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REVIEW

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Interventional radiology in trauma: current role and prospects

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Abstract

Trauma is a major cause of death worldwide. Interventional radiology provides a set of minimally invasive and effective options that are being integrated as part of the multidisciplinary care plan offered to the trauma patient. However, there are still a lot of areas of development that need to be explored. This article reviews the current role of endovascular interventions in trauma setting, the latest efforts to find the optimum ways to use them and highlights areas of knowledge and gaps in the literature.

Keywords Trauma, Interventional radiology, Emergency medicine, Transcatheter arterial embolization

Background

Trauma is the leading cause of mortality for people younger than 45 and is responsible for 10% of deaths globally per year. Uncontrollable hemorrhage is the major cause of preventable death in trauma setting [1]. The role of interventional radiology (IR) in management of bleeding in trauma patients has expanded in the last few decades, with endovascular intervention being a standard of care in managing hemodynamically stable individuals enhancing survival rates, lessening morbidity and minimizing surgical blood loss. Its efficacy has been proved across various anatomical regions such as the liver, spleen, kidneys and pelvis [2]. A shift is happening to extend its role in managing the hemodynamically unstable as well, especially in the setting of difficult surgical areas like pelvic trauma or for the sake of organ salvage [3].

Although the increasing expertise and availability of resources has aided this shift, it is also limited by lack of sufficient evidence and well-tested protocols to be reproduced universally. A literature search was conducted to review the latest efforts to improve the quality of care offered by IR in trauma and to highlight the areas of commonalities and gaps in the literature. The article first offers a brief overview of the spectrum of radiological interventions in trauma management, including an explanation for the technique of transarterial embolization, its merits and limitations. Then summarizes the recommendations issued by the Society of Interventional Radiology. It follows by a review of various efforts to deliver better IR services in trauma settings, illustrating the importance of proper time management and application of efficient protocols, and explores the value of novel introductions such as a combined surgical and angiographic operating room.

Role of IR in trauma

Interventional methods utilized for addressing injuries encompass procedures such as employing coils and occlusion agents for embolization, installing covered stents and temporary balloon occlusion. These options have been proved most successful in managing pelvic trauma, often making IR the modality of choice for arterial injuries. Especially that surgery has many drawbacks including difficult access, the release of the tamponade effect of the hematoma and the rich vasculature and anastomotic network makes ligating the internal iliac artery ineffective [4].

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IR has also been proved very effective in controlling hemorrhage from injured solid organs. Its role in splenic injuries is well established, and several studies showed that transarterial embolization (TAE) for hemodynamically stable patients with the American Association for the Surgery of Trauma (AAST) grade III/IV reduces failure of non-operative management and improves splenic salvage [2, 5]. With splenic embolization, there is a low risk of certain complications like recurrent hemorrhage, splenic abscess, coil migration or symptomatic infarct necessitating splenectomy [6]. Renal injuries have also benefited from angiographic interventions, in particular grade III/IV lesions in absence of hemodynamic instability or urine leakage when other abdominal injuries did not necessitate a laparotomy [2]. This is supported by studies with limited number of patients, but one prospective study documented the avoidance of nephrectomy in 90% of the cases [7]. Another study showed lower rate of acute kidney injury with TAE in comparison with nephrectomy [8]. Historically the role if IR in traumatic liver injuries has been questioned given that the major source of bleeding is usually venous [9, 10] and that high-grade injuries are usually associated with biliary and/or portal injuries that are better evaluated operatively [2]. However, a recent systematic review that studied the efficacy of TAE as primary treatment for grade III/IV injuries showed promising results [11]. In 24 studies reviewed, 659 patients underwent TAE and 3855 were treated non-operatively, the indication for TAE was contrast blush visualization on computed tomography (CT). The arterial embolization success rate ranged from 80 to 97%. Rate of complications was acceptable and included bile leakage, abscesses, bilomas and hepatic ischemia. Currently there is no established role of IR in bowel injury which essentially undergoes surgical repair, meanwhile isolated mesenteric vascular injuries may be managed endovascularly. However, this comes with a possibility of bowel ischemia or infarction, due to high risk of non-selective or non-target embolization, especially with more distal arterial branches that have a small caliber or angulated course. But with the continuous improvement in embolization technologies, it is expected to witness better results soon [12].

Endovascular management of aortic injuries has been gaining more preference due to evidence of lesser complication and length of stay [13]; however, limited evidence recommend the use of endovascular approach over open repair. Endovascular techniques have also been utilized with arteries supplying extremities, particularly subclavian-axillary and iliac. Lower morbidity and mortality have been reported [14] as well as often avoiding difficult surgical approaches (e.g., sternotomy). Thrombectomy could be used in occluded arteries, and stents could be deployed in pseudoaneurysms [15]. Kumari et al. reviewed the role in IR in venous injuries [16]. Higgins et al. also reported the use of IR in different cases of non-aortic thoracic injuries [17].

CT angiography (CTA) shows high diagnostic accuracy and is an excellent diagnostic tool for detection and localizing of intestinal bleeding sites. It is highly available, provides fast detection and localization of the bleeding site and is minimally invasive. Rarely, an initial CTA could miss an active hemorrhage, especially with lower rates. A meta-analysis by García-Blázquez et al. looked into the accuracy of CTA in detecting gastrointestinal bleeding and found that sensitivities and specificities vary widely between individual studies, ranging between 33.3% and 100% and 0% and 100% for sensitivity and specificity, respectively. The overall sensitivity of CT angiography for detecting active acute gastrointestinal hemorrhage was 85.2% (95% CI 75.5% to 91.5%). The overall specificity of CT angiography was 92.1% (95% CI 76.7% to 97.7%) [18]. In case of a negative CTA, a clinical decision needs to be made, whether to proceed to perform a digital subtraction angiography or wait, follow-up the patient and repeat the CTA if needed.

IR also offers a wide range of non-vascular solutions, of which, drainage procedures are useful in certain situations in trauma setting. For example, nephrostomy tubes and ureteral stents could be used in cases of ureteric injury or urinary leakage [19]. Posttraumatic urinomas, once an indication for surgery and possible nephrectomy, can also be treated radiologically with direct percutaneous drainage [20]. Percutaneous drainage under image guidance is also commonly used to evacuate hematoma and fluid collections following trauma. Martinez-Ramos et al. reported a case of traumatic pancreatic rupture and a symptomatic pseudocyst that measured 10 cm on a CT [21]. The decision was made to drain it percutaneously through the stomach, the collection continued to drain for 20 days and the patient's condition improved, with no recurrence of the pseudocyst on follow-up. Likewise, biliary drainage could be indicated in hepatic injuries and the percutaneous approach proves to be effective and safe [22].

Technique for embolization

As defined by the Society of Interventional Radiology (SIR), therapeutic embolization is the intentional endovascular occlusion of an artery or vein [23]. The choice between selective and non-selective embolization techniques relies on factors such as the location and size of the damaged blood vessel. For instance, when dealing with bleeding from an end artery, which can occur in organs like the liver, kidney or spleen, it may be

necessary to sacrifice the artery through embolization, either temporarily or permanently, which is acceptable. Microcatheters are usually needed when super-selective embolization of the peripheral most terminal branch is desired. At sites with rich anastomotic networks, such as the pelvis, the aim is to occlude small caliber arteries while preserving distal anastomoses. These arteries could be occluded using both gel foam distally and coils more proximally. If for example catheterization distal to a site of injury (e.g., pseudoaneurysm) is achieved, a series of coils could be deployed from distal to proximal, avoiding the possibility of retrograde blood flow that could result in failure of the procedure. In large caliber arteries like aorta or iliac artery, covered stent grafts are used, whereas bleeding from small vessels is managed by material embolization. Most embolic materials used depend on an intact coagulation cascade in their mechanism of action; therefore, early management is before coagulopathy sets in is desirable, and in case of coagulopathy, the choice of agent should be considered accordingly [24].

The procedure is started by gaining an arterial access usually via common femoral artery and a vascular sheath is placed (6F for adults and 5F for children). In cases of severe hemodynamic shock, it is possible that the femoral pulses may not be palpable. In such instances, ultrasound guidance can be employed to locate the artery. If pre-procedural imaging findings are known, then angiography should be targeted immediately to the site of injury to achieve hemostasis (Fig. 1). However, if imaging was not done or was not conclusive an extensive diagnostic angiography should be performed to detect site of vascular injury. Angiographic signs of vascular injury include contrast extravasation, arterial occlusion, arteriovenous fistula, pseudoaneurysm and diffuse abnormal blush. It is mandatory to perform multiple angiographic views as well as super-selective catheterization, to reduce the chance of missing significant findings [6]. Sometimes angiography may be negative due to intermittent vasospasm, spontaneous occlusion, non-arterial bleeder, failure to achieve super-selective catheterization or if a variant arterial anatomy is present [25]. There are certain considerations and specific techniques used for each organ or target artery; however, more detailed discussions, of which, are beyond the scope of this article.

Embolizing agents

Embolic agents could be generally classified according to the duration of their effect into temporary agents such as gel foam and autologous blood clots and permanent ones which include particles (e.g., polyvinyl alcohol and Embospheres), liquids (e.g., Glue [N-butyl

cyanoacrylate], ethylene vinyl alcohol copolymer [Onyx] and alcohol) and mechanical devices (Coils and Plugs) [23]. Each comes with its own properties, uses and limitations depending on its mechanism of action. Choosing the correct embolic for the case depends on a lot of factors, including patient characteristics, type and site of injury, cost and technical expertise of the interventional radiologist. These agents are continuously researched and developed, enabling practitioners a broader range of options to choose from, with newer agents introduced to the market each year.

Whether the target artery was super-selectively catheterized or not, will also determine the choice of embolic used. If not, a proximal embolization could be performed by large coils or Amplatzer vascular plugs, to decrease the perfusion pressure to the bleeding organ. In distal embolization, smaller vessels could be blocked by gel foam or particles. If they were able to super-selectively reach the target artery, coils are the

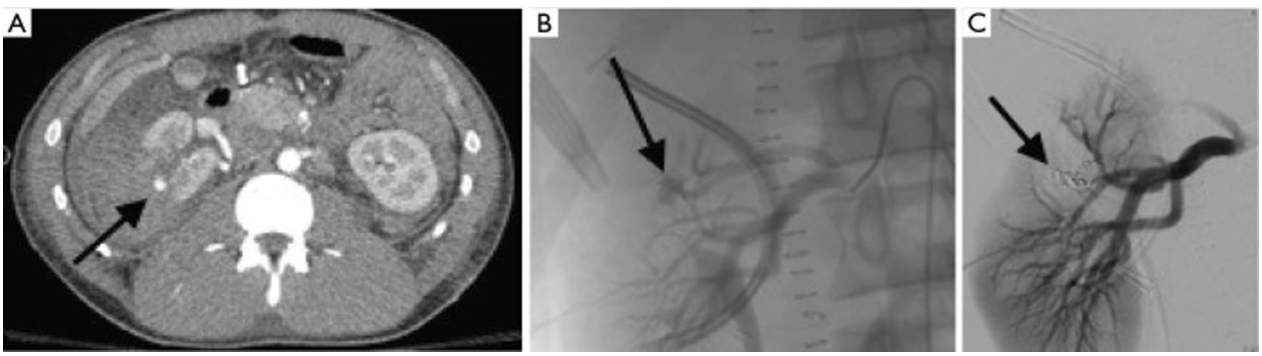


Fig. 1 Transarterial renal artery coil embolization. A 55-year-old male in a motor vehicle collision. Routine trauma scan demonstrated active extravasation of contrast from the right kidney (black arrow), consistent with renal artery injury (**A**). The patient was taken to angiography, which demonstrated active extravasation of contrast (black arrow) from an interlobar artery (**B**). Selective coil embolization was performed (black arrow) and final angiogram demonstrated cessation of contrast extravasation (**C**). (Reprinted with permission Smith TA, Eastaway A, Hartt D, Quencer KB. Endovascular embolization in renal trauma: a narrative review. Ann Transl Med. 2021;9(14):1198. https://doi.org/10.21037/atm-20-4310)

agents of choice followed by glue. Coils and gel foam depend on the coagulation cascade to perform their action, so if coagulopathy is suspected, liquid agents are preferred, as their mechanism of action is independent of the coagulation. Recently a lot of developers have been producing coils that work independently of coagulation; however, they come at a very high price, which might not be affordable in a lot of settings.

Limitations and complications

TAE is a relatively safe procedure with a high technical success rate; however, some complications and limitations have been reported. Some are inherent to the agents used and site of bleeding while others could be encountered with all procedures. These include inability to reach target vessel endovascularly, failure to control bleeding, rebleeding, non-target embolization and sepsis [26]. One of the most common complications reported is postembolization syndrome (PES), which manifests as a constellation of symptoms including pain, fever, fatigue, nausea and vomiting, starting within 72 h of the procedure and may last for 7–14 days. PES may be attributable to tissue infarction and necrosis, subsequent release of breakdown products, inflammatory mediators and vasoactive substances from the embolized tissue. PES should be differentiated from sepsis, as it is usually self-limiting and could be managed or prevented by supportive measures using analgesics, anti-emetics and anti-pyrectics [26, 27].

One of the demerits of particle embolization is its tendency to clump and aggregate at the catheter site leading to proximal embolization, catheter block, a high rate of non-targeted embolization due to small size and tissue necrosis. While that of liquids include the difficulty of its controlled delivery at target site and a high possibility of non-target embolization. With gel foam, there is a risk of rebleeding following clot dissolution after 3 weeks. Coils are less effective with coagulopathy and have limited utility when target artery could not be selected, as they come with a risk of coil migration to a more distal artery [6].

Society of interventional radiology recommendations

The Society of Interventional Radiology (SIR) [2] issued a position statement in 2020, based upon a comprehensive literature review conducted by a multidisciplinary group of experts in trauma management. Accordingly, they determined their recommendations for overall direction of IR in trauma setting as well as specific organ system management. Most notable of which was the necessity of a 24 h access to an IR suite as well as the importance of available anesthesia support, which should be ready to administer blood products, perform rapid perfusions and actively resuscitate patients in the IR suite. After discussions with the American College of Surgery Committee on Trauma (ACSOT), they agreed upon a cutoff time of 60 min for the interventional team to be ready to intervene in case a decision was made to proceed with angiography. Which allows for consideration of other therapeutic or diagnostic procedures needed without delaying care. This cutoff time is more relaxed than the 30 min previously set by the ACSOT as the ideal of care [28].

The statement also adds that the interventionalist should have sufficient experience operating with small-vessel embolization, and that small-vessel and large-vessel interventions require distinct skill sets and training. It also recommends development of multidisciplinary treatment algorithms specific for each institution, based upon evidence-based guidelines and available resources at the facilities. As per the SIR grading system, most of the literature regarding trauma management falls under level evidence D, and that strong recommendations were only made in the case when their benefits outweighed their risks.

The SIR also released a position statement in 2024 dedicated to trauma management in the pediatric population [29]. In the article they reviewed and gathered evidence supporting endovascular management in pediatrics, as well as, highlighting the special considerations needed for this age group. For example, they emphasized using clinical criteria instead of mechanism of injury to determine the need for CT in children to limit the use of CT and unnecessary radiation exposure. These criteria included the following history and physical exam findings: Glasgow coma scale of 3–13, evidence of abdominal wall trauma or seatbelt sign, complaint of abdominal pain, abdominal wall tenderness on exam, evidence of thoracic wall trauma, decreased breath sounds and vomiting and the following laboratory markers: serum aspartate aminotransferase > 200u/l, serum alanine aminotransferase > 125 u/l, hematocrit < 30%, urinalysis with greater than 5 red blood cells per high-powered field.

Optimizing IR workflow in trauma

Time to embolization was proved to be a major determinant of decreased mortality in exsanguinating patients [28, 30–33]. Various trauma centers and IR teams studied different ways to optimize a workflow that decreases response time. Matsumoto et al. proposed a rigorous time-conscious protocol for prompt evaluation and embolization in severely exsanguinating trauma patients, tailored according to a damage control interventional radiology (DCIR) algorithm. In which the IR team is alerted before the patient arrives to the

hospital, a femoral sheath is applied during the primary survey, a CT is done in less than 10 min or skipped altogether, a focused assessment of the CT scan is done in 3 min to evaluate for bleeding and patient is transferred rapidly to the Angio suite [34]. This method is intended for stopping bleeding and saving life in hemodynamically unstable patients, often requiring non-selective embolization to stabilize the patient, checkpoints are used every 5 min to evaluate each maneuver and a maneuver could be stopped and replaced with another, if it proved to be time consuming or unsuccessful.

A retrospective study explored the effect of the participation of an IR team in the primary survey, evaluating the imaging and performing IR procedures [35]. The surgical team and IR team were alerted when the hospital was notified that a patient is arriving in shock after trauma or sustained a fall from height over 10m (Fig. 2). They enrolled 160 patients with abbreviated injury score of 3 or above for torso injuries and underwent TAE as the initial hemostatic treatment. 125 were hemodynamically stable (HS) and 35 were hemodynamically unstable (US), the results showed significant increase in observational survival rate compared to the predicted (4.9% in HS and 24.6% in HU) and the median time to start procedures was 54 min in HU and 86 in HS. In this study, they adopted a workflow that fostered a collaborative effort between the IR and surgical teams, to decide on a treatment plan and resuscitate the patient. IR procedures were performed under standby surgeons, which enabled a safe and rapid switch to surgery if needed. Also, it hypothesized that letting radiologists review the imaging could reduce misdiagnosis by ER physicians [36].

This study also demonstrated the role of IR in managing hemodynamically unstable patients with abdominal injuries. A question that has only been reported in few studies. The largest of which was a retrospective study in 2012 by Bize et al. that reviewed 36 patients in hemodynamically unstable condition treated with TAE for retroperitoneal bleeding associated with at least one additional source of bleeding [37]. 35 (9%) of which had technically successful embolization and 29 (80.5%) had immediate and sustained hemodynamic improvement for more than 24h. Otsuka et al. also studied 16 patients with severe trauma and systolic blood pressure < 90 mmHg that did not improve after initial resuscitation and endovascular treatment was their first intervention [38]. The results demonstrated significant improvement in systolic blood pressure, pulse rate, base excess/deficit, serum-lactate levels and D-dimer values after IR treatment.

Some studies tested the value of a predetermined activation protocol for IR trauma services. Charissa et al. studied 110 patients who underwent angiography and embolization in a level 1 trauma center, before and after the implementation of a quality improvement (QI) project [39]. Before, the IR team was activated in one

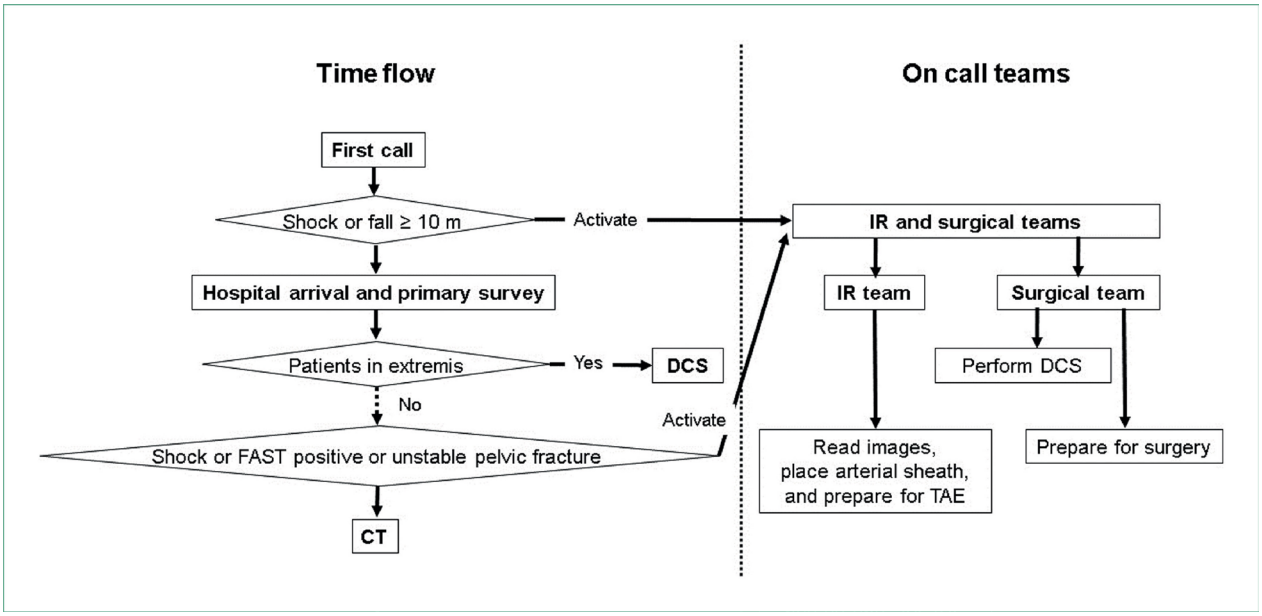


Fig. 2 Process of initial trauma management. IR = Interventional radiology; DCS = Damage control surgery; FAST = Focused assessment with sonography for trauma; CT = Computed tomography; TAE = Transcatheter arterial embolization. (Reprinted with permission: Okada I, Hifumi T, Yoneyama H, et al. The effect of participation of interventional radiology team in a primary trauma survey on patient outcome. *Diagn Interv Imaging*. 2022;103(4):209–215. https://doi.org/10.1016/j.diii.2021.11.002)

of two ways; in emergent cases, the IR physician would receive a direct call from the trauma physician and the trauma resident would page the IR resident, who would then get the IR team ready. In urgent cases, the trauma resident would page the IR resident, who will review the case and imaging, discuss it with the IR attending, and in case they decided to intervene, the IR team would be paged to proceed to the hospital. After the QI project, a group activation page is initiated to the entire IR and anesthesia teams without triage for 3 predetermined indications: 1. patients requiring resuscitative endovascular balloon occlusion of the aorta (REBOA) and not going to the operating room, 2. presence of active extravasation on CT or hemodynamic instability requiring transfusion of blood products, 3. patients with refractory bleeding despite packing in the OR. Time was calculated between the initial page and the arrival of all team members. It was significantly reduced in the second group; median time was 183 min before the QI protocol and 72 min after.

O'Connell et al. analyzed the time to embolization for pelvic trauma patients at their trauma center. A multidisciplinary team was trained on protocols to rapidly mobilize patients for IR in case it was indicated and demonstrated 86 min as median time to start angiography [31] (Fig. 3). It also recommends bypassing CT scan in patients who show pelvic fractures on plain radiographs and are hemodynamically unstable with no intraabdominal bleeding on screening. A group in Houston also showed that CT scanning might delay time to IR by a median of 87 min in daytime hours and 173 min during afterhours and weekends [40]. Which should prompt every institution to specify instances when CT is deferred and to find methods to mitigate the delay.

Another 10-year retrospective study in a level 1 trauma center in Taiwan, compared survival in patients who sustained unstable pelvic ring fractures with injury severity score ≥ 5, before and after implementation of a multidisciplinary protocol that dealt with pelvic fractures [41]. The result showed a decrease in annual mortality from 7.8% to 2.8%. Indications for endovascular interventions were specific, and the average time to transarterial embolization was 62.0 ± 33.4 min. Black S et al. also demonstrated similar results in an analysis of data of 1682 pelvic trauma patients from 2000 to 2013 after introducing of an institutional pelvic trauma protocol [42].

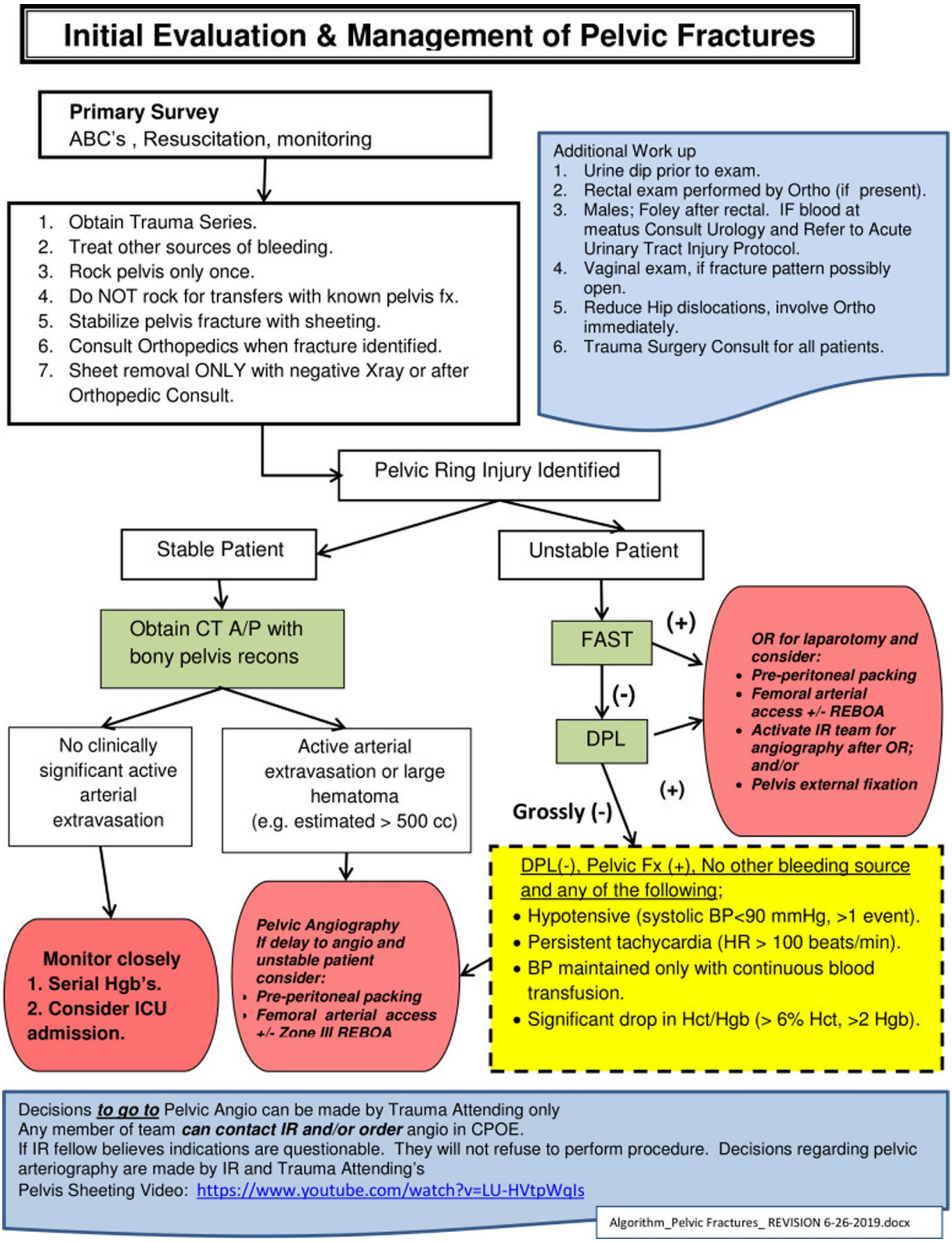
Novel workflows and hybrid operating rooms

Often in the setting in trauma a patient would need both a surgical intervention as well as an IR intervention, which still offers a challenge for many institutions that have their IR suite located away from the operating rooms (OR), this can be very time consuming and might result in adverse results for patients. This prompted the development of a trauma hybrid OR (THOR) that has both surgical and angiographic facilities. Some studies analyzed the impact of introducing this kind of OR on outcomes in trauma. Prichayudh et al. focused on the use of THOR in abdominopelvic injuries; they treated 35 patients in THOR and demonstrated significant decrease in procedure time (including transit time) from 238 min pre-THOR to 153 min [43]. They also showed lower death rates due to exsanguination (11% vs. 34%). Kataoka et al. also provided emergency surgical treatment and intraoperative IR using a portable C-Arm for 13 patients with torso trauma. Their study revealed reduced operation and interventional radiology time (229 vs 355 min. $p = 0.0.07$), along with a lower mortality rate (15% vs 36%, $p = 0.31$) in the group treated with this combined approach, compared to 45 patients who underwent surgery and interventional radiology procedures at different locations [44].

As CT remains indispensable for precise detection of bleeding sites to decide and plan TAE [45] and improved access would aid greatly in creating an ideal trauma workflow. In 2011, a trauma center in Japan introduced a CT scanner and a self-propelled C-arm to the trauma resuscitation room, which was also equipped with a movable ultrasound, monitoring screen and a mechanical ventilator [46]. While this setup might be expensive to replicate in many settings, it represents the ideal 'Hybrid ER,' which enables the performance of all necessary examinations and life-saving procedures including damage control surgery, burr-hole craniotomy and TAE for a trauma patient. They enrolled 696 trauma patients in a retrospective study comparing outcomes before and after the adoption of this new workflow. Data

(See figure on next page.)

Fig. 3 Harborview Medical Center's initial evaluation and management of pelvic fracture algorithm. ABC, airway, breathing, circulation; A/P, abdomen/pelvis; CPOE, computerized provider order entry; DPL, diagnostic peritoneal lavage; Hct, hematocrit, Hgb, hemoglobin; BP, blood pressure; Fx, fracture; HR, heart rate; ICU, intensive care unit; IR, interventional radiology; OR, operating room; REBOA, resuscitative endovascular balloon occlusion of the aorta. (Reprinted with permission: O'Connell KM, Kolnik S, Arif K, et al. 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). https://doi.org/10.1136/tsaco-2020-000663)



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of mortality in the hospital within 28 days of injury were collected and showed statistically significant decrease with the hybrid ER compared to conventional workflows (22%vs 15%). Time from arrival to ER till CT scanning or start of emergency procedure (surgery or TAE) was also significantly reduced. Umemura et al. also studied the use of hybrid ER to treat 690 patients with severe blunt abdominal injuries and showed a decrease in mortality (12.7% vs. 21.7%, $p < 0.001$), as well as reductions in blood transfusion requirements and bleeding control time (42 vs. 72 min., $p < 0.001$), in comparison with 360 patients treated during the pre-hybrid ER era [47].

Conclusions

The continuous advancement in technologies and expertise in IR has allowed safer and more effective treatment options in trauma management. Its scope is expected to continue growing as more knowledge is acquired and better tools are developed. However, more effort is needed to improve the level of evidence supporting radiological interventions. And a multidisciplinary approach needs to be adapted that optimizes its use as part of the care plan offered to the trauma patient.

Abbreviations

IR	Interventional radiology
TAE	Trans arterial embolization
AAST	The American Association for the Surgery of Trauma
CT	Computed tomography
CTA	CT Angiography
e.g.	For example
PES	Post Embolization Syndrome
fig.	Figure
min	Minute
SIR	Society of Interventional Radiology
ACSOT	American College of Surgery Committee on Trauma
DCIR	Damage control interventional radiology
HS	Hemodynamically stable
US	Hemodynamically unstable
QI	Quality improvement
REBOA	Resuscitative endovascular balloon occlusion of the aorta
THOR	Trauma hybrid OR
OR	Operating room

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Author contributions

The author Yousef Hisham Ahmed conducted the search, reviewed the literature and wrote the article.

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Availability of data and materials

The datasets generated during and/or analyzed during the current study are available in the Bibliography.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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