Peripheral Arterial Injuries in Infants and Children

JOHN J. WHITE, M.D., JAMES L. TALBERT, M.D.,
J. ALEX HALLER, JR., M.D.

From the Division of Pediatric Surgery of the Department of Surgery, The Johns Hopkins University School of Medicine and Hospital, Baltimore, Maryland 21205

THE MANAGEMENT of peripheral arterial injuries has become standardized in recent years as a result of extensive military and civilian experience. With the development of pediatric surgical referral centers and the use of more refined diagnostic methods, there is an increasing awareness of these injuries in infants and children.

Arterial injuries occur more frequently in infants and children than is generally realized. In addition, the types of injuries are peculiar to this age group. We have broadly categorized three basic patterns of peripheral arterial injuries seen in The Johns Hopkins Hospital:

(1) Injuries associated with trauma to an extremity;

(2) Injuries associated with diagnostic catheterization of arteries;

(3) Injuries associated with needling an extremity for either diagnostic sampling or therapeutic injection.

This paper will present our recent experience with these patterns of arterial injury and describe their management by pertinent case presentations. The prevention of many of these injuries, especially those which occur in hospitals, will be emphasized. The immediate and possible late consequences of arterial injury in a rapidly growing limb with a blocked major artery will be discussed.

1. Arterial Injuries Associated with Trauma to an Extremity

Peripheral vascular injuries result, in general, from penetrating injuries and fractures. Shotgun injuries produce the most extensive damage and provide a formidable challenge to reconstruction.

Case Reports

Case 1. JHH #112 17 02. A 5-year-old girl sustained an accidental 12-gauge shotgun wound of the left axilla, and was transferred to The Johns Hopkins Hospital 4 hours later. A 10 cm. × 10 cm. wound of entrance was present in the left axilla with buckshot scattered over her face and upper trunk. The arm was cold and no branchial, radial or ulnar pulses could be palpated. There were motor and sensory deficits in the distribution of the median and radial nerves; ulnar nerve function was intact. Prompt hemodynamic stabilization was achieved by blood transfusion and the patient was taken to the operating room for exploration. Massive soft tissue injury was found in the axilla with complete division of the axillary artery and vein, and the median nerve, with an approximately 4 cm. deficit in the vessels. The radial nerve was severely contused but, for the most part, intact; the ulnar nerve was undamaged. The wound was thoroughly debrided. After further exploration confirmed that the cephalic vein was intact, the proximal axillary vein was excised, reversed and used as a vein graft to bridge the 4 cm. arterial defect. The contused ends of the median nerve were excised and the perineurium was reapproximated. The skin was closed primarily with drainage and a Velpeau dressing applied.

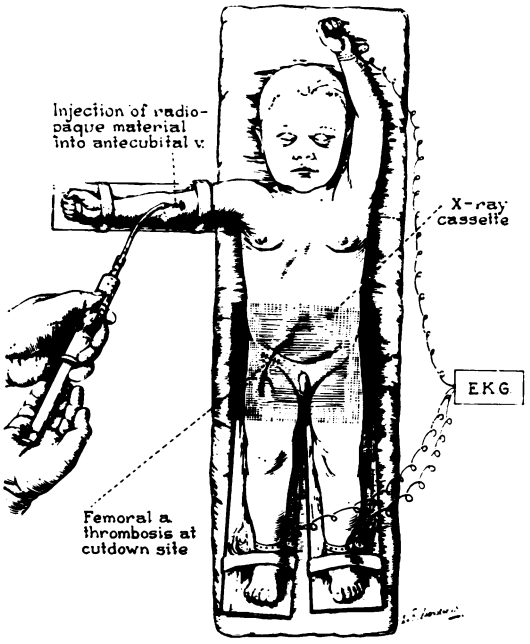

FIG. 1. Technic of intravenous arteriography. Contrast medium is rapidly instilled into an antecubital vein through a wide bore cannula. Serial roentgenograms of the area in question will demonstrate the status of vascular flow.

There was immediate reconstitution of circulation to the arm with only slight edema. The wound healed primarily. Most of the radial nerve function has returned. Because there was no return of median nerve function, she underwent a ring finger sublimis to opponens of thumb tendon transfer 1 year later with good results.

Comment: With the cephalic vein portion of the dual venous drainage of the arm intact, the axillary vein could be used as a reversed graft to bridge the arterial defect. Thorough debridement allowed primary closure of the wound.

Among the more occult penetrating injuries are those caused by falls through glass doors or windows. While it is generally appreciated that knife blades can cause critical damage through deep puncture, there appears to be less awareness that pieces of broken glass can likewise injure deeper structures. In addition, the momentum and torsion associated with falling impart an added force of injury. A major source of injury among children are glass storm doors. Recently, we treated five patients with neurovascular injuries of the upper arm. All were caused by falls through locked storm doors. All had transection of the upper brachial or distal axillary artery and associated nerve damage.

Case 2. JHH #123 86 73. An 8-year-old boy, running to join his companions, "straight-armed" a storm door expecting it to open. The door latch was fastened and his outstretched hand broke the glass. His momentum carried his arm through the glass and as he fell, a shard of broken glass pierced the medial aspect of his upper arm. There was minimal bleeding. His local physician inspected the small 1 cm. wound of entry and merely applied a dressing. Because of coldness, and pain and numbness of his fingers and hand, he was brought by his parents to The Johns Hopkins Hospital about 6 hours later. The arm was pulseless below the axillary artery, cold and dusky. Radial nerve motor and sensory functions were absent, and there was weakness of ulnar nerve motor function. At exploration, reanastomoses of a completely severed brachial artery, both brachial and cephalic veins, and radial nerve were accomplished. A partial division of the ulnar nerve was also repaired. Postoperatively, there was good circulation to the hand and no significant edema. Radial nerve function appears to be returning and there is good ulnar nerve function.

Comment: A glass shard may be more lethal than a knife blade, and a high index of suspicion must be maintained. Inasmuch as no one has yet devised a means of slowing down active children, more attention must be directed to the glass storm doors themselves. Installation of bars in front of the plate glass and designing storm doors with semipermanent screening might abolish this type of injury. Shatter-proof glass "pop-out" storm doors, akin to automobile safety windshields, may be another approach.

Peripheral arterial injury must be suspected whenever an extremity, distal to a fracture, is cold and pulseless. While the fracturing force may cause stretching and spasm of a nearby artery, arterial flow

should return with reduction of the fracture. If pulsatile flow does not return, occlusion by thrombus or entrapment by the fracture are very likely. In an area of large arteries and particularly where there is less collateral flow, early exploration may be advisable, especially if signs of ischemic pain or motor or sensory loss develop.

Case 3. JHH #126 10 51. A 4-year-old girl sustained a comminuted supracondylar fracture. When seen 1 hour later in the emergency room, no radial pulse was present. Despite immediate reduction and application of Dunlop's traction, the circulatory status was not improved. During the next 24 hours, decreased movement and numbness of the fingers supervened. At exploration, the brachial artery was released from its trapped position between the fracture fragments and considerable propagated thrombus removed. Postoperatively, no radial pulse returned, but there was evidence of good collateral circulation and no ischemic signs. Good forearm and hand function is returning with active physiotherapy.

Comment: There are differing opinions regarding a pulseless extremity following supracondylar fractures. Some orthopedic surgeons feel that arterial spasm is an important factor which will resolve by itself, and that most pulseless arms have adequate collateral circulation around a fracture so that few ischemic tragedies develop. Others argue that all traumatized arteries should be explored if the distal pulse does not return shortly after reduction of the fracture. The high incidence of amputations following peripheral arterial ligation for traumatic injury in World War II [2] and the low incidence following arterial repair in the Korean conflict,[3] is strong testimony in favor of exploration. Thrombosis with sufficient propagation to interfere with collateral circulation must be suspected when ischemic signs are present in a pulseless extremity following a fracture. Immediate exploration and thrombectomy, occasionally with graft replacement, may be necessary to prevent a Volkman's ischemic contracture.

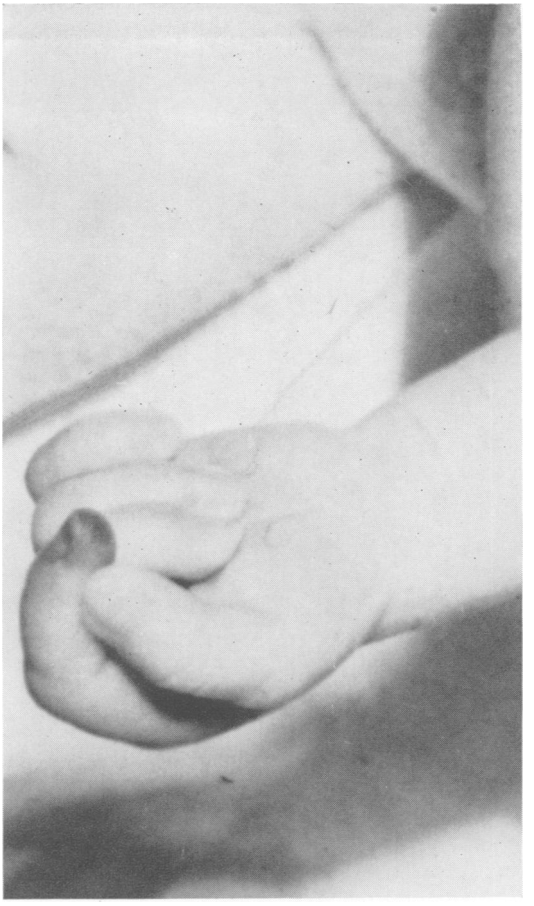

FIG. 2. Gangrene of index finger tip post cardiac catheterization, presumably from thrombosis and embolization.

2. Injuries Associated with Diagnostic Catheterization of Arteries

The refinement of retrograde arterial catheterization for arteriography or diagnostic heart studies has broadened investigative vistas and facilitated proper and timely therapy. While cardiac arrhythmias, perforation with resulting tamponade, fracture of catheter or leader with or without embolization of the fragment and aortic perforations have been reported, little attention has hitherto been paid to thrombosis at the arteriotomy site. A recent report from this hospital by Cahill *et al.*[1] has called attention to the frequency of this

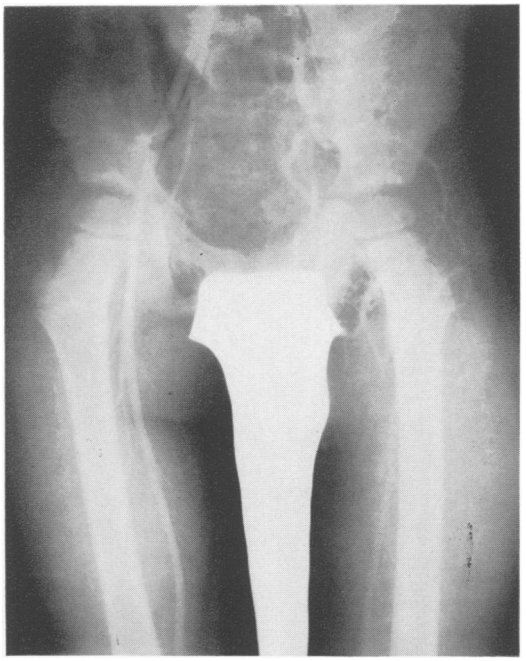

FIG. 3. Intravenous arteriogram 1 year following arteriotomy for cardiac catheterization (Patient 7). A complete external iliac artery occlusion is present with collateral flow from the internal iliac artery. This boy demonstrates underdevelopment of this leg in both length and mass.

complication, and the significant consequences which may result. This experience demonstrated that arterial thrombosis is a special hazard following retrograde arterial catheterization in infants and children, and that careful assessment must be made of peripheral circulation postcatheterization. Persistent absence of pulses more than 3 hours following catheterization indicated arterial thrombosis; a presumptive diagnosis of *arterial spasm* under these circumstances always proved erroneous. We have found the oscillometer to be valuable in assessing pulses and circulation in the chubby and uncooperative infant or child.

A modified technic of venous arteriography has been described,[1] which delineates true thrombosis from angiospasm, and allows accurate followup assessment after thrombectomy (Fig. 1). Further arterial injury can be avoided by this technic. Arteriography as well as exploration have repeatedly confirmed the presence of thrombosis in any child who has had a pulseless extremity more than 3 hours following arteriotomy.

From July 1966 to September 1967, 46 infant arteriotomies or needle punctures of exposed arteries were carried out on the Pediatric Cardiology Service of The Johns Hopkins Hospital. There were 13 episodes of thrombosis (28%). Despite this high thrombosis rate, which is typical of the few series so analyzed,[8, 9, 10] only five serious complications have been recognized over the past 4 years.

Case 4. JHH #109 95 79. A 3-month-old infant with cyanotic congenital heart disease was evaluated by retrograde femoral arterial cardiac catheterization. The patient proved to have levocardia with transposition of the great vessels and septal defects. On the day following catheterization, the right lower leg was noted to be cool with diminished pulsations. The ischemic symptoms progressed, and the patient was readmitted 7 days later with blackening and swelling of the leg. Because of progression of gangrene an above the knees amputation was necessary. Since this time, the little boy has progressed as satisfactorily as his cardiac malformations will allow. He has been fitted with a prosthesis, and is learning to walk.

Case 5. JHH #96 65 08. A 3-year-old boy underwent retrograde femoral arteriotomy in the course of cardiac catheterization. Edema and a painful foot with numbness and inability to dorsiflex his foot developed afterward. Thrombectomy was carried out about 24 hours later with return of good pedal pulses; there was, however, a residual foot weakness which was persistent on his last followup visit 6 months later.

Case 6. JHH #122 98 25. A 7-year-old girl had recurrent pneumonitis with a left lower lobe lung lesion containing several air fluid levels. Retrograde femoral artery catheterization confirmed direct aortic arterial branches to this segment of lung and confirmed the presumptive diagnosis of intralobar sequestration of the lung. Postcatheterization, she had a cold, pulseless and painful leg. Exploration confirmed thromboses of superficial and common femoral arteries, which were removed using Fogarty catheters. Following operation, her leg was warm, without pain, and faint pulses were palpable.

Comment: These three cases demonstrate the range of clinical presentation of

the few significant arterial thromboses. There is a spread from early symptomatology of motor and sensory loss through persistent ischemic damage to frank gangrene. The fourth case involved gangrene of a finger tip following brachial arteriotomy and retrograde catheterization (Fig. 2).

Any cold and pulseless extremity in which there is impaired capillary filling indicative of poor collateral flow should be suspected of clinically significant thrombosis. Inasmuch as pain, numbness and impaired motor function are difficult to elicit in an infant and young child, we favor early exploration and thrombectomy in the presence of strong clinical suspicion of thrombosis, which can be confirmed by intravenous arteriography if necessary.

Over and above the question of immediate tissue viability, remains the unanswered question regarding longterm effect of main arterial thrombus on growth of an extremity and development of claudication later. One child who had retrograde arteriotomy 1½ years ago, may now be demonstrating impaired growth in the affected leg.

Case 7. JHH #111 09 89. A 3-year-old boy was examined for airway obstruction due to greatly enlarged tonsils, and for increasing somnolence from CO_2 retention. Cardiac catheterization, performed via the left femoral artery and vein, demonstrated increased right heart pressures. Postcatheterization, he had a pulseless, cold limb which he would not move. After 1 week, he could bear weight on the leg, but walked with a decided limp. Adenoidectomy relieved the problem of airway obstruction. At followup 1 year later, the circumference of the left thigh was 2 cm. less than the right and the left calf 1 cm. less than the other leg. The left leg was 1 cm. shorter as measured by radiographic scanogram, but the limp had disappeared. An intravenous arteriogram demonstrated external iliac artery occlusion with collaterals to the leg from the internal iliac artery (Figure 3).

Comment: The syndrome of chronic adenoidal airway obstruction with cor pulmonale and CO_2 retention has previously been documented.[5] The postcatheterization arterial thrombus in this boy was undoubtedly an extensive one as evidenced by the pain and inability to walk. After 1 year of followup, there is evidence of early underdevelopment of the involved leg. Whether he will get sufficient collateral circulation to allow full development remains to be seen.

We have previously demonstrated the value of intravenous arteriography in evaluating a pulseless extremity.[1] In a series of pulseless postarteriotomy limbs, arteriography and exploration demonstrated thromboses to be present in all limbs in which a distal pulse did not return within 3 hours. Arterial thromboses may occur in the absence of arterial puncture. Thromboses were present in three femoral arteries which had been manipulated in the course of retrograde femoral vein right heart catheterizations. Pulsatile flow was returned in 60% of cases explored, and, in the others, removal of propagated thrombus was believed to be helpful in assuring patency of the collateral vessels. Exploration affords an opportunity to restore pulsatile flow and to open up collateral circulation, which may be important in the growth and development of the extremity, as suggested by Patient #7. In short, we believe that infants and young children with peripheral arterial obstruction should be explored and an attempt made to reestablish blood flow. An arteriogram should be performed if the diagnosis is in doubt because early exploration is necessary to prevent some of the serious complications which we have demonstrated.

To decrease the incidence of thrombosis following arteriotomy in cardiac catheterizations, Izukawa, Varghese and Rowe[4] have recently recommended the use of a Seldinger arterial catheterization technic on a surgically exposed artery, systemic heparinization and topical papaverine. Between March 1967 and September 1967, 36 arteriotomies or needle punctures of exposed arteries were performed with this

modification. Only three thromboses occurred (8%). This is a significant reduction from the previously noted 28% incidence.

3. Arterial Injuries Associated with Needling an Extremity

Many thousands of percutaneous injections are carried out daily in medical centers mainly for drug administration, but also for venous or arterial blood sampling. An infrequent but definite number of complications following intramuscular drug administration in several sites has led many pediatric centers to adopt the lateral thigh as the preferred site for intramuscular injections. This technic has significantly reduced the number of complications, but careful attention must still be paid to certain details.

Case 8. JHH #63 89 89. A 3-month-old girl with pneumococcal pneumonia was injected with 600,000 u of procaine penicillin in the muscles of the left mid lateral thigh. When the mother returned the baby to the outpatient department 20 hours later, a painful and cyanotic lower extremity was present. There was no toe movement and numbness to pinprick was present. No pulses could be palpated distal to the common femoral artery. An intravenous arteriogram demonstrated a complete block in the mid superficial femoral artery. Figure 4A. Exploration revealed a 1 cm. segment completely occluded by thrombus. Ecchymosis of the surrounding tissues of the adductor canal (Hunter's canal) coupled with a lack of evidence for direct needling of the artery argued for extraluminal occlusion secondary to instillation of penicillin into the closed space of the canal. Thrombectomy restored excellent distal blood flow, but sufficient damage to the toes had already ensued to necessitate amputation of the lateral four toes 2 weeks later. Figure 4B.

Comment: It has been demonstrated[7] that the standard 1½ inch long needle can completely traverse an infant's thigh. The substitution of 1 inch needles for all infant intramuscular injections, and use of the upper, outer lateral thigh as the only injection site can prevent these tragedies.

Diagnostic venipuncture may result in thrombosis, but is seldom of consequence because of the vast network of venous collaterals. Thrombosis following arterial blood sampling occurs a small number of times, especially in children and rarely propagates sufficiently to interfere with collateral blood supply and produce ischemia. On the other hand, complications may develop from the puncture wound in the artery, itself.

Case 9. JHH #102 61 91. At the age of 9 months, this girl underwent right femoral vein, right heart catheterization in the course of investigation of a small ventricular septal defect and mild pulmonic stenosis. Arterial blood gases were measured in samples obtained via arterial puncture of the opposite femoral artery. Over the following three years, she was constantly in borderline heart failure, with a pulse always exceeding 120/minute, and required digoxin up to 15 μg. /Kg./day. Her heart disease seemed stable although there was an increase in cardio-thoracic ratio to 69% during this time. At the age of 4½ years, a thrill was noted on palpating the left groin. The left leg was 2 cm. longer than the right, and the proximal fibular epiphysis was present on the left and not on the right. Exploration with operative arteriography (Figure 5A) demonstrated a large arteriovenous fistula between the deep femoral vein and the profunda femoris artery. The needle must have been inserted in a lateral and downward direction, penetrating the femoral vein before puncturing the profunda artery for the blood sample. On extracting the needle, a direct arteriovenous fistula was formed. The fistula was ligated and divided without sacrificing either vessel (Figure 5B). Over the next few months, her pulse rate gradually returned to normal, her cardiac failure cleared and digoxin was discontinued.

Case 10. JHH #91 15 13. A 4-year-old girl underwent basilic vein right heart catheterization and femoral arterial puncture for blood gas analysis in the investigation of a patent ductus arteriosus. One year later, she required excision of a false aneurysm at the puncture site, with good postoperative blood flow to the leg.

Comment: Improper sealing of arterial puncture wounds may lead either to arterial thrombosis or to false aneurysms or "pulsating hematomas." Careful arterial

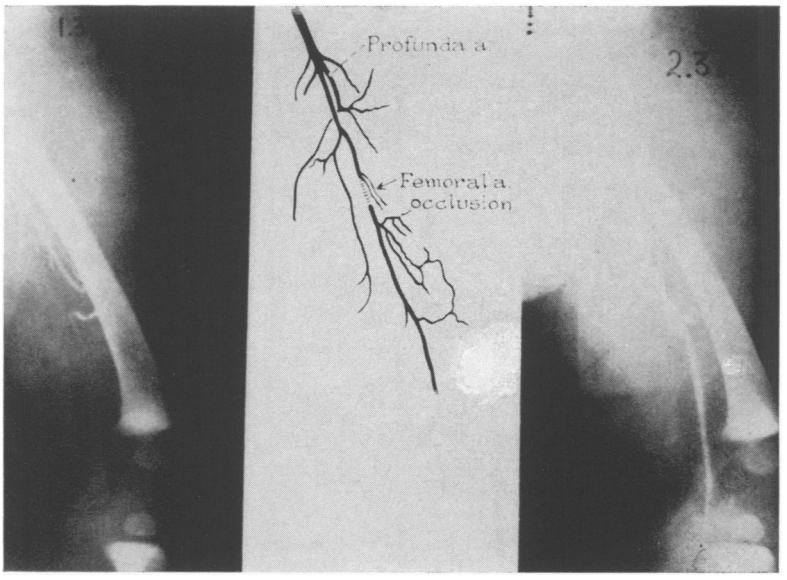

FIG. 4A. Complete occlusion of femoral artery in the adductor canal following penicillin injection in a 3-month girl (Patient 8) demonstrated by intravenous arteriogram.

puncture directly over the pulsating artery can help prevent inadvertent needling of accompanying veins and arteriovenous fistula formation. On withdrawing the needle, sufficient pressure must be maintained for at least 5 minutes by a knowledgeable person to allow complete sealing of the arteriopuncture. Sufficient pressure to shut off distal circulation encourages thrombosis at the puncture site. Ideally, enough pressure should be maintained over the point of entry of the needle into the artery to prevent bleeding but allow pulsatile flow under the finger.

Discussion

The cases presented demonstrate the scope and occasional tragedy of peripheral arterial injuries which we have encountered in a pediatric age group over the past few years. This experience does not appear to be limited to our Children's Medical and Surgical Center. While the management of adult arterial injuries is familiar to most surgeons, these injuries in children appear to have been overlooked because their frequency was unsuspected, and their occurrence is peculiar to this age group and more difficult to evaluate.

FIG. 4B. Gangrene of toes necessitated amputation of the lateral four toes.

The traumatic peripheral vascular injuries from automobile accidents, shootings and knife wounds do not seem to occur as frequently in children as in more violently active elders. We have been impressed, however, by the large number of injuries from falls through plate glass, particularly glass storm doors. The deep injuries from these shards of glass may be even more extensive than knife wounds, due to the force of the accompanying fall. The pediatric age group is not commonly involved in hip and knee fractures or dislocations which are so commonly associated with vascular injuries in adults. Supracondylar fractures, however, are common pediatric orthopedic

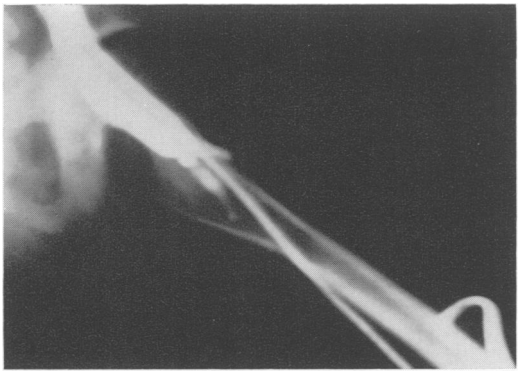

FIG. 5A. Arteriovenous fistula between profunda femoris artery and deep femoral vein following arterial puncture for blood gas analysis (Patient 9). Contrast medium in operative arteriogram flows mainly through the fistula into the distended proximal vein.

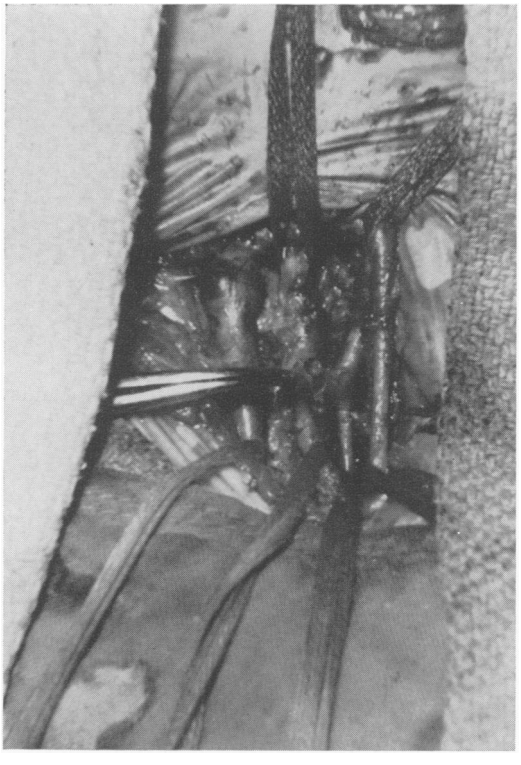

FIG. 5B. The fistulous connection at operation is indicated by the instrument tip.

problems, and are frequently associated with arterial injuries.

Thromboses resulting from diagnostic arteriotomies occur far more commonly in children than in adults. The smaller vessel, greater propensity to vasoconstriction, and significant incidence of polycythemia and sludging of the blood secondary to cyanotic heart disease all play roles in this heightened incidence. Finally, the small size of peripheral arteries necessitates the use of larger arteries, such as the femoral, for diagnostic arterial puncture in infants. Thromboses, arteriovenous fistulas and false aneurysms may develop due to complications in needling these small vessels. If these problems occur, they are more significant in these more proximal arteries.

Many of the arterial injuries presented might have been prevented by more care and foresight. These iatrogenic injuries arose in the course of essential diagnostic or therapeutic maneuvers and were the prices paid for the rewards of the procedures. Although a necessary evil, they may be tragic as we have demonstrated. Particular attention should be paid to the various details outlined in the case commentaries, and complacency must not be allowed to interfere with improvements in technic.

Principles of vascular repair have become standardized, but in the small vessels of young children, the technic must be meticulous. General anesthesia is usually essential, and the fine instruments of microsurgery prove advantageous. We have found a magnifying loupe very useful and prefer one with a 2 times magnification and a focal depth of about 12 to 14 inches.

Once arterial injury and obstruction have occurred, we believe that operative exploration and attempted reconstitution of flow is the ideal form of management. A pulseless distal extremity and an expanding hematoma following a penetrating injury are absolute indications for urgent investigation. Nerve, tendon and bone injuries which frequently accompany vascular problems should be handled at the same time. Delay may prove disastrous; if there is significant doubt regarding injury

or thrombosis, prompt arteriography permits proper diagnosis and treatment. Restoration of blood flow may be vital for the proper growth and development of a child's extremity.

Summary

Peripheral arterial injuries in infants and children occur more frequently than generally recognized. Arterial interruption may lead to ischemia and frank gangrene or fistula and aneurysm formation. Three groups of cases have been presented which illustrate peculiar vascular problems in a pediatric age group. They are:

(1) Trauma to an extremity, particularly from falls through glass doors and supracondylar fractures;

(2) Retrograde arteriotomy for diagnostic catheterization;

(3) Needling of an extremity for injections or diagnostic sampling.

Particular care and attention to details can minimize the complications which can result from these diagnostic and therapeutic procedures. For example, improved technic has reduced the incidence of thrombosis following arteriotomy for cardiac catheterization from 28% to 8%. Several serious complications have been documented in this report. If there is any doubt about arterial injury, intravenous arteriography will usually clarify questionable clinical manifestations. If there is arterial interruption or thrombosis, exploration and re-establishment of blood flow are of vital importance in young children.

References

1. Cahill, J. L., Talbert, J. L., Otteson, O. E., Rowe, R. D. and Haller, J. A., Jr.: Arterial Complications Following Cardiac Catheterization in Infants and Children. J. Pediat. Surg., 2:134, 1967.
2. DeBakey, M. E. and Simeone, F. A.: Battle Injuries of the Arteries in World War II. An Analysis of 2,471 Cases. Ann. Surg., 123: 534, 1946.
3. Hughes, C. W.: Arterial Repair During the Korean War. Ann. Surg., 147:555, 1958.
4. Izukawa, T., Varghese, P. J. and Rowe, R. D.: Topical Papaverine in Arteriotomies in Infants and Children. Effect on Incidence of Thromboses. Pediatrics, in press.
5. Luke, M. J., Mehrizi, A., Folger, G. M., Jr. and Rowe, R. D.: Chronic Nasopharyngeal Obstruction as a Cause of Cardiomegaly, Cor Pulmonale and Pulmonary Edema. Pediatrics, 37:762, 1966.
6. Mortensen, J. D.: Clinical Sequellae from Arterial Needle Puncture, Cannulation and Incision. Circulation, 35:1118, 1967.
7. Talbert, J. L., Haslam, R. H. A. and Haller, J. A., Jr.: Gangrene of the Foot Following Intramuscular Injection in the Lateral Thigh: A Case Report with Recommendations for Prevention. J. of Pediat., 70:110, 1967.
8. Vengsarker, A. S. and Swan, H. J. C.: Arteriotomy for Cardiac Catheterization and Angiocardiography in Infants and Children. Proc. Mayo Clin., 37:619, 1962.
9. Vlad, P., Hohn, A. R. and Lambert, E. C.: Retrograde Arterial Catheterization of the Left Heart. Experience with 500 Infants and Children. Circulation, 29:787, 1964.
10. Voci, G. and Hamer, N. A. J.: Retrograde Arterial Catheterization of the Left Ventricle. Amer. J. Cardiol., 5:493, 1960.

Discussion

Dr. Robert P. Kelly, Jr. (Atlanta): This is a familiar problem to the orthopedist, and we believe this injury occurs more often than is recognized. My first encounter with this was not with a child but with the 18-year-old son of a physician who had disclocated his elbow about 18 hours earlier. There was no severance, but there was thrombosis at the bifurcation of the brachial artery. The following morning after excision there was little temperature difference in the boy's hands and good function.

A number of papers have reported good results with children who had complete interruption of the brachial artery in connection with supracondylar fractures. This is attributed to the rich collateral system around the elbow. We observed these children and studied their ability to extend their fingers voluntarily. If they protested of pain when an attempt was made to extend the fingers passively, we knew something had to be done. Orthopedically, many of them will do well without repair, but certainly some will need the intervention of vascular surgery.