Acute Management of Pediatric Vascular Injuries

Gilbert Aidinian, MD, FACS, FSVS, RPVI
Vascular and Endovascular Surgery

William Beaumont Army Medical Center
Disclosures

- None relative to this presentation
Origins of Vascular Injury Management

- Alexis Carrel (1902)
  - Popularized Techniques for arterial anastomosis
  - Nobel Prize in Physiology and Medicine in 1912
Major Vascular Trauma

• Well studied in adult population
• Significant data from military conflicts
Origins of Vascular Injury Management

Evolution Through Military Conflicts

• WWII
  – Repair only minor injuries
  – Routinely ligated
  – Popliteal artery injury – 73% amputation
• Korea
  – Formal repair advocated
  – Repair with lateral suture or anastomosis
• Vietnam
  – Vascular repair with vein graft, vein repair
  – Popliteal artery injury – 32% amputation
• GWOT
  – Vascular repair with vein graft, vein repair, damage control, and shunts
  – Amputation rates ~ 5 – 15%
Modern Day Trauma

- Trauma (United States)
  - Leading cause of death
  - Leading cause of death in children older than 2

- More males younger than 18 years die from handgun injuries than MVAs, drugs or disease

- Survivors are frequently incapacitated
Civilian Vascular Injury

Violence In Society

- Homicide rates are loosely linked to the incidence of vascular injury

- In US, gun violence is the principal agent of death in 60% of cases
  - High-velocity penetrating trauma is increasing
High Velocity Missiles

- Widespread damage
- Cavitation effect
  - Vessels damaged remote from the wound tract

- As the blast cavity collapses, suction effect draws structures into the wound
- Significant soft tissue damage
- Destructive effect may not be suspected on initial inspection
Pediatric Vascular Injuries

Background

- Incidence (NTDB analysis)
  - 0.6% to 1.4% of all pediatric injuries
  - Likely underestimated
    - Does not include patients who died at the trauma scene
    - Does not include iatrogenic injuries
  - Traumatic injury progressively increases at age 14, peaking at age 21

- Leading cause of mortality in ages 2 to 18 years
  - 13.2% in-hospital mortality rate
    - 2.4% mortality at the time of presentation to the ED
  - Highest mortality (18.2%) in infants with chest vascular injuries

Pediatric Vascular Injuries

**Background**

- Challenging to diagnose and treat
  - More difficult to diagnose
    - Asymptomatic
    - Have more severe life-threatening injuries that take priority
  - Technically challenging to treat
    - Small caliber vessels
    - Associated with vasospasm
    - Considerations for ongoing axial growth

Pediatric Vascular Injuries

**Etiology**

- **Iatrogenic**
  - Most common (33% - 100%)
    - Misadventures of arterial and venous catheterization
      - ECMO cannulation injuries (20% - 52%)
        » Both femoral and carotid sites

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonates</td>
<td>Highest frequency</td>
</tr>
<tr>
<td>2-6</td>
<td>50</td>
</tr>
<tr>
<td>Over 6</td>
<td>33</td>
</tr>
</tbody>
</table>
Pediatric Vascular Injuries

Etiology

• Iatrogenic
  – Factors associated increased risk of iatrogenic femoral complications
    • Age younger than 3
    • Type of therapeutic intervention
    • ≥3 earlier catheterization
    • ≥6Fr or larger catheters
Pediatric Vascular Injuries

**Etiology**

- **Non-iatrogenic**
  - 2/3 of injuries for over age 6 years

<table>
<thead>
<tr>
<th></th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVA</td>
<td>24.3%</td>
</tr>
<tr>
<td>Firearm</td>
<td>19.6%</td>
</tr>
<tr>
<td>Stab wounds</td>
<td>16.6%</td>
</tr>
<tr>
<td>Falls</td>
<td>11.8%</td>
</tr>
</tbody>
</table>

Pediatric Vascular Injury

Anatomic Location

- Upper extremity
  - Most common location (37%)
  - Brachial artery injuries
    - Highest amputation rate
  - Blunt
    - Most commonly combined with orthopedic trauma
    - Supracondylar fracture
      - 10% brachial artery injury
      - Can result in amputation/Volkman Ischemic contracture
      - Explore/repair brachial artery if no return of pulses after orthopedic repair

TABLE 1. Injuries by Location in All Patients (Survivors and Nonsurvivors)

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Arterial Injuries</th>
<th>Vessel</th>
<th>Venous Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head/neck</td>
<td>8</td>
<td>Internal jugular vein</td>
<td>2</td>
</tr>
<tr>
<td>Common carotid artery</td>
<td>4</td>
<td>Hepatic vein</td>
<td>2</td>
</tr>
<tr>
<td>Internal carotid artery</td>
<td>4</td>
<td>Iliac vein</td>
<td>1</td>
</tr>
<tr>
<td>Torso</td>
<td>30</td>
<td>Innominate artery</td>
<td>2</td>
</tr>
<tr>
<td>Aorta</td>
<td>12</td>
<td>Epigastric artery</td>
<td>1</td>
</tr>
<tr>
<td>Iliac artery</td>
<td>5</td>
<td>Hepatic artery</td>
<td>2</td>
</tr>
<tr>
<td>Renal artery</td>
<td>3</td>
<td>Stylogastric artery</td>
<td>1</td>
</tr>
<tr>
<td>Innominate artery</td>
<td>2</td>
<td>Hypogastric artery</td>
<td>1</td>
</tr>
<tr>
<td>Ileal mesenteric artery</td>
<td>1</td>
<td>Ileal mesenteric artery</td>
<td>1</td>
</tr>
<tr>
<td>Internal mammamary artery</td>
<td>1</td>
<td>Superior mesenteric artery</td>
<td>1</td>
</tr>
<tr>
<td>Superior mesenteric artery</td>
<td>1</td>
<td>Splenic artery</td>
<td>1</td>
</tr>
<tr>
<td>Subelavian artery</td>
<td>1</td>
<td>Subelavian artery</td>
<td>1</td>
</tr>
<tr>
<td>Lower extremity</td>
<td>28</td>
<td>Popliteal vein</td>
<td>1</td>
</tr>
<tr>
<td>Femoral artery</td>
<td>10</td>
<td>Popliteal artery</td>
<td>7</td>
</tr>
<tr>
<td>Posterior tibial artery</td>
<td>8</td>
<td>Anterior tibial artery</td>
<td>2</td>
</tr>
<tr>
<td>Anterior tibial artery</td>
<td>2</td>
<td>Femoral vein</td>
<td>3</td>
</tr>
<tr>
<td>Peroneal artery</td>
<td>1</td>
<td>Venous Injuries</td>
<td></td>
</tr>
</tbody>
</table>

| Upper extremity       | 45                | Brachial vein         | 1               |
| Brachial artery       | 16                | Ulnar artery          | 16              |
| Ulnar artery          | 16                | Radial artery         | 12              |
| Radial artery         | 12                | Axillary artery       | 1               |
| Axillary artery       | 1                 | Total                 | 111             |

Pediatric Vascular Injury
Anatomic Location

- Upper extremity
  - Most common location (37%)
  - Brachial artery injuries
    - Highest amputation rate
  - Blunt
    - Most commonly combined with orthopedic trauma
    - Supracondylar fracture
      - 10% brachial artery injury
      - Can result in amputation/Volkman ischemic contracture
      - Explore/repair brachial artery if no return of pulses after orthopedic repair
Pediatric Vascular Injury

Anatomic Location

- **Truncal (30%)**
  - Blunt (53%), penetrating (47%)
  - Highest mortality rate (16% - 41%)
    - Chest 41%, abdomen 25%
    - Higher than all other regions combined
  - Have concomitant significant organ injuries
    - Significantly higher ISS (45.4 ± 19.8)
- **Aorta (26%)**
  - 50% mortality
- **IVC (26%)**
  - 67% mortality

**TABLE 1. Injuries by Location in All Patients (Survivors and Nonsurvivors)**

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Arterial Injuries</th>
<th>Vessel</th>
<th>Venous Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head/neck</td>
<td>8</td>
<td>Internal jugular vein</td>
<td>2</td>
</tr>
<tr>
<td>Common carotid artery</td>
<td>4</td>
<td>Ilaic vein</td>
<td>3</td>
</tr>
<tr>
<td>Internal carotid artery</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Torso</td>
<td>30</td>
<td>Vena cava</td>
<td>12</td>
</tr>
<tr>
<td>Aorta</td>
<td>12</td>
<td>Hepatic vein</td>
<td>2</td>
</tr>
<tr>
<td>Iliac artery</td>
<td>5</td>
<td>Ilaic vein</td>
<td>1</td>
</tr>
<tr>
<td>Renal artery</td>
<td>3</td>
<td>Superior mesenteric vein</td>
<td>1</td>
</tr>
<tr>
<td>Innominate artery</td>
<td>2</td>
<td>Epigastric artery</td>
<td>1</td>
</tr>
<tr>
<td>Epigastric artery</td>
<td>1</td>
<td>Hepatic artery</td>
<td>1</td>
</tr>
<tr>
<td>Hypogastric artery</td>
<td>1</td>
<td>Hypogastric artery</td>
<td>1</td>
</tr>
<tr>
<td>Ileal mesenteric artery</td>
<td>1</td>
<td>Ileal mesenteric artery</td>
<td>1</td>
</tr>
<tr>
<td>Internal mammary artery</td>
<td>1</td>
<td>Superior mesenteric artery</td>
<td>1</td>
</tr>
<tr>
<td>Splenic artery</td>
<td>1</td>
<td>Subelavian artery</td>
<td>1</td>
</tr>
<tr>
<td>Lower extremity</td>
<td>28</td>
<td>Popliteal vein</td>
<td>5</td>
</tr>
<tr>
<td>Femoral artery</td>
<td>10</td>
<td>Femoral vein</td>
<td>3</td>
</tr>
<tr>
<td>Posterior tibial artery</td>
<td>8</td>
<td>Popliteal artery</td>
<td>7</td>
</tr>
<tr>
<td>Popliteal artery</td>
<td>7</td>
<td>Peroneal artery</td>
<td>2</td>
</tr>
<tr>
<td>Anterior tibial artery</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peroneal artery</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper extremity</td>
<td>45</td>
<td>Brachial artery</td>
<td>16</td>
</tr>
<tr>
<td>Brachial artery</td>
<td>16</td>
<td>Ulnar artery</td>
<td>16</td>
</tr>
<tr>
<td>Ulnar artery</td>
<td>16</td>
<td>Radial artery</td>
<td>12</td>
</tr>
<tr>
<td>Radial artery</td>
<td>12</td>
<td>Axillary artery</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>111</td>
<td></td>
<td>27</td>
</tr>
</tbody>
</table>

Pediatric Vascular Injury

Anatomic Location

- Lower extremity
  - 25% of injuries
    - Femoral artery (28%)
    - Popliteal artery (19%)
      - Highest amputation rate
    - Popliteal vein most commonly injured vein (63%)
  - No deaths

General Principles of Management

Diagnostic Evaluation

<table>
<thead>
<tr>
<th>TYPE OF INJURY</th>
<th>CLINICAL PRESENTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial laceration</td>
<td>Decreased pulse, hematoma, hemorrhage</td>
</tr>
<tr>
<td>Transection</td>
<td>Absent distal pulses, ischemia</td>
</tr>
<tr>
<td>Contusion</td>
<td>Initially, examination may be normal; may progress to thrombosis</td>
</tr>
<tr>
<td>Pseudoaneurysm</td>
<td>Initially, examination may be normal; bruit or thrill, decreased pulses</td>
</tr>
<tr>
<td>AV fistula</td>
<td>Same as pseudoaneurysm</td>
</tr>
<tr>
<td>External compression</td>
<td>Decreased pulses; normal pulses when fracture aligned</td>
</tr>
</tbody>
</table>

- Prompt treatment in order to optimize outcomes
- Destruction of surrounding soft tissue
- Look for hard signs
# Signs of Traumatic Vascular Injury

## Hard Signs
- Observed pulsatile bleeding
- Arterial thrill by manual palpation
- Bruit auscultated over or near an area of arterial injury
- Absent distal pulse
- Visible expanding hematoma

## Soft Signs
- Significant hemorrhage by history
- Neurologic abnormality
- Diminished pulse compared with contralateral extremity
- Proximity of bony injury or penetrating wound
## General Principles of Management

### Associated Orthopedic Injuries

<table>
<thead>
<tr>
<th>Orthopedic Injury</th>
<th>Arterial Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supracondylar fracture of the humerus</td>
<td>Brachial artery</td>
</tr>
<tr>
<td>Clavicular, first rib fracture</td>
<td>Subclavian artery</td>
</tr>
<tr>
<td>Shoulder dislocation</td>
<td>Axillary artery</td>
</tr>
<tr>
<td>Elbow dislocation</td>
<td>Brachial artery</td>
</tr>
<tr>
<td>Distal femur fracture</td>
<td>Superficial femoral, popliteal artery</td>
</tr>
<tr>
<td>Posterior knee dislocation</td>
<td>Popliteal artery</td>
</tr>
<tr>
<td>Proximal tibia fracture</td>
<td>Popliteal artery, distal vessels</td>
</tr>
</tbody>
</table>
General Principles of Management

Diagnostic Evaluation

• Physical Examination
  – Examine contralateral extremity
    – Skin color
    – Capillary refill
    – Pulse exam
    – Consider vasospasm

• In absence of hard signs
  – Address life threatening injuries
  – Resuscitate and warm the child
  – Re-evaluate pulses
  – Avoids unnecessary diagnostic tests/interventions
General Principles of Management

Soft Signs

• Continuous hand held Doppler examination
• Measure ABI (ankle-brachial index)
  – Not as reliable in younger than 2 years
• Measure IEI (injured extremity index)
  – Concerning for vascular injury when <0.9 in children older than 2 and less then 0.88 in children under 2
• Pulse oximetry on injured extremity
• Duplex ultrasonography
  – Non-invasive
  – Portable
  – Sensitivity (>95%), specificity (>97%)
  – Nearly all major extremity injuries that require therapeutic intervention can be identified
General Principles of Management

Soft Signs

– CT angiography
  • Useful for blunt truncal injuries
  • Not as useful for extremity arterial injuries in children
General Principles of Management

Soft Signs

– Catheter based angiography
  • Selective cases
  • Most safe in 10 years and older
  • High complication rates in small children
  • Very useful in identifying the location of arterial injury and distinguishing arterial injury from vasospasm
Pediatric Vascular Injuries

Treatment

- Historic treatment
  - Ligation and systemic anticoagulation
    - Loss of axial growth and debilitating gait disturbance
    - Limb overgrowth due to traumatic AVF
    - Amputation

- Gold standard
  - IMMEDIATE restoration of perfusion
Pediatric Vascular Injuries

Medication Considerations

• Unfractionated heparin
  – Safe to use in children (bolus 75 – 100 u/kg)
• Protamine sulfate
  – Safe to use intraoperatively to reverse heparin (1 mg/100 units of heparin)
  – Not typically administered in neonates and young children
• LMWH
  – Anticoagulant agent of choice in preoperative and postoperative pediatric patients
• NOACs
  – Data on use in children is limited and not defined
• Antiplatelet agents (Aspirin/Clopidogrel) safe to use in appropriate doses
  – 30 day course
Pediatric Vascular Injuries

**Treatment**

- Principles of adult vascular trauma can be translated to the pediatric population
  - Pre-operative antibiotics (include Gram (-) if bony injuries)
  - Fluoroscopy table
  - Prep entire injured extremity AND prep uninjured extremity
  - Systemic heparanization
  - Harvest saphenous vein from uninjured leg
  - Proximal and distal control
  - Evaluate artery, vein, nerve, soft tissue
  - Intravascular temporary shunts
  - Use of appropriately sized embolectomy catheters
  - Liberal use of fasciotomy
Management of Pediatric Vascular Injuries

Treatment

Management and outcome of pediatric vascular injuries

Carl-Magnus Wahlgren, MD, PhD and Björn Kragsterman, MD, PhD, Stockholm, Sweden

ORIGINAL ARTICLE

J Trauma Acute Care Surg Vol 79, Number 4

TABLE 2. Operative Management of Vascular Injuries

<table>
<thead>
<tr>
<th>Operative Management (n = 222)</th>
<th>Frequency, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interposition graft</td>
<td>54 (24)</td>
</tr>
<tr>
<td>Exploration</td>
<td>51 (23)</td>
</tr>
<tr>
<td>Patch</td>
<td>43 (19)</td>
</tr>
<tr>
<td>Primary repair</td>
<td>27 (12)</td>
</tr>
<tr>
<td>Bypass</td>
<td>21 (9.5)</td>
</tr>
<tr>
<td>Endovascular</td>
<td>8 (3.7)</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>18 (8.1)</td>
</tr>
</tbody>
</table>
Pediatric Vascular Injuries

Treatment

- Temporary vascular shunts
  - Reduce ischemia time when revascularization needs to be delayed (damage control surgery)
  - Allow fracture fixation, vein repair
How to Place a Shunt

• Obtain proximal and distal control
  — Preferably out of the zone of injury

• Mobilize the artery in both directions

• Resect the injured segment of the artery

• Allow the distal end to back-bleed
  — Perform thrombectomy if necessary

• Flush the proximal artery until pulsatile flow is observed
  — Perform thrombectomy if necessary

• Insert the largest shunt without damaging the normal artery
  — Secure with silk or Rummel Tourniquet

• Confirm patency with continuous wave Doppler
Management of Pediatric Vascular Injuries

**Treatment**

- Define the extent of the vascular injury
- Accommodate vessel axial growth and luminal expansion
- Intravascular vasodilators
  - Papaverine
- Primary repair
  - Short segment injury
  - Can result in stenosis
  - Interrupted sutures
- Patch repair
  - Avoids luminal growth issues
  - Interrupted sutures
  - Vein patch with non-injured GSV
- Autologous grafts (reversed saphenous vein)
  - When primary repair not feasible
  - GSV is the conduit of choice
  - Prosthetic grafts have higher poor long term patency
Gsv vein graft (diameter is about 2 mm)

3 cm
Vascular Repair Rules

• It is imperative to ensure that vascular repairs are covered with healthy muscle and not left exposed or bathed in devitalized infected tissue.... EXPOSED GRAFTS WILL BLOW OUT!
Injury with ePTFE temporary vascular conduit
Injury with ePTFE temporary vascular conduit

Saphenous vein graft with early latissimus flap
Management of Pediatric Vascular Injuries

**Truncal**

- Thoracic aortic repair
  - Special diagnostic problem
  - Inaccessible on clinical exam
  - Clamp-and-sew technique
  - Delayed repair of blunt injuries
    - Initiate beta-blocker therapy
Management of Pediatric Vascular Injuries

Truncal

- Abdominal aortic repair
  - After age of 10, there is minimal longitudinal aortic growth
  - Synthetic graft
    - Aortic/caval injuries
  - Autologous conduit (GSV)
    - All other injuries
  - General principles
    - Broadly prep the patient
    - Transverse incision (young children)
      - Provides best exposure to abdominal aorta and its major branches
Management of Pediatric Vascular Injuries

Cervical

- **Zone III**
  - Above the angle of the mandible

- **Zone II**
  - Between the cricoid cartilage and the angle of the mandible

- **Zone I**
  - Below the cricoid cartilage
Anatomically accessible lesions (zone II) require repair via neck incision
Anatomically accessible lesions (zone II) require repair via neck incision.
ICA vein graft – Zone II
Management of Pediatric Vascular Injuries

Cervical - Penetrating

– Proximal (zone I) may require median sternotomy
  • Or start with cervical incision and extent down to median sternotomy
Management of Pediatric Vascular Injuries

Cervical - Penetrating

- Distal (zone III) may require ligation of internal carotid artery or endovascular repair
Management of Pediatric Vascular Injuries

Cervical - Blunt

– Hyperextension injury
  • ICA is forcibly stretched over the transverse process of C2 and the body of C1
– Medial/intimal tears/dissection
– Rarely require surgical intervention
– Careful observation, antiplatelet therapy and serial imaging
Management of Pediatric Vascular Injuries

Cervical

- Aerodigestive injuries frequently accompany carotid artery trauma
  - Penetrating >>> blunt
  - Endoscopy
    - Oropharynx, trachea, esophagus
    - Esophagography

- Higher risk of infection of vascular repair !!
Management of Pediatric Vascular Injuries

Endovascular Treatment

• Limited role in pediatric trauma
• Fraught with complications
  – Access site complications
• Can be used to control bleeding
  – Proximal balloon occlusion
  – Embolization
  – Covered stent placement
Management of Pediatric Vascular Injuries

Endovascular Treatment

- Limited role in pediatric trauma
- Fraught with complications
  - Access site complications
- Can be used to control bleeding
  - Proximal balloon occlusion
  - Embolization
  - Covered stent placement
Management of Pediatric Vascular Injuries

Endovascular Treatment

• Small thoracic stent grafts for adolescent thoracic aortic repair
  – Long term results are lacking

Endograft repair of traumatic aortic transection in a 10-year-old—a case report

Gilbert Aidinian, Michael Karnaze, Eugene P Russo, Dipankar Mukherjee
Left Carotid Injury
Covered Stent
Management of Pediatric Vascular Injuries

Endovascular Treatment

• Contrast volume
  – Neonates: Less than 4 – 5 mL/kg
  – Infants: Less than 6 – 8 mL/kg

• Hand injection instead of power injection for patients less than 15 kg

• Systemic heparanization to prevent common femoral artery thrombosis

• 3 to 5 Fr sheaths
Management of Pediatric Vascular Injuries

Postoperative

• Endograft repairs
  – Annual CTA until adulthood

• Duplex surveillance
  – Accessible sites
Conclusion

- Rare events
- Establish algorithmic institutional guidelines to treat these patients
- Guidelines on use of ultrasound for arterial access in this population
- Aggressive operative management
Questions?