WAR EXPERIENCES WITH THE NONSUTURE TECHNIC OF ANASTOMOSIS IN PRIMARY ARTERIAL INJURIES

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THE PRESENT COMMUNICATION is concerned with the problem of restoring blood flow through arteries damaged by missiles. Seven cases are reported here in which a nonsuture technic was attempted. The casualties were treated in an American Evacuation Hospital in the recent European War.

As is usually the case in war-time, the desire to restore the functional continuity of arteries became to us a problem of pressing and intriguing interest. We were fortunate in having the timely advances of Blakemore, Lord and Stefko[1] as the basis for our attempts. The devices with which surgeons have tried to repair arteries have been many in the past, and it is said that every sort of tubular structure from goose quills to chicken bones has been used. During World War I Tuffier[2, 3] had some success with a silver plated tube coated with paraffin. Makins[4] reported some good results with this method, and one specifically through which the distal pulsations were maintained for as long as ten days. The Carrel vein graft technic[1, 4, 5] was sometimes satisfactory in the last war, but was technically difficult, time-consuming, and very subject to thrombus formation. Direct arterial suture,[5, 6, 7] as stated by Leriche and Werquin,[8] is generally impossible in war wounds. It is tedious and difficult. Ragged tears and loss of substance may make even the apposition of the arterial ends impossible. Local thrombosis frequently follows the repair.[27] Besides these initial factors, suture is dangerous in a war wound which is left open, as hemorrhage is apt to occur. Infection is still too often present, and, finally, there may be little or no support of the vessel by healthy adjacent tissues. Mitchiner[9] stresses the complications developing late in patients after arteriorraphy in World War I; frequently these men developed aneurysm at the site of suture. Yet when a primary artery is simply ligated, and its continuity is not restored, the extremity may be lost due to ischemia, or there may be functional limitations evident later.[28, 30, 31]

In reviews of the subject in 1939 and 1940, Maurer,[10] and Mitchiner,[9] respectively, gave rather unhappy pictures of what could be expected in vascular surgery in battle casualties. Only under the most perfect conditions could they give any hope of preserving the function of an artery by direct suture. Yet these conditions seldom obtain in warfare, and even then may be followed by late complications. In the early part of American participation in this war, we were impressed by the unprecedented loss of limb due to ischemic gangrene. In the Tunisian campaign, 100 per cent of our cases requiring ligation of the popliteal artery came to amputation. These observations were confirmed by others,[11, 27] and attributed to the increased explosive effect of modern missiles. It became more important than ever to find a method to save these limbs. It had to be a method which would restore arterial blood flow, which would rarely cause thrombosis, and one that would be relatively free of the reported late complications. The nonsuture method advocated by Blakemore, and associates,[1, 11, 12, 13, 14] seemed to fulfill the prerequisites.

Blakemore and Lord[1, 12] at first sought a tubular structure to act as a prosthesis, and chose a Vitallium tube which could be inserted into the divided ends of the artery. This was done experimentally both with the ends of the artery sutured in continuity (Fig. 1 A), and with them distracted and ligated over the ends of the unlined tube (Fig. 1 B). The results of this method were

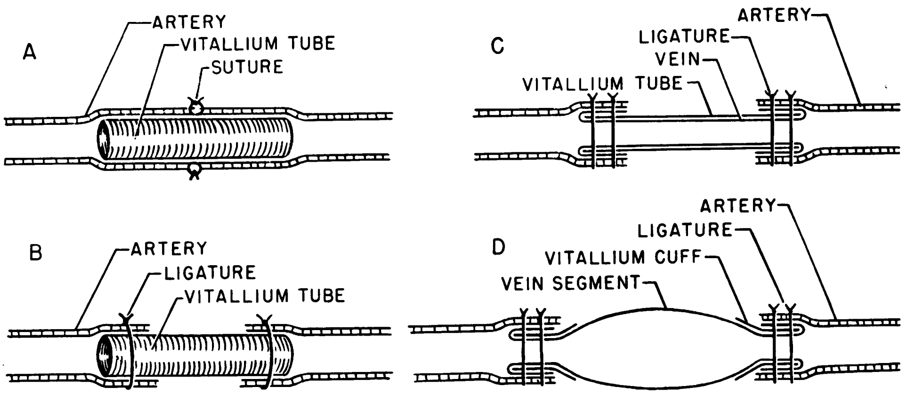

FIG. 1.—(A) Experimental: artery sutured in continuity over an unlined Vitallium tube. (B) Experimental: artery ligated over an unlined Vitallium tube with arterial ends separated. (C) Clinical: vein-lined Vitallium tube ligated in place to bridge arterial defect. (D) Clinical: vein segment reflected over Vitallium cuffs shown connecting arterial ends.

unfavorable in that only one in nine, and one out of six, respectively, were successful. Another method tried—without the use of anticoagulants—was that of reflecting the ends of the artery over metal cuffs and uniting them with a vein graft. Little success came of this plan either. The final development was the use of a Vitallium tube lined with a vein segment which overlapped the ends of the tube; this graft could be inserted into the artery with intima of vein in contact with intima of artery (Fig. 1 C). The prosthesis was held in place by two ligatures at each end. A modification of this, to bridge longer arterial defects, was the two-tube method (Fig. 1 D). In this, the vein was similarly applied, but using only a cuff of metal at either end with the interposed segment of vein not encased in metal. Both of the latter methods were highly successful experimentally, and were later applied to civilian vascular injuries, aneurysms, and other conditions, with excellent results.

We attempted the nonsuture technic in seven cases. The average time in getting these patients from the battlefield to the operating room was 12 hours and 50 minutes; the earliest one was three hours and 40 minutes. More forward installations, the Field Hospitals, devoted their time almost exclusively to critically wounded patients: Those with abdominal, chest and head wounds.

Entry to our hospital was frequently only a few hours after injury, but two factors delayed operation—the sometimes prolonged treatment of shock, and the precedence given to patients more desperately wounded. Usually the time required to get the patient ready for operation after admission was equivalent to that taken in his transportation to the hospital. Recognition of vascular injuries in war casualties was often difficult. Many times men with extremity injuries who were in shock would have very cold, pulseless limbs, all or several of which would return to normal color, temperature and function with the adequate treatment of shock. Often the presence of a vascular injury could only be suspected after shock treatment when the extremity with vascular damage failed to return to normal. Associated severe injuries usually made the treatment of shock unduly prolonged. As some authors had predicted, the war injuries were often extensive, leaving scant muscular support for an arterial anastomosis. All of the wounds were perforce left entirely open. Not even the vascular sheath was closed. Frequently, some degree of infection developed after operation, endangering the anastomosis. Collateral vessels were often severely traumatized. Major A. F. McBride observed that collateral blood supply seemed better in cases in which one or several of the large peripheral nerves was not functioning. Makins,[4] in contrast, states that associated nerve injuries favor the development of gangrene in a limb suffering an arterial injury. Some of us, in accord with McBride's opinion, were led routinely to inject the nerves in the affected extremity with novocaine. Sometimes, even where a lumbar sympathetic ganglion block had been done first, the peripheral nerve block seemed to improve the circulation of the limb. Fractures of the long bones were frequently associated with the vascular injuries and made anastomosis somewhat more hazardous, particularly in the femur where application of a hip spica was apt to put a strain on the prosthesis. Occasionally the graft lay directly on a fracture site.

On admission to the hospital, all of the seriously injured patients were treated in the shock ward. They had had first-aid treatment before entry. Broken extremities had been immobilized, usually in a Thomas splint. Sulfanilamide powder had been put in the wounds. Some of the vascular patients had pressure bandages on their wounds, others had tourniquets. Many of the patients with whom we are concerned were in severe shock. These were treated with plasma until blood was available; plasma alone was not enough.[17] Massive blood transfusions were given. When an extremity failed to give an appearance of viability after intensive supportive therapy, it was suspected that there was vascular damage to the primary artery and perhaps to collaterals. In such cases, when the primary vessel was found at operation to have been severed or thrombosed, the main collateral vessels were inspected, where possible. If they had been injured, a prosthesis was used. In some instances where it was feared that exposure of the collateral would disturb functional capacity, the decision to use or not to use a prosthesis was dictated by the clinical condition of the extremity. It must be stressed here that when collateral supply as well as the primary artery is damaged, every effort should be made to reëstablish functional continuity of the vessel. Ideally, an anastomosis should be done in all cases, as a limb supported only by its collateral is so frequently subject to easy fatigue, intermittent claudication, and is generally less competent than the normal one.[28, 30, 31] In our early war experience[11] we were surprised at the failure to survive of many limbs in which the prognosis was thought good. It was some time after that that we acquired the metal tubes essential to the nonsuture technic. Hence, many cases went through our hands before we accumulated the experience and the material with which to try this procedure.

CASE REPORTS

Case 1.—An American soldier with two gunshot wounds, one in the abdomen and one in the left thigh. Wounded at 10:00 A. M. November 13, 1944, at Montidaly, France. On admission to our hospital, a tag of omentum was seen protruding from an abdominal wound. Both lower extremities were so cold that it was impossible to note any difference in temperature between them. A vascular injury was not seriously considered. There was no evidence of a fracture of the left femur. B.P. 90/65; P. 100.

Operation.—Major William H. Cassebaum: 4:30 P. M. November 13, 1944.

Pathology: (1) A penetrating wound of the left buttock entering the pelvis, with lacerations of the lateral wall and apex of the bladder intraperitoneally. The tract made its exit suprapubically without injury to any other abdominal viscus. There was a severe compound comminuted fracture of the left superior pubic ramus. (2) A perforating wound of the left thigh with contusion and thrombosis of the superficial femoral artery about 12 cm. below the inguinal ligament. The missile had entered posteriorly and came out anteriorly in the upper third of the thigh.

Procedure: (1) Exploratory celiotomy through a left paramedian incision, with findings as described. Closure of the two perforations of the bladder followed by cystostomy with a catheter. The left first and second lumbar sympathetic ganglia were excised. Débridement of the fractured pubic ramus was carried out. The abdominal incision was closed in two layers. (2) Débridement of wounds of the left thigh. The femoral artery was then isolated: the thrombus and clot were removed through a longitudinal incision in the artery. Damage to the intima was seen but the artery wall was sutured. When control from above was released, a little blood leaked from the arterial suture line, and in a short while the artery seemed thrombosed again. Hence, the thrombosed section was resected, together with a section of the femoral vein. An anastomosis, using the vein segment and Vitallium tube, was attempted. The lower end of the prosthesis, however, pulled out of the artery while the upper end was being inserted. As the patient's pulse was 160 at that time, it was considered unwise to persist. Both ends of the artery were ligated. The distal arterial end bled slightly before ligation. Operating time three and one-half hours. From admission to completion of operation, the patient had received 2,500 cc. of whole blood.

Course.—November 17, 1944: Considerable pain in the affected leg for past two days. The foot was obviously dead, the calf tender and tense. Sensation to pinprick was noted as dullness to within three inches of the ankle. There was no sensation in the foot. "We have not been able to restore his blood volume for fear of damaging his liver or increasing the existing jaundice, which must certainly be due to transfusions."*

* We had many reactions—jaundice, pyrexia and hemolysis—resulting from massive blood transfusions. Most of these were in Group A recipients and seemed to occur after more than 1,500 cc. of pooled plasma or Group O blood. Type specific transfusions (*i.e.*, A donor to A recipient) completely eliminated this reaction. I hope Captain George H. Parks will report further on this subject).

Second Operation.—6:00 A. M., November 17, 1944.—Guillotine amputation of the left leg below the knee. The skin and gastrocnemius muscle bled moderately; and the latter muscle was of good color. The other muscles of the lower leg were grayish-purple and did not bleed. The anterior tibial muscles were "almost white."

Case 2.—An American soldier suffering from a shell fragment wound of the left leg received at 3:00 P. M. November 13, 1944, at Leintry, France. Examination on admission revealed a patient in profound shock. B.P. 85/35; P. 120. There was a perforating wound of the right leg with entry on the medial side of the knee at the patella, with the wound of exit about four inches above the knee cap on the lateral aspect of the thigh. Only slight movement of the toes and foot was noted. A dorsalis pedis pulse was said to be perceptible on admission (this was questioned). Roentgenograms revealed a fracture of the medial condyle of the femur extending into the joint. Patient's condition was good at 10:00 P. M. 1,200 cc. of blood and 750 cc. of plasma were given preoperatively.

Operation.—Major Andrew F. McBride, 4:00 A. M. November 14, 1944.

Pathology.—Severe shell fragment wound of the right lower thigh; traumatic arthrotomy of the right knee joint, with a complete compound comminuted fracture of the medial condyle of the femur. Severance of the tibial and peroneal divisions of the sciatic nerve. Division of the popliteal artery and vein. Absent distal pulsations; the popliteal pulse was absent with the patient under anesthesia. The affected foot was cooler than the well foot and insensible to stimuli.

Procedure.—A sciatic nerve block was done first. Exploration of the popliteal space was performed through a midline incision with a tourniquet fastened on the upper thigh. The vessels and nerves were exposed and found divided at a level believed to be between the superior and inferior geniculates. The popliteal artery was damaged from 0.5 cm. to 1.0 cm. beyond each divided end, and the ends were filled with thrombus. Two attempts were made to interpose a venous transplant with two metal cuffs. The great saphenous vein was used. The lower end of the transplant was hitched up first, and with release of the tourniquet there was a steady drip of blood from the distal artery through the vein segment. The prosthesis, however, came out when connected to the proximal end of the artery. A second attempt at union was successful at both ends, but after ten minutes the arterial pulse forced the transplant from the artery. The artery was then ligated. Nothing was done to the knee joint at this time. Plaster encasement applied. A sympathectomy was not done in view of the nerve section. 1,000 cc. of blood was given during operation. The operating time was three hours and ten minutes.

Course.—The leg became progressively more necrotic and an amputation through the lower third of the right thigh was done 46 hours after the first operation.

Case 3.—A German prisoner with a gunshot wound perforating the left thigh and penetrating the right thigh. Wounded at 8:00 A. M. February 1, 1945, near Colmar, France.

Examination of the patient revealed a 1 x 1 cm. wound on the posterolateral aspect of the left thigh at the junction of the middle and lower thirds. There was a 20 x 10 cm. wound of the anteremedial surface of this thigh. An obviously severely fractured femur complicated the situation. The sensibility to pain and touch were diminished in the affected foot. This foot was cold, pale and slightly cyanotic, with no pulse palpable. Circulation was described as "almost *nil*," yet the foot was not dead. There was an 8 x 3 cm. wound of the right thigh.

Operation.—Captain Charles F. Stewart, 2:00 A. M. February 2, 1945.

Pathology.—There was wide destruction of the vastus medialis muscle and less marked damage to the biceps femoris and adductor magnus. A complete compound comminuted fracture of the femur was associated with this perforating wound. The superficial femoral artery had been divided about 5 cm. above adductor hiatus. Division of the femoral nerve was noted.

Procedure.—Débridement of the skin, fascia, muscles and bone. Part of the femoral vein was resected. An anastomosis of the severed femoral artery was accomplished with Vitallium cuffs, using a segment of the femoral vein. (At first a segment of the saphenous vein was tried but was found to be too small in caliber.) A good stream of blood came through the free distal end of the vein segment with the proximal end fixed in place. Anastomosis was difficult because the cuffs slipped out of the artery both before and after they were ligated. Finally, the anastomosis was satisfactorily accomplished with a cuff 4 mm. in diameter above and one 3 mm. in diameter below. There was a palpable pulsation of the artery below the anastomosis. The completed bridge lay immediately against the fracture of the femur. The sciatic nerve was blocked under direct vision in the posterior wound. Five Gm. of sulfanilamide were placed in the wounds, which were left entirely open. The foot was warmer after operation; the calf muscles, however, were slightly firm. After the necessary manipulation of putting on a hip spica, the foot again became pale and cold. Operating time five hours.

Course.—February 2, 1945, 7:00 P. M. The left foot was warm but not as warm as the right. No feeling in the foot (nerve division and block) nor ability to move it. Temperature 102.4° F. at 4:00 P. M.

February 8, 1945: Fever, up to 101.2° F. The left foot was warm but considerably mottled and slightly bluish. No pulse palpable.

February 10, 1945: Foot warm. No pulse palpable. Could move toes moderately well. Patient evacuated to the rear February 12, 1945. Condition unchanged.

Final note: (by letter from the General Hospital to which the patient had been evacuated.) "The patient was received on February 12, 1945, in fairly good condition. The day following admission he had a small pulmonary embolus, with classical chest pain and hemoptysis. The left leg was of good color and remained so; no edema. Due to the embolus, no studies (arteriograms) were made, as you suggested. His condition was improving, but he suddenly had a large pulmonary embolus on February 26, 1945, and expired. Autopsy showed thrombosis of the left femoral artery; however, it must have remained patent for some time until collateral circulation was established because of good color and warmth of the extremity. The source of the pulmonary emboli was the left internal iliac vein. The patient's condition was never good enough to warrant examination of the wounds (hip spica) or any type of surgery."

Case 4.—An American soldier wounded at 11:00 A. M. February 5, 1945, by a shell fragment perforating the upper third of the left thigh.

On examination, the patient was found to have a 4 x 4 cm. wound on the anterior aspect of the thigh below the inguinal ligament, lateral to the femoral canal. The laceration was surrounded by a zone of swelling. The left leg and foot were quite cool, and the muscles of the thigh and leg were firm. No pulse could be felt in the foot. There was no evidence of fracture or of nerve injury. 500 cc. of plasma and 500 cc. of whole blood were given preoperatively.

Operation.—Major William H. Cassebaum. 6:00 A. M. February 6, 1945.

Pathology.—There was a thrombus in the femoral, the profunda femoral and the lateral femoral circumflex arteries. In the anterior wall of the femoral artery there was a slit a few millimeters long. The walls of the involved vessels were severely contused with resulting subadventitial hemorrhage. The wounds were very dirty.

Procedure.—The wound over the femoral artery was extended upward. A plasma tubing clamp was placed on the femoral artery proximal to the injured portion. The small slit in the femoral artery was enlarged and the thrombus and clot was removed, by milking it out from below. Some bleeding from below then became apparent, and the blood flow was controlled from below. A portion of the femoral vein was excised, reversed and transplanted into the artery after having been passed through two Vitallium tubes each about one inch long. After joining the anastomosis, no pulsation of artery distally became apparent. The wound was débrided. Little or no bleeding was encountered in the sartorius or quadriceps femoris muscle. Woolen material (clothing fragments) was removed from the wound. A considerable amount of venous bleeding was noted. After operation the leg still appeared cold and dead. Gas gangrene was feared because of destruction to collaterals and the extensive contamination of the wound.

During operation the patient received 1,000 cc. of 5 per cent glucose in saline, and 1,500 cc. of whole blood.

Course.—February 7, 1945. 7:00 A. M. Thigh swollen and gas present.

Second Operation.—February 7, 1945. 8:45 A. M. High thigh amputation of the left lower extremity. Clot occupied the vein graft, though when this was later removed the system was patent to water from a 30-cc. syringe under pressure of the weight of the plunger.

Case 5.—An American lieutenant with a severe gunshot wound of the right thigh received at 7:30 A. M. April 8, 1945. Admitted at 5:20 P. M.

Examination.—B.P. 125/80; P. 88. The patient had a large hematoma of the right thigh with an hemarthrosis of the right knee. General condition very good. The leg was in a Thomas splint. Motion of the toes was good; posterior tibial pulse feebly palpable. 1,000 cc. of 5 per cent glucose in saline and 500 cc. of blood were given the patient prior to operation.

Operation.—Captain George Crawford. 3:30 A. M. April 9, 1945.

Pathology.—A compound comminuted fracture of the right femur with laceration of the upper third of the popliteal artery. Good pulsations of the dorsalis pedis and posterior tibial arteries were noted in the operating room, but these disappeared just before the patient was anesthetized.

Procedure.—The wound on the laterosuperior aspect of the knee was opened and large blood clots were evacuated. The surrounding muscle was infiltrated with clotted blood. In its superior portion the knee joint had been pierced. Irrigation of the knee joint with saline was followed by the instillation of 10,000 U. of penicillin and closure of the capsule. On evacuation of blood clot from the thigh wound profuse hemorrhage was encountered; hence, the popliteal artery and vein were exposed. An incomplete tear was found in the upper third of the popliteal artery. The tear measured 2 cm. in length and encompassed two-thirds of the circumference of the vessel. A section of the popliteal vein was taken, threaded through a cannula which was placed in the torn popliteal artery. Upon release of the tourniquet, and after dissecting the adventitia off the superior end of the artery, a pulsation was felt in the distal segment. Sulfanilamide powder was dusted into the wound. A Tobruk splint was used. A right paravertebral sympathetic block was done with 2 per cent novocaine. The foot was warm and of good color after the cperation.

Course.—April 10, 1945: Foot warm and of good color but no palpable pulse.

April 11, 1945: Pentothal anesthesia; wound inspected. The popliteal artery was palpated. A definite pulsation was palpable below the anastomosis. Tobruk splint replaced by a plaster hip spica.

April 14, 1945: Good dorsalis pedis pulse palpable.

Case 6.—An American soldier suffering from a penetrating shell fragment wound of the right arm received at noon on April 25, 1945. He was admitted to this hospital at 6:45 P. M. On examination, a penetrating wound of the lower third of the lateral side of the right arm was seen; in the anterior axillary fold the skin had been torn slightly and the foreign body lay in the right pectoral muscles. No pulse was palpable in the right wrist and there was paralysis of the three major nerves. B.P. 120/60; P. 120. The forearm and hand were pale but not cold. The fingers were flexed and stiff. Some capillary circulation was thought to be demonstrable.

Operation.—Captain Edmund R. Taylor and Captain Charles F. Stewart. 10:20 P. M. April 25, 1945. B.P. 116/82; P. 138.

Pathology.—Wound as described, with severe damage to the triceps muscle. A compound comminuted fracture of the midthird of the humerus was revealed. The brachial artery was completely severed just below the origin of the profunda brachial artery. A profuse blood flow came from the distal end of the artery. In addition, the brachial vein was lacerated. The radial nerve had been completely divided and its ends were frayed for 6 cm. on each side. The median nerve was 30 to 50 per cent divided. Although the ulnar nerve was not functioning, it was thought to be anatomically intact. The profunda brachial artery was divided at the site of the fracture.

Procedure.—Débridement of the wound tract and curettage of the fracture ends. An anastomosis was carried out using a segment of the brachial vein and two Vitallium cuffs. After several attempts to insert a 3-mm. cuff at each end, a 2-mm. cuff had to be used at the lower end. No pulsation in the distal segment could be palpated at the termination of the procedure. All nerves in the wound were injected with 2 per cent novocaine; these were the radial, the musculocutaneous, the median and the medial antibrachial cutaneous nerves. The radial nerve ends were each transfixed, though separated, with a fine wire suture. A shoulder spica was applied. During operation the patient received 1,500 cc. of blood.

Course.—5:45 A. M. April 26, 1945: Cervical sympathetic block, right, with 5 cc. of 2 per cent novocaine. Heparin therapy was started by continuous intravenous drip—the patient receiving 20 cc. of heparin solution in 2,000 cc. of diluent in 24 hours.

10:40 A. M. April 27, 1945: Cervical sympathetic block. Fingers less stiff and cold. In sitting position, the hand veins distended and the color of the hands became pinker. The forearm was warmer and less tense.

6:00 P. M. April 28, 1945: Cervical sympathetic block with 20 cc. of 1 per cent novocaine. Resulting Horner's syndrome. Right hand was mottled and cold. The fingertips were quite blue.

April 29, 1945: Cervical sympathetic block. No change in hand.

April 30, 1945: Hand definitely gangrenous with a line of demarcation at the wrist.

Because of the tactical situation, the patient was evacuated to a General Hospital without his hand being amputated, though it was inevitable.

Case 7.—An American soldier with a gunshot wound of the left thigh incurred at 9:20 A. M. June 18, 1945, at Augsburg, Germany, when the patient was accidentally shot by another soldier. On examination, there was a perforating wound of the lower third of the left thigh. No pulse was felt in the foot, but the foot was warm. Motion of the foot was normal.

Operation.—Major Edgar L. Frazell. 1:00 A. M. June 19, 1945.

Pathology.—There had been considerable bleeding into the muscle planes. The superficial femoral artery, about 1.5 cm. proximal to the superior internal geniculate artery, was 50 per cent divided. The proximal and distal lumina were filled with soft blood clot. Both ends bled on removal of the clot.

Procedure.—The artery was approached from the posteromedial aspect, following the tract of the missile. A plastic tube without a vein-lining was used to bridge the defect, as much of the lateral wall was missing. The prosthesis was sutured (ligated) into place, and the lacerated vessel wall was partially approximated. There was a questionable dorsalis pedis pulse after the completion of the operation. Heparin was started: 30 cc. in 1,000 cc. of saline was given in the first 24 hrs. The sciatic nerve was blocked with novocaine.

Course.—Ten hours postoperatively: The left foot was warm and capable of motion. The posterior tibial pulse was definitely palpable. Blood coagulation time 60 minutes plus.

One week postoperatively: The left foot was warm, viable, and the pulses were easily palpable in the foot. Mild wound infection. Secondary closure of the wound was accomplished on the 14th day. Three weeks postoperatively, with wounds healed, palpable pulses and functioning toes, the patient was evacuated to the rear.

GENERAL DISCUSSION.—Seven cases of arterial injury with attempted nonsuture anastomosis have been presented. These are representative vascular injuries, demonstrating division of the artery in three cases, thrombosis in two, and lateral laceration in two. The limbs of three of these patients survived. Two of the satisfactory results were obtained with vein-lined tubes (Cases 3 and 5), while the third was accomplished with an unlined tube of plastic material (Case 7).[29] Of the failures, the limb in one patient (Case 4) was probably not viable at the time of operation. Two other patients had their arteries ligated after failure of efforts to insert the prosthesis. The remaining case was treated with a prosthesis which was certainly too small.

Three successes in seven attempts makes a survival rate of 43 per cent in this group. All seven cases had severe vascular injuries. It is impossible to state which of these limbs might have survived with ligation alone. All three of the satisfactory cases might have retained a viable extremity without restoration of continuity of the vessel. In Case 6, the loss of limb with ligation alone could have been predicted. Because of the inability to predict survival of limb in all cases of interruption of flow in primary artery injuries, it is safer to insert a prosthesis where possible. Comparison of statistics in so small a series is futile, but for general interest the results of our major vascular surgery in the first half of 1945 may be included. (Dr. Andrew F. McBride will publish later a more complete analysis of all of our vascular cases.) Excluding injuries to any except major arteries, and five of the cases described, our records in 1945 show these results:

Artery Ligated	No. of Cases	No. Amputated	% of Limb Survival
Common femoral	1	1	0
Superficial femoral	14	6	57
Popliteal	8	8	0
Axillary	2	1	50
Brachial	8	1	88

In 1944, the leg survived in only 25 per cent of 16 cases of ligation of the superficial femoral artery, and the limbs in 25 per cent of 12 ligated popliteal arteries survived.

Breaking our seven cases down into location and result, we have:

Artery Involved	No. of Cases	No. Amputated	% of Limb Survival
Common femoral	1	1	0
Superficial femoral	3	1	67
Popliteal	2	1	50
Brachial	1	1	0

When the prosthesis cases are included with the general data for the half-year period, the results are:

Artery Involved	No. of Cases	No. Amputated	% of Limb Survival
Common femoral	2	2	0
Superficial femoral	16	6	63
Popliteal	9	8	11
Axillary	2	1	50
Brachial	9	2	78

Cases 1 and 2 resulted in amputation. Neither of these cases had a prosthesis inserted, merely attempted. Since they were done in 1944, they are not included in the last table. Inclusion of the prosthesis cases in the statistics for 1945 raises the survival of limbs in superficial femoral artery cases from 57 to 63 per cent, and in the popliteal group from 0 to 11 per cent. Brachial artery statistics fall from 88 to 78 per cent, with the failure of one prosthesis case.

Our difficulties with the nonsuture vein graft technic become apparent from a study of the cases presented. A working knowledge of the method from previous experience or experimental work would have been of great help to us. The crucial and most difficult step in the procedure is the actual insertion of the prosthesis into the artery. Failure in Cases 1 and 2 was due to this factor. It is believed that failure in Case 6 was due to the use of too small a prosthesis. Blakemore[26] recommends the following technic for inserting the prosthesis: (1) Mosquito clamps are attached to the artery end at three or four points. The bite of the clamp includes all layers of the arterial wall for a distance of 1 to 2 mm. Care must be exercised not to tear the thickened, contracted arterial wall. (2) Assistants hold the mosquito clamps, slightly everting the edges of the artery. (3) The operator holds the bare rim of the vein-covered metal cuff in a hemostat. While the loose end is held taut to thin-out the vein, the operator pushes the prosthesis into the end of the artery. Doctor Blakemore recommends that steady constant pressure for a minute or more be exerted while inserting the cuff. This exertion is necessary to overcome the spasm of the arterial wall. Blakemore and Lord have observed a sudden release of spasm during this maneuver, allowing the cuff to slip into the artery. It can be compared to overcoming spasm by steady traction in reducing a dislocated shoulder.[26] In some of our cases, seen long after injury, the arterial spasm seemed almost irreversible. Use of too small a prosthesis, or tearing of the artery wall was apt to result in such cases. To overcome the strong spasm of an artery, dilatation with a small speculum might be of value. Such a speculum should be inserted only 2 to 3 mm. lest the intima be damaged beyond the distance of contact with the prosthesis. The speculum should be used as a very gradual dilator, and should be removed before attempting to insert the prosthesis. Certainly, in the light of present knowledge, preoperative nerve blocks and periarterial stripping[6, 8, 10] should be used in an attempt to dilate the affected artery.

Anastomosis by the described technic requires the lumen of the artery to be impinged upon, or narrowed by, three foreign layers of material. These are the Vitallium tube and two layers of the vein graft. When the vein segment is too large in circumference for the caliber of the cuffs, there will be a certain amount of pouting of the vein wall into the lumen of the prosthesis. This may be enough to be obstructing. To remedy this fault, a vein segment of the appropriate caliber must be used. It should be pulled taut in all axes. A piece of vein that is too small in caliber is equally unsatisfactory. In Case 3 a segment of saphenous vein was prepared for a superficial femoral anastomosis. When taken, this segment was in spasm, and could not be dilated or relaxed enough to provide an adequate lumen. A femoral vein graft was finally used. The required length of any vein transplant is surprisingly great. Doctor Blakemore[26] has arrived at this method of estimating the length of the vein segment needed: (1) The severed arterial ends are grasped with clamps, as described above, and drawn together with "physiologic" tension (*i.e.*, the degree of tension which would seem compatible with the normal elasticity of the vessel). (2) The resulting gap between the ends of the artery is then measured. (3) To the measured distance is added 2 cm. to allow for the length of the vein graft investing the cuffs. This computation gives the total length of the vein segment needed. The tension exerted on the inserted vein graft by the normal elastic retraction of the arterial ends decreases the opportunity for pouting and redundancy of the vein graft within the cuffs. Care, of course, must be exercised to install the vein graft in the reverse of its normal axis, allowing the blood to pass any valve that might be in the segment. A functioning valve would doom the procedure.

Extrusion of the prosthesis from the arterial lumen was the reason for failure in Case 2. The causes of this accident are several. First, as noted above, the introduction of this type of prosthesis considerably reduces the area of the arterial lumen, and does so abruptly. Naturally, the blood pressure against this partially obstructing device is great. Added factors, such as pouting of the vein and too small a prosthesis, may increase this hazard. Secondly, the low, rounded ridges on the cuffs may be inadequate to hold the ligature. It would seem preferable if these ridges, while low, could be sharply angulated on the side against which the ligature would rest. Finally, ligation is not sufficiently tight when such an accident occurs. The use of the surgeon's knot, when tying over the inelastic cuff, would seem to be the most dependable procedure.[26]

Mann, *et al.*,[18] report that the internal diameter of an artery may be reduced 70 per cent before there is a 50 per cent reduction in blood flow. What the effects of such a reduction of flow are on coagulation, and on the function of the part, is only conjecture. Thrombosis is a threat in all vascular surgery. The eddying of the stream of blood even around an intima-lined connection probably increases the likelihood of thrombus formation. This would be particularly true when the prosthesis is small. Careless handling of the vein segment and of the arterial ends increases the danger of coagulation. The utmost delicacy must be used in handling these structures. Heparin, or dicoumarol, should be used in all cases.[23, 25] Heparin did not become available to our hospital until the Spring of 1945, and then in only very limited quantities. As a result, only the last two cases in our series had the benefit of the drug. Its use in such a small group cannot be adequately evaluated. Undoubtedly an anticoagulant offers far greater chance of success. Now that the subcutaneous administration of heparin in Pitkin's menstruum has been developed,[25] a great chore has been removed from the postoperative care.

Gas gangrene and hemorrhage, the other principal complications, have been mentioned. Blakemore, and his colleagues, have not been troubled by secondary bleeding. Their technic, as shown by excised specimens, leads to firm union between artery and vein segments.

The time between injury and operation will doubtless seem long to many, but these were the existing conditions. At times the volume of work was overwhelming. During one advance, the time from the patient's admission until he could be operated upon (the "surgical-lag") was 54 hours! None of the cases presented was treated during that time.

The composition of the tube used in Case 7 is not known. It has been suggested that it may have been a polyvinyl acetate plastic. It seems to have been highly satisfactory. The tube was flexible; in hot water it was easily malleable and ridges were moulded on it before its use. The material was almost completely transparent, slightly opalescent.[29] Of course, the conditions for its use were good, for the vessel was incompletely divided and was partially sutured. What if the arterial ends are simply pulled over the ends of the tube and ligated in distraction? Does not the ligature cause necrosis and cut through the vessel wall leading to late hemorrhage? Would this not be particularly to be feared in a gaping wound where the prosthesis had little outside support? Temporary use of such a tube is plausible. That is the way in which Tuffier's tube came to be used in the last war,[3, 4] and the Canadians in this war were using a glass tube in the same way.[19, 29] Perhaps the plastic tube has further possibilities where anticoagulants are used in conjunction. It is quicker and easier to insert, and has not the necessary encroachment upon its lumen by a thickness of vein. Certainly, however, the vein-lined tube is more physiologic, and, when the technical difficulties of insertion are lessened, approaches the ideal alluded to by Leriche and Werquin.[8]

CONCLUSIONS

The nonsuture method offers new hope in the treatment of vascular injuries, and should be attempted when the limb is in danger of ischemic gangrene.

An outline of ideal treatment of a case with a lacerated, divided or thrombosed artery might be as follows:

I. Preoperative:

1. Shock treatment: morphine to allay pain. Papaverine is theoretically good in vascular cases, but not without danger.[24] Transfusions with type specific blood to restore blood volume; this should be controlled by hematocrits, and blood and plasma specific gravity determinations.

2. Prophylactic treatment: antitetanic toxoid or serum with polyvalent gas gangrene serum if the conditions indicate it. Penicillin should be used to counteract wound infection.

3. A sympathetic nerve block should be done on the affected side.

II. Operation:

1. Wide and thorough débridement of the wound.

2. Clean isolation of the vessels involved and temporary local occlusion of the artery with rubber guarded clamps.

3. A cursory examination of the collateral circulation which will give and idea of its ability to support the limb. (See page 3).

4. Preparation of the prosthesis of adequate size from the adjacent vein, being sure to reverse it and to keep one end marked. (Use of a preserved vein transplant would facilitate and speed the procedure.[12])

5. Débridement of the ends of the artery and periarterial stripping one inch away from the divided ends.

6. Removal of all clot from the vessel ends and irrigation of them with a heparin-saline solution.

7. Insertion of the largest-sized prosthesis that can be used, starting the procedure with the upper end of the artery, and releasing the upper clamp to be sure of the flow through the prosthesis.

8. Firm double ligation of the arterial ends over the prosthesis with heavy silk.

9. Release of the occluding clamps.

10. Closure of the vascular sheath and wound whenever possible.

11. Local block of the nerves of the involved limb may prove helpful.

III. Postoperative Care:

1. The blood volume should be kept up with whole blood transfusions as indicated.

2. Penicillin, or chemotherapy,[13] should be continued.

3. The patient should be heparinized by subcutaneous injection of the drug in Pitkin's menstruum.[20, 21, 25] Heparinization includes controlling the coagulation time by adequate measures.

4. Repeated nerve blocks should be given as long as the state of the circulation is in doubt.

5. The extremity should be splinted in a neutral position for ten to 14 days.[6, 9]

6. The limb should be maintained at a subnormal temperature.[22]

SUMMARY

(1) Seven cases with gunshot or shell fragment wounds of major arteries are presented. In all of these vessels a nonsuture anastomosis was attempted with varying results.

(2) A discussion of technical difficulties and possible improvements follows.

(3) The paper is concluded with a plan of ideal treatment of such cases.

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