Pelvic fracture-related hypotension: A review of contemporary adjuncts for hemorrhage control

Joseph J. DuBose, MD, FACS, FCCM, FSVS, Clay Cothren Burlew, MD, Bellal Joseph, MD, Meghan Keville, MD, Melike Harfouche, MD, Jonathan Morrison, MD, PhD, Charles J. Fox, MD, Jennifer Mooney, MD, Robert O'Toole, MD, Gerard Slobogean, MD, Lucas S. Marchand, MD, Demetrios Demetriades, MD, Nicole L. Werner, MD, Elizabeth Benjamin, MD, *and* **Todd Costantini, MD***, Baltimore, Maryland*

ABSTRACT: Major pelvic hemorrhage remains a considerable challenge of modern trauma care associated with mortality in over a third of patients. Efforts to improve outcomes demand continued research into the optimal employment of both traditional and newer hemostatic adjuncts across the full spectrum of emergent care environments. The purpose of this review is to provide a concise description of the rationale for and effective use of currently available adjuncts for the control of pelvic hemorrhage. In addition, the challenges of defining the optimal order and algorithm for employment of these adjuncts will be outlined. (*J Trauma Acute Care Surg.* 2021;91: e93–e103. Copyright © 2021 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Review, level IV.
KEY WORDS: Pelvic hemorrhage; hypotension; endovascular; pelvic packing; embolization.

Optimal care of patients with pelvic fractures remains a significant challenge of modern trauma care. While multiple variables have been associated with adverse outcome following these injuries,[1–3] the ability to expediently control ongoing hemorrhage from these fractures represents a modifiable of risk factor. In the largest contemporary multicenter study on the topic to date, Costantini and colleagues[2] identified that 13.3% of trauma victims with pelvic fractures will be in shock at admission and found that hypotension in this setting is associated with a mortality of 32.0%.

Pelvic fracture is associated with hemorrhage from arterial, venous, and bony sources. Available adjuncts for early hemorrhage control include pelvic binders, resuscitative endovascular balloon occlusion of the aorta (REBOA), preperitoneal packing (PPP), angioembolization (AE), external fixation (EF), and open ligation of the internal iliac artery in a damage-control approach. A number of recent publications have examined the effectiveness of these interventions in assisting in the arrest of pelvic hemorrhage.[1–18] Optimal selection, ideal conduct, and order of these interventions, however, remain matters of active investigation.

The purpose of this publication is to review the rationale and technique for each of the available interventions for major pelvic hemorrhage control and provide a succinct synopsis of the contemporary evidence for their use. We conclude this review with a discussion of the key issues related to optimal coordination of these interventions and elements of care requiring additional study.

PELVIC BINDERS

Rationale

Pelvic binders are frequently used in the prehospital environment or early hospital course as an inexpensive and expedient temporizing bridge to definitive care of pelvic hemorrhage. Published research suggests that pelvic compression devices reduce hemorrhage by increasing pelvic stability, decreasing hematoma volume, and promoting stable clot formation.[7,19–23] However, evidence regarding their benefit in terms of reducing transfusion requirements and improving hemodynamic and metabolic parameters remains conflicting.[24–29]

Technique

Optimal utilization of a pelvic binder requires early placement at the level of the greater trochanters and application of effective force to achieve fracture reduction and pelvic immobilization[30,31] (Fig. 1). Multiple studies demonstrate that 40% to 50% of binders are placed improperly and most often too high.[20,31–33] The potential dangers of extreme tightening or prolonged application must be appreciated, including skin and soft tissue damage, and visceral, vascular, and peripheral nerve compromise.[34] There are, however, no reports to date of overreduction causing harm, even in those cases where there is noted increased deformity on imaging.[20,35,36] Skin breakdown occurs most commonly in cases of

Submitted: April 20, 2021, Revised: June 19, 2021, Accepted: June 24, 2021, Published online: July 6, 2021.
From the R Adams Cowley Shock Trauma Center (J.J.D., M.K., M.H., J.M., C.J.F., R.O., G.S.), University of Maryland Medical System, Baltimore, Maryland; Department of Surgery (C.C.B., N.L.W.), Denver Health Medical Center, Denver, Colorado; Division of Trauma, Critical Care, Emergency Surgery, and Burns, Department of Surgery (B.J.), College of Medicine, University of Arizona, Tucson, Arizona; Baylor University Medical Center (J.M.), Dallas, Texas; Department of Orthopedic Surgery (L.S.M.), University of Utah, Salt Lake City, Utah; Division of Trauma and Surgical Critical Care (D.D., E.B.), LAC+USC Medical Center, University of Southern California, Los Angeles, California; Trauma/Surgical Critical Care (T.C.), Grady Memorial Hospital/Emory University School of Medicine, Atlanta, Georgia; and Division of Trauma, Surgical Critical Care, Burns and Acute Care Surgery, Department of Surgery (T.C.), University of California San Diego School of Medicine, San Diego, California.
Address for reprints: Joseph J. DuBose, MD, FACS, FCCM, FSVS, R Adams Cowley Shock Trauma Center, University of Maryland Medical System, 22 South Greene St, Room T4M14, Baltimore, MD 21201; email: jjd3c@yahoo.com.

DOI: 10.1097/TA.0000000000003331

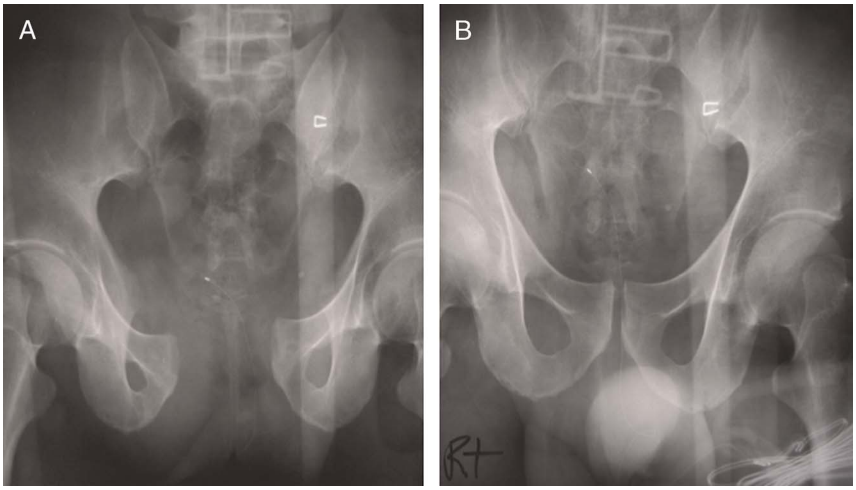

Figure 1. Before (*A*) and after (*B*) reduction of an open book pelvic fracture using a pelvic binder.

prolonged application (>24 hours), underlying soft tissue injury, and utilization of sheets instead of commercially available binders.[37–39] Skin damage appears more common when these binders are used in conjunction with prolonged spinal board immobilization for >2 to 3 hours.[40] False-negative imaging as a result of pelvic compression devices has also been described and represents a potential limitation of these devices.[41–44] In these instances, reduction of the fracture can mask the presence of fracture, particularly when the device was placed in the prehospital environment before the fracture could be radiographically characterized.

Pelvic binders may also present challenges for the vascular access required for other hemostatic adjuncts that can be used for pelvic hemorrhage control, including both REBOA and AE. These challenges may be circumvented by the use of sheets or binders that can sustain tailoring with scissors to afford the necessary access to the groin region or even the use of dual binders above and below the inguinal portal required for this access.

RESUSCITATIVE ENDOVASCULAR BALLOON OCCLUSION OF THE AORTA

Rationale

An evolution in endovascular technologies and borrowed experience from the use of aortic occlusion balloons in emergent vascular surgery have contributed to the subsequent introduction REBOA for traumatic hemorrhage control applications.[45–54] The expansion of REBOA use in the United States and abroad continues to be an area of active study across different cultures of utilization. Significant international experience using REBOA originates from the Japanese Trauma Data Bank, an environment where REBOA is used by interventional radiology and emergency medicine providers.[50,51] In the United Kingdom, REBOA use has been adopted by highly specialized groups of prehospital providers, who initiate aortic occlusion in the field based on predefined criteria.[52]

In the United States, REBOA has been primarily used at advanced trauma centers, where it remains a practice of active research. As Joseph et al.[4] and others have demonstrated, there remains a need for continued study of optimal patient selection and mitigation of complications such as reperfusion injury and extremity ischemia.[4,55] The most comprehensive experience with REBOA use for trauma in the United States has been collected by the Aortic Occlusion for the Resuscitation in Trauma and Acute Care Surgery (AORTA) registry of the American Association for the Surgery of Trauma (AAST).[49,54] Findings from this registry and other sources demonstrate that REBOA use by trauma surgeons for life-threatening hemorrhage continues to grow.[49,54,55]

The use of endovascular occlusion balloons for major pelvic hemorrhage control was originally described in a small series by Rieger et al.,[56] who placed them in the used internal iliac artery. Martinelli and colleagues[45] later reported the use of an intra-aortic balloon to temporize bleeding in patients presenting with hypotension or cardiac arrest following pelvic fractures. In this series, REBOA resulted in either return of spontaneous circulation or improvement in systolic blood pressure and facilitated transport of all treated patients to the interventional suite for attempted definitive hemorrhage control. Despite these preliminary reports, the 2015 multi-institutional study by Costantini et al.[2] noted that only 1 of 11 participating centers was using REBOA for pelvic indications.

More recently, however, increasing utilization of REBOA for severe pelvic bleeding has been documented. A 2020 AORTA study identified 160 patients undergoing zone 3 REBOA for management of pelvic fractures from 2013 to 2020.[13] In this series, REBOA was used as standalone hemorrhage-control tool in 37.5% of patients but was more commonly used as a bridge to some combination of hemorrhage control interventions that included EF, PPP, and/or AE. The optimal role of REBOA in this setting has also been examined using the Trauma Quality Improvement Program registry,[6,57] with conflicting results. The absence of standardized approaches to utilization of this adjunct and the lack of an ideal data set for examination of this issue continue to confound determination of the optimal role of REBOA for severe pelvic hemorrhage and underscore the need for additional study.

Technique

Resuscitative endovascular balloon occlusion of the aorta requires arterial access via the common femoral artery and delivery of the occlusion balloon into the aorta above the site of hemorrhage. Access to the common femoral artery is obtained percutaneously or through an open cut-down technique depending on user experience, clinical situation, and the ability to visualize the vessel using ultrasound. The effective deployment of REBOA is dependent on the establishment of early arterial access for this purpose.[55]

Initial modern REBOA experience used Coda balloons (Cook Medical, Bloomington, IN), which required advancement of a compliant balloon over a prepositioned wire through 12-Fr access. Lower profile, trauma-specific devices have since been developed, which obviate the need for over-the-wire techniques. The device most commonly used is the ER-REBOA catherer (Prytime Medical, Boerne, TX). The smaller 7-Fr arterial access required for this device appears to contribute favorably to decreased access site complications and subsequent limb ischemia.[58]

After intra-abdominal hemorrhage has been excluded by focused abdominal sonography for trauma (FAST) or other means, REBOA use for the control of pelvic hemorrhage can be achieved by deployment in the infrarenal aorta between the lowest renal artery and the iliac bifurcation. For the purpose of REBOA technique, this region is referred to as zone 3 (zone 1, left subclavian to celiac artery; zone 2, celiac to lowest renal artery; zone 3, lowest renal artery to iliac bifurcation) (Fig. 2). This more distal position mitigates the potential burden of ischemia associated with more proximal aortic occlusion and decreases the risk for major reperfusion injury following deflation.

Preperitoneal Pelvic Packing Rationale

Preperitoneal packing constitutes an expedient definitive treatment of pelvic fracture related bleeding that addresses both venous and bony bleeding sources present in 85% of fracture related hemorrhage.[59] Preperitoneal packing is also capable of controlling arterial bleeding, allowing resuscitation and physiologic restoration with delayed AE at a mean of 10 hours later.[60]

Figure 2. Resuscitative endovascular balloon occlusion of the aorta catheter inflated in the infrarenal aorta (zone 3) for temporary control of pelvic hemorrhage. A 6-Fr radial sheath tip is visible at the level of the balloon.

Pelvic packing as a technique for pelvic hemorrhage control was initially described by Tscherne et al.[61] in 2000, using laparotomy pads placed into the pelvis via laparotomy incision. Subsequent development of an anterior preperitoneal approach by the group at Denver Health Medical Center[62] was reported in 2005, and this group continues to have the largest reported PPP experience. Most recently, they reported on 128 hypotensive and severely injured PPP patients who sustained a 21% all-cause mortality rate. This compares favorably to the 32% rate reported by the 2015 AAST multicenter study,[2] a 41% mortality rate reported after AE alone,[63] an algorithm-driven management protocol study with a 35% mortality rate,[64] and a study prioritizing hemostatic resuscitation with a 37% mortality rate.[65] A recent analysis of the Trauma Quality Improvement Program database compared hemodynamically unstable pelvic fractures treated with PPP to with treated with zone 3 REBOA and found improved survival with PPP (37.3% vs. 52.0%, $p = 0.048$).[57] Several additional studies have noted significant reduction in mortality following pelvic hemorrhage when PPP was introduced as part of an algorithm of care for these challenging patients.[66–68] Preperitoneal packing has also proven useful in decreasing transfusion requirements in this setting[62] and has been effectively paired with AE as salvage for the minority of patients (15%) who have persistent arterial bleeding documented after packing.[69]

The most commonly reported complication after PPP is infection, ranging from 4% to 21% and most frequently occurring in the setting of open fractures, perineal degloving injuries, patients with associated bowel or bladder injuries, or the need for repeat packing.[60,62,68,70,71] Infection rate does not correlate with the duration of time the laparotomy pads are left in place[70] nor is PPP associated with an increased risk of surgical site infection after internal pelvic ring fixations.[72] Other complications that have been reported include wound dehiscence and deep venous thromboembolism.[71,73]

Technique

Preperitoneal packing is preceded by pelvic fixation, either with a pelvic binder or optimally with EF,[26,74] facilitating optimal packing tamponade against a stabilized pelvis. The anterior bar of the EF is positioned to allow access for the PPP incision or concurrent laparotomy as necessary. Preperitoneal packing uses a 6- to 8-cm midline incision starting at the pubis and extending toward the umbilicus (Fig. 3). The subcutaneous tissue and fascia are opened in the midline without entering the peritoneal cavity. Blunt finger dissection is performed behind the symphysis and along the pelvic ring laterally to identify the space to be packed, which commonly has already been created by the pelvic hematoma. Laparotomy pads are placed along the pelvic brim on each side, with the sacrum marking the posterior limit of packing. The first laparotomy pad is placed by retracting the lateral margin of the bladder toward the midline with the nondominant hand and pushing the pad down to the sacrum, often using a ringed forceps to effectively push it posteriorly. Two additional pads follow sequentially around the bladder, and the process is repeated on the opposite side (Fig. 4). The result is six laparotomy pads placed in an inverted "U" around the bladder. The fascia is closed with

Figure 3. Incision selection for PPP with pelvic binder in place.

a monofilament running suture and the skin with staples. This procedure consistently takes 5 minutes to perform.[75] If a REBOA catheter was inflated in zone 3 before the operating room, deflation of the balloon should be attempted after completion of PPP with concurrent resuscitation. For patients with a positive FAST examination or concern for intra-abdominal injuries, an abdominal exploration can be performed without affecting the PPP. Supraumbilical laparotomy incisions should be separate from the incision for pelvic packing, as connecting these incisions can decompress the pelvic hematoma into the abdomen.[75]

The laparotomy pads are removed after the patient is fully resuscitated and normothermic and has normal coagulation indices. Routine duplex has been used before pack removal to exclude deep vein thrombosis, with subsequent inferior vena cava filter placement when identified in the setting of anticoagulation contraindication. Once all packs have been removed, the preperitoneal pelvic space should be examined for bleeding and hemostasis obtained. This may include direct ligation of small vessels or application of topical hemostatic agents; however, large venous injuries that require ligation or reconstruction can be discovered. Repacking of the pelvis should be avoided, as it has been associated with significant infectious morbidity.[60]

ANGIOEMBOLIZATION

Rationale

Angioembolization constitutes an approach to definitive control of pelvic hemorrhage that avoids the need to disturb pelvic retroperitoneal hematoma and facilitates location and control of bleeding sources. Margolies and colleagues[76] were the first to describe AE for pelvic hemorrhage in 1972, injecting the posterior pituitary and the patients' own clotted venous blood via arteriography into identified extravasating vessels in three patients. In a subsequent larger experience, Panetta et al.[77] used AE to successfully control hemorrhage in 87% of patients, resulting in a mortality reduction of 35.5% with most fatalities occurring due to associated injuries. These and other early efforts launched pelvic AE to the forefront of the armamentarium against pelvic hemorrhage[78]

In contemporary practice, 10% of all patients with pelvic fractures undergo angiography, with approximately half exhibiting active extravasation.[2,78] Angioembolization remains among the most common adjuncts used for hemodynamically unstable patients with pelvic fracture hemorrhage in most series,[2] as this endovascular approach avoids entrance into the pelvic hematoma, thereby allowing for the combined effects of both embolization and tamponade.

In attempts to identify optimal indications for AE, several studies have focused on fracture pattern predictors. In one study of 86 patients with ongoing shock, Eastridge et al.[79] found that unstable pelvic fracture patterns were associated with a pelvic source of bleeding requiring embolization in 59% of cases, as opposed to 10% with stable fracture patterns. Unstable fracture

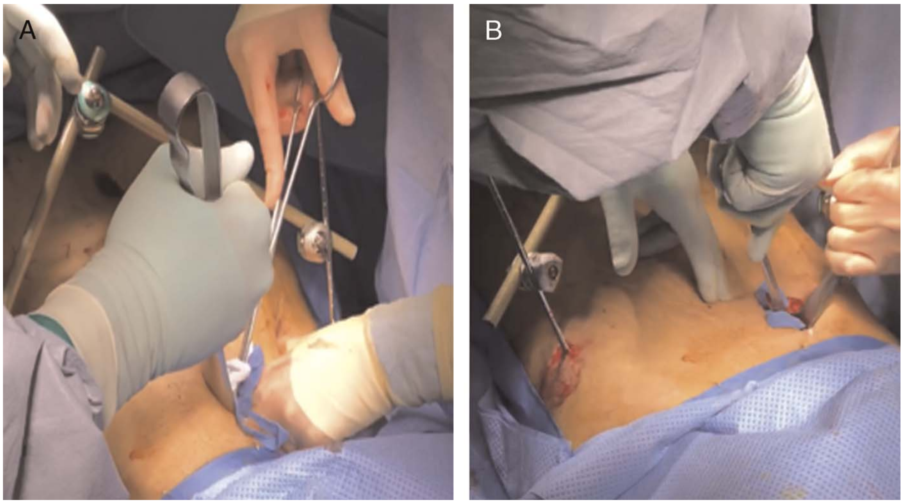

Figure 4. Preperitoneal pelvic packing. The first laparotomy pad is placed by retracting the lateral margin of the bladder toward the midline with the nondominant hand and pushing the pad down to the sacrum (*A*), often using a ringed forceps to effectively push it posteriorly. (*B*) Two additional pads follow sequentially around the bladder, and the process is repeated on the opposite side.

patterns were defined as anterior posterior compression (APC) type 2/3, lateral compression 2/3, and vertical shear.[80] In the aforementioned AAST multicenter study, Constantini and colleagues[1] also found that APC 3 and open book pelvic fractures were significantly associated with intervention need.

Contrast extravasation (CE) via modern computed tomography (CT) is frequently used to identify arterial hemorrhage and candidacy for AE.[81] While CE is associated with an increased need for embolization, increased transfusion requirements, and increased mortality, this finding in isolation does not appear to predict the need for intervention.[81,82] In one study, CE predicted the need for intervention in only 23% of patients.[82] Inversely, the absence of CE may be of significant clinical utility, with a negative predictive value approaching 100%.[82]

Angioembolization requires the rapid mobilization of significant resources to improve patient outcomes, with multiple studies demonstrating a direct relationship between delays of AE and higher mortality[83,84] and the value of reduced time to AE via institutional practices.[80] As a result, the American College of Surgeons Committee on Trauma recommends a 30-minute window from time of activation to catheter insertion for level 1 trauma center accreditation. For patients too unstable for CT scan, the presence of ongoing hemodynamic instability combined with an open book or APC 3 pelvic fracture and a negative FAST examination should be considered a potential indication for emergent AE at capable centers.

Potential complications of AE use in the setting of pelvic hemorrhage and hypotension include access-related complications, contrast-related renal dysfunction, and ischemic complications of embolization itself.[13] Ischemic complications may be exacerbated by the use of proximal internal iliac embolization versus more selective distal branch embolization and may include subsequent gluteal compartment syndrome, gluteal necrosis, and pelvic nerve dysfunction.

Technique

Angioembolization of pelvic hemorrhage is performed using portable, ceiling, or floor mounted fluoroscopic units, preferably in a hybrid operating room to minimize patient movement. Ultrasound-guided access using micropuncture kits and upsizing to 5-Fr sheaths likely reduces iatrogenic injury caused by blind punctures or large sheath insertions. Transfemoral angiography is most commonly used, with the access side based on the location of hemorrhage and need to select the internal iliac artery in either a retrograde or antegrade direction. Musculoskeletal deformity, body habitus, tortuous arterial anatomy, atherosclerotic disease, and the presence of preexisting vascular stents also influence site selection. Longer wires and catheters now allow for transradial access, which may have confer advantages in vessel selection and reduction of transfemoral complications.[85]

Once access is achieved, a distal aortogram with pelvic runoff is obtained. If a bleeding source is identified, selective embolization can be performed by advancement of a catheter into the offending secondary and tertiary branches of the bleeding vessel branch. When performing a more distal "super selection," microcatheters utilization is useful. When precise hemorrhage localization is unsuccessful, a nonselective embolization of the proximal internal iliac can be considered for select hemodynamically unstable patients[86] (Fig. 5).

Among available embolic agents, speed and ease of use guide applicability for trauma. Coils are selected by determining the length and diameter of the target artery, with some having detachable delivery systems that afford a more controlled release into the target vessel. Gel foam slurry is inexpensive and easy to prepare and may eradicate bleeding from the smallest vessels beyond what a coil can typically reach but may carry a higher risk of inadvertent embolism during delivery. Detachable and nondetachable coils, plugs, and hemostatic adjuncts are selected at the discretion of the operator.

EXTERNAL FIXATION

Rationale

External fixation remains a significant element of modern management algorithms for hemodynamically unstable pelvic ring injury.[87] Temporizing fixation affords definitive reduction and fixation of the pelvis in a delayed manner as other more emergent injuries are addressed.[88] External fixation benefit is achieved by both minimizing additional trauma via increased stability to the osseous and ligamentous injuries and by reducing pelvic volume in an effort to tamponade hemorrhage. While both of these mechanisms can be achieved with the application of a pelvic binder, EF has the added benefits of promoting improved access to the groin and pelvis while negating the risk of skin necrosis associated with circumferential wrapping via pelvic binder. External fixation can also be left in place for several weeks or serve as definitive treatment of these injuries.

Volume expanded pelvic ring injuries require AE in as much as 15% of instances,[89] and REBOA has emerged as an important adjunct at select centers. Treatment with either strategy requires unobstructed access to groin vasculature typically obstructed by pelvic binders but facilitated by EF. While a binder can be moved to the lower pelvis or even cut to improve groin access and endovascular interventions, both maneuvers potentially compromise the position and mechanical function of a binder.

Technique

EF Types

External fixation of the pelvis can be obtained through the use of a traditional external fixator or pelvic clamp. External fixation is commonly facilitated by the use of a radiolucent operating table and intraoperative fluoroscopic guidance, although certain methods of EF can circumvent these needs (Table 1).

EF Frames

Supra-acetabular Schanz pins are placed within a relatively large bony corridor but require fluoroscopy for appropriate positioning. The supra-acetabular frame uses two pins placed from the anterior inferior iliac spine to the posterior ilium in the bone of the sciatic buttress using multiplanar fluoroscopic views. The classic iliac crest frame uses two 5-mm partially threaded Schanz pins placed to each iliac wing starting at the iliac crest and connected by an anterior frame. The pins should be at least 2 cm posterior to the anterior inferior iliac spine to protect the lateral femoral cutaneous nerve and ensure that the largest corridor of iliac bone is accessible (Fig. 6). Schanz pins can be placed in the iliac wing with a percutaneous incision over the lateral ilium

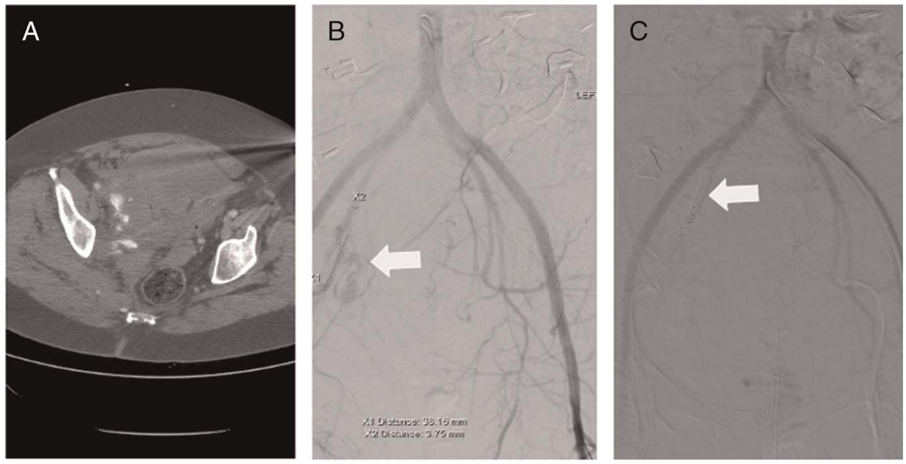

Figure 5. Pelvic fracture with CE on CT (*A*). Subsequent diagnostic angiogram confirmed extravasation from proximal right internal iliac artery (*B*), which underwent coil embolization (*C*).

through tactical feedback and without fluoroscopic guidance. However, the smaller osseous corridor in the ilium is less desirable as compared with one placed with use of supra-acetabular pins. While there are less concerns of injury to a major structure (hip joint, neurovascular bundle) with the use of iliac wing pins, the thinner nature of the ilium compromises maintenance of a stable bony corridor. In addition, iliac wing pins have less ability to resist rotational and abduction forces.[90] With stable osseous fixation, standard application of an EF can be left on for multiple days and even as definitive treatment.

Limitations and risks of standard EF application include injury to the hip joint or neurovascular structures of the sciatic notch, pin site infections, pin loosening, the cumbersome nature of the frame, and the inability to directly control posterior ring instability via an anterior based EF. For some fracture patterns, placement of a posterior based sacral screw may be needed to recreate some posterior stability to allow for a reduction of the anterior pelvis.

Pelvic Clamps

Another option for achieving EF of the pelvis is the use of a large pelvic C-clamp. The C-clamp provides temporary EF that provides pelvic stabilization through pins secured to the anterior ilium, posterior ilium, or trochanter.[91–93] One benefit of the C-clamp is the ability to freely move the device around an axis. This device mobility affords improved imaging or access to the abdomen or pelvis as needed without compromise of device mechanical advantage or pelvic stability. The greater trochanter serves as an easily palpable bony landmark that allows for pin placement without fluoroscopic imaging. In addition, if a pelvic binder is in place, an access hole can be cut in the binder to facilitate pin placement and EF before binder removal.

Several cautions must be used with C-clamp use. The powerful ratcheting nature of the C-clamp creates the potential for overreduction of fracture.[93] Pins placed in the ilium risk comminuted posterior pelvic ring fractures, pin perforation through the ilium, and even dislodgement of pins into the sciatic notch.[94,95] Placing the pins in the posterior ilium can potentially interfere with future surgical sites. The smaller caliber pins used for C-clamp are not durable enough for definitive fixation and may loosen or even break over the course of a few days.[93] In addition, the application of a C-clamp makes it very difficult, if not impossible, to position the patient in subsequent lateral decubitus (Table 1).

INTERNAL ILIAC ARTERY LIGATION

For select patients with severe hemodynamic instability, those in need of an immediate laparotomy for severe associated intra-abdominal injuries, or those in austere environments with no angiointerventional capabilities, a damage-control procedure may be the only available option for arrest of pelvic hemorrhage. In these instances, the use of bilateral internal iliac artery occlusion (BIIAO) may prove a useful adjunct. This approach includes a formal trauma laparotomy, management of any associated

TABLE 1. External Fixation Overview

	Traditional External Fixator		Pelvic Clamp	
Advantages	Universally available		Freely moving device allowing unimpeded access to abdomen, groin, perineum	
Disadvantages	Statically positioned and may impede patient positioning		Not available at every trauma center	
	Supra-acetabular Pins	**Iliac Wing Pins**	**C-clamp**	**T-clamp**
Advantages	Large bone corridor	Can be inserted without fluoroscopy	Very powerful	Can be inserted without fluoroscopy
Disadvantages	Requires fluoroscopy guidance	Small bone corridor	Requires fluoroscopy guidance	Cannot be used with proximal femur and acetabular fractures

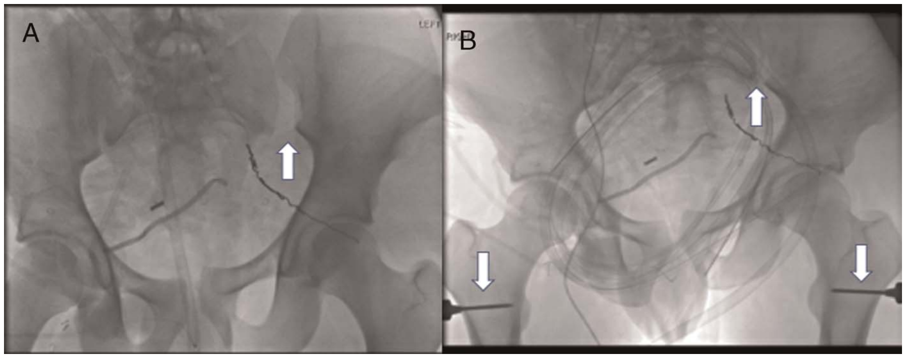

Figure 6. Before (*A*) and after (*B*) pelvic fracture reduction using EF under fluoroscopic guidance.

intra-abdominal injuries, exploration of the pelvic hematoma, occlusion of both internal iliac arteries, and direct packing of the fracture. In published experiences, BIIAO has been shown to reduce the internal iliac artery pressure-head flow to the pelvis with outcomes comparable with other damage-control techniques and without additional ischemia or reproductive system sequelae.[11]

Rationale

There are three main rationales for exploratory laparotomy and BIIAO. First, patients with severe pelvic fractures have a high incidence of associated intra-abdominal injuries. In a single-center series of 1,545 patients with pelvic fractures, associated abdominal organ injuries were found in 30.7% of patients with severe pelvic fracture (Abbreviated Injury Scale [AIS] score, ≥4), including small bowel injury in 8.8%.[96] In another National Trauma Databank (NTDB) study of 3,221 patients with severe pelvic fracture (AIS score of 4 or 5), 34.3% had associated abdominal injury, including 16.7% with bowel injury.[97] Particularly among patients without a reliable examination or antecedent CT scan because of hemodynamic instability, laparotomy as part of emergent intervention mitigates the risk of missed intra-abdominal injuries.

A second reason to consider exploratory laparotomy and exploration of the pelvic hematoma with possible BIIAO is the appreciable incidence of injuries to the major iliac vessels in patients with severe pelvic fractures. In a 2009 NTDB study of 6,377 patients with moderate and severe pelvic fracture, iliac artery injury was identified in 3.5% of patients with severe pelvic fractures.[98] In a more recent NTDB study of 3,221 patients with severe pelvic fracture (AIS score of 4 or 5), 10.7% had common or external iliac vessel injury.[97] Exploratory laparotomy with potential BIIAO facilitates expedient control of this injury when they are identified.

A third reason for exploring the pelvic hematoma is the direct visualization of the bleeding areas and application of local hemostatic agents, which may significantly aid in hemostasis. Pelvic hematoma exploration has the potential to facilitate direct visualization of sources of hemorrhage and permit more precise positioning of these useful adjuncts.

It should be recognized, however, that there are potential complications that can occur related to the use of BIIAO in the setting of trauma. These include the potential for pelvic or gluteal necrosis or sexual dysfunction. Documented experience with this damage-control approach, however, appears to suggest that these complications are rare.[11]

Technique

Bilateral internal iliac artery occlusion can be achieved using a standard laparotomy incision. The abdominal viscera are retracted cranially, and the iliac arteries may be accessed directly, by opening the pelvic hematoma, through the peritoneum or using a medial rotation of the cecum on the right side and the sigmoid colon on the left side. The hematoma is evacuated, and any obvious major bleeding from the large vessels is controlled with sutures, ligation, or repair. Proximal control of the common iliac artery is obtained, and the bifurcation is

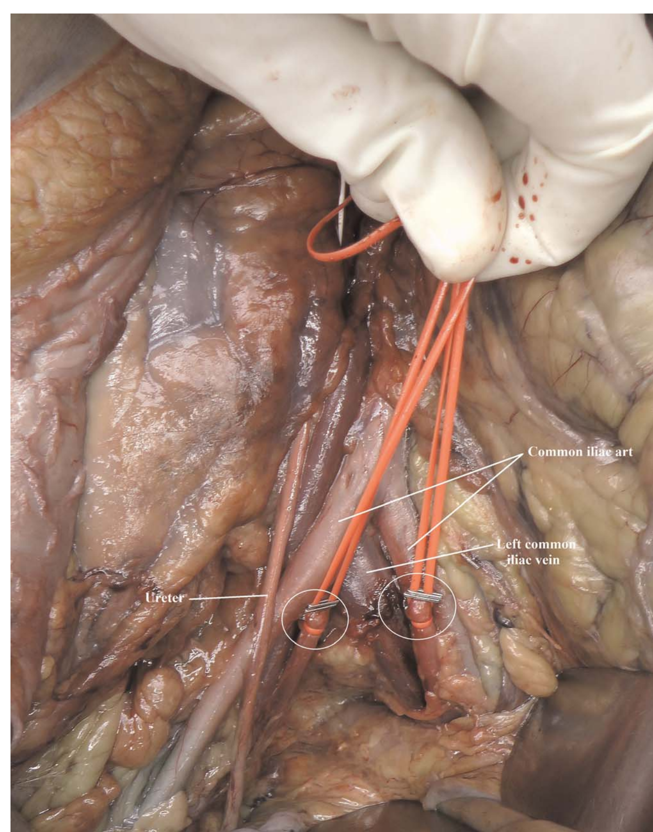

Figure 7. Bilateral internal iliac artery temporary occlusion with vessel loops (reproduced with permission from Demetrios D, Inaba K, Velmahos G, eds. *Atlas of Surgical Techniques in Trauma*. New York, NY: Cambridge University Press; 2019).

identified as the artery curves over the sacral promontory. The internal iliac artery is carefully dissected circumferentially. Posterior to the artery lies the iliac vein, and iatrogenic venous injury at this level can be hazardous. Care must also be taken to avoid the ureter, which crosses over the bifurcation of the common iliac artery. The internal iliac artery is encircled twice using a vessel loop. Tension is placed on the vessel loop to interrupt flow, and reversible occlusion is achieved using a large clip on the vessel loop to maintain traction. Alternatively, the internal iliac arteries can be occluded using surgical clips (Fig. 7).

Bilateral internal iliac artery occlusion is followed by application of local hemostatic agents and pelvic packing, with return to the operating room in 24 to 72 hours. Should AE be needed, the vessel loop ligatures or surgical clips may be removed in a hybrid suite to allow for passage of the endovascular wire and catheter into the internal iliac system. Once hemorrhage control is achieved and the patient returns to the operating room for definitive management and closure, the internal iliac arteries' vessel loops or clips are removed to reestablish flow.

DISCUSSION

Available adjuncts for control of major pelvic hemorrhage constitute an array of potential interventions that can be used along a spectrum of early care environments from the field to the operating room/interventional suite. Each of these tools has valid rationales for use and can be safely and effectively used in support of hemorrhage control for this challenging population. It is important to recognize, however, that each of these adjuncts also requires appropriate expertise and capabilities to use effectively and safely.

Several recent examinations have contrasted the effectiveness of individual interventions against respective alternatives.[6–8,13] While important contributions to the understanding of optimal pelvic hemorrhage control, these investigations may not, however, adequately reflect clinical practice for the most challenging of pelvic hemorrhage cases. In these instances, tailoring of a progressive escalation of response from the emergency room to the operative theater may be required to achieve hemorrhage control. Accordingly, the synergistic employment of available pelvic hemorrhage adjuncts in a thoughtful algorithm of response may be required.

A recent review by Harfouche and colleagues[13] illustrates the potential challenges that might occur with defining the optimal order of a coordinated response to hemorrhage control following pelvic fracture. In this review of patients undergoing REBOA of the distal aorta for emergent hemorrhage control in the emergency department, 31.3% of patients required a second hemostatic adjunct and 30.6% required a third hemorrhage control intervention. Increasing numbers of interventions were associated with both higher transfusion requirements and complications. Among the 52 contributing centers to the used AORTA registry, there was considerable variation in practices across centers, with no specific algorithm of care proving superior to others in terms of complications or survival.

While the aforementioned AORTA registry data suggest that significant variations in actual clinical care exist, algorithms for the management of pelvic fracture with hemodynamic instability have been proposed. Tran et al.[18] from the Western Trauma Association published in 2016 a revised algorithm for care that incorporates all of the contemporarily available adjuncts for the arrest of pelvic hemorrhage. While this decision tool is both well referenced and thoughtfully created, the ability to extrapolate these recommendations to a wide array of trauma centers may be problematic. Key among the challenges is institutional resources and the availability of appropriate expertise for an emergent response.

The utilization of adjuncts for pelvic hemorrhage control has also continued to evolve since the publication of the Western Trauma Association algorithm[18] and the AAST multicenter study conducted by Costantini et al.[2] For example, the AAST study is marked by relative absence of both pelvic PPP and REBOA utilizations from their 2016 effort. More recent reports have documented increased enthusiasm for these interventions among leading trauma centers. In addition, hybrid operating rooms now afford a single location for the conduct of more advanced adjuncts such as EF, PPP, and REBOA without necessitating transition of the patient from the operating room to a traditional interventional radiology suite. These unique environments also afford the ability to combine AE and other procedures with other required operative procedures in a more seamless fashion. These innovations represent potential improvements in the expediency of care that have not yet been adequately studied.

Previous data sets regarding pelvic hemorrhage control are also characterized by the absence of crucial data required to understand the optimal timing, order, and conduct of hemostatic adjuncts. Available data do not adequately characterize the sequence of intervention and are limited by the ability to determine the relative impact of pelvic hemorrhage on subsequent mortality in the multiply injured patient with these fractures. For these reasons, additional multicenter study with appropriate granularity is required.

SUMMARY

Pelvic fracture–related hemorrhage remains a significant challenge of modern trauma care that is associated with a mortality of more than 30%. While a variety of hemostatic adjuncts are available to modern trauma providers, there has been little change in this lethality over the last decade. Additional study is required to discern the optimal order and conduct of these procedures within an applicable algorithm designed to achieve improved outcomes.

AUTHORSHIP

All authors contributed to the design, data/literature interpretation, construction, and editing of this review effort.

DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

1. Costantini TW, Coimbra R, Holcomb JB, et al. Pelvic fracture pattern predicts the need for hemorrhage control intervention — results of an AAST multi-institutional study. *J Trauma Acute Care Surg*. 2017;82(6): 1030–1038.
2. Costantini TW, Coimbra R, Holcomb JB, et al. Current management of hemorrhage from severe pelvic fractures: results of an American Association for the Surgery of Trauma multi-institutional trial. *J Trauma Acute Care Surg*. 2016;80(5):717–723; discussion 723–5.

3. Coleman JR, Moore EE, Vintimilla DR, Parry J, Nelson JT, Samuels JM, Sauaia A, Cohen MJ, Burlew CC, Mauffrey C. Association between Young-Burgess pelvic ring classification and concomitant injuries requiring urgent intervention. *J Clin Orthop Trauma*. 2020;11(6):1099–1103.
4. Joseph B, Zeeshan M, Sakran JV, Hamidi M, Kulvatunyou N, Khan M, O'Keefe T, Rhee P. Nationwide analysis of resuscitative endovascular balloon occlusion of the aorta in civilian trauma. *JAMA Surg*. 2019;154(6): 500–508.
5. Jarvis S, Kelly M, Mains C, Corrigan C, Patel N, Carrick M, Lieser M, Banton K, Bar-Or D. A descriptive survey on the use of resuscitative endovascular balloon occlusion of the aorta (REBOA) for pelvic fractures at US level 1 trauma centers. *Patient Saf Surg*. 2019;13:43.
6. Asmar S, Bible L, Chehab M, Tang A, Khurrum M, Douglas M, Castanon L, Kulvatunyou N, Joseph B. Resuscitative endovascular balloon occlusion of the aorta vs. pre-peritoneal packing in patients with pelvic fracture. *J Am Coll Surg*. 2021;232(1):17–26.
7. Duchesne J, Constantini TW, Khan M, et al. The effect of hemorrhage control adjuncts on outcome in severe pelvic fracture: a multi-institutional study. *J Trauma Acute Care Surg*. 2019;87(1):117–124.
8. Petrone P, Rodriguez-Perdomo M, Perez-Jimenez A, Ali F, Brathwaite CEM, Joseph DK. Pre-peritoneal packing for the management of life-threatening pelvic fractures. *Eur J Trauma Emerg Surg*. 2019;45(3):417–421.
9. Magee GA, Fox CJ, Moore EE. Resuscitative endovascular balloon occlusion of the aorta in pelvic ring fractures: the Denver Health protocol [published online January 31, 2020]. *Injury*. doi:10.1016/j.injury.2020.01.044.
10. Sepehri A, Sciadini MF, Nascone JW, Manson TT, O'Toole RV, Slobogean GP. Initial experience with the T-Clamp for temporary fixation of mechanically and hemodynamically unstable pelvic ring injuries. *Injury*. 2020;51(3): 699–704.
11. DuBose J, Inaba K, Barmparas G, Teixeira PG, Schnuriger B, Talving P, Salim A, Demetriades D. Bilateral internal iliac artery ligation as a damage control approach in massive retroperitoneal bleeding after pelvic fracture. *J Trauma*. 2010;69(6):1507–1514.
12. Bugaev N, Rattan R, Goodman M, et al. Preperitoneal packing for pelvic fracture-associated hemorrhage: a systematic review, meta-analysis, and management guidelines from the Eastern Association for the Surgery of Trauma. *Am J Surg*. 2020;220(4):873–888.
13. Harfouche M, Inaba K, Cannon J, Seamon M, Moore E, Scalea T, DuBose J. Patterns and outcomes of zone 3 REBOA use in the management of severe pelvic fractures: Results from the AAST Aortic Occlusion for Resuscitation in Trauma and Acute Care Surgery database. *J Trauma Acute Care Surg*. 2020;90(4):659–665.
14. Jarvis S, Orlando A, Blondeau B, Banton K, Reynolds C, Berg GM, Patel N, Meinig R, Carrick M, Bar-Or D. The effect of orthopedic surgeons' and interventional radiologists' availability on the priority treatment sequence for hemodynamically unstable pelvic fractures: a survey of US Level 1 trauma centers. *J Orthop Surg Res*. 2019;14(1):411.
15. Sutherland M, Shepherd A, Kinslow K, McKenney M, Elkbuli A. REBOA use, practices, characteristics and implementations across various US trauma centers [published online January 31, 2020]. *Am Surg*. doi:10.1177/0003134820988813.
16. Blondeau B, Orlando A, Jarvis S, Banton K, Berg GM, Patel N, Meinig R, Tanner A 2nd, Carrick M, Bar-Or D. Variability in pelvic packing practices for hemodynamically unstable pelvic fractures at US level 1 trauma centers. *Patient Saf Surg*. 2019;13:3.
17. Jarvis S, Orlando A, Blondeau B, Banton K, Berg GM, Patel N, Kelly M, Carrick M, Bar-Or D. Variability in the timeliness of interventional radiology availability for angioembolization of hemodynamically unstable pelvic fractures: a prospective survey among U.S. level 1 trauma centers. *Patient Saf Surg*. 2019;13:23.
18. Tran TLN, Brasel KJ, Karmy-Jones R, et al. Western Trauma Association Critical Decisions in Trauma: management of pelvic fracture with hemodynamic instability — 2016 updates. *J Trauma Acute Care Surg*. 2016;81(6): 1171–1174.
19. Bonner TJ, Eardley WG, Newell N, Masourous S, Matthews JJ, Gibb I, Clasper JC. Accurate placement of a pelvic binder improves reduction of unstable fractures of the pelvic ring. *J Bone Joint Surg Br*. 2011;93(11): 1524–1528.
20. Krieg JC, Mohr M, Ellis TJ, Simpson TS, Madey SM, Bottlang M. Emergent stabilization of pelvic ring injuries by controlled circumferential compression: a clinical trial. *J Trauma*. 2005;59(3):659–664.
21. Bottlang M, Simpson T, Sigg J, Krieg JC, Madey SM, Long WB. Noninvasive reduction of open-book pelvic fractures by circumferential compression. *J Orthop Trauma*. 2002;16(6):367–373.
22. DeAngelis NA, Wixted JJ, Drew J, Eskander MS, Eskander JP, French BG. Use of the trauma pelvic orthotic device (T-POD) for provisional stabilisation of anterior-posterior compression type pelvic fractures: a cadaveric study. *Injury*. 2008;39(8):903–906.
23. Dreizin D, Bodanapally U, Mascarenhas D, O'Toole RV, Tirada N, Issa G, Nascone J. Quantitative MDCT assessment of binder effects after pelvic ring disruptions using segmented pelvic haematoma volumes and multiplanar caliper measurements. *Eur Radiol*. 2018;28(9):3953–3962.
24. Agri F, Bourgeat M, Becce F, Moerenhout K, Pasquier M, Borens O, Yersin B, Demartines N, Zingg T. Association of pelvic fracture patterns, pelvic binder use and arterial angio-embolization with transfusion requirements and mortality rates; a 7-year retrospective cohort study. *BMC Surg*. 2017; 17(1):104.
25. Ghaemmaghami V, Sperry J, Gunst M, Friese R, Starr A, Frankel H, Gentilello LM, Shafi S. Effects of early use of external pelvic compression on transfusion requirements and mortality in pelvic fractures. *Am J Surg*. 2007;194(6):720–723; discussion 723.
26. Pizanis A, Pohlemann T, Burkhardt M, Aghayev E, Holstein JH. Emergency stabilization of the pelvic ring: clinical comparison between three different techniques. *Injury*. 2013;44(12):1760–1764.
27. Fu CY, Wu YT, Liao CH, Kang SC, Wang SY, Hsu YP, Lin BC, Yuan KC, Kuo IM, Ouyang CH. Pelvic circumferential compression devices benefit patients with pelvic fractures who need transfers. *Am J Emerg Med*. 2013; 31(10):1432–1436.
28. Croce MA, Magnotti LJ, Savage SA, Wood GW 2nd, Fabian TC. Emergent pelvic fixation in patients with exsanguinating pelvic fractures. *J Am Coll Surg*. 2007;204(5):935–939; discussion 940-2.
29. Hsu SD, Chen CJ, Chou YC, Wang SH, Chan DC. Effect of early pelvic binder use in the emergency management of suspected pelvic trauma: a retrospective cohort study. *Int J Environ Res Public Health*. 2017;14(10).
30. Williamson F, Coulthard LG, Hacking C, Martin-Dines P. Identifying risk factors for suboptimal pelvic binder placement in major trauma. *Injury*. 2020;51(4):971–977.
31. Vaidya R, Roth M, Zarling B, Zhang S, Walsh C, Macsuga J, Swartz J. Application of circumferential compression device (binder) in pelvic injuries: room for improvement. *West J Emerg Med*. 2016;17(6):766–774.
32. Pierrie SN, Seymour RB, Wally MK, Studnek J, Infinger A, Hsu JR. Pilot randomized trial of pre-hospital advanced therapies for the control of hemorrhage (PATCH) using pelvic binders. *Am J Emerg Med*. 2021;42:43–48.
33. Naseem H, Nesbitt PD, Sprott DC, Clayson A. An assessment of pelvic binder placement at a UK major trauma centre. *Ann R Coll Surg Engl*. 2018;100(2):101–105.
34. Wang E, Benjamin E, Byerly S, Llaquet H, Matsushima K, Inaba K, Demetriades D. Liberal use of pelvic binders in the pre-hospital and emergency room setting may be harmful. *J Am Coll Surg*. 2016;223:e200.
35. Toth L, King KL, McGrath B, Balogh ZJ. Efficacy and safety of emergency non-invasive pelvic ring stabilization. *Injury*. 2012;43(8):1330–1334.
36. Bottlang M, Krieg JC, Mohr M, Simpson TS, Madey SM. Emergent management of pelvic ring fractures with use of circumferential compression. *J Bone Joint Surg Am*. 2002;84-A(Suppl 2):43–47.
37. Schaller TM, Sims S, Maxian T. Skin breakdown following circumferential pelvic antishock sheeting: a case report. *J Orthop Trauma*. 2005;19(9): 661–665.
38. Krieg JC, Mohr M, Mirza AJ, Bottlang M. Pelvic circumferential compression in the presence of soft-tissue injuries: a case report. *J Trauma*. 2005; 59(2):470–472.
39. Mason L, Boyce D, Pallister I. Catastrophic myonecrosis following circumferential pelvic binding after massive crush injury: a case report. *Injury Extra*. 2009;40:84–86.
40. Knops SP, Van Lieshout EM, Spanjersberg WR, Patka P, Schipper IB. Randomized clinical trial comparing pressure characteristics of pelvic circumferential compression devices in healthy volunteers. *Injury*. 2011;42(10): 1020–1026.

41. Jamme S, Poletti A, Gamulin A, Rutschmann O, Andereggen E, Grosgurin O, Marti C. False negative computed tomography scan due to pelvic binder in a patient with pelvic disruption: a case report and review of the literature. *J Med Case Rep*. 21 2018;12(1):271.
42. Fagg JAC, Acharya MR, Chesser TJS, Ward AJ. The value of 'binder-off' imaging to identify occult and unexpected pelvic ring injuries. *Injury.* 2018;49(2):284–289.
43. Clements J, Jeavons R, White C, McMurtry I. The concealment of significant pelvic injuries on computed tomography evaluation by pelvic compression devices. *J Emerg Med*. 2015;49(5):675–678.
44. Swartz J, Vaidya R, Hudson I, Oliphant B, Tonnos F. Effect of pelvic binder placement on OTA classification of pelvic ring injuries using computed tomography. does it mask the injury? *J Orthop Trauma*. 2016;30(6):325–330.
45. Martinelli T, Thony F, Declèty P, Sengel C, Broux C, Tonetti J, Payen JF, Ferretti G. Intra-aortic balloon occlusion to salvage patients with life-threatening hemorrhagic shocks from pelvic fractures. *J Trauma*. 2010; 68(4):942–948.
46. White JM, Cannon JW, Stannard A, Markov NP, Spencer JR, Rasmussen TE. Endovascular balloon occlusion of the aorta is superior to resuscitative thoracotomy with aortic clamping in a porcine model of hemorrhagic shock. *Surgery.* 2011;150(3):400–409.
47. Morrison JJ, Ross JD, Houston R, Watson JDB, Sokol KK, Rasmussen TE. Use of resuscitative endovascular balloon occlusion of the aorta in a highly lethal model of noncompressible torso hemorrhage. *Shock*. 2014;41(2): 130–137.
48. Brenner ML, Moore LJ, DuBose JJ, Tyson GH, McNutt MK, Albarado RP, Holcomb JB, Scalea TM, Rasmussen TE. A clinical series of resuscitative endovascular balloon occlusion of the aorta for hemorrhage control and resuscitation. *J Trauma Acute Care Surg*. 2013;75(3):506–511.
49. Brenner M, Inaba K, Aiolfi A, et al. Resuscitative endovascular balloon occlusion of the aorta and resuscitative thoracotomy in select patients with hemorrhagic shock: early results from the American Association for the Surgery of Trauma's Aortic Occlusion in Resuscitation for Trauma and Acute Care Surgery registry. *J Am Coll Surg*. 2018;226(5):730–740.
50. Norii T, Crandall C, Terasaka Y. Survival of severe blunt trauma patients treated with resuscitative endovascular balloon occlusion of the aorta compared with propensity score-adjusted untreated patients. *J Trauma Acute Care Surg*. 2015;78(4):721–728.
51. Yamamoto R, Cestero RF, Suzuki M, Funabiki T, Sasaki J. Resuscitative endovascular balloon occlusion of the aorta (REBOA) is associated with improved survival in severely injured patients: a propensity score matching analysis. *Am J Surg*. 2019;218(6):1162–1168.
52. Lendrum R, Perkins Z, Chana M, Marsden M, Davenport R, Grier G, Sadek S, Davies G. Pre-hospital resuscitative endovascular balloon occlusion of the aorta (REBOA) for exsanguinating pelvic hemorrhage. *Resuscitation*. 2019;135:6–13.
53. Inoue J, Shiraishi A, Yoshiyuki A, Haruta K, Matsui H, Otomo Y. Resuscitative endovascular balloon occlusion of the aorta might be dangerous in patients with severe torso trauma: a propensity score analysis. *J Trauma Acute Care Surg*. 2016;80(4):559–567.
54. DuBose JJ, Scalea TM, Brenner M, et al. The AAST prospective Aortic Occlusion for Resuscitation in Trauma and Acute Care Surgery (AORTA) registry: data on contemporary utilization and outcomes of aortic occlusion and resuscitative balloon occlusion of the aorta (REBOA). *J Trauma Acute Care Surg*. 2016;81(3):409–419.
55. Romagnoli A, Teeter W, Pasley J, Hu P, Hoehn M, Stein D, Scalea T, Brenner M. Time to aortic occlusion: it's all about access. *J Trauma Acute Care Surg*. 2017;83(6):1161–1164.
56. Rieger J, Linsenmaier U, Euler E, Rock C, Pfeifer KJ. Temporary balloon occlusion as therapy of uncontrollable arterial hemorrhage in multiple trauma patients. *ROFO Fortschr Geb Rontgenstr Nuklearmed*. 1999;170(1):80–83.
57. Mikdad S, van Erp IAM, Moheb ME, Fawley J, Saillant N, King DR, Kaafarani HMA, Velmahos G, Mendoza AE. Pre-peritoneal pelvic packing for early hemorrhage control reduces mortality compared to resuscitative endovascular balloon occlusion of the aorta in severe blunt pelvic trauma patients: a nationwide analysis. *Injury.* 2020;51(8):1834–1839.
58. Moore LJ, Fox EE, Meyer DE, et al. Prospective observational evaluation of the ER-REBOA catheter at 6 U.S. trauma centers [published online June 23, 2020]. *Ann Surg*. doi:10.1097/SLA.0000000000004055.
59. Huittinen VM, Slätis P. Postmortem angiography and dissection of the hypogastric artery in pelvic fractures. *Surgery.* 1973;73(3):454–462.
60. Burlew CC, Moore EE, Stahel PF, Geddes AE, Wagenaar AE, Pieracci FM, Fox CJ, Campion EM, Johnson JL, Mauffrey C. Preperitoneal pelvic packing reduces mortality in patients with life-threatening hemorrhage due to unstable pelvic fractures. *J Trauma Acute Care Surg*. 2017;82(2):233–242.
61. Tscherne H, Pohlemann T, Gansslen A, Hufner T, Pape HC. Crush injuries of the pelvis. *Eur J Surg*. 2000;166(4):276–282.
62. Smith WR, Moore EE, Osborn P, Agudelo JF, Morgan SJ, Parekh AA, Cothren C. Retroperitoneal packing as a resuscitation technique for hemodynamically unstable patients with pelvic fractures: report of two representative cases and a description of technique. *J Trauma*. 2005;59(6):1510–1514.
63. Tesoriero RB, Bruns BR, Narayan M, Dubose J, Guliani SS, Brenner ML, Boswell S, Stein DM, Scalea TM. Angiographic embolization for hemorrhage following pelvic fracture: Is it "time" for a paradigm shift? *J Trauma Acute Care Surg*. 2017;82(1):18–26.
64. Lewis RH Jr., Sharpe JP, Berning B, Fabian TC, Croce MA, Magnotti LJ. Impact of a simplified management algorithm on outcome following exsanguinating pelvic fractures: a 10-year experience. *J Trauma Acute Care Surg*. 2019;86(4):658–663.
65. Gaski IA, Barckman J, Naess PA, Skaga NO, Madsen JE, Kløw NE, Flugsrud G, Gaarder C. Reduced need for extraperitoneal pelvic packing for severe pelvic fractures is associated with improved resuscitation strategies. *J Trauma Acute Care Surg*. 2016;81(4):644–651.
66. Ron G, Epstein D, Ben-Galim P, Klein Y, Kaban A, Sagiv S. Extra-peritoneal pressure packing without external pelvic fixation: a life-saving stand-alone surgical treatment. *J Emerg Trauma Shock*. 2015;8(4):181–187.
67. Cheng M, Cheung MT, Lee KY, Lee KB, Chan SC, Wu AC, Chow YF, Chang AM, Ho HF, Yau KK. Improvement in institutional protocols leads to decreased mortality in patients with haemodynamically unstable pelvic fractures. *Emerg Med J*. 2015;32(3):214–220.
68. Chiara O, di Fratta E, Mariani A, Michaela B, Prestini L, Sammartano F, Cimbanassi S. Efficacy of extra-peritoneal pelvic packing in hemodynamically unstable pelvic fractures, a Propensity Score Analysis. *World J Emerg Surg*. 2016;11:22.
69. Burlew CC, Moore EE, Smith WR, Johnson JL, Biffl WL, Barnett CC, Stahel PF. Preperitoneal pelvic packing/external fixation with secondary angioembolization: optimal care for life-threatening hemorrhage from unstable pelvic fractures. *J Am Coll Surg*. 2011;212(4):628–635; discussion 35–7.
70. Shim H, Jang JY, Kim JW, Ryu H, Jung PY, Kim S, Kwon HY, Kim KM, Chung H, Bae KS. Effectiveness and postoperative wound infection of preperitoneal pelvic packing in patients with hemodynamic instability caused by pelvic fracture. *PloS one*. 2018;13(11):e0206991.
71. Li Q, Dong J, Yang Y, Wang G, Wang Y, Liu P, Robinson Y, Zhou D. Retroperitoneal packing or angioembolization for hemorrhage control of pelvic fractures—quasi-randomized clinical trial of 56 haemodynamically unstable patients with Injury Severity Score ≥33. *Injury.* 2016;47(2):395–401.
72. Stahel PF, Moore EE, Burlew CC, Henderson C, Peña AJ, Harry D, Pieracci FM. Preperitoneal pelvic packing is not associated with an increased risk of surgical site infections after internal anterior pelvic ring Fixation. *J Orthop Trauma*. 2019;33(12):601–607.
73. Heelan AA, Freedberg M, Moore EE, et al. Worth looking! venous thromboembolism in patients who undergo preperitoneal pelvic packing warrants screening duplex. *Am J Surg*. 2020;220(6):1395–1399.
74. Prasarn ML, Horodyski M, Conrad B, Rubery PT, Dubose D, Small J, Rechtine GR. Comparison of external fixation versus the trauma pelvic orthotic device on unstable pelvic injuries: a cadaveric study of stability. *J Trauma Acute Care Surg*. 2012;72(6):1671–1675.
75. Burlew CC. Preperitoneal pelvic packing: a 2018 EAST Master Class Video Presentation. *J Trauma Acute Care Surg*. 2018;85(1):224–228.
76. Margolies MN, Ring EJ, Waltman AC, Kerr WS Jr., Baum S. Arteriography in the management of hemorrhage from pelvic fractures. *N Engl J Med*. 1972 17;287(7):317–321. PMID: 5041699.
77. Panetta T, Sclafani SJ, Goldstein AS, Phillips TF, Shaftan GW. Percutaneous transcatheter embolization for massive bleeding from pelvic fractures. *J Trauma*. 1985;25(11):1021–1029.
78. Cullinane DC, Schiller HJ, Zielinski MD, et al. Eastern Association for the Surgery of Trauma practice management guidelines for hemorrhage in pelvic fracture- update and systematic review. *J Trauma*. 2011;71(6):1850–1868.

79. Eastridge BJ, Starr A, Minei JP, O'Keefe GE, Scalea TM. The importance of fracture pattern in guiding therapeutic decision-making in patients with hemorrhagic shock and pelvic ring disruptions. *J Trauma*. 2002;53(3):446–450; discussion 450–1.
80. O'Connell KM, Kolnik S, Arif K, Qui Q, Jones S, Ingraham C, Rivara F, Vavilala MS, Maier R, Bulnger EM. Balloons up: shorter time to angioembolization is associated with reduced mortality in patients with shock and complex pelvic fractures (original study). *Trauma Surg Acute Care Open*. 2021;6(1):e000663.
81. Juern JS, Milia D, Codner P, Beckman M, Somberg L, Webb T, Weigelt JA. Clinical significance of computed tomography contrast extravasation in blunt trauma patients with a pelvic fracture. *J Trauma Acute Care Surg*. 2017;82(1):138–140.
82. Verbeek DO, Zijlstra IA, van der Leij C, Ponsen KJ, van Delden OM, Goslings JC. Management of pelvic ring fracture patients with a pelvic "blush" on early computed tomography. *J Trauma Acute Care Surg*. 2014;76(2):374–379.
83. Matsushima K, Piccinini A, Schellenberg M, Cheng V, Heindel P, Strumwasser A, Benjamin E, Inaba K, Demetriades D. Effect of door-to-angioembolization time on mortality in pelvic fracture: every hour of delay counts. *J Trauma Acute Care Surg*. 2018;84(5):685–692.
84. Schwartz DA, Medina M, Cotton BA, Rahbar E, Wade CE, Cohen AM, Beeler AM, Burgess AR, Holcomb JB. Are we delivering two standards of care for pelvic trauma? Availability of angioembolization after hours and on weekends increases time to therapeutic intervention. *J Trauma Acute Care Surg*. 2014;76(1):134–139.
85. Adnan SM, Romagnonli AN, Elansary NN, Martinson JR, Madurska MJ, Dubose JJ, Scalea TM, Morrison JJ. Radial versus femoral arterial access for trauma endovascular interventions: a noninferiority study. *J Trauma Acute Care Surg*. 2020;89(3):458–463.
86. Hymel A, Asturias S, Zhao F, et al. Selective versus nonselective embolization versus no embolization in pelvic trauma: a multicenter retrospective cohort study. *J Trauma Acute Care Surg*. 2017;83(3):361–367.
87. Copp J, Eastman JG. Novel resuscitation strategies in patients with a pelvic fracture [published online January 30, 2020]. *Injury*. doi:10.1016/j.injury.2020.01.042.
88. Grimm MR, Vrahas MS, Thomas KA. Pressure-volume characteristics of the intact and disrupted pelvic retroperitoneum. *J Trauma*. 1998;44(3):454–459.
89. Starr AJ, Griffin DR, Reinert CM, Frawley WH, Walker J, Whitlock SN, Borer DS, Rao AV, Jones AL. Pelvic ring disruptions: prediction of associated injuries, transfusion requirement, pelvic arteriography, complications, and mortality. *J Orthop Trauma*. 2002;16:553–561.
90. Ganz R, Krushell RJ, Jakob RP, Kuffer J. The antishock pelvic clamp. *Clin Orthop Relat R*. 1991;267:71–78.
91. Heini PF, Witt J, Ganz R. The pelvic C-clamp for the emergency treatment of unstable pelvic ring injuries. A report on clinical experience of 30 cases. *Injury*. 1996;27:38–45.
92. Richard MJ, Tornetta P. Emergent management of APC-2 pelvic ring injuries with an anteriorly placed C-clamp. *J Orthop Trauma*. 2009;23:322–326.
93. Sepehri A, Sciadini MF, Nascone JW, Manson TT, O'Toole RV, Slobogean GP. Initial experience with the T-Clamp for temporary fixation of mechanically and hemodynamically unstable pelvic ring injuries. *Injury*. 2020;51:699–704.
94. Pohlemann T, Braune C, Gänsslen A, Hüfner T, Partenheimer A. Pelvic emergency clamps: anatomic landmarks for a safe primary application. *J Orthop Trauma*. 2004;18:102–105.
95. Schütz M, Stöckle U, Hoffmann R, Südkamp N, Haas N. Clinical experience with two types of pelvic C-clamps for unstable pelvic ring injuries. *Injury*. 1996;27:46–50.
96. Demetriades D, Karaiskakis M, Toutouzas K, Alo K, Velmahos G, Chan L. Pelvic fractures: Epidemiology and predictors of associated abdominal injuries and outcomes. *J Am Coll Surg*. 2002;195:1–10.
97. Cho J, Benjamin E, Inaba K, Lam L, Demetriades D. Severe bleeding in pelvic fractures: considerations in planning damage control. *Am Surg*. 2018;84:267–272.
98. Cestero RF, Plurad D, Green D, Inaba K, Putty B, Benfield R, Lam L, Talving P, Demetriades D. Iliac artery injuries and pelvic fractures: a national trauma database analysis of associated injuries and outcomes. *J Trauma*. 2009;67:715–718.

