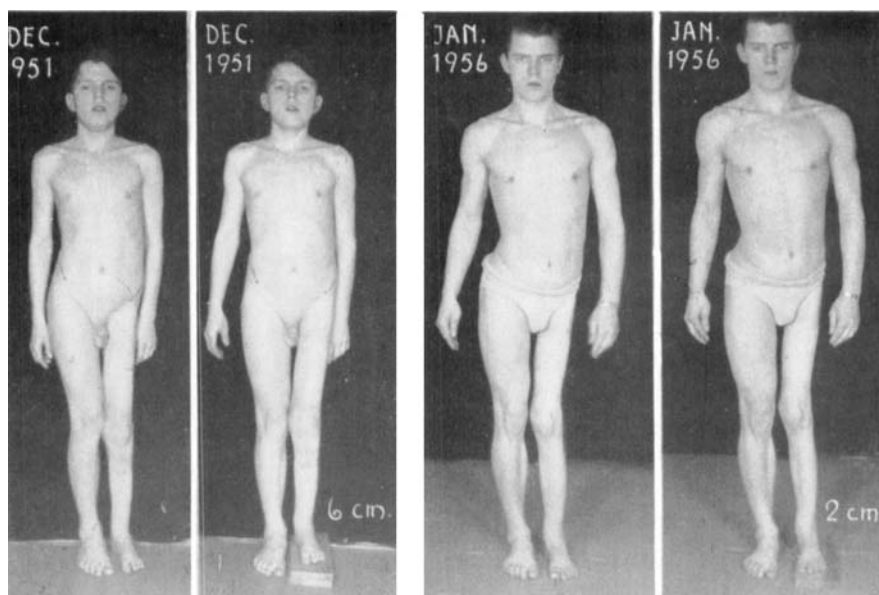


Fig. 10 A. (Case 1)

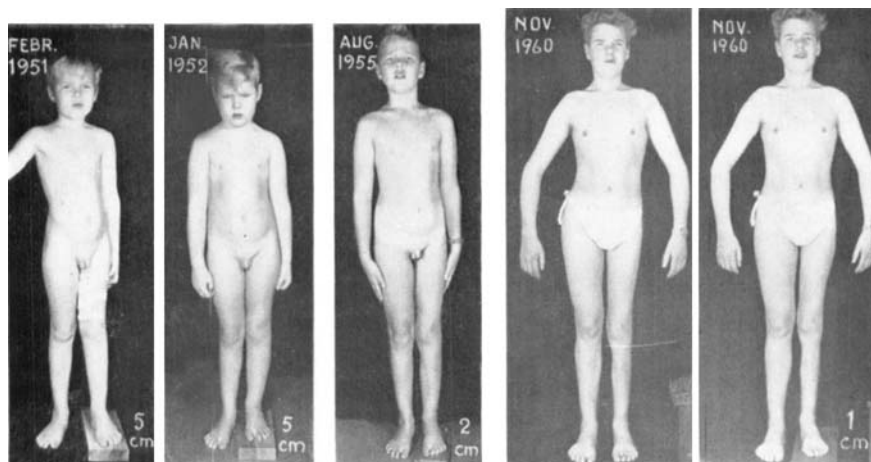


Fig. 10 B. (Case 4)

cases (case 1 and 5). Deviations of 0.5 cm. and less are probably not significant. According to the orthoroentgenographs, the reduction in case 1 amounted to 2.5 cm. and in case 5 to 1 cm. during the time the fistula was open.

Based on clinical measuring methods, and partly on orthoroentgeno-

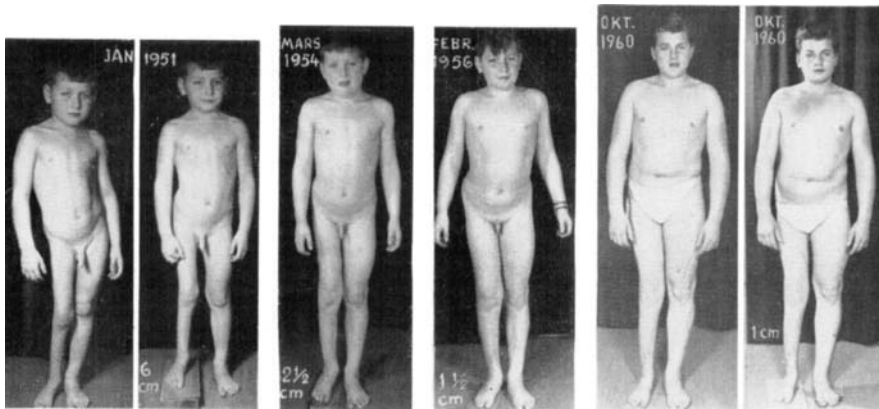


Fig. 10 C. (Case 5)

Fig. 10.

Photograms of patients operated on for discrepancy in length of lower extremities.

graphic methods during a limited time, a significant reduction of the leg length differences is demonstrated (Figs. 9-10). This is interpreted as a growth stimulation of the short poliomyelitic extremities.

CLOSURE OF THE ARTERIOVENOUS FISTULAE

Operative closure of the fistulae was undertaken in case 1 and case 3 at eighteen and seventeen years of age respectively. The large venous sacs were ligated and the fistulae resected. In case 1, a minor resection of the artery was performed because of thickening of the walls and luminal narrowing at the level of the fistula. Arterial continuity was restored by end to end suture (see Fig. 2 C, 11 and 3). There was calcification in the walls of the fistula in case 3 and these changes prevented direct arterial suture after ligation of the venous sac. Arterio-plasty was withheld because of very good pulsating hemorrhage from the distal part of the artery and instead the artery was also ligated. Oscillometry post-operatively showed the previously hypernormal readings to be somewhat less than the readings on the non-operated side. The ulcerations on the calf healed.

In case 5 the fistula was closed after 7 years when the patient was thirteen. The reason for this somewhat too early closure was that the patient's parents were worried about the longstanding ulceration on the lateral malleolus (see Table III). The large venous sac was ligated and the arterial wall could be sutured and the patency retained. After

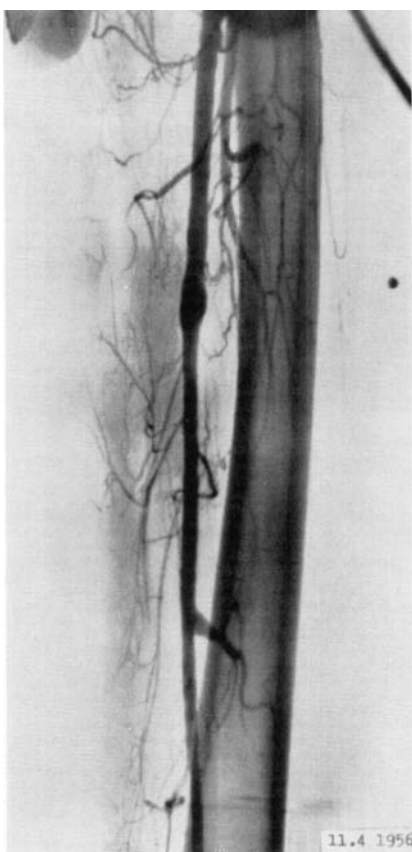


Fig. 11.

Arteriogram after operative closure of fistula and arterial reconstruction (Case 1). For comparison see (Fig. 7).

some months the artery became occluded over an area of about 10 cm. The collateral circulation was, however, satisfactory, the ulceration healed quickly. Furthermore a subsequent triarticular subtalar arthrodesis healed without delay.

Spontaneous closure by thrombosis of the femoral vein occurred in case 4 probably already after 6 years, i.e. 1956 (see Fig. 5). Angiography in 1959 and 1960 showed passage in the femoral artery but no longer an arteriovenous shunt.

Case 2 lives in another country and could not be reached at the time of the last follow-up examinations.

Complications from the long term arterialization of the veins were not observed in any of the cases after closure of the fistulae. No case of massive edema has occurred either during the time of function of the fistulae or afterwards.

DISCUSSION

The number of operated cases has been limited to five in order to follow these carefully and study the effect and possible complications. The results of the larger series which have been operated in the Mayo Clinic and in Toronto are awaited with great interest. Regarding the technique for establishing the arteriovenous fistulae, the two-staged method developed by *Johnston et al.* 1950, seemed to be suitable.

The local effect of the arteriovenous fistula could be determined by simple clinical methods of examination. A loud "machinery" type of murmur and a clearly palpable thrill were demonstrable over the whole thigh, with the maximal point over the fistula. The veins in the thigh and foreleg became tense and pulsating, and their contents lighter red. The pathophysiological condition was studied closer by a number of laboratory studies.

It was feared that the valves in the veins might offer such a resistance that the arterial blood would quickly turn in a centripetal direction. But this was shown not to be the case. An increased vascularization throughout the thigh and foreleg and into the knee epiphyses was confirmed by angiographic studies. In this connection may be mentioned that when congenital vascular abnormalities with arteriovenous communications are situated close to the growth zones, the risk of overgrowth of the affected extremity is greater (according to *Ward & Horton* 1940) than when the arteriovenous connections lie farther away.

The increased pressure in the veins in the vicinity of the fistula likely produced a certain degree of stasis. Artificial venous stasis has long been recognized as a growth stimulating factor and was employed most by *Bier* (1903) in the form of a tourniquet left in place for several hours a day in order to cause a temporary blockage of the venous return.

A general survey of other methods for producing local hyperemia in the vicinity of the growth zones can be found in "Surgical Treatment of Unequal Extremities" by *Goff* 1960.

The growth stimulating affect which is undoubtedly obtained after the construction of the arteriovenous fistula probably can be explained by 1) *increased circulation*, 2) *venous stasis* and 3) *constant increased temperature in the growth zones*. The obtained effect appears to be greater than by other hyperemic measures. The local complications have not been serious but in one case a prolonged ulceration over the lateral malleolus led to an earlier operative closure of the fistula than was

planned. Careful studies of the heart and blood volume during the time the arteriovenous fistulae were open showed no unfavourable effect.

Thus it seems that the method might be used in children with grossly retarded growth in one leg due to previous poliomyelitis. Careful twice-yearly control of the blood and heart volumes, and the E.C.G., is desirable.

S U M M A R Y

Surgical construction of a 3 armed arteriovenous fistula between the femoral artery and vein has been used as a growth-stimulating measure in 5 children between 6-12 years of age, who showed progressive leg length discrepancies.

The pathophysiological background and operative technique are described. The local and general effects of the arteriovenous fistula, examined and recorded by different methods are discussed. After functioning for 5-7 years, the growth-stimulating effects of the fistulae were obvious.

Minor complications in the form of ulcerations of the leg appeared, but no adverse effect on the heart or blood circulation.

No venous insufficiency trouble appeared after closure of the fistulae and the distal chronic ulcerations healed.

R E S U M E

Formation chirurgicale d'une fistule artério-veineuse de trois branches entre arteria et vena femoralis a été utilisé comme opération pour stimuler l'accroissement en cas de différence progressive des jambes à cinq enfants de l'âge de 5-12 ans.

La base physio-pathologique et la technique de l'opération sont décrites. Les effets locaux et universels de la fistule artério-veineuse, enregistrés et contrôlés par des méthodes différentes, sont discutés.

Après 5-7 ans de fonction de la fistule l'effet stimulant sur l'accroissement était manifeste. Des effets secondaires insignifiants en forme d'ulcérations au tibia se sont manifestés; par contre aucun effet défavorable sur le cœur ou la circulation.

Z U S A M M E N F A S S U N G

Die artifizielle dreiwegige arterio-venöse Fistel zwischen arteria und vena femoralis wurde zur Stimulierung des Längenwachstumes an

fünf Kindern im Alter von 5 bis 12 Jahren mit zunehmender Längendifferenz der Beine angewandt.

Der pathologisch-physiologische Hintergrund und die Operationstechnik werden beschrieben. Die mit verschiedenen Methoden registrierten Lokal- und Allgemeinreaktionen nach Anlegung der a.-v. Fisteln werden diskutiert.

5–7 Jahre funktionierende Fisteln gaben einen deutlichen stimulierenden Effekt auf das Längenwachstum. Geringfügige Nebenwirkungen in Form von Ulcerationen an den Unterschenkeln kamen vor, jedoch keine ungünstigen Nebenwirkungen auf Herz oder Blutzirkulation.

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