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Vascular Damage Control

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Abstract

Purpose of Review This article reviews vascular damage control, with a focus on the importance of immediate hemorrhage control, indications for damage control surgery rather than definitive repair, and methods of hemorrhage control including temporary shunting to maintain distal perfusion, simple ligation, or immediate reconstruction, as well as prioritizing temporary or definitive vascular repair in the setting of multisystem trauma in the care of the injured patient.

Recent Findings The indications and methods of damage control surgery in vascular trauma continue to evolve. The importance of early hemorrhage control is well known as a preventable cause of mortality related to hemorrhagic shock, but decisions regarding the practice of damage control, including ligation, shunting, and definitive repair continue to be a subject of debate in the literature. It is the purpose of this text to discuss the current practice of damage control regarding vascular trauma.

Summary Vascular damage control is an essential part of damage control surgery. Ligation and intravascular shunting are the primary options and should be applied to patients requiring damage control, to those with combined vascular and bony injuries, and for those surgeons where definitive reconstruction is beyond their skillset.

Keywords Extremity trauma · Damage control surgery · Vascular trauma · Hemorrhage control · Temporary vascular shunt

Introduction

Damage control surgery has become an essential part of the initial resuscitation and treatment of the critically ill trauma patient. Since the early description of the abbreviated laparotomy by Stone in 1983 [1], the rapid control of exsanguinating hemorrhage and gross contamination in patients with high-risk injury patterns and severe physiologic derangements has been well described [2••]. In early work by Rotondo, a substantial improvement in survival was demonstrated in patients with combined abdominal visceral and vascular injuries who were treated in this manner [3]. Though initially described as an innovative method of staged operative treatment after severe abdominal trauma, this has been expanded to include the management of extra abdominal injuries, including thoracic and vascular injuries [4•]. As the indications and methods of damage control surgery continue to evolve from these initial descriptions, a critical evaluation of vascular damage control is warranted. The focus of this chapter is to provide a detailed discussion of damage control surgery as it relates to vascular injury, ranging from simple compression to definitive repair.

Historical Perspective

The current treatment of vascular trauma has been shaped not only by our experience in civilian injuries, but by the results derived from wartime intervention. Vascular trauma before and during World War II consisted predominantly of ligation and amputation, largely due to the abysmal medical evacuation times [5]. Although saphenous vein bypass was described as early as 1949 [6], arterial reconstruction after injury was not widespread until the Vietnam War, where amputation rates were significantly improved from the traditional 50–60% rate of limb loss with ligation during combat to an acceptable 13% [7]. However, not all injuries are amenable to immediate arterial repair, leading to the need for temporary restoration of vascular perfusion while awaiting formal reconstruction.

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With early technical descriptions provided by Tuffier [8] and experience reported by Makins in World War I, the initial concept of an implantable prosthetic shunt was to be a temporary solution, with planned failure. The practice relied on restoration of flow allowing time for collateralization as the shunt thrombosed and failed over time, preventing the neuromuscular damage created by permanent or prolonged ischemia associated with acute arterial disruption or occlusion [9]. As shunt materials were improved and methods of arterial reconstruction became more widespread, modern descriptions of temporary vascular shunts began to be reported. Once again, this progressive technique resulted in a decrease in amputation rate with the early and routine use of temporary arterial shunts compared to conventional treatment [10]. It was not until medical air evacuation became a reality that the concept of temporary, removable arterial shunting became truly useful in wartime vascular trauma. In the modern era, this practice has been increasingly well documented [11••, 12–14]. Surgical intervention in civilian trauma has followed suit, and temporary shunting is now a standard of care in damage control treatment of vascular trauma [15••, 16, 17•].

Vascular Injury and Hemorrhagic Shock

According to the Centers for Disease Control, trauma is the leading cause of death for all patients in the USA up to the age of 45 years and is the fourth leading cause of death across all age groups. Within this population, exsanguinating hemorrhage is the cause of 30–40% of trauma-related mortality and is the leading cause of preventable death, underscoring the need for early hemorrhage control to salvage both life and limb. In the setting of compressible hemorrhage, this intervention should be performed immediately via direct compression or tourniquet use, as up to 56% of hemorrhage-related deaths occur in the prehospital period. Unfortunately, up to 70% of deaths from otherwise survivable injuries result from noncompressible torso hemorrhage, requiring more invasive intervention [18, 19].

Methods of initial hemorrhage control (and therefore damage control) in the prehospital setting range widely. From simple direct compression and application of topical hemostatic agents, to proximal tourniquet application, all are paramount in temporizing or minimizing ongoing blood loss and mitigating the onset of hemorrhagic shock. The widespread use of tourniquets has been a major improvement in trauma care in the setting of bleeding extremity injuries, again paralleling trends seen in the analysis of wartime injuries. This intervention has the benefit of temporizing ongoing hemorrhage with minimal complications [19, 20•, 21•]. The rapid expansion of the "Stop the Bleed" campaign across the USA aims to improve even lay bystander awareness and preparedness. These early methods of intervention are simple and widely applicable and may prevent worsening metabolic derangements and progression to the deadly triad of trauma: coagulopathy, hypothermia, and acidosis.

In the hospital setting, definitive hemorrhage control and restoration of distal perfusion become the goal. If ongoing bleeding is noted on initial evaluation, the focus should be on immediate intervention to prevent ongoing blood loss. Again, direct pressure must not be overlooked. In the setting of extremity injuries, tourniquet placement, or the need for additional tourniquets, must be evaluated. Placement of Foley catheters or other occlusive devices into junctional penetrating wounds for tamponade via balloon inflation can also be considered. Topical hemostatic agents may be available in the emergency department setting and can improve hemorrhage control. Balloon occlusive devices may also be considered in non-compressible torso or junctional hemorrhage not amenable to other methods of control.

The success of the above interventions will dictate the subsequent treatment algorithm. Other life-threatening injuries must be ruled out prior to discussion of definitive repair or restoration of distal perfusion. The patient's physiology and overall injury burden should be rapidly assessed. Balanced blood product transfusion should be followed as an essential component of damage control resuscitation to optimize survival for those who present with significant vascular trauma and hemorrhage [22, 23]. Temporizing bleeding and resuscitation should not delay definite operative control of the bleeding source.

Indications for Vascular Damage Control

Vascular damage control should be considered in several clinical situations:

- *Physiologic derangements:* Patients who present in hemorrhagic shock with severe associated metabolic derangements will require truncated operative interventions in favor of damage control resuscitation in the ICU setting with massive transfusion and aggressive rewarming. Attempts to reconstruct or repair all associated injuries will result in worsening of hypothermia, coagulopathy, and acidosis.
- *Severe injury burden:* In the setting of multisystem trauma with a large injury burden requiring emergent intervention, vascular damage control should be considered. Even if the patient is stable, if definitive reconstruction is likely to result in a physiologically deranged patient, damage control should be used.
- *Associated bony injury in the extremity:* Patients with mangled extremities or unstable fractures that require

bony fixation should have temporary restoration of distal perfusion. If the patient remains stable, orthopedic fixation can be performed. If the patient tolerates this, definitive vascular reconstruction can then be performed.

Other considerations for damage control are related to non-clinical factors:

- *Austere environments:* In settings where the provider skillset is insufficient or the infrastructure will not support definitive reconstruction, temporary flow restoration will buy time for transfer to definitive care.
- *Lack of experience:* Some surgeons or facilities may not be familiar with or capable of managing complex vascular reconstruction, necessitating medical evacuation to a higher level of care that offers specialty surgical intervention.
- *Mass casualty events:* When patient volume is high, resource allocation must be considered. Surgeons and support staff may be unable to devote hours to meticulous reconstruction necessitating temporary measures of hemorrhage control and restoration of distal perfusion.

Underestimating the physiologic insult of the trauma patient, or overestimating the capabilities of the surgical team may result in disastrous outcomes if damage control tenets are not followed.

Methods of Vascular Damage Control

When the decision to proceed with vascular damage control surgery is made (or forced), several options should be considered, including ligation, shunting, and packing. In a broad sense, most venous injuries may be ligated, arterial injuries excluding distal extremities should be shunted, and retroperitoneal or parenchymal bleeding should be controlled with cautery, topical hemostatic agents, or gauze packing. However, specific consideration should be given to anatomic location, tolerance of ligation, and intricacy of definitive repair, even at the time of the index operation.

For ease of discussion, these injuries can be divided into arterial or venous. This can often be quickly identified preoperatively, on imaging, or intraoperatively when hemorrhage control and vessel exposure are achieved. Once this distinction has been made, the decision of repair, shunting, or ligation is dictated by the anatomic location, severity of injury, and ability of the collateral circulation to tolerate ligation versus the necessity for restoration of flow. Proximal and distal control should be obtained to assure reliable hemorrhage control and assessment of injury, followed by the following decision-making strategies.

Arterial Injuries

Arterial injuries are not only life- and limb-threatening but also time-sensitive. The classic "six-hour window," originally described by Miller in 1949, highlights the importance of timeliness regarding restoration of vascular inflow for both survival and return to normal function [24]. This is certainly not an absolute, but the earlier flow is restored, the better the outcome.

Ligation

Classically, non-named arteries can be treated with simple ligation. Of the larger, named vessels, the profunda femoris, unilateral renal artery, bilateral internal iliac, and external carotid arteries can also be ligated in a damage control situation [25–27]. Safe results after ligation have been reported even with mesenteric vessels, assuming adequate collateral flow can be assured, as with the celiac axis and inferior mesenteric arteries [28–30]. This is unlike injury to the proximal superior mesenteric artery, which results in significant ischemia of the small bowel and right colon if ligated [31]. Regarding the distal extremities, ligation should only be considered after the bifurcation or trifurcation in the upper and lower extremities respectively. In the upper extremity, this includes the radial or ulnar artery with an intact palmar arch [32]. In the lower extremity, this includes vessels below the trifurcation. Here, as long as one of the runoff vessels is patent, outcomes in a damage control setting will be acceptable [33]. Although ligation of more proximal extremity vessels has been reported, significant morbidity should be expected due to the lack of reliable collateral flow, and alternative methods of temporary flow restoration should be used instead [5, 34, 35].

Shunt Placement

As discussed earlier in this chapter, there are vessels that will not tolerate ligation. In the damage control setting, these vessels can be temporarily reconstructed functionally with a shunt [36•]. It is fast and requires basic materials and a minimal technical skillset. As such, this should be part of the armamentarium of any surgeon taking trauma call.

The practice of shunting has proven particularly effective in the combat setting as a temporizing means of flow restoration. This allows forward deployed surgical teams to provide rapid damage control prior to evacuation for definitive reconstruction. Similarly, civilian data has shown temporary shunt placement to be an effective means of damage control, particularly in the setting of more proximal vessels that cannot be safely ligated. Specifically, outcomes noted with common and external iliac shunt placement result in superior outcomes when compared to traditional ligation, resulting in a decreased risk of amputation [37•]. This practice has essentially replaced the need for ligation. As discussed above, the benefit of establishing arterial inflow also allows for complex orthopedic fixation or tissue reconstruction to be carried out without concerns for prolonged ischemia, or disruption of delicate vascular repair [15••, 16].

Mesenteric vessels have been treated similarly, in situations where simple primary repair is impossible, or ligation is prohibitive due to the proximal nature of the injury and subsequent risk of bowel ischemia. Successful reports include superior mesenteric artery shunting as a bridge to definitive vein harvest and repair after the patient's condition has stabilized [38].

Definitive Repair

A detailed description of the wide range of possible repair techniques is beyond the scope of this review text. However, for completeness, simple non-destructive arterial injuries may be repaired with primary repair at the time of initial damage control, as long as it is rapid and effective. More important is the discussion of the operative timing for definitive reconstruction after damage control shunting. The patient's clinical condition, rather than the time since initial operation, should dictate the timing of definitive repair. Physiologic parameters such as temperature, coagulation, and acid base status, as well as need for ongoing resuscitation or vasopressor support, must be considered.

Fasciotomy

The need for fasciotomy at the time of definitive repair or damage control surgery should be considered in all patients. A liberal approach has been shown to significantly reduce the morbidity and mortality of muscle swelling after revascularization, showing as much as a fourfold reduction in overall complications, including amputation [39••]. The longer the ischemic insult, the more important is this consideration.

Fasciotomy after venous injury, however, should be carefully considered. Certainly, when clinical concern for compartment syndrome exists, compartment release is mandatory. However, the routine use of the fasciotomy often utilized after arterial injury may result in significant bleeding related to elevated venous pressure due to venous stenosis or ligation [40].

Venous Injuries

When considering damage control for venous trauma, any complex injuries should be ligated. Aside from injuries amenable to simple lateral venorrhaphy, there is little utility for venous repair in the hemodynamically unstable patient, excluding a few specific circumstances that warrant brief discussion.

Ligation

Apart from the portal vein, superior mesenteric vein, perinephric or suprarenal inferior vena cava, right or perinephric left renal, and bilateral internal jugular veins, almost all venous injuries can and should be ligated. Certainly, if a simple repair is feasible without creating significant stenosis, it is encouraged. However, anatomic drainage excluding those vessels mentioned above is reliably mitigated by adequate collateral flow. Even in cases where significant collateral flow is not present, as in the iliac veins, the most substantial noted morbidity with vessel ligation is typically unilateral extremity edema, which is almost always transient. This is preferable to a repair that results in flow-limiting stenosis due to the associated risk of thrombosis and pulmonary embolism [41]. Should ligation of the infrarenal vena cava or iliac veins be required, the lower extremities should be wrapped and elevated as soon as feasible to prevent complications associated with the subsequent edema.

Shunt Placement

While shunt usage in the venous system has theoretical advantages, data supporting a definite clinical benefit of this practice is yet to be reliably demonstrated [42]. For veins that cannot be ligated however, this is an excellent option.

Definitive Repair

If repair is to be considered, it is important to consider the overall injury burden, the complexity of the repair, and the additional time required for definitive repair prior to subjecting the patient to additional operative time. This is perhaps most well illustrated by the report of Stone et al. regarding the observed mortality reduction when early ligation was used rather than ligation after failed attempts at reconstruction [43]. Most reports of complex venous repair demonstrate poor outcomes regarding short-term patency, questioning the utility of this practice [44].

Shunting Technique

Temporary vascular shunt placement is a relatively straightforward procedure. After identification and assessment of the injury, proximal and distal hemorrhage control is obtained. This is followed by evaluating the appropriateness for ligation, simple repair, or temporary shunting in the damage control situation.

Choice of Shunt

The next critical decision is choice of shunt. Ideally, the largest conduit that the injured vessel lumen can accommodate should be used to reduce risk of flow limitation or thrombosis. Several commercially manufactured shunts are available, but any sterile atraumatic tubing will suffice if the caliber is appropriate. Options for use range from sterile intravenous tubing, pediatric chest tubes or feeding tubes, to purpose-built commercial shunts. At our center, for peripheral injuries, we use Argyle (15 cm) vascular shunt kits as they are inexpensive and provide a range of sizes (8–14 Fr) that are rapidly available in a single kit. For central injuries, non-commercial devices must be utilized. Preparation is a key, and these devices should be readily available in the trauma operating room.

Embolectomy and Heparinization

Prior to shunt insertion, all thrombus should be evacuated with a Fogarty embolectomy catheter. For the distal extremities, we prefer 3–4-Fr embolectomy catheters, with 5–6-Fr catheters for larger, proximal injury locations. Once adequate back bleeding and inflow are assured, local infusion of heparinized saline (5000 U in 100 mL normal saline) can be performed via an olive tip syringe. Although additional systemic heparinization may be used for isolated extremity injuries, it is not necessary and should not be used in the damage control setting. Reliable shunt patency has been reported without the routine use of heparin.

Shunt Insertion

While many authors suggest trimming the damaged vessel, it is our practice to leave the damaged edges intact, reserving debridement of the affected portion until the time of definitive repair. Because any vessel wall proximal to the ties will be lost, there is no advantage to trimming the edges, as this will waste vessel length. The distal end of the shunt should be inserted and gently secured with 0-0 or 2-0 silk around the native vessel. Care should be taken to insert the shunt directly into the lumen without dissecting the wall. This process is repeated with the proximal end of the shunt, and each tie is secured to a long silk tie placed around the central portion of the shunt to assure migration is prevented.

Shunt Evaluation

After shunt insertion, distal pulses, Doppler signals, or a confirmatory angiogram must be evaluated prior to leaving the operating room to assure appropriate distal perfusion and for establishing a baseline to monitor interval shunt patency. Should distal perfusion be deemed inadequate, shunt positioning and vascular inflow and outflow should be re-evaluated and corrected. Intraoperative angiography can be beneficial in this setting to localize any technical complication.

Conclusion

Vascular damage control is central to the concept of damage control surgery and resuscitation. The need for time-limited interventions to save life and limb should be a part of the armamentarium of all surgeons who care for the injured patient. Rapid intervention is critical for reversal of the physiology caused by unabated hemorrhagic shock: profound metabolic acidosis, worsening coagulopathy, hypothermia, and ultimately death. The above interventions provide a method of rapid intervention to control life-threatening hemorrhage, preventing this progression while maintaining distal perfusion, allowing survival to definitive repair.

Compliance with Ethical Standards

Conflict of Interest The authors declare no conflicts of interest relevant to this manuscript.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance
•• Of major importance

1. Stone HH, Strom PR, Mullins RJ. Management of the major coagulopathy with onset during laparotomy. Ann Surg. 1983;197:532–5.
2.•• Roberts DJ, Bobrovitz N, Zygun DA, Ball CG, Kirkpatrick AW, Faris PD, et al. Indications for the use of damage control surgery and damage control interventions in civilian trauma patients: a scoping review. J Trauma Acute Care Surg. 2015;78:1187–96. **A thorough literature review evaluating indications for and techniques utilized in damage control surgery.**
3. Rotondo MG, Schwab CW, McGonigal MD, et al. "Damage control": an approach for improved survival in exsanguinating penetrating abdominal injury. J Trauma. 1993;35:375.
4• Roberts DJ, Ball CG, Feliciano DV, Moore EE, et al. History of the innovation of damage control for the management of trauma patients: 1902–2016. Ann Surg. 2017;265:1034–44. **Recent publication detailing the progressive history of damage control interventions in traumatic injury.**
5. DeBakey ME, Simeone FA. Battle injuries of the arteries in World War II: an analysis of 2471 cases. Ann Surg. 1946;123:534–79.
6. Menzoian JO, Koshar AL, Rodrigues N. Alexis Carrel, Rene Leriche, Jean Kunlin, and the history of bypass surgery. J Vasc Surg. 2011;54:571–4.
7. Rich NM, Baugh JH, Hughes CW. Acute arterial injuries in Vietnam: 1000 cases. J Trauma. 1970;10:359–69.

8. Tuffier. French surgery in 1915. Br J Surg. 1917;4:420–32.
9. Makins GH. On gunshot injuries to the blood-vessels, founded on experience gained in France during the Great War, 1914–1918. Bristol: John Wright and Sons; 1919. p. 109–11.
10. Eger M, Goleman L, Goldstein A, Hirsch M. The use of temporary shunt in the management of arterial vascular injuries. Surg Gynecol Obstet. 1971;132:67–70.
11.•• Kragh JF Jr, Littrel ML, Jones JA, Walters TH, Baer DG, Wade CE, et al. Battle casualty survival with emergency tourniquet use to stop limb bleeding. J Emerg Med. 2011;41(6):590–7. **Reference discusses the improved survival associated with pre-hospital tourniquet application in battlefield injuries, prior to onset of shock.**
12. Kragh JF Jr, Walters TJ, Baer DG, Fox CH, Wade CE, Salinas J, et al. Survival with emergency tourniquet use to stop bleeding in major limb trauma. Ann Surg. 2009;249(1):1–43.
13. King DR, van der Wilden G, Gragh JF Jr, Blackbourne LH. Forward assessment of 79 prehospital battlefield tourniquets used in the current war. J Spec Oper Med. 2012;12(4):33–8.
14. Lairet JR, Bebarta VS, Burns CJ, Lairet KF, Rasmussen TE, Renz EM, et al. Prehospital interventions performed in a combat zone: a prospective multicenter study of 1,003 combat wounded. J Trauma Acute Care Surg. 2012;73(2 Suppl 1):S38–42.
15.•• Inaba K, Aksoy H, Seamon M, Marks J, et al. Multicenter evaluation of temporary intravascular shunt use in vascular trauma. J Trauma Acute Care Surg. 2016;80:359–65. **Multicenter study characterizes contemporary use of temporary intravascular shunt use, demonstrating an acceptable complication.**
16. Subramanian A, Vercruysse G, Dente C, Wyrzykowski A, King E, Feliciano DV. A decade's experience with temporary intravascular shunts at a civilian level I trauma center. J Trauma. 2008;65(2):316–24.
17.• Mathew S, Smith BP, Cannon JW. Temporary arterial shunts in damage control: experience and outcomes. J Trauma Acute Care Surg. 2017;82:512–7. **This reference indicates that shunt dwell times of less than 6 h may decrease shunt-associated adverse outcomes.**
18. Kumar DS, Lefering R, Wade CE. Impact of hemorrhage control on trauma outcome: an overview of epidemiology, clinical presentations, and therapeutic considerations. J Trauma. 2006;60(6 suppl): S3–11.
19. Eastridge BJ, Mabry RL, Seguin P, Cantrell J, Tops T, Uribe P, et al. Death on the battlefield (2001–2011): implications for the future of combat casualty care. J Trauma Acute Care Surg. 2012;73(6 Suppl 5):S431–7.
20.• Kragh JF, Walters TJ, Baer DG, et al. Practical use of emergency tourniquets to stop bleeding in major limb trauma. J Trauma. 2008;64:S38–50. **This analysis demonstrates absence of limb loss solely related to pre-hospital military tourniquet use, with no associated increase in morbidity.**
21.• Inaba K, Siboni S, Resnick S, Zhu J, Wong MD, Haltmeier T, et al. Tourniquet use for civilian extremity trauma. J Trauma Acute Care Surg. 2015;79(2):232–7. **The above describes the safety and efficacy of tourniquet use in a large volume civilian trauma center.**
22. Holcomb JB. Damage control resuscitation. J Trauma. 2007;62: S36–7.
23. Borgman MA, Spinella PC, Perkins JG, Grathwohl KW, Repine T, Beekley AC, et al. The ratio of blood products transfused in patients receiving massive transfusions at a combat support hospital. J Trauma. 2007;63:805–13.
24. Miller HH, Welch CS. Quantitative studies on the time factor in arterial injuries. Ann Surg. 1949;130:428–38.
25. Weaver FA, Papanicolaou G, Yellin AE. Difficult peripheral vascular injuries. Surg Clin North Am. 1996;76:843–59.
26. Dubose J, Inaba K, Barmparas G, Teixeira PG, Schnuriger B, Talving P, et al. Bilateral internal iliac artery ligation as a damage control approach in massive retroperitoneal bleeding after pelvic fracture. J Trauma. 2010;69(6):1507–14.
27. Nasr MM. Bilateral external carotid artery ligation: a life saving procedure severe maxillofacial trauma. Int J Surg Case Rep. 2015;8:81–3.
28. Osborne Z, et al. Celiac artery avulsion secondary to blunt trauma: a case report and review of the literature. J Med Cases. 2013;4(5): 280–3.
29. Conti S. Splenic artery ligation for trauma: an alternative to splenectomy. Am J Surg. 1980;140:444–6.
30. Aaron S, Fulton RL, Mays ET. Selective ligation of the hepatic artery for trauma of the liver. Surg Gynecol Obstet. 1975;141(2): 187–9.
31. Asenia JA, et al. Multi-institutional experience with the management of superior mesenteric artery injuries. J Am Coll Surg. 2001;193:354–65.
32. Johnson M, Ford M, Johansen K. Radial or ulnar artery laceration. Repair or ligate? Arch Surg. 1993;128(9):971–4.
33. Padberg FT, Rubelowsky JJ, Hernandez-Maldonado JJ, et al. Infrapopliteal arterial injury: prompt revascularization affords optimal limb salvage. Vasc Surg. 1992;16(6):877–86.
34. Carillo EH, Spain DA, Miller FB, Richardson JD. Femoral vessel injuries. Surg Clin N Am. 2002;82:49–65.
35. Carillo EH, Spain DA, Wilson MA, Miller FB, Richardson JD. Alternatives in the management of penetrating injuries to the iliac vessels. J Trauma. 1998;44:1024–30.
36.• Hancock H, Rasmussen TE, Walker AJ, Rich NM. History of temporary intra-vascular shunts in the management of vascular injury. J Vasc Surg. 2010;52(5):1405–9. **Provides an excellent historical perspective on intravascular shunt use.**
37.• Ball CG, Feliciano DV. Damage control techniques for common and external iliac artery injuries: have temporary intravascular shunts replaced the need for ligation? J Trauma. 2010;68:1117–20. **Highlights the reduction in both amputation and need for fasciotomy when temporary vascular shunting is utilized in place of ligation in damage control surgery for iliac arterial injury.**
38. Reilly PM, Rotondo MF, Carpenter JP, Sherr SA, Schwab CW. Temporary vascular continuity during damage control: intraluminal shunting for proximal superior mesenteric artery injury. J Trauma. 1995;39:757–60.
39.• Faber A, et al. Early fasciotomy in patients with extremity vascular injury is associated with decreased risk of adverse limb outcomes: a review of the National Trauma Data Bank. Injury. 2012;43:1486–91. **Demonstrates a fourfold reduction in amputation rate when comparing early vs late fasciotomy after extremity vascular injury.**
40. Velmahos GC, Theodorou D, Demetriades D, Chan L, Berne TV, Asensio J, et al. Complications and nonclosure rates of fasciotomy for trauma and related risk factors. World J Surg. 1997;21:247–53.
41. Demetriades D, Murray JA, Asensio JA. Iliac vessel injuries. In: Rich N, et al., editors. Vascular trauma. Philadelphia: WB Saunders; 2004. p. 339–51.
42. Rasmussen TE, Clouse WD, Jenkins DH, Peck MA, Eliason JL, Smith DL. The use of temporary vascular shunts as a damage control adjunct in the management of wartime vascular injury. J Trauma. 2006;61:8–15.
43. Stone HH, Fabian TC, Turkelson ML. Wounds of the portal venous system. World J Surg. 1982;6:335–41.
44. Timberlake GA, Kerstein MD. Venous injury: to repair or ligate, the dilemma revisited. Am Surg. 1995 Feb;61(2):139–45.