Experience with Iatrogenic Pediatric Vascular Injuries

Incidence, Etiology, Management, and Results

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During a 32-month period, 79 extremities in 76 children (age 1 day–13 years, mean = 31 months) were evaluated with regard to iatrogenic vascular injuries. Prospectively, 42 children were studied pre- and post-cardiac catherization. Ten of these children sustained vascular injuries (incidence = 24%). Thirty-four additional children were referred because of 35 iatrogenic vascular injuries as a result of transfemoral cardiac catheterization (n = 20), umbilical artery catheterization (n = 10), or recent surgery (n = 5). All 45 injuries were evaluated by lower extemity segmental Doppler pressure measurements in addition to routine physical examination at the time of injury and at frequent follow-up. An ankle/brachial pressure index (ABI) < 0.9 was considered abnormal. Selected children (ABI < 0.9 for >30 days) underwent orthoroentgenograms to assess limb growth. The average ABI immediately following injury was 0.34 +/− 0.33. Thirty-four injuries were treated nonoperatively. Twelve injuries were excluded from further study due to death (n = 7) or being lost to follow-yp (n = 5). A return of ABI to normal was seen from 1 day to 2 years in 93% of children treated with heparin (n = 14) compared to 63% of children who were simply observed (n = 8) ($p < 0.10$). The initial severity of ischemia did not correlate with the subsequent rate of improvement. Only patients with absent femoral pulses were selected for operative intervention, which consisted of aortic thrombectomy (n = 2), femorofemoral bypass (n = 2), femoral artery patch angioplasty (n = 1), or femoral artery thrombectomy (n = 7) with no mortality. Nine patients had immediate return of a normal ABI after surgery. A delayed return of ABI to normal occurred in the other two. Nine per cent of surgically treated children and 23% of nonsurgically treated children developed leg length discrepancies (0.5–3.0 cm) as a result of ischemia lasting >30 days. Overall, 91% of the children in this series eventually regained normal circulation following injury and no child lost a limb. This study indicates that iatrogenic pediatric vascular injuries are common and can result in significant limb growth impairment. Immediate operative intervention is highly successful when the injury is proximal to the common femoral artery bifurcation and avoids the prolonged ischemia seen with nonoperative therapy. For more distal occlusions, heparin therapy provides better results than simple observation. Although therapeutic intervention for these injuries is generally successful, a limb length discrepancy rate of 14% mandates that indications for invasive vascular monitoring and diagnostic procedures be strict.

Presented at the 103rd Annual Meeting of the American Surgical Association, Boca Raton, Florida, May 12–14, 1983.

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Submitted for publication: May 16, 1983.

Sponsored by Lloyd M. Nyhus, M.D.

THE PRINCIPLES of management of arterial trauma in adults are well established.[1] Adult arterial trauma is significantly more common than pediatric arterial trauma. Diagnostic procedures in adults are reasonably standardized; the indications for operation in adults are nearly uniformly agreed upon. The methods of vascular repair in adults have been refined to the point that successful results can be expected in all but the most serious of injuries.[2,3]

The principles of management of pediatric arterial trauma are not as well defined. Because of the rarity of arterial trauma in infants and children, only a few centers have been able to accumulate sufficient numbers of patients for meaningful analysis. Most large series of patients reported in the literature have required a decade or more of experience for accrual.[4-8] Because of the infrequent nature of pediatric arterial injuries, it has been difficult to design prospective studies to evaluate various methods of management, especially in the face of rapid advancements in the field of vascular surgery.

Pediatric arterial trauma poses special problems not encountered in the treatment of adult vascular trauma.[8] Because of the small size of these vessels surgeons tend to be less enthusiastic about recommending surgical repair in infants and children. Unlike adults, limb growth must be considered in the pediatric age group.[9-13] The inability of very young patients to communicate their symptoms and the rich potential for rapid collateral de-

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velopment may give the surgeon a false sense of security in the long-term significance of arterial injuries in children. Numerous reports have now documented subsequent limb growth retardation as a result of uncorrected circulatory impairment in the absence of symptomatic evidence of ischemia.[9-13]

As in adults, arterial trauma in children has been seen as a result of gunshot wounds, stab wounds, falls through glass structures, fractures and dislocations, and blunt trauma.[14] Although uncommon, these injuries in children are increasing in frequency.[5] The major causes of arterial injuries in children are iatrogenic, accounting for two thirds of pediatric arterial injuries.[6] Iatrogenic injuries are most commonly a result of arterial catheterization for diagnostic or monitoring purposes. Umbilical artery catheterization, transfemoral cardiac catheterization, and transfemoral arteriography have been primarily responsible for most iatrogenic pediatric arterial injuries.[6] A less common but significant cause of iatrogenic injury have been surgical procedures, including arterial cannulation for cardiopulmonary bypass.[7]

The University of Illinois Hospital is a major pediatric referral center for the Chicago area because of its extremely active pediatric cardiology service and its large neonatal intensive care unit. Because of this activity, we have been able to treat a large number of iatrogenic pediatric arterial injuries during a relatively short period of time using modern techniques of vascular diagnosis and therapy. It is the intent of this report to analyze this experience for the purpose of developing principles which, hopefully, will be useful in the subsequent management of iatrogenic pediatric arterial trauma.

Clinical Material

Over a 32-month period, 79 lower extremities in 76 children were evaluated in regard to iatrogenic arterial injuries. Early in the course of this experience, because of concern about complications associated with transfemoral catheterization, a prospective study to assess the incidence and severity of arterial injury following transfemoral cardiac catheterization in children was begun. Forty-two children were entered into this study. All arterial punctures were carried out under general anesthesia and all catheterizations were performed percutaneously. Patients were anticoagulated with heparin sulfate (1 mg/kg) immediately following arterial cannulation. Doppler derived segmental arterial pressures were measured in both extremities in all children the day before catheterization and recorded. All children underwent repeat Doppler pressure measurements following cardiac catheterization. Pre- and post-catheterization studies were compared through the calculation of the ankle/brachial pressure index (ABI). Any extremity with an ABI < 0.9 following catheterization was considered abnormal. All extremities had normal ABIs precatheterization.

Ten children in this prospective study sustained 10 arterial injuries. An additional 34 children, sustaining 35 arterial injuries affecting 37 lower extremities, were referred during the 32 month period giving totals of 44 children sustaining 45 injuries affecting 47 extremities for the entire experience. The additional 35 arterial injuries were secondary to transfemoral cardiac catheterization in 19 children (20 injuries, 20 extremities) who were not part of the prospective study, umbilical artery catheterization in 10 children (10 injuries, 12 extremities), and recent surgery in five children (5 injuries, 5 extremities) (Table 1).

TABLE 1. *Sources of Pediatric Arterial Injuries*

Etiology	No. of Injuries
Transfemoral cardiac catheterization	30
Umbilical artery catheters	10
Surgical procedures	5
Total	45

Of the 45 injuries, two were of the aorta by umbilical artery catheters, 30 were of the common femoral artery by angiographic catheters, one was of the external iliac artery as a result of surgical removal of aggressive fibromatosis surrounding the artery, two were of the iliac artery as a result of umbilical artery catheters, and 10 were of vessels distal to the common femoral artery and were believed to be a result of emboli, originating from umbilical artery catheters or proximal surgical sites (Table 2).

The mean age was 31 months (range, 1 day–13 years). Eighty-four per cent of these children were 4 years of age or less. Additionally, because of a high prevalence of congenital heart disease in this group of patients, most patients were very small for their age (Fig. 1). There were equal numbers of boys and girls. Most children were too young to relate specific symptoms. Those who could verbally communicate related only coolness or numbness of the extremity. All children had absent palpable pulses distal to their injuries. In many children, no signs of ischemia were present despite absent pulses. In the more severe injuries, the usual signs of ischemia consisting of decreased

TABLE 2. *Arteries Occluded*

Arteries Occluded	Number
Aorta	2
Iliac	3
Common femoral	30
Distal to common femoral*	10
Total	45

* Exact locations undetermined. Presumably thromboembolic.

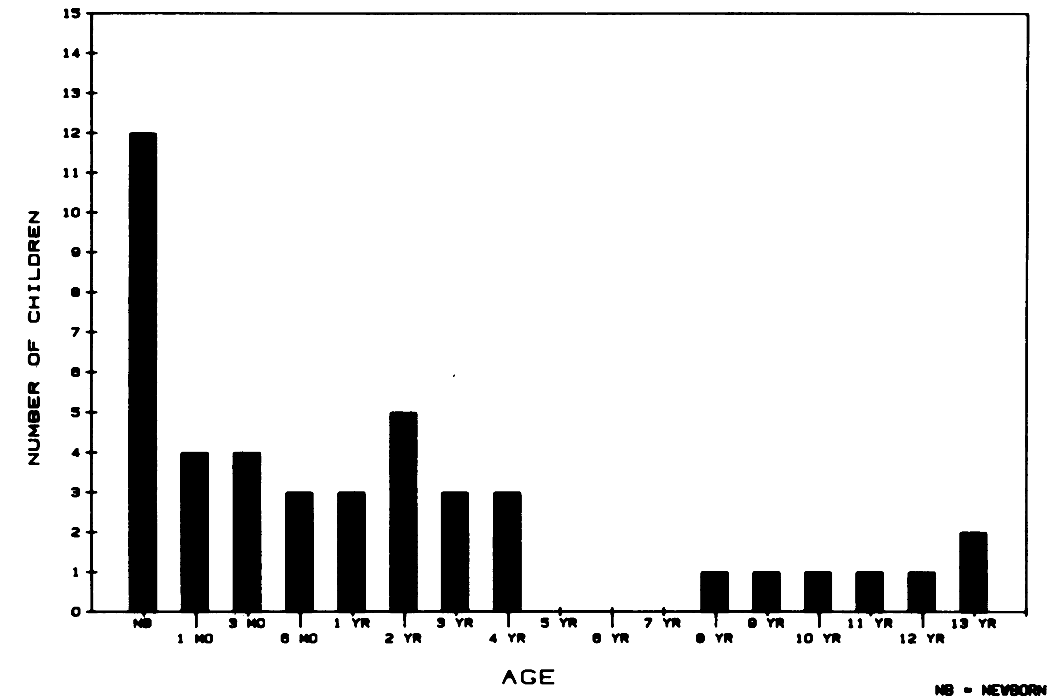

FIG. 1. Age distribution in children sustaining arterial injuries.

temperature, paralysis, and pallor or mottling were present. All injuries were confirmed with Doppler-derived segmental lower extremity arterial pressure measurements. Diagnostic arteriography was specifically avoided in these children. For aortoiliac injuries, imaging ultrasound, and radioisotope arteriography were also employed (Fig. 2).

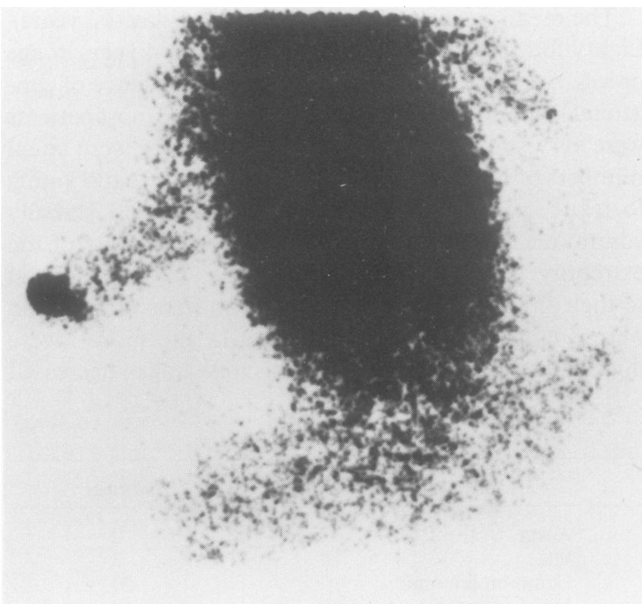

FIG. 2. Radionuclide arteriogram showing complete occlusion of the infrarenal aorta.

Doppler pressure measurements were repeated periodically following injury until pressures returned to normal, until the patient died or was lost to follow-up, or until this writing. Because of the known risk of impaired limb growth, any patient with an ischemic extremity (ABI < 0.9) for longer than 30 days was studied with serial orthoroentgenograms to assess limb growth. A difference in limb length of >0.5 cm was considered abnormal.[7]

As a result of experience gained early in the care of our patients, general guidelines regarding management were established. Any patient whose lower extremity pulses did not return following cardiac or umbilical artery catheter removal, or any patient having loss of pulses for other iatrogenic reasons was to be immediately heparinized (1 mg/kg), if not contraindicated, and observed for 6 hours. All patients with an absent femoral pulse after 6 hours of observation were considered as surgical candidates in the absence of specific contraindications to surgery. Patients with palpable femoral pulses but absent distal pulses and Doppler evidence of impaired distal perfusion were recommended to continue heparin therapy (1 mg/kg, q6h) in the absence of contraindications to anticoagulation.

These general guidelines led to 12 operations consisting of aortic thrombectomy in two patients, crossover femoro-femoral bypass (on two occasions) in one patient, femoral artery patch angioplasty in one patient, and femoral artery repair with thrombectomy in seven patients (Table 3).

Thirty-four injuries (33 patients) were recommended for nonsurgical management because of palpable femoral pulses or contraindications to surgery. Of the nonsurgical patients, seven died from other causes and four (five injuries) were lost to follow-up. Of the 22 remaining patients, 14 were treated with heparin until return of Doppler pressures to normal or for a maximum of 4 days. Two of these patients were also treated with urokinase. Eight injuries were not treated with heparin because of contraindications to anticoagulation (Fig. 3).

No patient followed for less than 2 months is included in this report. Living patients with and without impaired circulation as a result of their injuries are being followed indefinitely to assess long-term results, particularly in regard to limb growth.

Results

Of the 42 children entered into the prospective study, 10 incurred arterial injuries for an incidence of 24%. There was no difference between the injured group and the uninjured group in age (unpaired Student's t test) (Fig. 4). In the injured group the mean age was 57 months, while in the uninjured group it was 58 months.

Thirty-five additional injuries affecting 37 extremities were encountered. The mean ABI following injury was 0.34 ± 0.33; however, no relationship between the initial severity of the injury as assessed by Doppler and clinical outcome following therapy could be discerned.

Thirteen children (15 extremities) had no palpable femoral pulse following injury. Two of these 13 patients (newborns suffering from severe respiratory failure following meconium aspiration) were too ill for surgery and, thus, were treated medically. Both of these patients sustained iliac artery thromboses secondary to umbilical artery catheters. Both newborns were treated with heparin (1 mg/kg, q6h) and urokinase. Both infants survived but neither had a palpable femoral pulse nor a normal ABI at the time of discharge. These two children eventually had normal circulation restored at 13 months and 18 months, respectively, presumably as a result of collateral development. Neither child developed a leg length discrepancy as a result of the prolonged ischemia.

The remaining 11 patients without palpable femoral pulses (13 extremities) were treated surgically. In nine children (10 extremities) there was immediate return of normal circulation following surgery. In one patient undergoing common femoral artery repair and thrombectomy, normal distal circulation did not return until 24 hours after surgery; although, there was a palpable femoral pulse immediately following operation. The re-

TABLE 3. *Vascular Procedures Performed*

Operations	Number	Ages
Aortic thrombectomy*	2	NB‡, NB
Femoro-femoral bypass	2†	12 yr
Femoral patch angioplasty	1	18 mo
Femoral thrombectomy and repair	7	9 mo, 2 yr, 2.5 yr, 2.5 yr, 4 yr, 4 yr, 13 yr
Total	12	

* Transabdominal.
† One patient.
‡ NB = newborn.

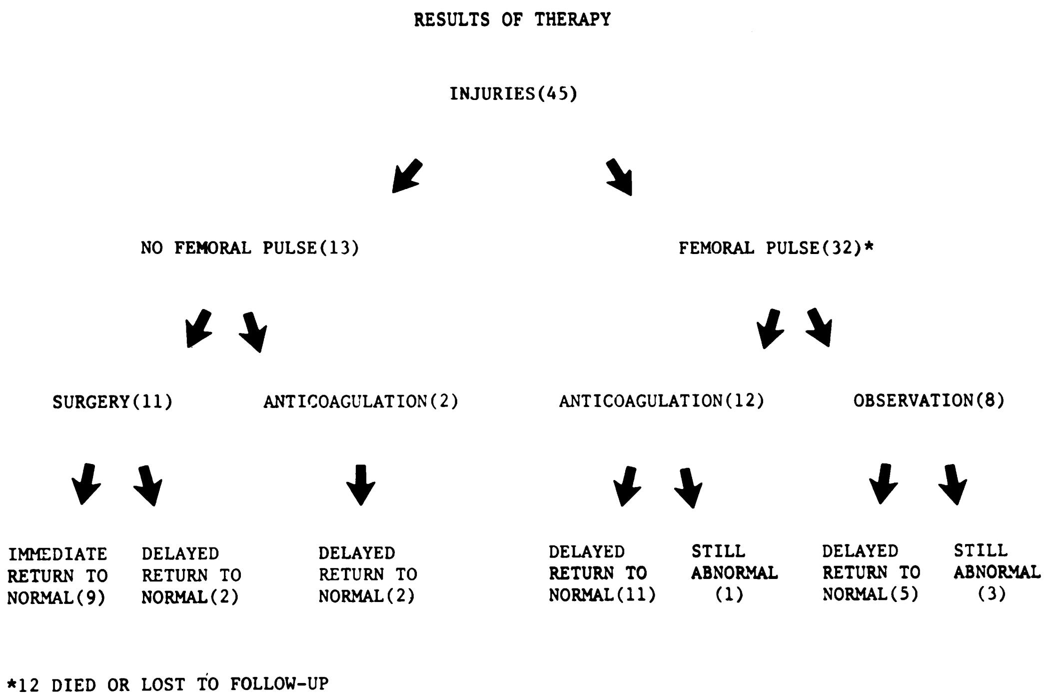

FIG. 3. Types and results of therapy.

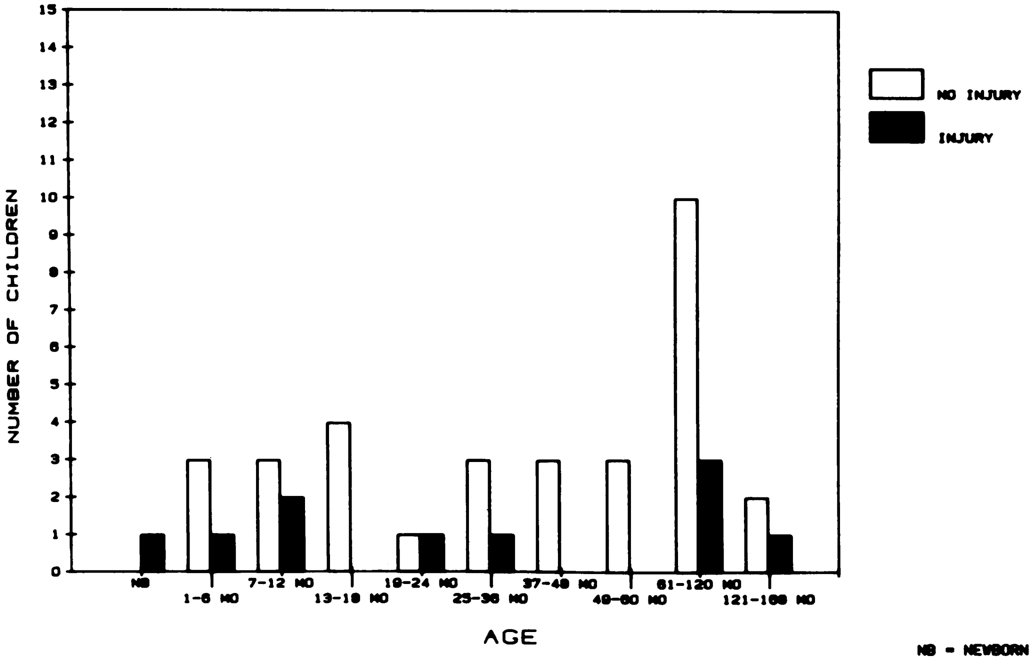

FIG. 4. Age distribution as regards incidence of injury in children undergoing transfemoral cardiac catheterization (prospective study). There was no statistical difference between groups.

maining patient was a newborn who underwent transabdominal aortic thrombectomy. Distal circulation was markedly improved as measured by Doppler pressures after surgery but palpable femoral pulses did not return. This patient eventually regained normal circulation 20 months after surgery. This child developed a leg length discrepancy of 1 cm as collateral development was assymetric as assessed by periodic Doppler pressure measurements. There was no operative mortality in our patients.

Thirty-one children (32 extremities) had palpable femoral pulses following injury and, thus, were not subjected to operation. Eleven of these children (12 injuries) could not be further evaluated because of death or being lost to follow-up. Of the 20 remaining children (injuries), 12 were treated with heparin and eight were not. Of the 12 treated with heparin, 11 had eventual return of normal circulation and one did not. Of the 11 children having eventual return of the ABI to normal, five returned to normal in less than 30 days while six required more than 30 days to return to normal. Of the eight patients who could not be heparinized, five returned to normal (one at <30 days, 4 at >30 days) and three remain abnormal (Fig. 3).

A return of ABI to normal was seen from 1 day to 2 years in 93% of patients treated with heparin ($n = 14$) compared to 63% of patients who were observed ($n = 8$). This difference was not significant at the $p < 0.05$ level ($p = 0.07$, chi-square analysis) but was significant at the $p < 0.10$ level. Early analysis of ABIs (1 month), however, revealed that there was clearly no difference between patients receiving heparin and those who did not.

Analysis of the ages of patients in the surgical v the nonsurgical groups (unpaired Student's t-test) revealed that there was no statistical difference between the groups. The mean age in the surgical group was 44 months while in the nonsurgical group it was 27 months (Fig. 5). Sixty-four per cent of the children operated upon in this series were less than 2 years old and 82% of the children were 5 years old or less.

One child (9%) in the surgically treated group and five children (23%) in the medically treated group developed limb length discrepancies of >0.5 cm as a result of ischemia lasting >30 days for an overall incidence of 14% (Table 4). However, when analyzed against all patients having ischemia lasting >30 days ($n = 18$) the incidence is 33%. When considering all patients with ischemia lasting >30 days there were no differences in age at the time of injury, length of ischemia, ABI immediately following injury, or the ratio (length of ischemia/ABI) between those children who developed limb length discrepancies and those who did not (unpaired Student's t-test).

Overall, normal resting circulation had returned in 91% of children at the time of this writing with the longest period between injury and a return of ABI to normal being 20 months. Four children with abnormal ABIs are still being followed. No patient in this series suffered tissue loss or amputation.

Discussion

Children may experience arterial occlusion from multiple sources. Embolization from cardiac sources and spontaneous arterial thrombosis secondary to dehydration, polycythemia, infection, and congestive heart fail-

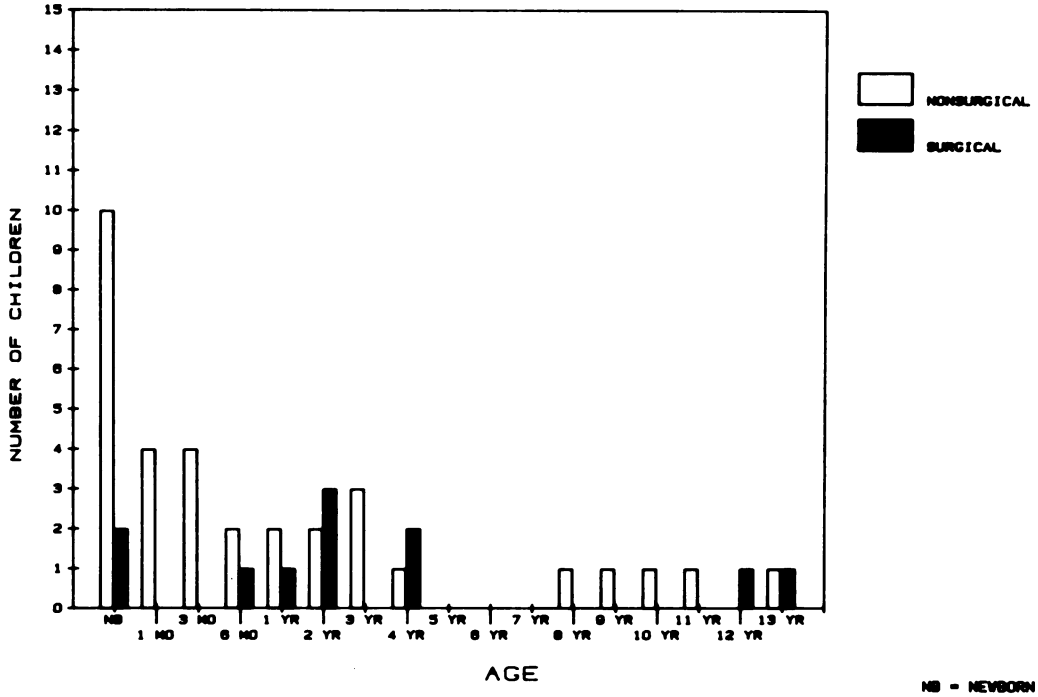

FIG. 5. Age distribution in operated and unoperated children. There was no statistical significance between groups.

ure account for most nontraumatic etiologies.[15-23] These events are rare compared to the incidence of traumatic arterial occlusions.[24] The incidence of pediatric arterial trauma is on the increase with the major cause of arterial injury in children being iatrogenic, especially in children less than 2 years old.[25] During the 32-month period that this report encompasses, no child with noniatrogenic arterial trauma was seen at our institution. Similar findings have been reported by others and in almost all reports iatrogenic injuries account for well in excess of 50% of arterial injuries in children. The noted exceptions are from major trauma referral centers.[5,14]

In the present report, all injuries involved the arteries to the lower extremities. This has been reported by most investigators and most likely reflects the trend away from brachial artery puncture for invasive diagnostic and monitoring procedures.[26-32] The majority of arterial injuries occur following arteriography, cardiac catheterization, umbilical artery catheterization, and needling procedures for arterial blood samples.[32] The high incidence of complications following these procedures is not surprising since the vessels are usually very small and the children are usually very ill with decreased cardiac output, polycthemia, and dehydration.

Transfemoral cardiac catheterization accounted for 67% of the injuries in this report. Freed reported a 40% incidence of arterial injury from this procedure in patients under 10 years old.[25] Mortensson reported an incidence of 26%.[29] Both Freed and Mortensson used repeat arteriography in their determination of the complication rate. Certain techniques of transfemoral catheterization have been shown to lead to a lower incidence of subsequent arterial thrombosis. Freed showed, in a prospective randomized study, that the use of systemic heparinization, while the catheter is in position, was associated with a significant reduction in thrombic complications from 40% to 8%.[25] Ample evidence exists for the formation of fibrin sleeves on these catheters. A suspected mechanism of occlusion is stripping of this sleeve during catheter removal with subsequent arterial occlusion at the site of arterial puncture or from distal embolization.[33]

Rubenson found a lower incidence of thrombotic complications using the percutaneous method of arterial puncture rather than using an arteriotomy for cannulation.[28] An additional risk factor is patient age. Freed and others have found a significantly higher rate of thrombotic occlusions in younger patients.[25] In Freed's investigation, no patient older than 10 years developed complications, whereas patients less than ten had a complication rate of 40%. The prospective study performed as part of the present investigation revealed a thrombosis rate of 24%. In our patients, heparin was routinely used during catheterization and all cannulations were percutaneous. Since our method of injury detection was Doppler pressure measurements, it is likely that the complication rate was actually higher than 24%, since pressure measurements would only be expected to detect injuries causing stenoses of greater than 70%. The young ages of the patients in our report might be thought to explain a complication rate of 24% despite heparinization and the use of the percutaneous method. However, in our patients, age could not be shown to be associated with a higher complication rate (Fig. 4).

Ten neonates in the present experience sustained arterial occlusions secondary to umbilical artery catheterization. Although umbilical artery catheters have about one half the complication rate of umbilical vein catheters, they are still responsible for considerable morbidity.[34,35] Besides lower extremity thrombotic complications, these catheters have been responsible for urologic complications, pelvic hemorrhage, hypertension, embolization and pseudoaneurysm formation.[34–49] The incidence of thrombosis after umbilical artery catheterization has been shown by O'Neill to be 95% by angiography; however, clinical sequellae were present in only one patient in O'Neill's report.[42] Other reports have shown a high incidence of thrombi on arteriography following umbilical artery cannulation but most investigators report clinical complications of less than 5%.[39,41] Nevertheless, complications from umbilical artery catheters can be lethal, especially when involving the aorta and its visceral branches.[38,40,41] Lower extremity arterial occlusions secondary to these catheters have resulted in tissue necrosis and occasional limb loss.[6]

Like angiographic catheterization, certain techniques relative to umbilical artery catheterization seem to favor a lower complication rate. The use of end-hole catheters, heparin drips, high aortic position, and hypothrombogenic catheter materials have been beneficial.[38] Although catheters placed high in the aorta have fewer complications, the complications associated with lower aortic placement are less severe in nature.[37] Conflicting reports exist regarding an association of increased thrombosis rate with longer durations of catheterization; however, it would seem wise to remove any catheter which is not absolutely needed.[41,42]

The diagnosis of arterial occlusion is usually evident from the history and physical examination. In our patients, all clinically significant injuries were associated with the absence of distal pulses. We used Doppler pressure measurements in an attempt to detect lesser lesions in the prospective part of our study. Doppler measurements were most useful, however, to follow the efficacy of therapeutic interventions and to document the development of collateral circulation. In the case of suprainguinal arterial occlusions, imaging ultrasound, and isotope arteriography have been more helpful to localize the extent of thrombosis than to make a diagnosis.[38,50,51] Arteriography is seldom indicated in these children in view of the potential for further complications with its use and the accuracy of less invasive diagnostic methods.[6]

The problem of arterial spasm with transfemoral arterial cannulation deserves special attention in children. Mortensson has nicely demonstrated complete arterial occlusion due to arterial spasm around a catheter.[29] This problem is worse in younger patients. Many investigators have attested to spasm as a common cause of absent pulses following catheterization; however most have found it to be a transient event within the first few hours following catheter removal.[4,8,25,26,29,32] Mansfield demonstrated that arterial thrombosis was present in all cases in which absent pulses persisted beyond 8 hours.[26] White reported the same findings after 3 hours.[32] Freed and Klein have suggested 48 hours as a cutoff point.[4,25] Most of these authors have recommended heparinization during this waiting period. Our clinical protocol called for no longer than 6 hours of observation on heparin before a decision for operation was entertained. In all of our patients who came to operation arterial occlusion was confirmed.

A pivotal point in our patient management was the presence or absence of a palpable femoral pulse. This decision was based upon the fact that, in most neonates, #2Fr Fogarty catheters will not pass below the common femoral arteries. Also, to our knowledge, bypass procedures have not been previously attempted in neonates. Our early experience was similar to O'Neill's in regard to the relatively benign course of more distal occlusions;[41] nevertheless, a limb length discrepancy of 14% in this study has led to a reconsideration of this approach. Some patients with femoral pulses might have thrombosis of the common femoral artery bifurcation, which could easily be removed by simple thrombectomy and repair. Also, in larger children, Fogarty catheter thromboembolectomy or even bypass procedures should be possible. Both of these procedures have been successfully reported in older children.[7,14] The decision for such an approach might be facilitated by imaging procedures. With the advent of digital subtraction arteriography and high resolution ultrasound this may now be possible.

The decision for or against operation in these children is multifactorial. The incidence of immediate limb threatening ischemia following iatrogenic arterial injuries is low. Smith, in a recent review of the literature, found only eight cases of limb loss. Although unusual, such ischemia does occur and would indicate the need for early revascularization when possible. Many of these patients are poor surgical risks and the risk of operation must be weighed against the risk of limb loss or limb growth impairment. Another consideration must be the likelihood of successful surgery. The size of the patient and the injured vessel is important in this regard. Whitehouse has reported successful thrombectomy in a 1-month-old infant and Whitehouse and others have reported successful infrainguinal bypasses in children.[7,14] Also, O'Neill's group and our group have performed successful aortic surgery in neonates.[38,41] On the contrary, an operation for a femoro-popliteal occlusion in a neonate is not likely to succeed. Another consideration in the decision for operation is the problem of possible growth retardation with persistent ischemia. Growth retardation has been documented by many investigators following arterial injury, even in the absence of symptomatic ischemia.[9-13]

Nonoperative therapy is often a viable option to be considered. In our patients, 18 of 22 children treated without surgery eventually developed normal ABIs, although retarded limb growth was a problem (Fig. 6). Late revascularization has been successfully performed; however, the effect of late revascularization on limb growth is controversial.[4,7,10]

Surgery is almost mandatory in aortic thrombosis. Nonoperative treatment for neonatal and childhood aortic thrombosis has been uniformly unsuccessful with a 100% mortality rate.[38] Both of our neonates with aortic thrombosis were treated successfully with surgery, as were three of the four infants reported by O'Neill.[38,41]

The age of the patients in this report is considerably younger than in most previous reports (Fig. 1). Sixty-four per cent of the children operated on in this series were less than two years old. Two neonates underwent transabdominal aortic thrombectomy; an 18-month-old child had a femoral patch angioplasty; femoral artery repair with thrombectomy was performed in seven children aged 9 months to 13 years; and femoro-femoral bypass was performed in a 12-year-old patient (Table 3). All operations in this series were successful with the exception of the femoro-femoral bypass. Failure in this patient was due to an inadequately sized autogenous saphenous vein graft placed in an effort to avoid prosthetic material because of nearby infection. Because of leg growth impairment, this patient underwent successful femoro-femoral bypass with prosthetic material 1 year later.

O'Neill has previously reported a 77% success rate in 92 children undergoing arterial repair.[50] The initial success rate in our surgically treated patients was 91%. Several factors are probably responsible for the excellent results in our surgical patients. Because of a close working relationship with the pediatric cardiology and neonatology services, all patients were promptly evaluated by the vascular service. The importance of early therapy has previously been emphasized by Shaker and O'Neill.[8,41] All of our surgical patients were heparinized immediately, thus, decreasing the likelihood of proximal and distal clot propagation. Patients who did not have return of femoral pulses were taken to the operating room within 6 hours, except in two cases in which additional preparation was required. Heparin administration was generally continued for 24 hours after surgery.

Transabdominal aortic thrombectomies were performed through transverse abdominal incisions and a transverse arteriotomy in the distal aorta just proximal to its bifurcation. In these neonates, #2Fr Fogarty catheters would pass only to the level of the common femoral arteries. Closure of the aorta was accomplished with interrupted 7–0 polypropylene sutures. Femoral artery patch angioplasty was performed as it would be in an adult, but using 2.4× loupe magnification. The operating microscope was not required in any of our children; however, its use in repairing smaller vessels in the future is being considered. Femoral artery repairs with thrombectomy usually required only tacking of the intima following clot removal. This can be accomplished following debridement of the arterial edges by using the same interrupted 7–0 sutures which are used to close the vessel. We have not transsected the artery to perform a spatulated anastamosis, since 50% of the vessel (usually the posterior wall) is generally intact (Fig. 7). Whatever

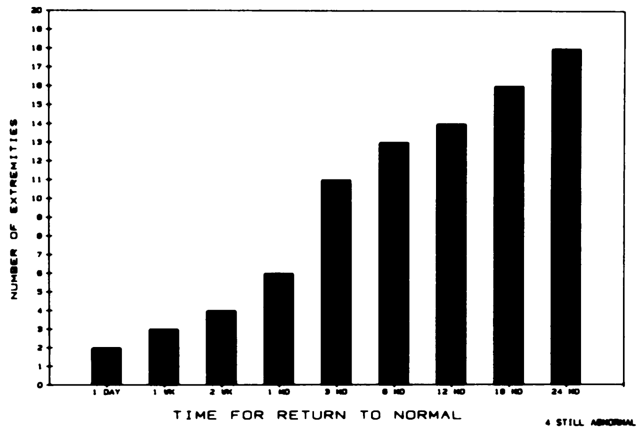

FIG. 6. Cumulative return of normal resting circulation in patients treated nonsurgically.

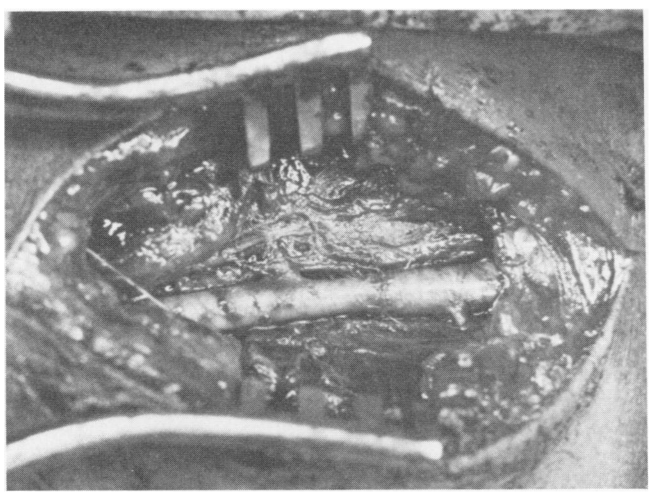

FIG. 7. Operative photograph demonstrating interrupted suture closure of the common femoral artery. Diameter = 2.5 mm.

TABLE 4. *Children Developing Leg Length Discrepancies*

Patient	Age* (Mo)	Length of Ischemia (Mo)	ABI†	Leg Length Discrepancy (cm)
1	1	5	0	0.50
2	2	2	.6	0.75
3	48	7	.78	2.25
4	3	14	.58	3.00
5	NB‡	20	0	1.00
6	13	13	.2	0.50

* At time of injury.
† Immediately following injury.
‡ NB = newborn.

type of arterial repair is undertaken, it is recommended that interrupted sutures rather than a continuous suture be employed to allow for subsequent arterial growth.

The results achieved in the nonsurgical group were also gratifying, although five of the six limb length discrepancies were seen in this group (Table 4). It is possible that a more aggressive approach might have improved these results; however, the data in our study does not allow this conclusion. The effect of heparin therapy in this group is difficult to evaluate. Our late results indicated a beneficial effect of heparin as they did in Klein's experience.[4] However, results at 1 month following injury showed benefit to heparin in neither our nor Klein's patients.[7]

A fact that has not yet become widely appreciated is that children with persistant ischemia run a high risk of limb growth retardation. Rosenthal found no evidence of growth retardation following cardiac catheterization. However, unlike the following studies, he used a tape measure rather than roentgenograms for measurement purposes.[12] Currarino and Engle demonstrated retarded growth of soft tissues and retarded longitudinal bone growth in 25 of 28 arms following subclavian artery ligation for tetrology of Fallot.[13] Bassett demonstrated retarded limb growth in 24 of 28 children following femoral catheterization injuries and Whitehouse showed a 50% incidence of growth retardation due to persistent ischemia.[7,9] In the present study, 6 of 18 limbs (33%) with ischemia lasting longer than 30 days developed limb length discrepancies. The fact that there was neither a direct relationship to the length of ischemia nor an indirect relationship to ABI in regard to the severity or incidence of limb growth retardation was unexpected.

The subsequent course of patients with limb length discrepancies is currently ill defined. Bassett, in following 12 of his patients found that six children remained unchanged, three worsened, and three improved, although two of the three were still abnormal.[9] Whitehouse found that subsequent revascularization did not lead to accelerated growth and amelioration of limb length discrepancies.[7] Conversely, Bloom has reported three patients in whom revascularization led to increased growth, although not to normal, and Klein has reported late revascularization leading to equal leg length in two children.[4,10] We have performed only one late revascularization. This procedure has resulted in increased growth of soft tissues but not in increased longitudinal bone growth 1 year after surgery.

As a result of this experience, certain recommendations can be made. The results obtained in the treatment of our patients indicate that the current approach has been reasonably successful. Patients with aortic thrombosis should be heparinized and undergo immediate operation, as this is a lethal condition. Ultrasound and radionuclide arteriography may be helpful in establishing the diagnosis of thrombosis; however, they probably are not necessary in most cases and should not be done if they inordinately delay operation. Children sustaining loss of pulses following nonaortic iatrogenic arterial trauma should be heparinized immediately, when possible, and observed for 6 hours for signs of improvement. Nearly all children with absent pulses after this time will have arterial occlusions. Doppler pressure measurements are useful primarily for monitoring purposes. Patients without a femoral pulse after 6 hours should, in most instances undergo arterial reconstruction. Standard arteriography is probably ill advised in these patients and may entail more risk than operation.

In patients with a femoral pulse but with distal ischemia, we would hope that noninvasive imaging techniques might be useful, in the future, to identify patients with common femoral artery thrombi. Such children would probably benefit from operation. Patients with more distal occlusions should probably be treated nonoperatively with continued heparin therapy, although in older patients a more aggressive approach may be indicated. The role of thrombolytic therapy should probably be evaluated further, although it did not appear helpful in our two cases. Obviously, good judgment should be used in the selection of patients for operation in weighing patient risk against the risk of limb loss or limb growth retardation, and the feasibility of operative repair. Although still somewhat unclear, there is some evidence now indicating that later revascularization may be effective in some patients in relieving limb length discrepancies.[4,6,10]

Proper selection of patients in the application of invasive diagnostic and monitoring techniques is important. These techniques can be life saving but probably should not be performed for academic curiosity. Although no child lost a limb in our series, both the economic and emotional costs to these patients and a limb length discrepancy in 14% of patients mandate that the indications for these invasive procedures be strict.

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