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REVIEW

Indications for embolization in a French level 1 trauma center

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Summary Abdominal trauma accounts for nearly 20% of all traumatic injuries. It often involves young patients sustaining multiple injuries, with a high associated mortality rate. Management should begin at the scene of injury and relies on a structured chain of care in order to transport the trauma patient to the appropriate hospital center. Management is multi-disciplinary, involving intensive care specialists, surgeons and radiologists. Imaging to precisely define injury is best performed with whole body dual phase computed tomography, which can also identify the source of bleeding. Non-operative management has developed considerably over the years: this includes selective embolization in case of active bleeding or vascular anomalies in stable or stabilized patients after resuscitation. Embolization has become one of the corner stones of abdominal trauma management and interventional radiologists must play an active role on the trauma team. This overview details the different embolization procedures according to the involved organ and embolic agent used.

Essential points
- Pre-hospital management and triage of trauma patients to appropriate trauma centers based on the degree of injuries are indispensable elements of regional care networks.
- Management of patients with abdominal trauma should be multi-disciplinary, involving the surgeon, the intensive care physician and interventional radiologist.
- Total body dual (arterial and venous) phase CT is the investigation of reference in visceral trauma.
- Embolization is indicated based on CT findings when faced with active bleeding or arterial anomalies that are at risk of bleeding.
- Prophylactic proximal embolization can be entertained for high-risk organs such as the spleen.

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Introduction

Abdominal trauma accounts for nearly 20% of all traumatic injuries. Mortality can be high depending on the organs involved and particularly when there are multiple injuries [1]. In France, most injuries results from blunt abdominal trauma. Each organ and type of injury may require specific treatment. Lesions vary greatly: deep organ contusion, hollow organ perforation, mesenteric tears, vascular injury with active bleeding, complex pelvic fractures that require multi-disciplinary management (intensive care, surgery and interventional radiology) in specialized trauma centers. For unstable patients, initial diagnosis relies on Focused Assessment with Sonography for Trauma (FAST) to identify intra-peritoneal fluid or air, and can orient care toward emergency surgery if needed [2]. For stable patients, sonography is inadequate and a total body CT scan should be ordered [3,4]. The indications for interventional radiology are determined according to the images obtained with this CT. The goal of this update is to clarify which abdominal injuries are amenable to interventional radiology and to elaborate the primary therapeutic principles.

Triage of patients with abdominal trauma: from the site of injury to the angiology suite

Triage of patients with abdominal trauma begins at the site of the accident; every effort must be made to determine where the patient should be directed based on the type and severity of injury and the available local facilities. In the region of Grenoble, we have set up a network called TRENAU (Trauma système du REseau Nord Alpin des Urgence) (North Alpine Emergency Trauma System network) that federates 40 hospital in six regions (Drome, Rhône, Ain, Isère, Savoie, Haute Savoie) [5]. Patients are classified into three categories (A, B and C according to the VITTEL criteria: A: unstable patient; B: stabilized patient; C: stable patient with risk factor [6]) according to the severity of their trauma and the type of injury suspected, in order to organize their transport to the most appropriate medical facility. The University Hospital of Grenoble is the reference trauma center. This pre-hospital triage allows the patient to be rapidly transported to the best-adapted facility based on severity of injury, to decrease the delay in management and thereby to reduce mortality [7].

FAST

Upon arrival in the hospital, all unstable patients with free fluid detected by FAST are sent to the operating room for emergency operation. Conservative treatment is the rule for stable patients (or those who stabilize with resuscitation). Management of these patients requires the availability on-site 24/7 of a surgeon, an intensivist, and a diagnostic and interventional radiologist.

Total body CT

All stable patients with a suspicion of abdominal injury should have a dual phase (arterial and venous) total body CT that:

- allows better and more complete injury workup than sonography [4];
- decreases mortality [8] and reduces the duration of hospital stay [9];
- reduces the costs while allowing better management and limits the number of complementary investigations [10].

CT allows triage of the patients and notably selection of the patients who are eligible for interventional radiology.

Embolization

In case of active bleeding or a post-traumatic injury with a risk of delayed bleeding (such as a false aneurysm or arterio-venous fistula) embolization can prevent or rapidly control the bleeding. This is called hemostatic embolization. Depending on the organ involved, ''preventive embolization'' can also be proposed aiming to avoid secondary rupture, as in the case of splenic injury. An interventional radiologist should be consulted for all patients with an arterial injury or a deep organ injury with AAST grades 3, 4 or 5.

Patient position

Ideally, all patients referred for embolization should have an arterial phase CT. This CT angiography provides a complete arterial map while aiding to plan and anticipate the difficulties of catheterization. Embolization should achieve rapid control of bleeding. Patients with multiple injuries should be managed by the intensive care team who should remain with the patient in the angiography suite along with the interventional radiologist. This is because these patients can start to bleed actively and decompensate rapidly, even when young and hemodynamically stabilized.

Embolization technique

Approach

The procedure is performed with the patient lying supine, after injecting local anesthesia at the site of arterial puncture. The right common femoral artery is the preferred site because it is closest to the deep organs and therefore allows the most direct and precise catheterization. This means that the right common femoral artery should be spared as much as possible during the initial stages of resuscitation. If the right femoral approach is not accessible, then the left femoral or brachial arteries can be used.

Catheters

The procedure begins by insertion of a 4 or 5 Fr introducer catheter. Catheters have different shapes are introduced into different vessels under fluoroscopic guidance according to the desired target and the iodinated contrast injected. Three Fr microcatethers can be used for difficult cases when the artery caliber is small. Digital subtraction angiography is best to obtain a precise arterial map. Image fusion systems exist that use tomographic slices to facilitate endovascular navigation in the angiography suite according to the type of apparatus available.

Embolization agents (Fig. 1)

Temporary agents

Gelfoam sponge is the principle embolic agent (Fig. 1A) for use in trauma because it is inexpensive, easy and rapid

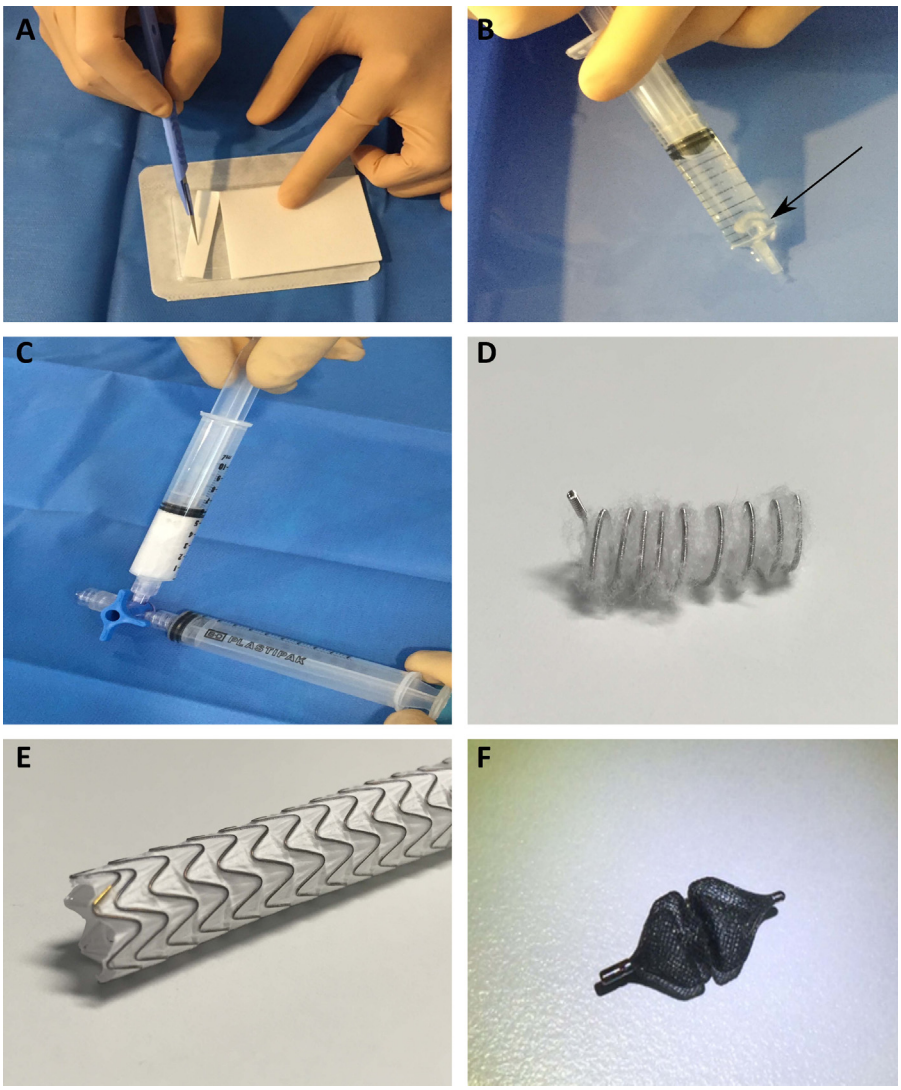

Figure 1. Embolization material. A. Gelfoam torpedo carved out of gelfoam sponge. B. Gelfoam torpedo within syringe (arrow), ready to be injected through the catheter. C. Gelfoam slurry prepared between two syringes with a three-way stopcock. D. Fiber coil. E. Coated stent (polytetrafluoroethylene membrane). F. Plug.

to use, and allows temporary arterial occlusion that is reversible within a few days. The Gelfoam sponge can be tailored into small torpedo shapes for rapid embolization of larger vessels (Fig. 1B) or prepared as a slurry by injecting it back-and-forth between two syringes connected to a three-way stopcock; one syringe contains the contrast material and the other contains Gelfoam sponge (Fig. 1C). It is preferable to use highly purified porcine gelatin such as Curaspon (Curamedical B.V. Holding, Zwanenburg, the Netherlands) because it has been shown to be completely eliminated within 3 to 14 days leaving the vessels patent [11]. Other gelatins can cause vascular injury such as strictures due to inflammation caused by gelatin-induced intimal hyperplasia [12].

Permanent particles

These are composed of hydrogel, gelatin derivatives or polyvinyl alcohol (PVA) and have the advantage of being calibrated (from 100 to 1000 μm) allowing more precise and more distal embolizations. They are used more for tumor embolizations and very rarely for trauma.

Coils

Metallic coils can be non-coated (more supple), or covered with fibrogenic fibers (more thrombogenic) (Fig. 1D). These are available in nearly all diameters and lengths. Likewise, there are several types of microcoils that can be used with microcatheters. These coils can be pushable or deployable to perform complex embolizations while controlling the winding and the deployment of the coils. In trauma, push coils are more commonly used because they can be easily flushed through the catheter to rapidly occlude the vessel. The role of coils is to mechanically occlude the vessels, meaning that several coils are necessary to create a compact pack and facilitate thrombogenesis, creating a scaffold for thrombus. They allow more precise and targeted embolizations than Gelfoam. Along the same principles, vascular plugs Amplatzer (St Jude Medical, St. Paul, MN, USA) have been developed. These are true plugs made out of nitinol and allow rapid occlusion of larger caliber arteries (Fig. 1F).

Liquid agents

Glues (cyanoacrylates) are used for very distal and rapid embolizations. They provoke true sclerosis of the vessel. On the other hand, they are very difficult to control and are reserved for experts. Effectively, it is quite difficult to control the dose of the injection and to avoid unwanted reflux into vessels. For more security, Onyx® (ev3 endovascular, Inc, Plymouth, Minnesota) can be used. Onyx is a polymer

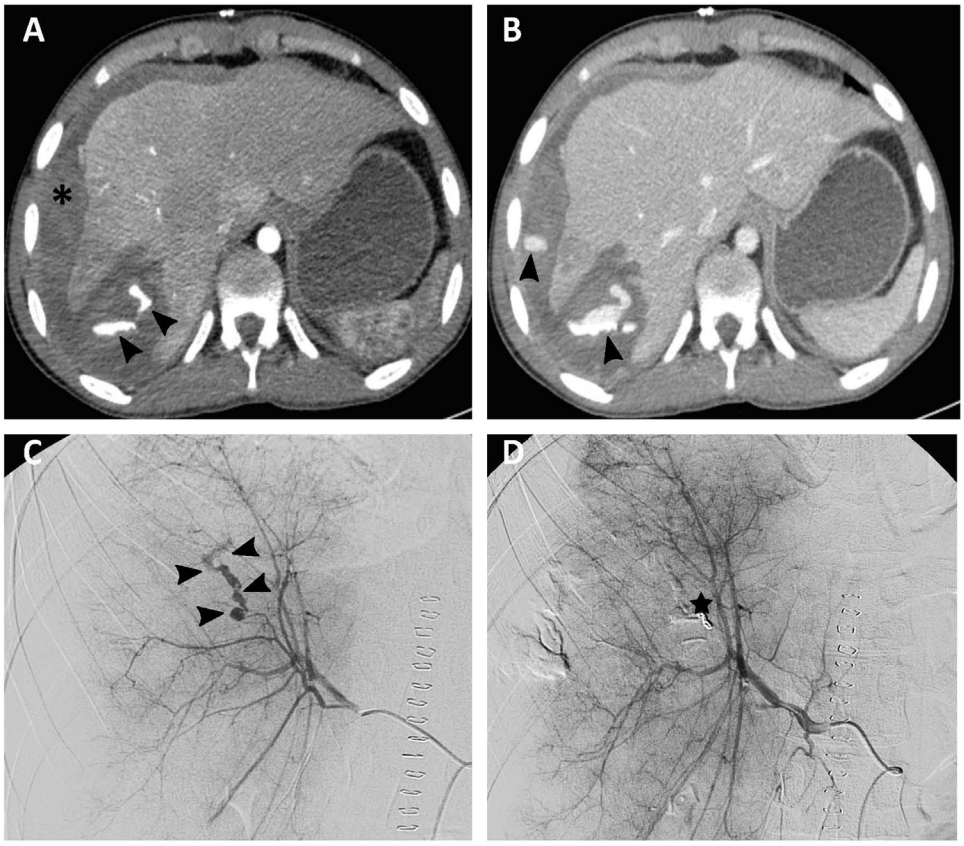

Figure 2. Embolization for liver trauma. A 16-year-old patient who had sustained an AAST grade 3 liver trauma after a scooter accident: active bleeding detected on total body CT upon arrival. Nine days after removal of initial damage control hepatic packing performed for major hemodynamic instability, the patient developed sudden hypotension and abundant bleeding via the drains. Emergency CT showed massive active contrast extravasation during the arterial phase (arrow head image A), increasing during the venous phase (arrow heads image B), and bleeding into the perihepatic peritoneal space (asterixes A et B). Selective hepatic arteriography localized the active bleeding in segment VII. Microcoil embolization was delivered with a microcatheter (black star image D). Final angiography showed occlusion of the injured vessel (image D).

dissolved in a solvent, that releases progressively in the bloodstream as a foam, while the injection is monitored on the fluoroscopic screen. Preparation takes a long time while injection must be slow and therefore the technique is not compatible with rapid embolization for bleeding when immediate hemostasis is necessary. Conversely, it is effective in case of rebleeding, allowing for distal and controlled embolizations [13].

Covered stents

These are only occasionally used for large caliber vessels when it is necessary to preserve the host vessel (Fig. 1E). In this case, a 6—8 Fr introducer is used to insert the stent into the artery.

Type of embolization

There are specific embolization techniques adapted to the specific vascular problem. For an end artery (renal artery, hepatic artery, splenic artery proximal to the hilum), embolization should be as selective as possible because it results in ischemia of the end organ; every effort must be made to spare as much parenchyma as possible. Conversely, if the embolization concerns an artery that is part of a vascular arcade with downstream collateral communication (superior mesenteric artery, gastroduodenal artery, splenic artery trunk), a ''sandwich'' technique is used (downstream and upstream embolization above and below the arterial anomaly to avoid reperfusion). For preventive embolization, the goal of which is to lower the arterial pressure to limit the bleeding risk; proximal embolization takes advantage of collateral blood supply to ensure low-pressure distal vascularization (*e.g.*: internal iliac artery, splenic artery trunk).

Particularity by organ

Liver trauma

Management of liver trauma depends less on the trauma grade than on whether the patient is stable or not with conservative management, which is currently the standard treatment [14]. In our experience [15], embolization is part of a multi-disciplinary management approach and may be necessary at two difference moments:

- either initially, when the patient is stable or stabilized, but is bleeding actively, as detected on CT. Embolization of the injured artery (organ) is performed as selectively as possible to limit the area of ischemia;
- or secondarily, after surgery, in unstable patients who have undergone exploration and packing or possibly external clamping of the hepatic pedicle. As soon as the patient is stabilized, embolization can take place once the bleeding site has been identified by declamping in the arteriography suite (Fig. 2).

Other teams recommend routine angiography for AAST grades 3 or greater, with the intent of preventing further

bleeding, even in the absence of active bleeding on CT [16]. Patients with liver trauma are a serious health care burden as up to 70% will present a complication: biliary leak, abdominal compartment syndrome, inflammatory peritonitis, hepatic necrosis... [17]. The main complications of embolization are related to ischemia: ischemic cholangitis, and gallbladder necrosis occurred in two of 14 patients in our series [15].

Splenic trauma

Splenic preservation has replaced routine splenectomy and is now the standard for splenic trauma with a mean success rate is 85% [18]. The spleen's blood supply is particular with a major main vascular supply via the high flow splenic artery, with a vast collateral vascularization provided by the pancreatic, short gastric and gastro-epiploic arteries. This vascular pattern explains the need for several embolization techniques:

- distal embolization: this involves selective embolization of the injured artery distal to the splenic hilum;
- proximal embolization: this concerns truncal embolization, in the middle portion of the splenic artery counting on parenchymal preservation by low-flow distal reperfusion via collateral vessels;
- combined embolization: embolization can combine both techniques, first distal embolization, followed by proximal embolization.

Distal embolization is reserved for isolated intra-splenic arterial injuries: intra-splenic or intra-peritoneal active bleeding, false aneurysms and arterio-venous fistulas. Proximal embolization is reserved for high-grade trauma (AAST grades 4—5) without active bleeding (requiring surgery) or with multiple active bleeding sites that are too numerous to be totally embolized (Fig. 3). Combined embolization is used for high-grade trauma associated with isolated arterial anomaly. There is no consensus as to the ideal management and the efficacy of proximal ''preventive'' embolization for high-grade lesions that are not actively bleeding, and this remains a subject of debate [18]. In our experience, the efficacy of all three techniques is similar in terms of complications [19]. In our experience, 62% of patients with splenic trauma developed complications, but none of these complications was related to embolization in multivariable analysis [20]. The only risk factors for complications were the severity of trauma and associated injuries.

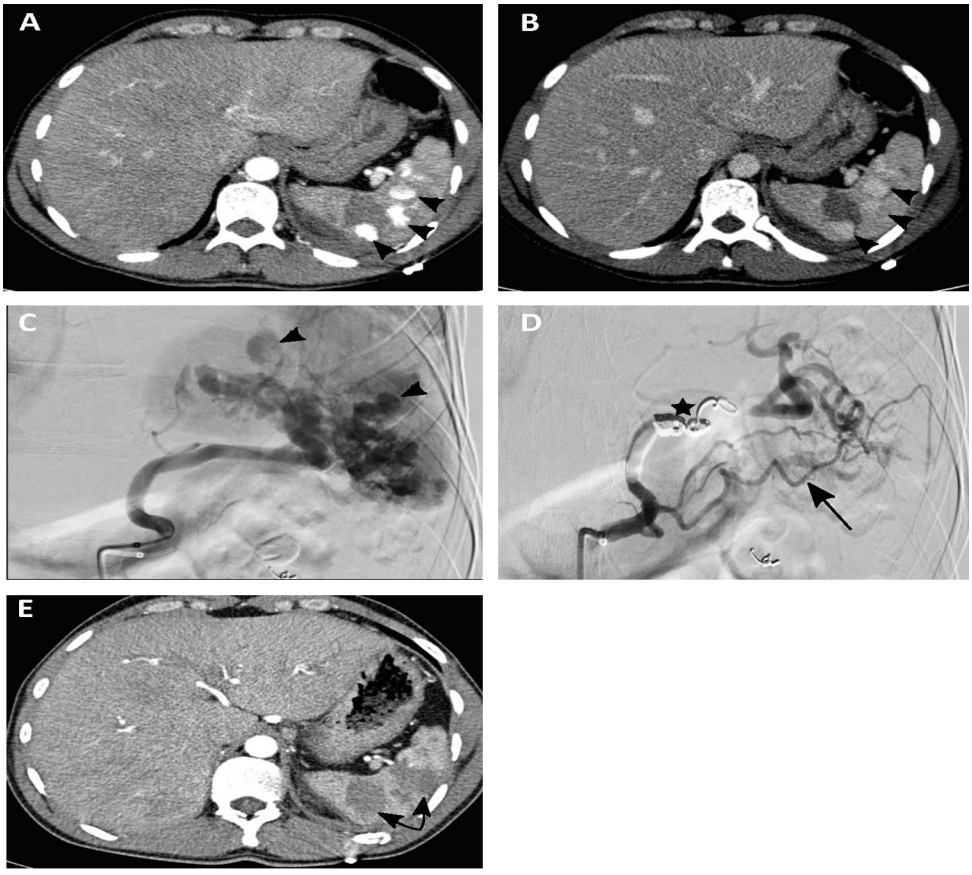

Figure 3. Embolization for splenic trauma. A 29-year-old patient hospitalized for abdominal trauma sustained in a ski accident with AAST grade III splenic trauma and AAST grade 4 renal injury, without active bleeding on initial total body CT, was managed by non-operative treatment. On day 5, a control CT showed multiple saccular enhanced arterial images compatible with intra-splenic false aneursyms (arrowhead image A), preserving the contrast material during the venous phase without changing shape (arrowhead image B). Arteriography showing multiple intra-splenic false aneurysms (arrowhead image C). Because of the large number of aneurysms to treat, and in order to avoid extensive necrosis of the spleen, proximal coil splenic embolization was performed (star image D). Note the segmental thrombosis of the artery near the coils and revascularizaton of the distal portion of the artery via the pancreatic arcades (arrows image D). On day 10, follow-up CT showed that all the false aneurysms were thrombosed (double arrows image E) while splenic parenchyma remained well-perfused.

Renal trauma

Renal trauma is rare, representing only 1—5% of injuries; most are low grade and do not require invasive management [21,22]. Embolization is reserved for patients with arterial anomalies visible on CT. For high-grade injuries (AAST grades 4—5), embolization should be discussed with the urologist who might prefer to perform nephrectomy, even in the stable patient [23]. Embolization should be as selective as possible because the kidney is an end organ and the parenchyma has already been damaged by the trauma. The main complication is the post-embolization syndrome associating pain and inflammatory syndrome, seen in 10% of cases [21]. The risk of contrast toxicity with the secondary risk of kidney failure should not contra-indicate embolization because the literature seems to indicate that angiography does not affect kidney function in these patients [24].

It is important to identify renal artery lesions, although they are very rare (0.05 to 0.08% of cases) and therefore not well recognized [25]. For avulsion or laceration of the renal artery with active bleeding (AAST grade 5), treatment should be surgical [22]. Traumatic aortic or renal artery dissections with renal artery thrombosis are exceptionally rare (AAST grade 4). Since the distal kidney is no longer vascularized, it is difficult to know whether the arterial injury is intimo-medial or sub-adventitial associated with a proximal, continuous spasm, or complete rupture of the artery. The kidney tolerates warm ischemia poorly, with irreversible ischemic lesions appearing within three to four hours. While there is no consensus on the matter, early endovascular angioplasty or stent can be proposed [25]. The technical efficacy is good but outcome in terms of nephronic salvage remains debated.

Mesenteric injury

Mesenteric injuries are rare, involving less than 5% of blunt abdominal trauma, but they seem to be on the rise lately due to high velocity accidents and seat belt injuries [26,27]. Standard treatment is evacuation of the mesenteric hematoma and exploration of the intestines for viability and mural injury. In case of active bleeding, several cases confirming the efficacy of embolization have been reported. Hagiwara et al., reviewing seven of such patients, found that embolization was effective in terms of hemostasis with no associated gastrointestinal necrosis [28]. These results should be interpreted with caution however because these observations concerned only patients for whom the treatment was effective. In our experience of eight patients who underwent embolization for mesenteric trauma, the main complication was distal ischemia, which could also have been due to compressive hematoma. Superior mesenteric artery embolization is tolerated better because extensive collaterality limits ischemia while surgical access to the artery is usually complex. Inferior mesenteric artery embolization carries a higher risk of ischemia but surgical access is easier.

Pelvic trauma

While these injuries do not specifically concern abdominal trauma, it seems important to focus on the management of unstable pelvic injuries. We have previously shown that a therapeutic algorithm based on hemodynamic status at arrival along with total body CT findings allows adequate triage of patients who are at risk of bleeding and should undergo embolization; this represented 25% of patients with severe pelvic injuries in our experience [29]. Patients with unstable pelvic fractures can be divided into three groups: hemodynamically stable, unstable, and critically unstable. Bleeding is often abundant because it can arise from three different sources: arterial, venous and osseous. It is important to act quickly to control venous and osseous bleeding by pelvic stabilization using external fixation, clamp, or femoral traction.

Depending on the hemodynamic status, three management plans can be proposed [30,31]:

- stable patient: total body CT and embolization if active bleeding is detected;
- unstable patient: certain authors propose surgical packing [32,33] but we prefer embolization (level 1 recommendation according to the AAST). This consists of selective embolization of the branches of the internal iliac artery if a specific and localized anomaly is detected (active bleeding or false aneurysm) or proximal (global) embolization with large Gelfoam particles when multiple arterial branches are involved, in order not to lose too much time performing hemostasis. Proximal embolization allows rapid hemodynamic recuperation followed by classical injury evaluation. The proximal and temporary character of this type of embolization with absorbable material avoids cutaneous ischemia since effective albeit low-flow vascular collaterality is present. In our experience of more than 70 embolizations for unstable pelvic fractures, we have never observed any muscular or cutaneous necrosis;
- extremely unstable patient: management of these patients poses major problems even after optimal resuscitation. Salvage retroperitoneal packing is always a possibility. Intra-aortic balloon occlusion is also effective in restoring blood pressure. The balloon, placed at the bedside by the interventional radiologist, should be positioned by ''blind'' estimate to lie in the infrarenal abdominal aorta, allowing the patient to be rapidly transported to the angiography suite for bilateral internal iliac artery embolization with the balloon inflated [34]. This remains a complex procedure and should be reserved for expert interventionalists familiar with the technique.

Conclusion

Arterial embolization has revolutionized trauma care allowing the physician to gain rapid, elective, durable and minimally invasive hemostasis. Indications for hemostatic embolization are increasing, either for active bleeding or preventively, but proper selection of patients is indispensable based on information provided by high quality total body CT. Embolization is most often integrated into combined interventional radiological and surgical strategies. Obviously multi-disciplinary management, involving surgeons, anesthesiologists and radiologists must be available 24/7.

Disclosure of interest

The authors declare that they have no competing interest.

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