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Application of an external fixator vascular compressor (EFVC) in the critically injured trauma patient: a novel damage control technique

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Abstract

Methods of controlling hemorrhage in penetrating abdominal injuries are varied, ranging from electrocautery, ligation, laparotomy sponge packing, angiography, hemostatic agents, and direct manual pressure. Unfortunately, traditional methods are sometimes unsuccessful due to the location or nature of the hemorrhage, and manual pressure cannot be held indefinitely. We describe a novel damage control technique for hemorrhage control in these situations, followed by three cases where an external fixator vascular compressor (EFVC) was used to hold continual pressure. Three patients are presented to a Level 1 trauma center following multiple ballistic injuries, all requiring emergent exploratory laparotomy. The first had a two-pin iliac crest EFVC placed during repeat exploratory laparotomy to control bleeding. The second patient had a supra-acetabular EFVC placed during initial exploratory laparotomy after emergent embolization failed to control bleeding from the L3 vertebral body. The third patient had a two-pin iliac crest EFVC placed at initial exploratory laparotomy due to uncontrollable bleeding from the sacral venous plexus and internal iliac veins. Of the three patients, two stabilized and survived, while one passed away due to multi-organ failure. We describe a novel damage control technique that may be a useful means of temporarily stemming intraabdominal bleeding that is otherwise recalcitrant to traditional hemostatic methods. Additionally, we provided a limited case series of patients who have undergone this technique to illustrate its utility and versatility. This technique is simple, fast, effective, and adaptable to a variety of circumstances that may be encountered in patients with intraabdominal bleeding recalcitrant to conventional hemorrhage control.

Keywords Intraabdominal hemorrhage · Hemorrhage control · Hemostasis · External fixation · Damage control

Introduction

Penetrating abdominal injuries frequently lead to intraabdominal vascular damage and have an estimated overall mortality rate of 37% [1]. Abdominal vessel injuries have been estimated to account for 25 to 30% of all vascular injuries following penetrating wounds in urban trauma centers [2]. Methods of controlling hemorrhage in these scenarios are varied, ranging from electrocautery, ligation, laparotomy sponge packing, angiography, hemostatic agents, and direct manual pressure [3, 4]. In certain instances, intraabdominal vasculature may be adherent to the periosteum of the sacrum, pelvis, or lumbar spine making traditional methods of proximal and distal control unfeasible. Direct manual compression allows for focused pressure at a specific anatomic location; however, prolonged direct manual compression is a not a practical means for controlling hemorrhage for obvious reasons [5]. Therefore, there is a need for improved methods of hemostasis in these multiply injured patients at risk for exsanguinating.

The use of pelvic external fixation was first described in the early 1970s as an alternative to bed rest in the treatment of pelvic fractures [5–7] and was popularized as an

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orthopedic damage control technique in the late 1990s [8]. At a similar time, damage control was also gaining popularity in the world of general trauma surgery as the mortality benefits of damage control techniques like abdominal packing were being realized [9]. More recent research looks at the metabolic markers of hypovolemic shock, with the goal of stratifying trauma patients into those that will benefit from damage control techniques and those that will not [10, 11]. Despite these many advances in the world of damage control surgery, the mortality rate from penetrating abdominal wounds with vascular injury remains very high; therefore, there remains a need for new damage control techniques [1]. The following guide describes the placement of an external fixator vascular compressor (EFVC), a damage control technique which can provide persistent direct manual pressure at the site of intraabdominal bleeding which has failed conventional techniques. The goal of this technique is to stem uncontrollable life-threatening hemorrhage so that embolization and/or resuscitation can be accomplished before return to the OR and more definitive surgery.

Orthopedic techniques

Thus far, we have performed this technique on three patients, two of whom survived their injuries. Although a limited number have been performed to date, there are several modifications and learning points that have been gleaned thus far. We noted that when hemostasis could not be successfully obtained through conventional techniques, the EFVC was able to provide hemostasis and decrease ongoing transfusion requirements. This technique is particularly useful for rapid application in the trauma setting. As such, timely application of the EFVC can contribute to smaller transfusion requirement as was seen in Case 3 with only 18 units of blood products. Fluoroscopic guidance, although helpful, is not "required" for application and has not been used in any of our emergent cases. We discussed supplementing our tactile feedback with radiographic guidance; however, we have realized anatomic landmarks and tactile feedback appear to be adequate for rapid application and have been shown to be safe for standard external fixation techniques in a damage control setting [12, 13]. We also learned to individualize the size of the clamp on the end of the compression bar based on the need for broad or focused compression (Figs. 6, 8a, b, Table 1). We learned that compared to the iliac crest pin, the supra-acetabular pin may be slightly more technically challenging given the difficulty in palpating landmarks in the setting of generalized swelling, general surgery retractor (omni retractor) placement, and an open abdomen.

Below, we describe two different techniques to create a temporary direct pressure device using an external fixator. The technique requires the application of a standard pelvic external fixator using either supra-acetabular or iliac crest pins. A central crossbar is used at the level of the injury, and a compression arm is placed from the crossbar to the

Table 1 Photographs showing the various sizes of bars and clamps used for the distal "footprint" compression device

	Footprint size	Various "footprints" for hemostasis	
Rod	1×1 cm		
Bar to bar clamp	2.5 cm×4 cm		
Half of a 5-pin connector clamp	2 cm×5 cm		

abdomen to hold direct pressure. A variety of external fixator components can be selected to customize the angle, location, and "footprint" of pressure that is applied (Table 1).

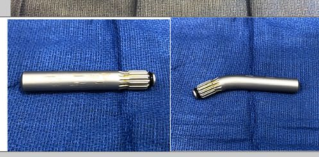
Supra-acetabular technique

Components needed for the construction of the frame (Table 2):

1. Threaded pins (Schanz pins) standard or self-drilling either 5 mm or 6 mm in diameter ×2.
2. Carbon fiber rods or metal tubes from a large spanning external fixation sets ×2.
3. Standard bar-to-bar and pin-to-bar clamps available on the set ×4.
4. Straight or curved outrigger (optional).
5. One of the following: bar-to-bar clamp or half of a five-pin connector clamp (optional).

The patient is typically already prepped and draped by general surgery with a trauma sterile field. This generally has the patient in the supine position with an open abdomen, and the pelvis draped into the sterile field. We begin by making a 2–3 cm transverse incision over the AIIS. The AIIS can be found by palpating the anterior superior iliac spine (ASIS) and traveling approximately 4 cm distally (Fig. 1a, b). The subcutaneous tissue is spread with a hemostat, and the AIIS is palpated. A cannulated system is used to protect the surrounding soft tissues. The cannula is pressed firmly onto the AIIS and directed toward the SI joint, roughly 15° cephalad and 25° medially. Pins are either predrilled and placed or directly placed through the cannula if self-drilling self-tapping pins are available. As pins are advanced, fluoroscopy may be used to assure proper trajectory and depth and to avoid intraarticular pin placement (Outlet obturator oblique and iliac oblique are of the greatest utility) (Fig. 2a–c). Alternatively, if fluoroscopy is unavailable or time does not permit, a progressive increase in resistance will be felt signifying appropriate depth. Once fully seated, gentle force can be applied on the pins to confirm solid purchase in bone. A log roll of the hip should be performed to confirm the pins are extraarticular to the hip joint if fluoroscopy is not utilized. Once bilateral AIIS pins are

Table 2 Photographs of all individual components required for assembly of an EFVC

Component Name	Picture	# needed for supra-acetabular frame	# needed for single iliac crest pin frame	# needed for double iliac crest pin frame
Carbon fiber bar (comes in multiple sizes)		2	4	4
Bar-to-bar/pin-to-bar connector		4	6	8
Schanz pin		2	2	4
Outrigger (left-straight, right-bent)		1	1	1
½ of five pin bank (left-as used in vivo, right-both halves together for reference)		1	1	1

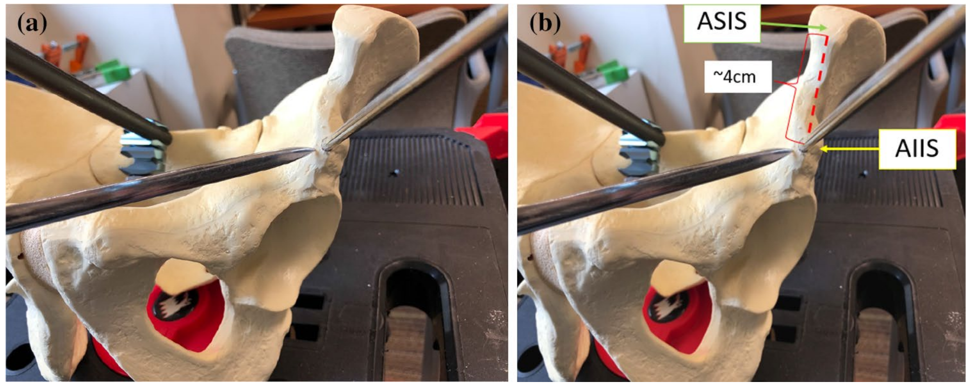


Fig. 1 Photographs on sawbones model. **a** A 5-mm threaded Schanz pin placed with 15° of cephalad and 25 of medially direction in the AIIS as indicated by the probe. **b** Annotated landmarks for identification or proper starting point

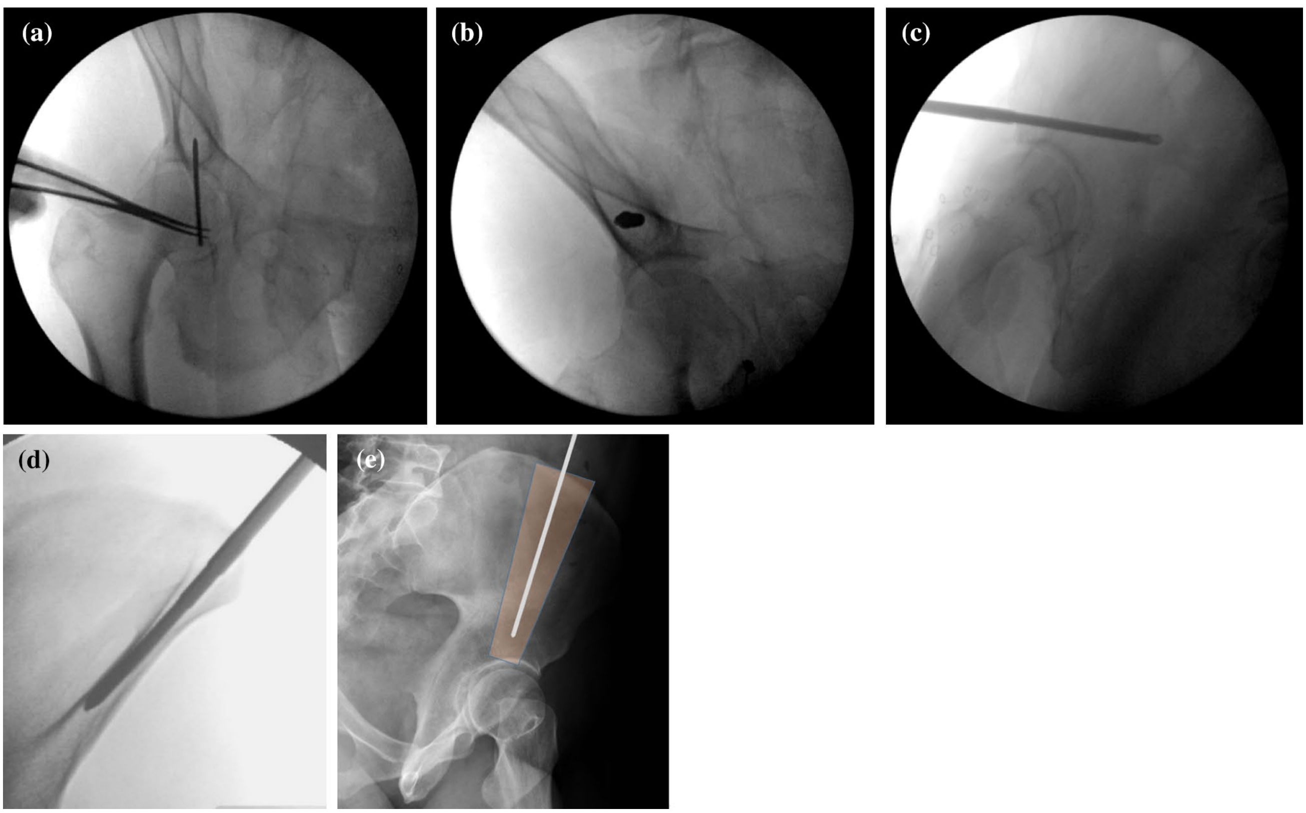


Fig. 2 Radiographic images showing proper pin placement for both supra-acetabular (**a**–**c**) and iliac crest techniques (**d**–**e**). **a** Outlet obturator oblique demonstrating the "teardrop view" for proper starting point determination for supra-acetabular technique. **b** Outlet obturator oblique demonstrating "down the pike" pin placement for supra-acetabular technique. **c** Iliac oblique demonstrating extraarticular pin placement above the acetabular dome for supra-acetabular technique. **d** Obturator oblique demonstrating proper pin trajectory for iliac crest pins, avoiding penetration of inner or outer tables of the pelvis. **e** Iliac oblique demonstrating appropriate pin trajectory for iliac crest pins, starting 1.5 cm posterior to ASIS and stopping short of acetabular dome/greater sciatic notch. The shaded region represents the gluteus medius pillar, a region of thickened bone which serves as a solid anchor for iliac crest pins

in place, they are connected using two pin-to-bar clamps and a long transverse bar. A second bar (compression bar) is then attached to the center of the transverse bar using a bar-to-bar clamp and directed into the abdomen to the site of bleeding (Figs. 3, 4, 5). An additional half of a five-pin connector clamp can be used in combination with lap pads and hemostatic agents to enlarge the effective "footprint" (Figs. 6, 8a, b, Table 1).

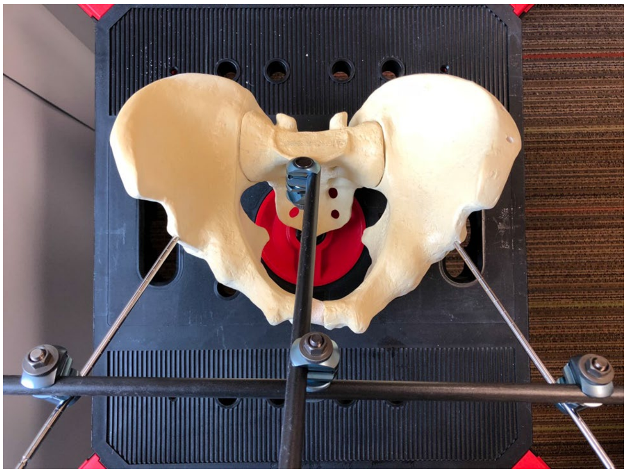


Fig. 3 Final construct with bilateral AIIS pins and bar-to-bar clamp applying pressure over the presacral area

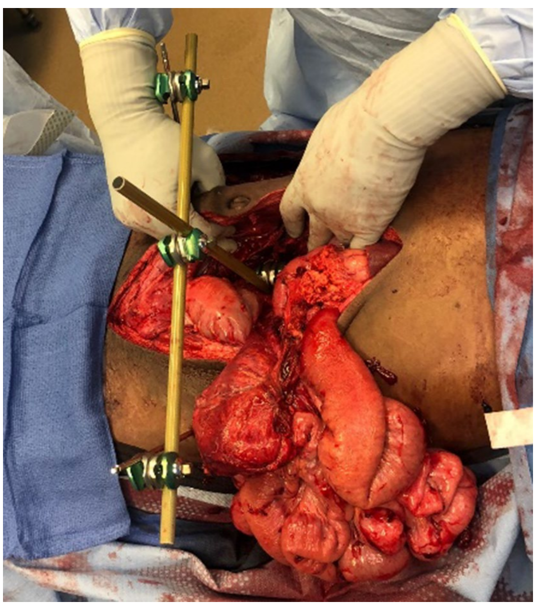


Fig. 4 Final construct intraoperatively prior to closure

Iliac crest technique

Components needed for the construction of the frame (Table 2):

1. Threaded pins (Schanz pins) standard or self-drilling, 5 or 6 mm ×2 (can use 4 for stronger construct).
2. Carbon fiber rods or metal tubes from large spanning external fixation set ×4.
3. Standard bar-to-bar and pin-to-bar clamps available on the set. ×6 minimum (additional if 2 pins are placed per crest).

Fig. 5 Final construct following temporary abdominal closure

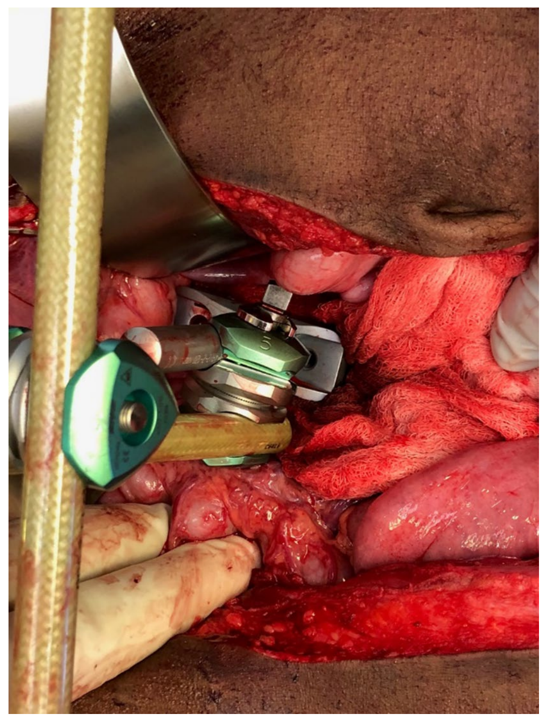


Fig. 6 Close-up of the abdomen, demonstrating the use of an additional half of the five-pin connector clamp creating a "footprint" over a larger area

4. Straight or curved outrigger (optional).
5. One of the following: bar-to-bar clamp or half of a five-pin connector clamp (optional).

The iliac crest technique is less technically demanding but can require additional bars due to the cephalad trajectory of the pins. Additionally, the resulting construct can be weaker than the supra-acetabular technique, which can be remedied by adding an additional pin in each iliac crest.

The patient will already be in the supine position with an open abdomen and the pelvis draped into the sterile field. Localize the ASIS by palpating the most prominent point on the anterior portion of the iliac wing. We begin by making a 2 cm longitudinal incision 3–4 cm posterior to the ASIS (Fig. 1b), thereby avoiding injury to the lateral femoral cutaneous nerve. The orientation of the iliac wing can be manually palpated in thin patients or a spinal needle can be gently slid directly on the outer table to confirm trajectory. A cannula system is used to protect the surrounding soft tissues. The cannula is pressed firmly onto the ASIS while aiming 45° caudal and parallel to the outer table pin or in line with palpated iliac wing. Pins are predrilled and placed or directly placed through the cannula if self-drilling self-tapping pins are available. As pins advance successive fluoroscopic images (Iliac oblique and obturator oblique) can be used to assure proper depth and trajectory (Fig. 2d, e). Alternatively, if fluoroscopy is unavailable or time does not permit, a progressive increase in resistance will be felt signifying appropriate depth. Once fully seated, gentle force can be applied on the pins to confirm solid purchase in the iliac wing. Following the same steps, a second pin is placed on the contralateral side. If additional strength is needed, a second pin can be placed in each iliac crest, 3 cm posterior to the first pin (Fig. 7).

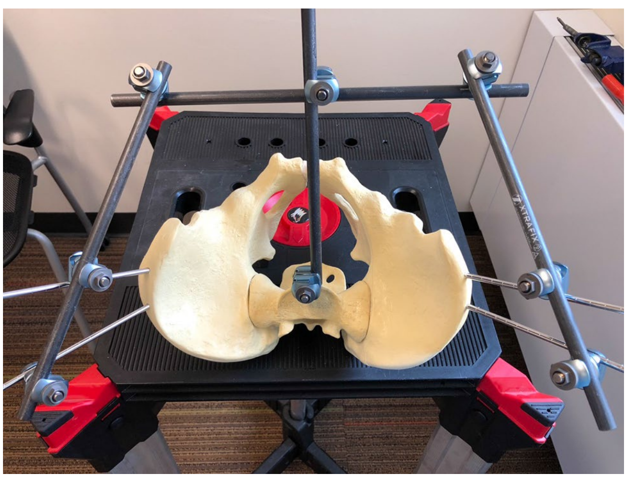


Fig. 7 A final construct created using the iliac crest for pin placement

Different configurations of bars can be used depending on the area of interest. We recommend the use of four bars: a short bar attached to each pin directed anteriorly, connected by one long transverse bar. As with the supra-acetabular technique, a compression bar is placed from the center of the transverse bar to the abdomen and a clamp is used to create a "footprint" (Fig. 8). Additional configurations can be used based on frame stability, patient hemodynamic status, and the location requiring direct compression.

Case reports

Case 1

A 17-year-old male was victim to a single gunshot to his right lower abdomen. He was taken to the operating room emergently after attempted stabilization in the emergency room. Operative finding included a right-sided inferior vena cava and right common iliac vein injury which were repaired with 4–0 prolene, as well as a duodenal injury which was temporarily over sewn. An injured section of colon was resected, the abdomen was packed, and an abdominal wound vacuum closure device was placed.

He was brought back to the OR the following morning due to increasing transfusion requirements and loss of vacuum seal with a presumed intraabdominal bleeding. A bleeding mesenteric artery was found at the distal colonic mesentery resection and controlled with 2–0 silk ties. Inferior vena cava (IVC) bleeding remained well controlled; however, there was brisk bleeding from the right-sided L4

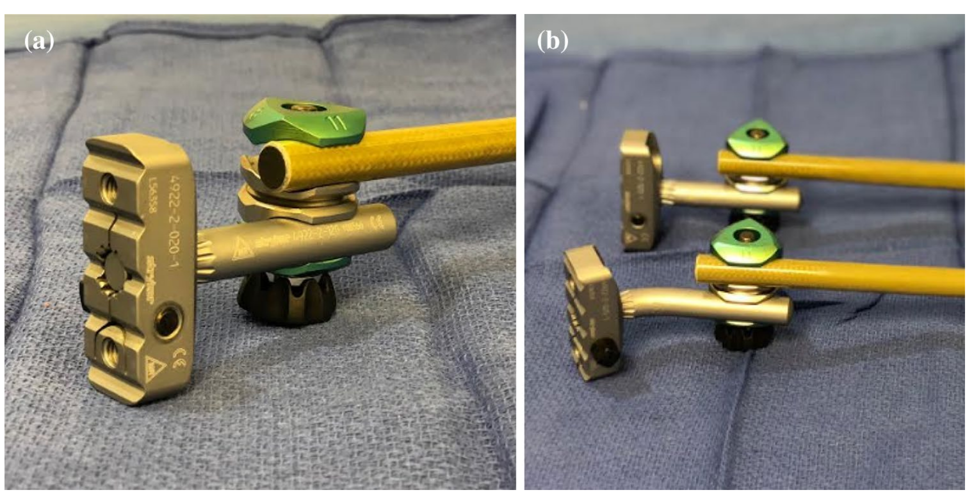


Fig. 8 Demonstration of compression rod modification. **a** One half of a five-pin clamp can be used instead of a bar-to-bar clamp, creating a more efficient compression foot print. **b** The five-pin clamp can be attached with a straight of a bent outrigger, thereby modifying the angle of compression for uses deep in the pelvis

vertebral artery and the bullet tract into the body of L4. Attempts to control bleeding were made with ligation, bone wax, and hemostatic agents; however, only direct pressure was effective in controlling the bleeding.

Orthopedics was consulted to construct an external fixation device allowing continuous direct pressure over the anterior aspect of the L4 vertebral body. A pelvic external fixator was placed utilizing two 6.0-mm shanz pins in each iliac crest, which were connected with a crossbar. A second vertical bar was directed into the abdomen and augmented with half of a five-pin connector clamp attached with a straight arm outrigger to create a larger "footprint" (Figs. 5, 8a, b). Following placement of the frame, the patient was stabilized and was taken to the angiography suite for embolization of right L3, L4, and L5 vertebral arteries. The external fixator was removed uneventfully 2 days later during abdominal closure. There was a total of 55 units of blood products used during the hospitalization (24 pRBCs, 9 platelets, 20 FFP, 2 cryo), and the patient survived.

Case 2

A 32-year-old male presented to the trauma bay with multiple ballistic wounds to the left forearm, right back, left medial thigh, and left posterior thigh. He was taken to the OR emergently for exploratory laparotomy due to a positive FAST examination and decreased responsiveness in the setting of hemorrhagic shock. Initial findings included: an IVC injury requiring ligation, superior mesenteric vein injury repaired primarily, gastroduodenal artery and lumbar artery injuries, and high-volume bleeding from the L3 vertebral body. Additionally, there were injuries to the pancreatic head and duodenum. After initial exploratory laparotomy, the patient was taken to the IR suite with an open abdomen for embolization of the gastroduodenal artery, pancreaticduodenal arcade and right L1–L3 lumbar arteries.

Following embolization, he was emergently brought back to the operating room due to ongoing high-volume transfusion requirements. The patient was hypothermic, coagulopathic, and acidotic. Further exploration revealed persistent high-volume hemorrhage from the bullet tract exiting from the anterior body of L3.

Orthopedic surgery was consulted intraoperatively to aid in the placement of a pelvic external fixator for focused direct pressure at L3. The AIIS was identified by direct palpation (approximately 4 cm inferior to the ASIS and 2 cm medial). A self-drilling, self-tapping 6.0-mm Schanz pin was placed free-hand beginning at the AIIS and directed toward the SI joint. It was advanced based on tactile feel until there was adequate purchase. This was repeated on the contralateral side, after which the pins were connected with a carbon fiber crossbar. A second bar was placed at the midpoint of this bar, directed into the abdomen, and augmented with a straight outrigger and half a five-pin connector to act as a pressure surface increasing the effective "footprint" of compression (Figs. 6, 8a, b, Table 1). This provided adequate hemorrhage control, and the patient was stabilized and transferred to the ICU for further resuscitation. Unfortunately, the patient expired on POD1 due to massive intraabdominal ischemia and multi-organ failure. A total of 347 total units of blood products were used (184 pRBCs, 126 FFP, 26 platelets, 11 cryo).

Case 3

A 17-year-old male presented to our facility with multiple ballistic injuries to the right abdomen, left abdomen, right buttock, left buttock, left ankle, right foot, and scrotum. He was taken directly to the OR for exploratory laparotomy due to positive FAST examination and hemopneumothorax. Intraoperative findings included profuse bleeding from the sacral venous plexus and confluence of the internal iliac veins. General surgery attempted over sewing; however, this was insufficient and failed to provide hemostasis due to a lack of soft tissue mobility in the area. Orthopedics was consulted for placement of an EFVC as direct pressure was felt to be the only means of controlling the hemorrhage. A single free-hand shanz pin was placed in each iliac crest using anatomic landmarks, as the patient was draped in such a way that fluoroscopic guidance was not possible. These were connected with a crossbar, with a second bar (compression bar) projecting into the abdomen as previously described. Bleeding was adequately controlled, allowing for IR embolization of the left internal iliac artery and posterior subdivision of the right internal iliac artery. The EFVC was removed on POD3 without complication. There were a total of 18 units of blood products (10 pRBCs, 8 FFP), and the patient survived his injuries.

Discussion

Damage control surgery has a long history in the world of general and orthopedic trauma. Initially coined by the military, damage control surgery is a concept first used by general trauma surgeons, whereby the use of abdominal packing during initial exploratory laparotomy led to improved survival rates [9, 14]. Orthopedic traumatologists adapted these ideas to fracture care, using the external fixator as a means of rapid fracture fixation with minimal physiologic impact. The pelvic external fixator, which was first used to stabilize pelvic fractures which would have otherwise been treated with bed rest [5–7], gained popularity with the advent of damage control orthopedics and the recognition that urgently stabilizing an unstable pelvis and decreasing the intra-pelvic volume helped to restore hemodynamic stability [8, 15].

Further studies by Vallier define those patients that will benefit from damage control orthopedics and differentiate them from patients who are physiologically stable enough to undergo early definitive fixation [10]. The goal of the EFVC is to provide yet another technique in the damage control tool box, a construct which can be applied quickly and can provide prolonged manual pressure at the site of uncontrollable hemorrhage, allowing for further resuscitation before return to the operating room.

This novel technique modifies two standard external fixator configurations to apply temporary direct pressure over the presacral/lumbar area in cases of intraabdominal bleeding not otherwise controlled by traditional techniques. A prior case report has described the use of other temporary devices such as a Richardson retractor for temporary direct pressure [16]. In our technique, we used a carbon fiber external fixator bar augmented on its distal end with an external fixation clamp to create a pressure "footprint" (Figs. 6, 8a, b). These items can be found in any facility with external fixation trays, and the techniques can be applied by orthopedic surgeons who are adept at placing external fixator frames to the pelvis. Alternatively, with this technique guide, general trauma surgeons without orthopedic support or those in remote areas can quickly learn and employ these or similar techniques to be used in life-saving scenarios.

The use of radiographic guidance is recommended when possible, especially when using the supra-acetabular pin construct (Fig. 2a–e). However, scenarios in which this technique would be used will always be an emergent life-threatening situation. Patients will rarely be positioned optimally on the surgical table to allow for easy radiographic imaging to guide pin placement. In an unguided scenario, it is important to be mindful of anatomic landmarks, proper starting points, and trajectories to avoid any iatrogenic injury. Misguided pins may injure "at risk structures" as seen in Fig. 9a–d.

We present a simple and resource-friendly technique with the understanding that a variety of constructs could be used. Multiple compression bars may be used to provide compression to multiple sites of bleeding rather than a single location. In our case series we used a standard bar to bar clamp or a pin connector clamp for compression, however if a larger surface area were desired larger clamps or pin connectors could be used. Similarly, clamps can be modified with lap sponges or other agents to provide diffusion rather than pinpoint compression.

In our case series, using this technique, we have yet to encounter any specific complications; however, given the speed with which these frames are placed, there are several anticipated issues. Possible complications may be broadly characterized into general and technique dependent. Generally, increasing clamp size may lead to broader compressive area that potentially inadvertently compress nearby structures (ureter, large vessels, nerve roots, etc.). As with any internal device communicating with the external environment, there is a theoretical high risk of infection if the device is left in place for a prolonged duration. Using an AIIS technique, the following issues may be encountered;

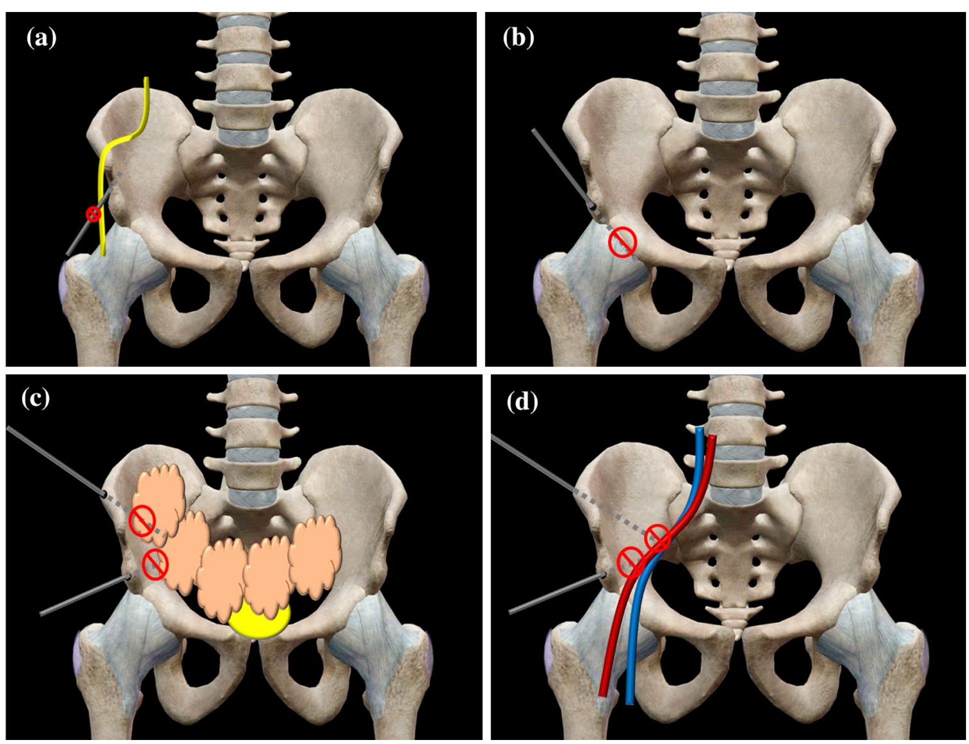


Fig. 9 Illustration "at risk structures." **a** Lateral and proximal starting point from AIIS puts the lateral femoral cutaneous nerve at risk. **b** Caudally guided AIIS pins can enter the hip joint proper. **c** Medially directed AIIS or iliac crest pins can injure abdominal viscera. **d** Medially directed AIIS or iliac crest pins can injure the iliac vessels

failure to direct pins proximally may put the native hip at risk for penetration; directing pins too medially during the AIIS could place the viscera or iliac vessels at risk. If the inner table is penetrated and there is failure to confirm secure placement of the pins, loosening of the construct may occur with patient transfer and potentially lead to a “floating clamp” in the abdomen. Complications that may arise from the iliac crest technique include iliac crest fracture and poor bone purchase, especially if the inner or outer table is violated. Additionally, as with the AIIS technique, the visceral structures are always at risk if a pin is placed too medially.

It should be noted that this is a novel technique to use in a specific group of highly traumatized patients, and therefore, it has not been heavily studied. Unfortunately, given the patient population, extensive randomized trials may be difficult or impossible to perform. Nonetheless, given the success in our short case series, we hope that this technique guide provides an additional tool for those managing these complex trauma patients.

This technique represents a rapid means of temporarily controlling life-threatening hemorrhage that cannot be controlled by other measures. The information in this guide can be used for the rapid placement of an EFVC.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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