Nonselective Arterial Embolization for Pelvic Fractures

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Introduction

Trauma is a leading cause of death in the young population [1]. Pelvic injuries and their associated hemorrhage pose a significant challenge for trauma surgeons. These fractures are present in up to 9.3% of patients with high-energy blunt trauma [2]. Due to the high energy mechanism, 90% of patients have associated injuries and 50% have other sources of hemorrhage [3]. The mortality rate in patients with any type of pelvic fracture is approximately 13.5–16% [2, 4]. This significantly rises to 32–60% in patients with pelvic fractures and hemodynamic instability [2, 5, 6] and although accounting for less than 10% of pelvic fractures presenting to level 1centers, they represent the bulk of the mortality in this group [7]. Pelvic fracture continues to carry the highest mortality rates of any skeletal injury with hemorrhage being the major reversible contribution to mortality [8] (Table 13.1).

Table 13.1 PICO table

Patients	Intervention	Comparator	Outcomes
Patients with pelvic fractures	Pelvic angioembolization	Selective vs. nonselective angioembolization	Complications, re-bleeds, death

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Arterial angioembolization (AAE) has been used more and more frequently to control pelvic-related bleeding since it was described in the literature in the 1970s by Margolies et al. [9]. AAE is shown to have a high success rate of 80–100% [10, 11] and is effective against arterial hemorrhage, which is the source of bleeding in about 15% of pelvic fracture associated hemorrhage but is uniformly present among life-threatening pelvic bleeders [7, 12]. AAE can be performed as a primary intervention or in secondarily stabilized patients with arterial contrast extravasation seen on CT.

Resuscitation, timely identification, and adequate treatment of pelvic hemorrhage and significant associated injuries are essential [13]. Unfortunately, the management algorithms in recent years have become so complex that they have limited use in practice with no gold standard guidelines or multicenter analysis established. Verbeek et al. [6] studied 11,109 major blunt trauma patients who were admitted to 11 Australian/New Zealand trauma centers between 2000 and 2003. Major pelvic fractures were seen in 1050 patients, of which 217 were hemodynamically unstable. Pelvic angiography was performed in 27% and showed an acute bleed in 74%.

All patients with suspected unstable pelvic fractures should be managed by a multidisciplinary team. Hemostatic resuscitation should begin early. Primary and secondary surveys follow the Advanced Trauma Life Support (ATLS) guidelines [14]. The main goals of initial management are to identify the pelvic fracture, achieve bleeding control, and to identify associated life-threatening extra-pelvic injuries. The hemodynamic response of that patient after initial resuscitative measures indicates the next step in management.

The interventions available for hemorrhage control in pelvic fractures are the application of a pelvic binder [15], surgical application of an external fixator [16], arterial angioembolization (AAE) [17], extraperitoneal pelvic packing [18], and retrograde endovascular balloon occlusion of the aorta [19].

Up to 76% of patients who have persistent hemodynamic instability despite resuscitation with blood products, pelvic compression, and exclusion of other sources of major bleeding will have arterial bleeding and should undergo angiography if immediately available [10, 20]. The recent Western Trauma Association update has outlined arterial angioembolization as the primary method of hemorrhagic control in patients resistant to fluid resuscitation and mechanical stabilization [21]. When time and logistics allow, CT is the gold standard in diagnosing arterial bleeding or looking for ongoing bleeding. If a blush is detected, the patient should be transported to the angiography suite.

Nonselective arterial embolization can be achieved in a timely fashion in either interventional radiology suites, in hybrid operating theaters, or REBOA technique in the resuscitation bay. Selective angioembolization requires skill, time, resources, and local protocols. In extrremis, for an unstable patient bleeding from a pelvic fracture, bilateral nonselective embolization of the internal iliac arteries could be considered.

This chapter will address the use of nonselective arterial embolization in the management of pelvic fractures and will review the anatomical considerations, technique, timing, patient selection, comparable outcomes between selective and nonselective embolization, complications, and clinical utility.

Results

Embolization is the deliberate blockage of a target vessel or territory to stop hemorrhage. A thorough knowledge of anatomy and its variants are essential before proceeding. Angiography for the control of hemorrhage has an important role in the treatment of pelvic fractures and is supported by the highest level of evidence. Pelvic angiography with embolization can be performed in a selective or nonselective manner, it can be performed bilaterally if needed and even repeated to control bleeding. Moore et al. [22] in 1987 performed surgical ligation of the internal iliac artery in four clinically unstable patients with blunt or penetrating trauma in which they successfully ceased pelvic bleeding, paving the way for the use of this technique to treat unstable patients.

Anatomic Considerations

Arterial bleeding has been reported in up to 10–15% of major pelvic fractures and it is uniformly present among hemodynamically unstable pelvic fractures. In this group, embolization saves lives and reduces the need for transfusions [12]. Although with hemostatic resuscitation the often-self-limited cancellous bone and venous bleeding are the most frequent sources of hemorrhage with pelvic fractures, arterial bleeding is the leading cause of life-threatening hemorrhagic shock in patients with pelvic trauma [23].

The landmark study by Huittinen et al. informed our early knowledge of patterns of bleeding in pelvic fracture. In 1973, Huittinen et al. [24] performed postmortem angiographies in 27 patients with pelvic fractures and found that extravasation results mostly from venous structures and fractured cancellous bone. They revealed only 11.1% of their patients exhibited arterial bleeding. Venous and cancellous bone bleeding was present in all pelvic fracture patients. The iliolumbar vein was noted to be disrupted in 60% of fractures; this pattern of venous hemorrhage is seen with fractures in the sacroiliac portion of the pelvis [25]. Venous pelvic bleeding does not however feature heavily in the literature. The proposed thought is venous bleeding occurs into the retroperitoneum, which is a closed space. Most bleeding occurs from small/medium veins that can stop naturally if the patients' cardiovascular function, blood volume, and coagulation profiles are kept within acceptable limits [3].

Anterior pelvic bleeding originates mainly from the internal pudendal (27%) and the obturator arteries (16%) [4]. Posterior bleeding occurs from the superior gluteal (25%) and the lateral sacral arteries (23%) [4]. Ligation of the internal iliac artery during laparotomy was previously used to control pelvic arterial hemorrhage. However, this method was proven ineffective because of the rich collateral blood supply to the pelvis [26].

Pelvic Ring

The pelvis is a ring structure made up of three bones: the sacrum and the two innominates. The ring is formed by the connection of the sacrum to the innominated bones at the sacroiliac joints at the back and the pubic symphysis in the front [27]. An important ligamentous complex also gives these joints strength and stability. The SI joints are the strongest in the body and resist both vertical and anterior-posterior displacement [28]. Anteriorly, the opposed bony surface of the pelvis is covered by hyaline cartilage and fibrous tissue. The pubic symphysis is the weakest link in the ring and supplies only 15% of the intrinsic pelvic stability. Significant disruption and displacement of one area of the pelvic ring is usually accompanied by a disruption in another and is usually the result of both bone and ligament disruption. It is well known that the volume of the pelvis increases with mechanically unstable pelvis fractures [29]. This increased volume is thought to decrease the tamponade effect of the retroperitoneal tissues and intrapelvic organs, leading to further bleeding. Baque et al. [25] demonstrated a 20% increase in pelvic volume with a 5-cm pubic diastasis using cadaver models. The absolute volume increase is still negligible in terms of blood loss even with the increase of 20%. In a closed pelvic ring, the venous bleeding from the low-pressure system cannot expand, but arterial bleeding can pose continued threat to life.

Pelvic Fracture Classification

The Tile fracture [30] and the Young–Burgess [31, 32] classifications are the two most common radiological classification systems used.

There is controversy about the clinical usefulness of both classification systems in determining the risk of significant bleeding and mortality [33, 34]. In the only study that compared the two, both classifications have similar predictive values for mortality, resuscitation fluid, and transfusion requirements [35]. Hussami et al. [33] found a significant correlation between the tile fracture type and arterial, but not venous bleeding. Agri et al. [13] found that significantly more patients with Tile C fractures underwent embolization for bleeding control. They also found Tile C fractures were associated with higher transfusion requirements and a higher mortality rate than Tile A or B fractures. Overall, published data shows only low to moderate interobserver reliability of both systems [36, 37].

Basing the decision to perform angiography on pelvic fracture type alone is not recommended. Force vectors and fracture patterns inconsistently predict those with arterial bleeding and the need for angiography. Exsanguinating hemorrhage can and does occur in all fracture patterns, even simple rami fractures in the elderly [11, 38, 39].

Use of Angioembolization

Contrast extravasation on a CT scan is highly predictive of active arterial bleeding with sensitivity and specificity values ranging between 66–90% and 85–98%, respectively [39, 40]. The exact hemorrhagic site can often be identified on CT which guides the time-critical AAE treatment by the interventional radiologist [41]. The absence of contrast extravasation on admission CT is an excellent screening test to exclude the presence of an active arterial hemorrhage and therefore the need for AAE, with negative predictive values over 98% [42]. An active bleeding site is identified as a high-density focus due to a leaking blush/jet of contrast seen on the arterial phase scan, with further pooling of the contrast on the Portal Venous scan. Any site of contrast extravasation or arterial injury should be embolized. While extravasation on CT indicates arterial injury, studies have shown that nearly half of the patients with contrast extravasation on CT did not require embolization as active bleeding was not identified on interventional radiography [43]. The discrepancy between CT and angiographic findings is thought to be due to vessel spasm, which may be secondary to local inflammatory responses generated by bleeding [44]. Therefore, it is imperative to consider proceeding to angiography and embolization urgently following a trauma scan if the clinical suspicion remains high.

The real prognostic question is if the patient can make it to a CT scan at all before embolization. Historically, a CT scan before AAE was not recommended due to the urgency of hemorrhage control in a critically bleeding patient. More recently, most resuscitation bays have rapid CT scans immediately adjacent and trauma patients are less likely to present in severe coagulopathy due to overzealous crystalloid resuscitation. These advances made it possible to have a new group of patients with CT scan before angiography and a selected smaller group of patients who are critical and still needs AAE immediately [45] (Fig. 13.1).

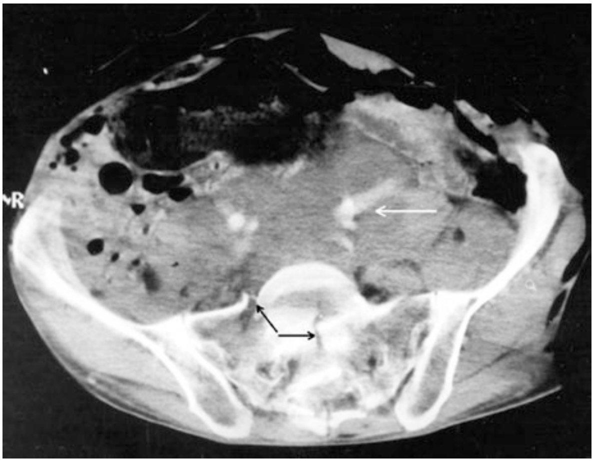

Fig. 13.1 Contrast-enhanced helical computed tomography of the pelvic region shows comminuted sacral fractures (black arrows) and contrast extravasation around the left iliac vessels (white arrow) surrounded by a large pelvic hematoma. Additional findings included pneumoretroperitoneum and subcutaneous emphysema secondary to bilateral pneumothorax

The use of angiography depends on several factors, including the patients' clinical scenario, vital signs and continued need for resuscitation, angiographer availability, and physician experience [46]. Lai et al. [47] identified three independent predictors of active arterial hemorrhage that can assist in patient selection for embolization. These predictors include contrast extravasation seen on CT (OR 74.6, $p < 0.001$), patients requiring more than 8 units of packed red blood cells (PRBC) (PR 12.5, $p = 0.018$), and injury severity score (ISS) ≥ 16 (OR 11.1, $p = 0.029$). Eastridge et al. [7] reported that 27 of 46 patients with both persistent hypotension and a severely unstable pelvic fracture indicate arterial bleeding. Using the patient's hemodynamic status and response to resuscitation in addition to the results of contrast-enhanced CT is helpful in predicting the need for angiography. Pelvic hematoma size can also inform patient selection for embolization. Blackmore et al. [48] found that hematomas >500 cm^3 had a significantly increased risk ratio of 4.8 for arterial injury at angiography. In the setting of major pelvic fracture, age >60 regardless of hemodynamic status is highly associated with the need for embolization (OR 15) [49]. The problem with many of these prediction models is that they include information that is not available at the time of the decision-making at the resuscitation bay (ISS score, 24-h transfusion rate, and size of pelvic hematoma). Toth et al. [50] prospectively utilized only the variables, which were available within 30 min of the arrival of the patient. The prediction model showed that patients who definitively required AAE had pelvic ring injury, negative FAST, metabolic acidosis with base deficit worse than −6, and no extra-pelvic sources of bleeding. It is hypothesized that the higher levels of bleeding in the elderly are due to atherosclerotic vessels and loose periosteum which leads to ineffective physiological hemostasis [47].

Arterial Angioembolization Technique

Most treatment algorithms undergo a dual-phase CTA (computed tomography angiogram) scan as first-line imaging in adults with suspected high energy pelvic fractures. The routine initial phase is taken at 20 s post contrast medium to obtain an arterial phase, followed by a 70-s portal venous phase [41]. Multiphase CT scans might not be feasible for critically ill trauma patients. These patients will usually undergo a single-phase contrast-enhanced CT with portal venous phase imaging after a 70-s delay from initiation of contrast medium.

The angiography suite should be prepared as a mini-intensive care setting [51]. The equipment required for the angiography include fluoroscopy, power injectors, vascular access sheaths, guidewires, catheters, and intravenous access.

Regarding the angiography procedure itself, most authors describe a standard approach via the common femoral artery (CFA). Under local anesthetic, the CFA is punctured with a micro-puncture needle set or a 4 or 5 French sheath which is introduced at the level of the midpoint of the femoral head to access the arterial tree. In some patients, access to the femoral artery can be difficult due to obesity, hematoma, hypotension, or degloving injuries [20]. An aortogram is then performed to delineate the anatomy. Then guided by the CT findings, a direct catheterization of the suspected internal iliac is performed. Contrast is then infiltrated to identify the bleeding point, noted by contrast blush or extravasation. Digital subtraction angiography (DSA) is used to guide the operator along with the arterial map. Most modern angiography units use pulsed fluoroscopy where radiation is produced in a pulsating fashion instead of a continuous beam. The primary advantage of pulsed fluoroscopy is the significant reduction in radiation dose [27]. Standard catheters are used however, if the bleeding point is not evident, further selective micro-catheterization and angiogram of the pelvic arterial branches on the affected side may be necessary. Once this is evident, the bleeding artery is embolized using embolic materials.

Various embolic agents are available, they can be broadly divided into temporary or permanent. They are then further divided into mechanical occlusions, particulate agents, and liquid agents. Gelfoam and coils seem to be the most commonly used materials either as a single agent or in combination. Gelfoam is a biodegradable gelatine sponge, which can be cut to size and mixed with contrast and normal saline prior to delivery. It remains the most popular choice as it is temporary lasting 7–21 days, relatively easy to use, quick, economical, and has relative independence from coagulation [52, 53]. Scatter embolization of multiple distal smaller branches can be achieved with gel foam suspension mixed with contrast providing temporary occlusion. Gel foam/contrast mix is injected under direct visualization until flow in the vessel ceases or is markedly diminished.

Coils should be used for nonselective embolization of main arteries and larger branches. They allow for very precise positioning. Metallic coils come in various sizes and are coated with thrombogenic material (fibrogenic fibers) or are uncovered. They work by damage to the intima and provide a large thrombogenic surface and mechanical obstruction of the lumen. They allow rapid mechanical occlusion of the vessel as they are injected through the microcatheter. Several coils are usually required to conform into an occlusive coil ball which creates a scaffold for thrombosis [54]. The downsides to this technique are that extensive coil usage precludes distal access in cases of rebleed and that their efficacy depends on the patient's coagulation as clot needs to be formed in the coils before hemostasis is achieved. Thus, in the presence of coagulopathy which is common in trauma patients, a combination of coil placement followed by injection of gel foam can be very useful. Liquid agents such as glue or Onyx may be considered for very distal vessels and can be used in the cases of re-bleeding.

After vessel embolization, the potential collateral vessels should be evaluated to identify additional supply. Completion angiography should be undertaken to document the cessation of bleeding.

Timing of Arterial Angioembolization

Delay to embolization is associated with significant increases in mortality. Tanizaki et al. [55] found mortality rates of 16% with embolization within 60 min compared to 64% when delayed. Additionally, Balogh et al. [56] described their protocol of pelvic angiography within 90 min of admission improved mortality. Hemodynamically unstable patients had a median time interval from ED arrival to AAE that was 10 min shorter for survivors than nonsurvivors, but not statistically significant due to the smaller sample size. Agolini et al. [10] reported a mortality increase from 36 to 75% if embolization was delayed beyond 3 h of admission. Evers et al. [26] reported a high mortality rate, relating to its long mean time to embolization (>4 h) which can lead to a prolonged flow state, multisystem organ failure, and sepsis. In a multicenter Australian Study delay to angiography when used as the primary treatment modality was common, only 15% of embolization occurred within 90 min of arrival [6]. Time intervals from ED arrival to AAE found in the literature vary, with a median time of 280 min in one recent study from a high-volume trauma center [57]. The availability in different centers to IR plays a crucial role, especially after hours. Angiography and embolization itself can be time-consuming. The overall time for performing embolization has been reported from 50 min to 5.5 h [10, 20].

More recently, some institutions started to promote preperitoneal packing (PPP) again due to no timely access to AAE and consistently reporting that around 15% of the PPP patients still need AAE later [58, 59]. We believe these are the patients who would need timely AAE in the first place. Generally, AAE as a lifesaving hemorrhage control measure should be performed with the same urgency as trauma laparotomy or thoracotomy to stop bleeding.

A recent prospective analysis from a high-volume level 1 trauma center analyzed all pelvic fractures over a 10-year period between 2009 and 2018 [45]. They found that over this time period, the time to AAE did not improve even though mortality rates remained low (14%, of which none were related to exsanguination). Overall, timely embolization is critical and reduces mortality. The patient should have immediate treatment as per the local guidelines and protocols, such as Resuscitative Endovascular Balloon Occlusion of the aorta (REBOA) in the emergency department, embolization in the interventional radiology department or be taken to a hybrid operating room.

Selective Versus Nonselective Angioembolization Indications

Angiography for pelvic fractures allows for both selective embolizations of bleeding arteries and nonselective embolization of bilateral internal iliac arteries.

A critically bleeding, non-responding unstable patient with a pelvic fracture is a typical indication for nonselective embolization of both internal iliac arteries. The indication for nonselective embolization is usually an angiogram showing multiple bleeding arteries, or a high suspicion of multiple vessel injury in a patient with substantial hemodynamic instability. Occasionally, when there are multiple distal bleeding sites, the operator may choose to perform proximal or nonselective embolization using temporary embolic materials to save valuable time in hemodynamically unstable patients [41]. Nonselective bilateral embolization of the entire Internal iliac system should be a last resort for severe bleeding. Clinical instability or worsening in the angiography suite may also influence nonselective angiography. Due to the generous collateral pathways and anastomoses between each artery and cross circulation to the other side, bilateral embolization at their common trunk is required in order to stop truly significant bleeding [51, 59, 60].

In most clinical situations, operators may attempt more selective embolization. This is often in hemodynamically stable patients or patients who have responded to initial fluid resuscitation. Selective embolization is used when an active source of bleeding is identified. The most commonly reported vessels for selective embolization in decreasing order are the internal iliac artery (67.2%), unnamed branches of the internal iliac (17%), the superior gluteal artery (4.4%), the obturator artery (4.1%), and the internal pudendal artery (3.2%) [61]. Super-selective embolization, which often requires the use of 2–3 Fr micro-catheters through a coaxial system is technically more difficult and therefore time-consuming and has a higher incidence of pelvic arterial hemorrhage [62]. Fang et al. [62] demonstrated that recurrent pelvic bleeding also seems to be more common after selective embolization than after nonselective embolization, suggesting this practice should be limited.

Complications

The etiology of complications after angioembolization is a mixed scenario involving both the direct effects of embolization and the results of the often-substantial initial trauma [63]. Although AAE is considered to be a safe procedure that can stem uncontrolled bleeding, there are reports of complications in the literature [51]. The rates vary substantially from 0 to 63% [61].

Puncture site hematoma due to poor closure may lead to the pseudo-aneurysm formation or groin hematoma, femoral artery thrombosis, or subintimal dissection [51, 52]. Cases of gluteal necrosis associated with embolization seem to be related to primary trauma along with protracted hypotension rather than a direct complication of AAE [64]. Other complications such as bladder, femoral head, distal colon, and ureter and skin necrosis have been described [59, 65]. Travis et al. [66] described paresis, impotence, and surgical wound compromise. Ramirez et al. [67], however, examined sexual dysfunction in males undergoing bilateral internal iliac embolization and found no difference compared with case-matched pelvic fracture patients not undergoing embolization, suggesting that when it does occur, it may be due to the injury.

Travis et al. [66] also compared complications between selective and nonselective AAE and found no statistical difference in complications, this finding is also corroborated by the multicenter study by Hymel et al. [63]. The nonselective embolization group, however, had a significantly increased rate of thromboembolic complications (12.1 vs. 0%). The lack of discrepancy in complications between both groups is likely due to the rich collateral arterial supply within the pelvis.

Radiation exposure is an important consideration, the dose in a single pelvic embolization procedure is reported to be as much as 3Gy [68]. The incidence of allergic reaction to contrast materials range from 3 to 13% [69]. Furthermore, unnecessary use of contrast should be avoided, as trauma patients are prone to developing contrast-induced nephropathy [70].

Pelvic re-bleeding can occur following initial angiography and embolization, re-bleeding may occur up to a rate of 9.7% [40]. Authors have [62, 71] identified hypotension, pre-procedural hemoglobin of <7.5 mg/dl, pubic symphysis disruption, absence of concomitant intra-abdominal visceral injury, a transfusion rate >2 U of blood per hour, and the presence of two or more pelvic arterial injuries on initial angiogram as statistically significant predictors of recurrent arterial hemorrhage. Alternatively, post initial angioembolization, rebleed has been linked with dislodgement of the embolization material, post-procedural transfusion requirement of >6 units PRBC, continued hemodynamic instability, super-selective embolization, and a persistent base deficit [28, 62, 71]. No-selective AAE should be used in the treatment of a rebleed.

Overall, the high success rates and potentially lifesaving effect of emergent non-selective embolization outweigh the marginal and uncertain risks of complications of the procedure.

Recommendations Based Upon the Data

Pelvic hemorrhage from fractures after blunt trauma has a high mortality and continues to represent the most frequent source of preventable death following blunt trauma. Even in the face of improved diagnostic and therapeutic techniques, the mortality rate for this population remains high. There are three major sources of bleeding from pelvic fractures. The management of each of these bleeding sites would ideally be specific. Critically bleeding patients with properly bound pelvis not responding to hemostatic resuscitation have arterial bleeders. Treatment options include pre-hospital or early pelvic binding, fracture stabilization with external fixation, intraoperative peritoneal packing, and angiographic embolization.

The patient's clinical condition is the most important consideration in deciding between surgical versus endovascular intervention. Rapid diagnosis of potential trauma hemorrhage via radiography and FAST is critical in the early assessment of hemodynamically unstable patients. CT has now become the standard investigation to identify solid organ, mesenteric, pelvic, and retroperitoneal bleeding [27]. Toth et al. [50] prospectively utilized only the variables, which were available within 30 min of the arrival of the patient. The prospective prediction model showed that patients who definitively required AAE had pelvic ring injury, negative FAST, metabolic acidosis with base deficit worse than −6, and no extra-pelvic sources of bleeding. Prospectively, predictors of arterial injury requiring embolization include age >60, contrast extravasation on CT, patients requiring more than 8 units of PRBC, ISS >16, pelvic hematoma size >500 cm^3, and hemodynamic instability not responsive to resuscitative measures in the absence of other bleeding sources.

It is clear that successful management is best accomplished by a multidisciplinary team approach involving a variety of specialities. The best outcomes can be expected from a high-volume trauma center that can practice advanced algorithms 24 h per day, 7 days a week, and collect this data for systematic review. Although all trauma centers have interventional radiology available, the considerable variation in the management of this high-risk cohort may be due to differences in institutional systems to provide timely angioembolization and access to orthopedic surgery.

Arterial angioembolization remains a principal choice of treatment for pelvic fractures-related arterial hemorrhage combined with mechanical stabilization of the pelvis. Pelvic angiography can specifically identify the source of bleeding and effectively stop arterial hemorrhage with various embolic agents. However, patients must be carefully selected for embolization. Timely AAE has also been shown to be critical to the outcome and reduction of mortality. Nonselective embolization is considered time-saving, safe, and effective with minimal morbidity [41, 72].

Summary of the Data

- Unfortunately, the management algorithms in recent years have become so complex that they have limited use in practice with no gold standard guidelines or multicenter analysis established (evidence quality moderate; weak recommendation).
- In most clinical situations, operators may attempt more selective embolization. This is often in hemodynamically stable patients or patients who have responded to initial fluid resuscitation (evidence quality moderate; moderate recommendation).
- The best outcomes can be expected from a high-volume trauma center that can practice advanced algorithms 24 h per day, 7 days a week, and collect this data for systematic review (evidence quality moderate; strong recommendation).

Personal View of the Data

The future of trauma care should have diagnostic, operative, and interventional radiological capabilities in one setting. This could be achieved with the addition of a CT angiography system in close proximity to the resuscitation area ameliorating access barriers for timely angiography and embolization.

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