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Endovascular Management of Pelvic Trauma: The Interventional Radiology Point of View

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Background: Traumatic pelvic injuries are associated with high injury severity scores and significant morbidity and mortality. Active bleeding is the most common cause of death among those patients. Due to limitations of surgery for pelvic hematomas, angiographic treatment is at the forefront of pelvic trauma management.
Objective: The present article aims to discuss the available endovascular treatment modalities, and common angiographic treatment strategies and techniques.
Conclusion: Interventional radiologists plays a key role in the management of patients with pelvic trauma. New standardized protocols are needed to minimize the time spent on deciding the correct treatment for each patient.

Keywords: *Pelvic Trauma; Hemorrhage; Interventional Radiology; Endovascular Treatment*

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INTRODUCTION

Worldwide, deaths resulting from trauma are still among the most frequent, especially in the under-45 population [1].

Pelvic trauma (PT) is an umbrella term that encompasses several types of injury, such as pelvic ring fractures, acetabular fractures, and avulsion injuries. The majority of pelvic fractures in younger individuals are caused by high-energy blunt trauma such as a car/motorcycle accident (43–58%), a fall from height (5–30%), and a pedestrian struck by a vehicle (about 20%) [2,3]. Fragile and elderly adults may incur such injuries from a low-energy mechanism (e.g., a fall from a standing posture). Concomitant injuries, most commonly involving the abdominal and pelvic viscera, are more frequent with high-energy trauma [4].

Pelvic fractures account for around 3% of all bone injuries [5]. These injuries are seen in patients who are often young, with a high overall injury severity score (ISS) [6]. Because of the quick exsanguination, difficulties in achieving hemostasis, and concomitant injuries, mortality rates remain high, with rates reported to be between 5 and 15%, and in patients with hemodynamic instability mortality rates can be up to 50% [5,7].

The therapy of patients with PT is difficult, necessitating multidisciplinary efforts to comprehend and manage patients with PT at all its severity levels. It is also critical to have treatment standardization governed by protocols that measure mechanical and hemodynamic stability. Interventional radiology is complementary to rather than a substitute for surgery, and plays a critical role in the management of these patients. Here a systematic review of the literature was performed, to highlight the actual role of interventional radiology in PT. The methodological quality and certainty of evidence were evaluated using PRISMA.

Physiopathology of Pelvic Trauma

Severe hemorrhage is a life-threatening condition. Fractured trabecular bones and ruptured pelvic veins constitute the majority of bleeding sources, while arterial

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bleeding is reported in about 20% of cases [8]. Different fracture types, including lateral compression, anteroposterior compression, vertical shear, and combined mechanisms, can cause varying degrees of bleeding. Usually, the last three cause the most severe damage and require angiography in 20% of cases [1]. For unstable patients, early fracture stabilization is crucial to stabilize the pelvic ring and reduce hemorrhage [5]. The type of fracture underlying the bleeding has a large impact on hemorrhage control: in cases of lateral compression injury, bleeding stops in 99% of cases, whereas the intrinsic instability of posterior compression, vertical shear, and combined mechanism fractures results in ineffective bleeding control after compressive maneuvers in 18% to 22% of cases, especially if arterial involvement is present [1]. Another critical factor to consider is trauma-induced coagulopathy (TIC), which is caused mostly by hypothermia and repeated transfusions. Wherever possible, the presence of coagulopathy should guide the interventional radiologist in choosing the embolic material. In fact, it is widely known that because their methods of action are essentially dependent on clot formation, coagulopathy limits the effectiveness of embolization performed with gelatin sponges and coils [9–12]. Many authors have advocated for the use of non-adhesive liquid embolic agents (NALEA) and *n*-butyl cyanoacrylate (NBCA) in patients with coagulopathy because their embolization mechanisms are based on mechanical actions of polymerization (NBCA) and solidification (NALEA) rather than thrombus formation [9,13].

Pelvic Anatomy

Before performing vascular embolization, it is imperative to have a comprehensive understanding of the vascular anatomy of the pelvis and any potential variations. The primary arterial vascular supply of the pelvis is given by the dividing branches of the internal iliac arteries and, to a lesser extent, by the branches of the external iliac artery [14]. The internal iliac arteries are typically divided into anterior and posterior branches. The anterior trunk serves the majority of the pelvis organs through the obturator, umbilical, inferior vesical, gonadal, internal pudendal, and inferior gluteal branches. The posterior trunk serves the posterior abdominal wall and pelvis through the iliolumbar, lateral sacral, and superior rectal branches [4].

About 30% of patients also have middle rectal arteries. These arteries usually originate together with prostatic arteries in the prostate-rectal trunk [14]. Both non-targeted embolization and recurrent hemorrhage can result from anastomoses with the superior and inferior rectal arteries, which are frequently seen [15].

A relatively high risk of hemodynamically significant bleeding, death, and morbidity is also associated with injuries to the external iliac artery, which have been reported to occur in 3.5–17% of cases of PT [16,17]. For effective endovascular therapy, a complete evaluation of the external iliac arteries is therefore mandatory. One particularly significant anatomic variant is the Corona Mortis, which is a vascular anastomosis between the external iliac artery and the obturatory artery. It is reported to be present in a third of patients on routine CT examination [18].

MANAGEMENT OF PELVIC TRAUMA

The two most important variables in PT are hemodynamic stability and mechanical stability of the fracture; the subsequent diagnostic and therapeutic workflow will depend on these variables, and hemodynamic stability is particularly important. Regarding hemodynamics, Advanced Trauma Life Support (ATLS), considers patients hemodynamically unstable when they present with blood pressure <90mmHg and heart rate >120 bpm with signs of cutaneous vasoconstriction, altered level of consciousness, and shortness of breath [19].

The anatomical description of pelvic ring lesions (mechanical stability–instability) is not definitive in the management of pelvic-related hemorrhage since there is not a clear correlation between the type of fracture and the bleeding risk, even if some fractures such as anterior-posterior compression are related with a requirement for a greater number of transfusions [5,20].

The most recent and used classification for the management of PT patients is the one provided by the World Society for Emergency Surgery (WSES) [5].

According to this classification, patients are classified following the severity of injury, which is evaluated by the Young–Burgees classification for pelvic ring fractures, and, most importantly, the hemodynamic status according to the ATLS. The primary objectives of effective PT management include stabilizing hemodynamic status, addressing coagulation disorders, ensuring the mechanical integrity and stability of the pelvic ring, and preventing various complications such as septic, urogenital, intestinal, vascular, sexual, and walking-related issues. Subsequently, the goal is to achieve definitive stabilization of the pelvis.

The WSES classification divides traumatic pelvic ring injuries into three grades:

- *minor* (stable hemodynamics and mechanics);
- *moderate* (stable hemodynamics, unstable mechanics);
- *severe* (hemodynamic impairment regardless of mechanical stability).

If patients have hemodynamic stability, they should always have a multiphasic CT scan with contrast medium injection that will be used to guide further therapeutic procedures.

On the other hand, in the hemodynamically unstable setting, immediate intervention is necessary.

Patients with a *minor* degree of injury usually undergo a CT scan and then are referred to non-operative management (NOM).

Patients with a *moderate* degree of injury receive pelvic binder fixation as soon as possible, then a CT scan is performed and if necessary (signs of bleeding on the CT scan) embolization carried out.

The most threatening scenario is obviously when the patient is not hemodynamically stable.

Resuscitation, mechanical stabilization, pre-peritoneal pelvic packing (PPP), resuscitative endovascular balloon occlusion of the aorta (REBOA), and embolization are commonly used treatments for severe pelvic injuries. However, it seems that the order in which these techniques are used varies greatly depending on the local expertise and experience. Currently, there are no clear recommendations, and opinions on how to treat hemodynamically unstable pelvic fractures are divided [21].

According to the First Italian Consensus Conference on Pelvic Trauma [7] the management of hemodynamically unstable patients should rely on the results of Focused Sonography for Trauma (FAST) ultrasound. If there is free fluid in the abdomen (positive FAST) the patient will be transferred immediately to the operating room, where they will be prepared for an exploratory laparotomy and treated with pelvic stabilization and PPP. Patients who do not have free fluid will only require external pelvic fixation and a PPP. If the patient regains hemodynamic stability following surgery, a contrast-enhanced CT scan will be conducted. The patient will receive embolization if active blushing is seen, since it has a strong correlation with bleeding on angiography. If, on the other hand, the patient's instability persists following surgery, embolization will be performed without a CT scan since there is a high probability that the bleeding has an arterial origin [22].

It should be acknowledged that the time necessary for an on-call interventional radiologist (IR) to show up to the hospital and find/embolize vascular injuries during angiography might cause procedural delays. In addition, venous injuries (80% of cases as previously said) will persist after embolization. Because of this, endovascular treatment should be taken into consideration for unstable patients when there will not be an undue delay in care or when other measures, such as PPP, aortic balloon occlusion, and/or blood transfusions, have already been performed [4,21,23].

ENDOVASCULAR TREATMENT

When Should Angiography be Performed?

The undisputed indications for performing angiography are active extravasation of contrast medium on CT, the presence of pseudoaneurysms, and the presence of arteriovenous fistulas [1]. Nevertheless, the sensitivity of a CT scan in detecting active bleeding after trauma is known to be between 60 and 90% [24,25]. There are several cases in which angiography may be necessary even in the absence of evidence of arterial injury on CT examination, such as, for example, in patients with persistent hemodynamic instability after PPP or in the presence of a large (>500 cm^3) pelvic hematoma even in the absence of active blush on CT examination [26].

Embolization Technique

The common femoral artery is punctured at the level of the femoral head, generally on the opposite side to the hematoma, to facilitate pelvic vessel catheterization. Two femoral accesses could be obtained in some elderly individuals or in patients with especially convoluted arteries to shorten the amount of time needed for the procedure. Puncture on palpatory guidance is not always possible given the hypotension these patients might have. In addition, pelvic binders may hide the artery. In these cases, the use of ultrasound guidance for a puncture may help.

As regards the upper limb arteries approach, these arteries have historically been punctured in situations of significant pelvic soft-tissue injury or when pelvic devices prevent transfemoral access. Nevertheless, radial artery access is becoming more and more popular in trauma patients, with technical success rates comparable to those of femoral access [27,28].

If there are no obvious sources of bleeding on the CT scan, non-selective as well as selective angiographies in various projections should be performed to search for sources of bleeding.

Selective angiographies should always be performed and are of the utmost importance to rule out or confirm bleeding spots [29].

The primary goal of embolization is to quickly stop blood flow to the injured vessels to restore hemodynamic stability. Whenever feasible, super-selective embolization is preferable; however, it should be considered that the time required to manipulate a microcatheter into smaller pelvic visceral arteries might cause the treatment to take longer than necessary.

If, for instance, the patient is hemodynamically unstable or has deteriorating vital parameters, a quick embolization of the entire anterior or posterior division branch of the internal iliac artery is preferable to a time-consuming super-selective embolization of the single vessel responsible for the bleeding. Moreover, the increased risk of ischemia given by non-selective embolization is mitigated by the rich collateral network present in this anatomical region [1]. Other authors, however, assert that selective embolization may be carried out as quickly as proximal embolization without reducing the survival rate of trauma patients [30].

The hemodynamic status of the patient should also guide the IR to choose between multiple embolic agents and devices that can be used in the management of PT. The choice of the embolic agent depends on the physician's experience and the vascular injuries on a case-by-case basis. Generally, temporary embolic agents such as gel foam should be used in the case of large territory embolization or empiric embolization, while definitive embolic material, liquids or solids, should be preferred for super-selective embolization. In addition, as previously mentioned, it is important to access the coagulation profile of the patient prior to embolization. If coagulation is altered, as is frequently seen in trauma patients, some embolic materials (i.e. coils, gel foam) will not achieve hemostasis easily.

A borderline case is when there are no signs of bleeding on angiography in a hemodynamically unstable patient who has not had a CT scan and there is free fluid in the abdomen on FAST ultrasound. In these cases, prophylactic embolization with resorbable material (i.e. gel foam) is recommended for temporary occlusion [31,32]. In addition, no significant differences in survival, complications, and days of hospitalization are reported in patients who underwent this procedure.

Complications related to embolization are not frequent and are mostly related to access site points, including bleeding, hematoma, pseudoaneurysms, and arteriovenous fistulae. Other complications associated with arterial embolization itself arise either accidentally from non-target embolization or as an inevitable consequence of big vessel or bilateral embolization. The femoral head, lower leg, pelvic viscera, and gluteal muscles can all be affected by ischemia or necrosis [33].

REBOA

REBOA is a relatively new temporary measure to control hemodynamically unstable trauma patients in the early resuscitative phase. It consists of the inflation of an endovascular aortic balloon through a femoral introducer sheath.

In short, REBOA is an alternative to emergent resuscitative thoracotomy (RT) in hemodynamically unstable trauma patients [34,35], whose only requirement is a femoral arterial access. It enables the reestablishment of a systolic blood pressure >90 mmHg, which allows for further diagnostic investigations (CT scan with contrast medium injection) or interventions such as pelvic packing or embolization.

Due to the potential for visceral organ ischemia, REBOA should ideally not be positioned in Zone 2 (para-renal), but rather in Zone 1 (supra-celiac or descending aorta) or Zone 3 (infra-renal).

Zone 3 REBOA may be the best option for pelvic bleeding since it allows for a prolonged occlusion period of 4–6 hours and prevents ischemic/reperfusion injury to visceral organs [36].

REBOA complications can be severe and bring the resuscitative effort to a premature end due to arterial disruption or dissection [37,38].

International registries on the use of REBOA in trauma have yielded positive results, but there are still open questions regarding its application, such as the best location and timing for access, the best zone for inflation, and which medical specialist should oversee the procedure [5].

OUTCOME AND FUTURE PERSPECTIVES

Endovascular procedures in the management of PT injuries are safe procedures with a high success rate ranging from 74% to 100% of cases [39].

Most reports in the literature on the subject are retrospective, for obvious ethical reasons.

The application of embolization and pre-peritoneal packing in hemodynamically unstable PT patients varies greatly around the world. Historically, PPP has been more extensively utilized in Europe, while embolization has more commonly been employed in the United States [40,41].

More recently, PPP was adopted in North America too, given the assumption that delays in embolization due to a lack of staff availability or the need for trips to the angiography suite have shown an increase in patient mortality. In the early 2000s, Verbeek et al. in a large multicentric study showed improved outcomes and a faster time to intervention with pre-peritoneal packing, but they also revealed that embolization was consistently required for the most critically ill patients to achieve hemorrhage control [23].

On the other hand, in a recent review and meta-analysis on the comparison of pre-peritoneal packing and embolization in unstable PT patients, McDonogh et al. showed that analysis of dual-arm studies showed no significant difference in mortality between PPP and embolization, with 27% of patients treated with PPP requiring subsequent embolization for inadequate hemorrhage control. The authors believe that a definitive comparison between modalities is unachievable due to bias, heterogeneity, and insufficient reporting of physiological data, underscoring the necessity of standardized reporting in this high-risk subset of trauma patients [42].

To overcome the gap in published guidelines, Renzulli et al. proposed a possible standardization of the angiographic procedure in the setting of PT, concerning how and when to perform the procedure, the interventional technique, and embolization materials used [29].

A new standardization protocol was proposed in Hong Kong in order to minimize the time required for the intervention needed by the PT patient. It consists of performing sequentially in the same room the three pillars of therapy of hemodynamically unstable PT patients: external fixation, PPP, and embolization. In a recent multicenter analysis, this protocol was identified

as the single most independent predictive factor for 30-day, 7-day, and 24-hour mortality rates [43,44].

However, a large workforce comprising a multidisciplinary team of anesthetists, orthopedic surgeons, general surgeons, and IRs would need to be available around the clock in trauma care centers to accomplish this one-step resuscitation and therapeutic action.

CONCLUSIONS

PT is a life-threatening condition with a very high rate of variability in presentation and outcomes. The management of such pathology involves medical specialists from multiple fields and, among them, the IR plays a key role. New standardized protocols for the management of these patients must be implemented to minimize the time spent on deciding the correct treatment for each patient.

Ethics Statement

(1) All the authors mentioned in the manuscript have agreed to authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.
(2) The authors declare that they have read and abided by the JEVTM statement of ethical standards including rules of informed consent and ethical committee approval as stated in the article.

Conflict of Interest

The authors declare that they have no conflicts of interest.

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