

Operative and nonoperative management of children aged 13 years or younger with arterial trauma of the extremities

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Background: Previous studies have suggested that open repair of arterial injuries in very young children often leads to less satisfactory outcomes. The aim of this study is to describe a decade's experience in the management of pediatric arterial trauma of the limbs, with an additional specific objective to evaluate the long-term outcome of arterial traumas in preschool children treated conservatively.

Methods: Hospital charts were reviewed for all children aged ≤ 13 years with arterial trauma of the extremities who underwent operative or nonoperative treatment. Twenty-three children were located who had arterial traumas equally divided between the upper extremity (13) and lower extremity (10).

Results: The method of treatment was either open surgical repair or medical treatment consisting of systematic heparin administration. In 11 of 12 school-aged children (>6 years; mean age, 10 years), open surgical repair was performed. In six of 11 preschool children (≤ 6 years; mean, 3.2 years) medical treatment was offered. Open repair was deferred in all children <2.5 years. Autologous vein interposition grafting was the most common surgical procedure and was performed in 10 patients. There were no deaths, and 87% limb salvage (21/23) was achieved. Two patients, both in the surgical arm, underwent lower limb amputation. The long-term outcome of those treated conservatively was excellent in all but one child, in whom minor limb-length discrepancy was detected.

Conclusion: Surgical repair can be performed in school-aged children as in adults. Surgical treatment of arterial injuries in neonates, infants, and those children <2.5 years old might best be deferred in ischemic but nonthreatened limbs. In a nonthreatened ischemic extremity in this age group, systemic heparinization is an alternative safe method of management. Limb loss is rare if distal Doppler signals are present; but as children grow, limb shortening is a threat. In preschool children, the risks of an open surgical repair must be weighed against any potential benefits. (*J Vasc Surg* 2006;43:72-6.)

Arterial traumas in children present a challenging problem, even to experienced vascular surgeons; however, there is no consensus regarding the necessity of immediate surgical treatment for all such injuries in neonates and infants with nonthreatened extremities.¹ Arterial injuries in school-aged subjects (age >6 years) are more easily handled. Occlusion of an extremity artery in a child may cause impaired growth of the affected limb²; however, studies describing the long-term outcome after nonoperative management of pediatric arterial injuries are scarce. This case series describes a decade's experience in the operative and nonoperative management of pediatric arterial trauma. An additional specific objective of this study was to evaluate the long-term outcome of such arterial traumas in preschool children treated conservatively.

PATIENTS AND METHODS

Hospital charts were reviewed for all children aged ≤ 13 years with arterial trauma of the extremities who underwent operative or nonoperative treatment during a

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Competition of interest: none.

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10-year period. All arterial trauma cases treated by our staff in the St. Sofia and "Aglaia Kyriakou" Hospitals system (Athens), which are tertiary children's care facilities (1996-1999), and in Demokritos University Hospital (Alexandroupolis), a regional general and children's hospital (2000-2005), were recorded in a database. Patients identified by hospital charts were cross-checked with the database to make sure that all such cases were included.

Twenty-three such patients had arterial traumas equally divided between the upper extremity (13) and lower extremity (10). The most frequently injured vessels were the brachial (10 patients, 43%) and the common and/or superficial femoral (6, 26%) artery followed by the popliteal (3, 13%), the ulnar (2, 9%), the axillary (1, 4%), and the external iliac (1, 4%) arteries.

The mechanism of injury was penetrating lesion in 8 patients, blunt trauma in 7, shotgun in 2, and iatrogenic trauma in 6. Blunt traumas included falls in five and car accidents in two patients. Iatrogenic traumas were associated with arterial catheterizations in three cases; one resulted from inadvertent injury of the common femoral artery during a hernia repair in a 30-day-old neonate, one from brachial artery trauma during a malignant tumor resection, and one caused by mechanical trauma of the axillary artery during birth.

The diagnosis was based on a physical examination and was confirmed by color Doppler scans in 14 children (61%); angiography was performed in only four children (17%). In

Table I. Etiology, location, and method of repair of arterial injuries in children of two different age groups

<i>Age group</i>	<i>n</i>	<i>Male/female</i>	<i>Iatrogenic</i>	<i>Upper/lower limb</i>	<i>Treatment (open repair/medical)</i>
>6 years (10 ± 2.4)*	12	11/1	1	6/6	11 [†] /1
≤6 years (3.2 ± 2.5)*	11	7/4	5	7/4	5 [‡] /6

*Mean value in years ± 1 SD.

[†]Vein grafting in 8, end-to-end reconstruction in 2, ligation in 1.

[‡]Vein grafting in 2, end-to-end reconstruction in 2, thrombectomy in 1.

Table II. Clinical characteristics and outcome of children with limb arterial injuries treated medically

<i>Patient</i>	<i>Age</i>	<i>Sex</i>	<i>Artery</i>	<i>Type of injury</i>	<i>Length of f/up</i>	<i>Outcome</i>
1	6 yrs	F	Brachial	Blunt/ humeral fracture (fall)	2 mon*	Palpable distal pulses
2	5 days	F	Axillary	Iatrogenic, mechanical trauma during birth	8 yrs	Palpable distal pulses, minor limb-length discrepancy
3	1 mon	M	Common femoral	Iatrogenic, during congenital hernia repair	7 yrs	Normal limb
4	1.5 yrs	F	Common femoral	Iatrogenic/catheter-induced	1 mon*	Audible distal signal
5	7 yrs	M	Brachial	Blunt/humeral fracture (fall)	6 yrs	Palpable distal pulses, normal limb
6	15 days	M	Ext. iliac	Iatrogenic/catheter-induced	4 yrs	Palpable distal pulses, normal limb
7	5 yrs	M	Brachial	Blunt/humeral fracture (fall)	6 mon	Palpable distal pulses, normal limb

*Lost to follow up at this point.

nine children, the diagnosis was based on clinical examination and arterial pressure index measurements. In all but two ulnar injuries, the predominant clinical manifestation was distal ischemia.

Long-term outcome was assessed by means of postdischarge clinic visit records. For those treated conservatively, additional telephone interviews were also conducted.

RESULTS

The method of treatment was either open surgical repair or medical treatment that consisted of systematic heparin administration (Table I). In the medical treatment group, unfractionated heparin was administered with a 100-unit/kg bolus dose followed by a constant hourly infusion of 20 to 25 units/kg. Autologous vein interposition grafting was the most common surgical procedure and was performed in 10 patients; reversed saphenous vein graft was used in 7, and reversed cephalic vein graft in 3 cases. Five bypasses were short, 5- to 7-cm grafts bridging brachial artery injuries. Two were femoropopliteal below-knee grafts, two were 10-cm interposition superficial femoral artery grafts, and one bypass was a long femoroposterior tibial graft. An end-to-end anastomosis was achieved in four patients; and in two cases, simple balloon catheter thrombectomy with primary closure and ligation of an ulnar false aneurysm were performed, respectively.

There were no deaths, and 87% limb salvage (21/23) was achieved. Two patients, both in the surgical arm,

underwent lower-limb amputation. A 5-year-old girl with extended second-degree burns, whose femoral catheter caused a common femoral artery thrombosis that was not immediately recognized, underwent amputation despite surgical thrombectomy. That case was the only delayed diagnosis in these series. Another 13 year-old boy who sustained a blunt popliteal artery injury, a comminuted tibial fracture, and extended soft-tissue damage of the calf as a result of a car accident, also underwent amputation despite a popliteal-posterior tibial bypass.

Palpable distal pulses were re-established postoperatively in all the remainder in the surgical arm. Those surgically repaired within the ≤6-year-old children were in the older age range (≥2.5 years old) within this category. Four of five in this subgroup presented with severe ischemia, no audible distal Doppler signal, and neurologic impairment, and the decision to operate was dictated by a definite threat of limb loss.

In preschool children aged ≤6 years, the decision not to intervene surgically was never clear-cut. In the non-threatened extremity with a palpable proximal pulse, the choice for conservative therapy was based on the presence of distal Doppler signals, capillary refill, and absence of mottling of the skin, signs that justify surgical intervention. The "conservative" treatment group consisted of seven children, six of who were ≤6 years old. All but two had audible distal Doppler signals at presentation. In those children (patients 2 and 3 in Table II), proximal pulses were



Fig 1. Ischemic lesions in a 5-day-old child with iatrogenic axillary thrombosis.

absent and localized skin necrosis had developed in one (Fig 1). The latter was a neonate with a mechanical trauma of the axillary artery during birth, and the decision to avoid open repair was based on a range of comorbidities. In this child, compartment syndrome was diagnosed from the clinical findings; it was the only case with compartment syndrome in the conservatively treated group. No fasciotomies were performed, however, because of the aforementioned severe comorbidities. Interestingly, no amputation was required, and after 8 years of follow-up, the child has a functional limb with palpable wrist pulses; however, this is the only case of the series with minor limb-length discrepancy.

Two additional children (patients 4 and 6 in Table II) had absent proximal pulses but an audible distal Doppler signal and marked improvement within hours after the start of heparin treatment. During the follow-up period, five children of the conservative treatment group regained palpable distal pulses and no limb-length discrepancy was recorded. Table II lists the clinical summary and treatment outcomes of the seven patients treated conservatively.

Six patients in the series had long-bone fractures that required external fixation or open reconstruction, three patients had neural injuries necessitating microsurgical repair, and one patient had a popliteal gunshot injury and a large soft-tissue defect that necessitated secondary pedicled flap coverage (Fig 2).

DISCUSSION

The diagnosis and management of arterial injury is more complex in children than in adults and requires a high degree of suspicion combined with prompt and appropriate management. Precise assessment of a potential arterial trauma, especially in preschool children, can be limited by the difficulties of assessing motor and sensory deficits in an uncooperative child as well as by verbal communication problems.³⁻⁶

Color-coded duplex imaging (CDI) and arteriography can establish the diagnosis and define the exact location and type of injury; however, the latter must be reserved for questionable or for complex multilevel lesions.⁷⁻⁹ In one of



Fig 2. Popliteal artery gunshot injury in a 13-year-old boy. Arteriography was required because of a potential multilevel injury caused by the wide spread of pellets in the area. The large, soft-tissue defect necessitated a secondary pedicled flap coverage.

our cases, the decision to perform an arteriography in an obvious popliteal artery gunshot injury was to assess a potential multilevel arterial trauma caused by the wide spread of pellets in the area (Fig 2). The use of arteriography for suspected proximity vascular injuries, especially in small children, is unwarranted because it is an important cause of arterial thrombosis.^{3,10} CDI is an alternative to arteriography; however, there is some controversy regarding its ability to detect all arterial injuries in certain locations, especially where bone structures interpose arteries.¹¹

Special technical problems are encountered when dealing with pediatric arterial injuries because the vessels are small and thin-walled, with a tendency to spasm, and tissue support is poor. Surgical repair can be performed in older children as in adults, but such a procedure may be extremely difficult in infants and neonates. In this age group, a carefully performed simple thrombectomy under visual magnification may be all that is necessary in iatrogenic traumas.^{3,12} In most series of preschool children, iatrogenic injuries represent the main cause of arterial trauma.^{1,4,6}

Because the long-term morbidity of a thrombosed limb artery in infants and neonates is uncertain and because there is a great potential for rapid development of adequate collateral circulation in these age groups, avoidance of open repair with conservative treatment consisting of heparin administration has been suggested. While using our standard routine to repair every pediatric trauma, we found that some infants and neonates were doing well after just heparin alone; following this policy, all <2.5-year-old children were treated conservatively. Additionally, the mechanism of such injuries is highly correlated with age: an infant is unlikely to sustain a gunshot wound or complex trauma that would likely require open surgery. The positive long-

Table III. Review of articles including detailed descriptions of arterial injuries presented with acute ischemia of the extremities in preschool children aged ≤ 6 years and managed with open repair

<i>Author</i>	<i>Age*</i>	<i>Number of patients/limbs</i>	<i>Type of repair simple thrombectomy/other</i>	<i>Restoration of distal pulses</i>	<i>LLD/limb loss/death</i>
Smith, ⁴ 1981	9 d-11 mo	5/6	5/1	2	1/0/2
Rothrock, ¹⁴ 1990	5 y	1/1	0/1	1	NS/0/0
LaQuaglia, ⁶ 1991	1 mo-2 y	9/9	1/8	6	1/0/2
Stylianou, ¹⁵ 1991	6 y	1/1	0/1	0	0/0/0
Chaikof, ¹ 1992	5 d-5.5 mo	7/9	8/1	5	2/0/1
Copley, ¹⁶ 1996	5 y	1/1	0/1	1	1/0/0
Friedman, ⁵ 1999	16 d-42 d	2/2	2/0	1	0/0/0
Lin, ¹⁷ 2001	0.5 y-5 y	11/11	10/1	7	NS/0/2
Kumar, ¹⁸ 2001	3 y	1/1	1/0	1	NS/0/0
Lewis, ¹⁹ 2003	3 y-6 y	6/6	0/6	6	NS/0/0
Dalsing, ²⁰ 2005	6 y	1/1	0/1	0	0/1/0
Present study	2.5 y-6 y	4/4	1/3	3	0/1/0
TOTAL		49/52	28/24	33 (63%)	5(16%)/2(4%)/7(14%)

LLD, Limb-length discrepancy; NS, not stated.

*Ages are expressed as y (year), d, (day), and mo (month).

term outcome of those children treated medically in these series supports the latter concept.

This conservative policy is also based on the far-from-successful results of surgery recorded in children who weighed < 12.5 kg.^{3,4} Few series, however, contain a sufficient number of patients to permit a precise evaluation of open repair compared with conservative management of these injuries. The decision for medical or surgical treatment depends on the type of lesion. Arterial lesions that present with bleeding, false aneurysms, and arteriovenous fistulae require open repair. If distal ischemia is the only finding, however, many authors prefer to use heparin or thrombolytic agents with additional careful observation and thus avoid an open repair unless limb viability is jeopardized.¹³

A review of recent articles published after 1980 that include detailed descriptions of the arterial injuries was performed to assess the outcome of surgical repair in preschool children aged ≤ 6 years old (Table III). A total of 49 children were located with 52 affected limbs. Despite open repair, the restoration of distal palpable pulses was possible in only 63% of extremities. The mortality was 14%, two limbs (4%) were amputated, and limb-length discrepancy was recorded in 16% of patients in the long-term follow-up. More discouraging outcomes were recorded when an analysis from the same data collection of the results of surgical intervention in very young children (≤ 2.5 years old) was conducted. In a total of 31 limbs (28 children), only 15 (48%) regained palpable pulses. The mortality of this age group was 25% (7/28), and limb-length discrepancy was detected in 15% of patients.^{1,4-6,17}

In our view the decision to intervene surgically in children aged ≤ 2.5 years should be dictated by a definite threat of limb loss. In a non-threatened ischemic extremity, systemic heparinization, or thrombolytic therapy, or both, are safe, alternative methods of management. If distal Doppler signals are present, limb loss is rare, but limb shortening is a threat as children grow. Preschool children

within the age range of 2.5 to 6 years represent a grey area regarding the decision to operate for a moderately ischemic extremity, whereas surgical repair can be performed in school-age children as in adults.

The major limitation of this study is the marginally comparable medical and surgical groups with different types and locations of injuries. Additionally, all but two patients in the conservatively treated group had less severe ischemia at presentation. It is obvious that the risks of an open surgical repair, especially a prolonged revascularization procedure, must be weighed against any potential benefits in limb-threatening arterial traumas.

An occluded artery can be detected in otherwise symptom-free children, usually as a result of a previous catheterization.^{17,21} The affected artery is typically the femoral artery and is not an indication for repair. The management and the timing of "prophylactic" surgical repair, if any, has been debated mainly because these lesions are associated with limb-length discrepancy. The clinical improvement after open repair of these "chronic" arterial occlusions is also questionable.^{1,21} Although secondary correction of limb-length discrepancy after late arterial repair in the adolescent has been reported, a wide range of newly established bone-lengthening techniques, as the Ilizarov procedure, may be better alternatives than arterial interventions in young patients.^{1,17}

AUTHOR CONTRIBUTIONS

Conception and design: MKL

Analysis and interpretation: MKL, GSG TTP

Data collection: GSG, TTP

Writing the article: MKL, GSG, SG

Critical revision of the article: MKL, CM

Final approval of the article: MKL, GSG, TTP, SG, CM

Overall responsibility: MKL

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INVITED COMMENTARY

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Doctor Lazarides and colleagues present a decade's experience of 23 children with extremity arterial trauma. Their standard policy was to repair all injuries tempered by the knowledge and observation that some neonates and infants did well with anticoagulation alone. This quite extensive experience provides an opportunity for the reader to clarify his or her approach and comfort in dealing with these children.

Fifteen children 2½ to 12 years old underwent surgical repair, with excellent initial results. Operation restored palpable pulses and prevented amputation except in one severely crushed leg and a case of diagnostic delay. These children were distinguished by penetrating etiology (10 cases) and severe ischemia. In the four younger patients (<6 years old), neurologic impairment and an absence of Doppler signals defined the degree of ischemia. Clearly, these children had limb-threatening ischemia. Reverse vein bypass grafts (n = 10) were often long and did allow limb salvage. No postoperative follow-up was reported.

Seven children were treated with anticoagulation alone and are the focus of this article. These children were distinguished by young age (three younger than 31 days old and one each 1½, 5, 6, and 7 years old), blunt or iatrogenic etiology, and borderline

limb-threatening ischemia, defined in five patients as the presence of distal Doppler signals and capillary refill with an absence of skin mottling. This definition of ischemia is important because it provides criteria for conservative treatment. The last five patients had palpable pulses at follow-up. More extensive ischemia is tolerated in some neonates, as demonstrated by the 1 month old with absent distal Doppler signals initially but a normal limb at 7 years and, more impressively, by the 5 day old with entire arm skin necrosis but palpable pulses, with minor limb length discrepancy at 8 years. Retrospective studies suffer in follow-up, and this is no exception in that phone interview alone may have sufficed, and no quantitative data, except for pulse presence, were provided.

These authors confirm that operative repair, even with long reverse vein bypasses, does allow initial limb salvage after childhood trauma. It is a safe, effective, and often mandated approach in children with penetrating injury and severe ischemia, thus confirming what others have reported. In the very young, especially in the absence of severe limb ischemia, anticoagulation alone is effective and long lasting. In addition, in very difficult cases of severe ischemia in neonates not conducive to an aggressive approach, anticoagulation may allow limb salvage.