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Polytraumatism and solid organ bleeding syndrome: The role of imaging



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Abstract In multiple injuries, features of bleeding from solid organs mostly involve the liver, spleen and kidneys and may be treated by embolization. The indications and techniques for embolization vary between organs and depend on the pathophysiology of the injuries, type of vascularization (anastomotic or terminal) and type of embolization (curative or preventative). Interventional radiologists should have a full understanding of these indications and techniques and management algorithms should be produced within each facility in order to define the respective place of the different treatment options.

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Traumatology is becoming increasingly important in our everyday practice because of developments in sports and leisure activities. At present, injuries are the leading cause of death in patients under 40 years old. This increase in incidence and the urgent nature of these injuries is a driving force towards increasingly complex, rigorous organization into traumatology networks and centers. Within this organization, the place of the interventional radiologist is increasing as embolization plays a major role in the treatment of patients because of its efficacy and low complications rate.

Radiologists need to understand the pathophysiology of injuries and its consequences on endovascular treatment, together with the indications and techniques for embolization in trauma.

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Organization of patient care

Depending on the severity of the injury, the patient may be admitted through an emergency department or into a resuscitation unit.

If the patient is hemodynamically stable or has been stabilized by initial resuscitation procedures, he/she will have a whole body CT with contrast enhancement and chest and abdominal views in the early phase of opacification, followed by views at a later phase. These two phases are essential to detect and study the kinetics of the hemorrhage, which is important in deciding on the indication for embolization.

If the patient is hemodynamically unstable or in uncontrolled shock, he/she will have a minimum assessment with a chest radiograph, pelvic radiograph and screening ultrasound (fast-echo). The purpose of pelvic and chest radiographs is to exclude potentially hemorrhagic injuries at these levels. Ultrasound can triage patients with abdominal injuries: if a large peritoneal effusion is present the patient is generally managed surgically, whereas if the ultrasound does not show a peritoneal infusion but solid organ injuries or a retro-peritoneal hematoma, patients are directed to the angiography suite for arteriography and possible embolization.

Embolization is generally reserved for solid organ injuries not associated with a hemoperitoneum. However, in some circumstances in which a hemoperitoneum and multisite hemorrhages are present, particularly if these are combined with pelvic and solid intra-abdominal organ injuries, or aortic injury, endovascular treatment can allow successive, rapid and particularly effective treatment of these different bleeding sites. The indication for its use should be discussed on an individual case basis in conjunction with the traumatology team in the resuscitation room.

General principles of catheterization and embolization

Angiographic investigation for active bleeding should be performed both with overall opacification after intra-aortic injection of contrast medium, and by selective catheterization. The overall injection is designed to provide wide anatomical detection of bleeding sites but is relatively non-sensitive, whereas selective arterial catheterization increases the sensitivity of detection, but is limited to the area being investigated. Conversely, excessively selective catheterization can reactivate a bleed by injecting contrast medium at excessive pressure into an area in which hemostasis has been achieved without treatment through an intravascular clot or spasm.

Depending on each patient's situation, investigations may begin with overall or selective opacification, although both investigation methods should be performed during the investigation.

Catheterization of arteries in a polytrauma patient uses low diameter (4F), highly-flexible atraumatic catheters in order to reduce the risk of spasm in these patients, many of whom are receiving pressor amines (noradrenaline). The end of the catheter should not contain side holes because

of the possible use of coils, which may become blocked in these openings.

The choice of embolization materials always raises the debate between temporary or permanent devices. In young patients with healthy arteries, we feel it is preferable as a general rule to use resorbable materials in order to allow the vasculature to return to normal after the injury and not leave materials within the body. Some situations, however, require permanent materials to be used. These include occlusion of a large diameter arterial trunk, the need for very precise embolization of a small diameter artery or when necrosis of an occluded area is likely to occur (in which case there is no benefit in restoring normal vascularity). The overall cost of implantation materials is also a factor which should be considered when several devices offer equal performance.

It may be necessary in traumatology practice to repeat the embolization because of secondary reactivation of other bleeding sites. The introducer sheath should therefore preferably be left in position until the patient has become stable.

Liver injuries

Pathophysiology of injuries

The liver is a partially intra-peritoneal organ. Because of this, bleeding may occur into the liver parenchyma, the retroperitoneum or the peritoneal cavity. Various traumatic injuries are seen, with combinations of injury to the parenchyma itself, the biliary tract, and branches of the hepatic artery, portal veins or hepatic veins. Peri-hepatic surgical packing is designed to treat venous and biliary injuries by increasing tissue pressure, whereas embolization only applies to hepatic arterial injuries, which are difficult to achieve hemostasis with surgery. The hepatic artery vascularization is terminal in nature, although in practice, the co-existence of arterial and venous vascularization may explain why no complications occur with arterial embolizations outside of the gall bladder territory. These embolizations cause no ischemic biliary complications in healthy people, as opposed to hepatic artery embolization in liver transplant patients. Only obstruction of the cystic artery may result in gall bladder necrosis and this artery should therefore be spared wherever possible. Biliary injuries in liver trauma are responsible for an intense inflammatory reaction in the initial weeks of hospitalization, which very often requires surgery to clean up effusions or drain collections. Embolization therefore forms part of a global management process in which surgery plays a predominant role [1,2].

The place of endovascular treatment in management

The indications for embolization are listed in the guidelines of the American Association for Surgical Trauma (AAST) [3].

Embolization is indicated in a hemodynamically stable patient in whom CT has shown an intrahepatic leak of contrast medium (Fig. 1).

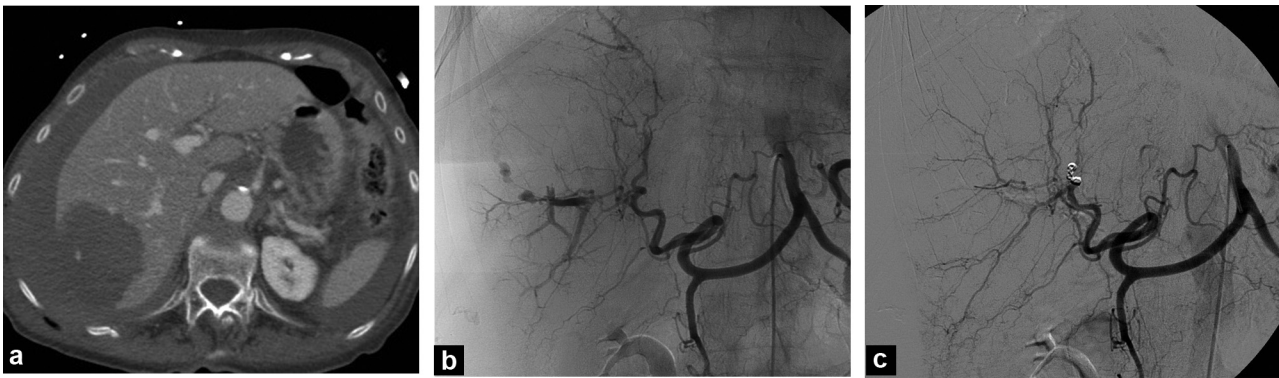


Figure 1. Eighty-seven year old man who had fallen on her right hypochondrium. Hemorrhagic shock compensated after resuscitation: a: CT after portal phase of classification: hematoma on the right side of the liver with contrast enhancement inside the hematoma; b: arteriography before embolization: extravasation of contrast medium from the branch of segment VII with arterioportal fistula; c: control angiography after embolization showing microcoils *in situ* at the origin of the branch of segment VII and abolition of the arterial leakage.

Embolization may also be indicated following the per-operative finding of a deep arterial hemorrhage. Surgeons may then position a removable clamp on the arterial pedicle and then reclose the abdominal wall, with the clamp to the skin (Fig. 2). The patient is then transferred to the angiography suite, where the clamp is released, before

carrying out hepatic arterial arteriography [1]. This management sequence is extremely effective in patients who are in severe hemorrhagic shock.

Embolization can also be considered in a patient in uncontrolled hemodynamic shock with severe liver injuries but no hemoperitoneum.

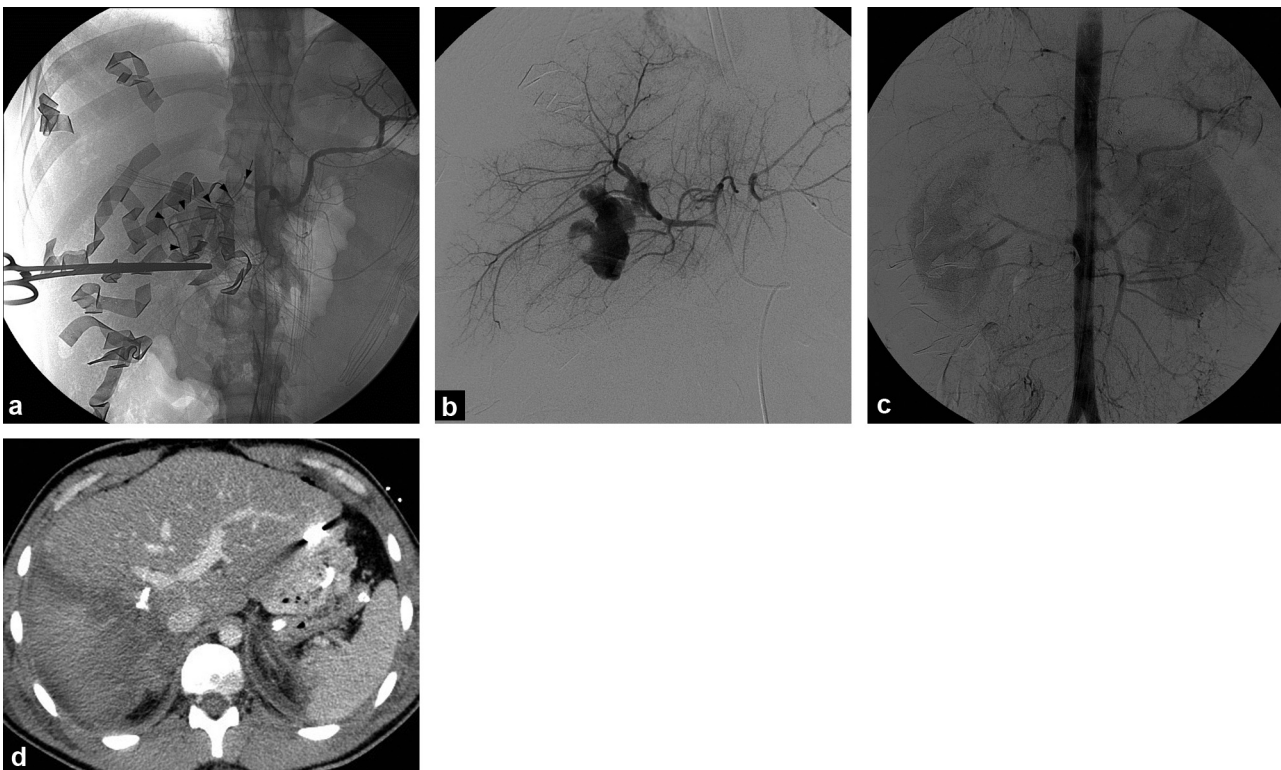


Figure 2. Twenty-five year old man, who suffered a road traffic accident. Multiple injuries with major hemorrhagic shock. Admitted to the closest hospital. First line hepatic surgical packing. Uncontrollable arterial hemorrhage. Introduction of removable clamp onto the hepatic artery pedicle, stabilizing the patient hemodynamically. The patient was transferred from the admitting hospital to the university hospital: a: arteriography without subtraction with injection into the celiac axis before removing the arterial clamp: hepatic artery occluded at the hepatic artery clamp. Multiple band-like opacifications representing the perihepatic packing compresses; b: hepatic arteriography (arrow) after releasing the clamp (arrow-heads): massive hemorrhage from the right branch of the artery; c: CT repeat after embolization after intra-aortic embolization: disappearance of the hemorrhagic leakage. No other site of bleeding; d: CT control after embolization showing ischemia on the right side of the liver, mostly due to traumatic injuries to the right portal branch.

Specific technical features of hepatic embolization

The anatomy of the celiac axis needs to be assessed wherever possible before arteriography in order to select the most appropriate catheters for the patient's anatomy (whether or not an arcuate ligament is present with vertical displacement of the course of the celiac axis).

Investigation of bleeding and embolization sites generally uses a microcatheter.

The embolization material used may be temporary or permanent, although the embolization itself should be precise. If permanent occlusion is carried out, a collateral supply network will develop rapidly.

Results of embolization

Hemostasis is achieved for arterial injuries in over 95% of cases in one session [1] and it is rare to require several embolization sessions. These may be needed in liver fracture with a large intraparenchymal hematoma and bleeding from the fracture margins, and in a local or disseminated intravascular coagulation state.

The main complication to be feared is gall bladder necrosis. Whilst hepatic parenchymal necrosis has been reported following embolization, this is generally due to pre-existing traumatic injuries to the portal venous branches, worsened by arterial obstruction.

Kidney injuries

Pathophysiology of traumatic injuries

Kidney injuries generally result in fractures of the parenchyma. Bleeding may occur from each divided section and therefore arise from several segmental arteries from different territories.

Post-traumatic renal bleeding occurs into a closed space. Its course is slow, and it represents a good indication for

embolization treatment. A hematoma within the renal space however, causes distortion of the intra-renal arteries, with curving or acute angle divisions, which can occasionally be very difficult to catheterize.

The renal vascularization is terminal and any embolization results in a loss of territory from the occluded vasculature. Embolization should therefore be used sparingly.

The place of endovascular treatment in management

Embolization is indicated for an intra-renal hemorrhagic injury discovered on computer tomography. It is also indicated in a proximal hemorrhagic injury due to rupture of the renal arterial trunk, prior to nephrectomy or as the sole treatment (Fig. 3).

Embolization technique

Distal embolization is performed using a microcatheter. It may be helpful to use angled tip microcatheters and highly curved microguides. Embolization very often uses microcoils as the delivery must be very precise (Fig. 4).

In proximal trunk embolization, a plug can be used to control detachment and avoid non targeted embolization (Fig. 3). The renal artery trunk can also be embolized with coils, provided that catheterization is stable (using a Simmons curved or a shepherd's crook catheter).

Results of embolization

The effectiveness of embolization on bleeding is reported to be between 70 and 90% [4,5], although repeated embolizations may be required in 15 to 30% of cases [4,6–8], because of a fracture with multisite bleeding from the fracture margins.

Tissue necrosis is proportional to the extent of the territory embolized. In arterial trunk embolization the main risk of complication is migration of the embolism into the aorta with a need to carry out percutaneous removal. Renal



Figure 3. Forty-nine year old male patient suffered a skiing accident: a: CT after opacification in the arterial phase with frontal reconstruction: piecemeal left kidney with destruction of the major part of the renal parenchyma and leakage of contrast medium from the inferior branch (arrows); b: left renal arteriography: rupture of the inferior branch and vascular injury to the superior branch. Decision taken to undertake embolization of the arterial trunk because of the severity of the parenchymal lesions; c: repeat angiography after proximal embolization with a plug (arrow). The patient developed sepsis, which was controlled. No nephrectomy performed.

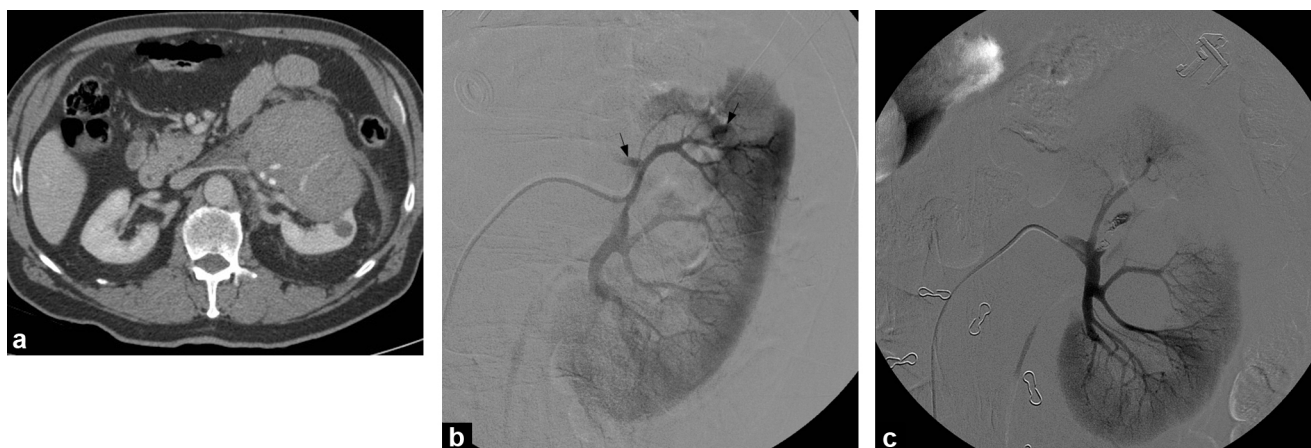


Figure 4. Sixty-three year old man who suffered a skiing accident: a: axial CT with enhancement in the parenchymal phase: large hematoma on the anterior lip of the left kidney with extravasation of contrast medium inside the kidney; b: Left renal arteriography: two bleeding sites from a superior branch (arrows); c: arteriography after embolization of the superior segmental branch by microcoils, showing cessation of the bleeding and sacrifice of the corresponding parenchyma.

necrosis due to proximal embolization may also be complicated by infection of the renal space.

Splenic injuries

The treatment of splenic injuries has changed considerably in recent years, with the development of the concept of preventative embolization of high-grade non-hemorrhagic injuries.

Pathophysiology of splenic injuries

Splenic parenchymal trauma may create a sub-capsular hematoma, an isolated intrasplenic hematoma (rare) or a fracture with rupture of the capsule, and perisplenic or even intra-peritoneal hematoma.

The spleen is a vascular sponge with highly developed sinusoidal cavities and relatively limited conjunctive tissue. This has two consequences: the fragility of the splenic tissue, which fractures easily and which enables bleeding injuries and diffusion towards the peritoneum. Contusions

to the parenchyma can also enable opacification of the sinusoidal cavities from arteriolar injuries, which may be mistaken with hemorrhagic leaks. CT images performed in the early phase followed by the late phase of opacification then shows extravasation of contrast medium which may be either localized or diffuse. Diffuse contusions give the parenchyma a dappled or “starry night” appearance (Fig. 5) which can be seen on CT and angiography. Localized extravasations are irregular and poorly defined in appearance and relatively non-intense in the early arterial phase, washing out in the parenchymal phase (through normal venous drainage) (Fig. 6). These intra-parenchymal extravasations of contrast medium mostly disappear in the venous phase of opacification and should not be confused with true hemorrhagic injuries, which enhance better, although the distinction between these two can occasionally be difficult.

The vascular supply to the spleen from the splenic artery trunk to the first two dividing branches in their extra-parenchymal path is an anastomotic supply. The splenic artery trunk gives rise to many branches leading the pancreas, forming a vascular arcade in parallel with the arterial trunk itself. The superior segmental branches

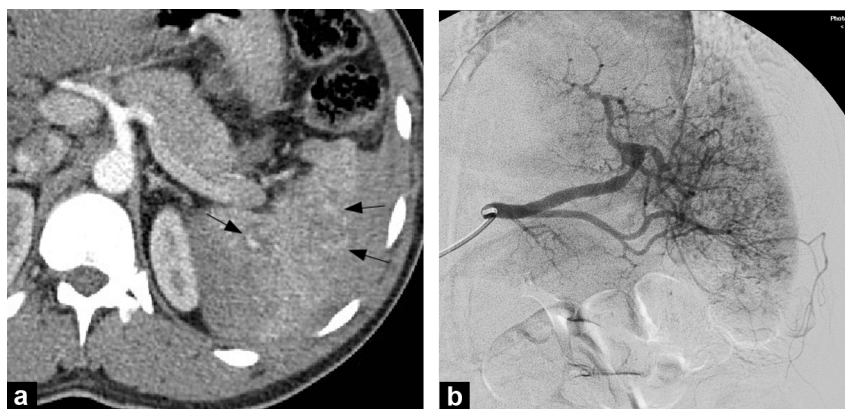


Figure 5. Diffuse splenic parenchymal contusion without bleeding: a: CT image with enhancement in the early phase: multiple punctiform hyperdensities (arrows); b: splenic angiography showing a dappled appearance reflecting simple non-hemorrhagic parenchymal contusion.

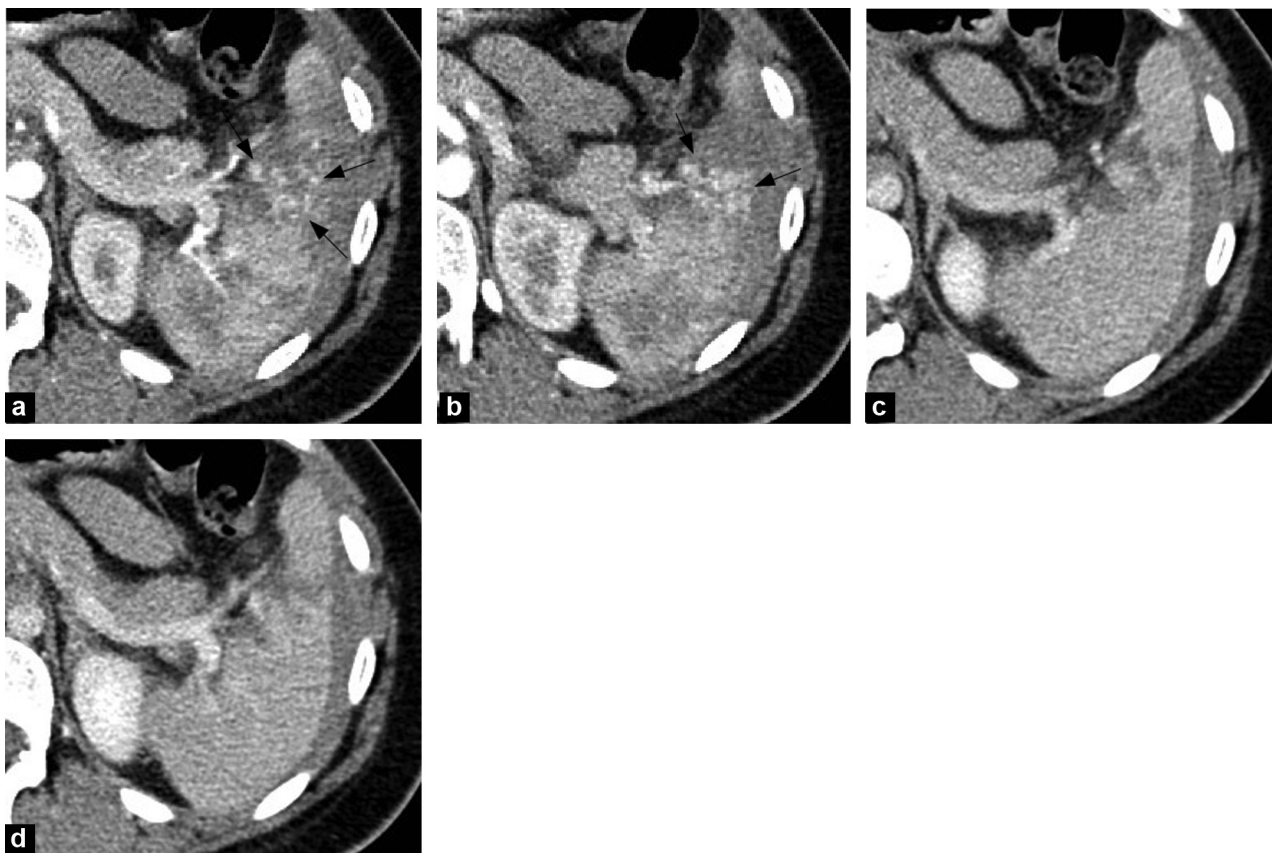


Figure 6. Localized splenic parenchymal contusion without hemorrhage: a–b: CT views after opacification in the early phase: multiple hyperdense spots in the anterior edge (arrows); c–d: CT views after opacification in the late phase: homogeneous appearance of the contusion area. Monitored without embolization.

anastomose in the extra-capsular segment with right gastric vessels and inferior segmental branch with the right gastroepiploic artery. All of these arteries can maintain splenic vascularization if the splenic arterial trunk is occluded. Intra-parenchymal splenic vascularization, on the other hand, has a terminal vascularization in which any occlusion results in necrosis of the splenic parenchyma, which is proportional to the territory occluded.

Splenic vascular lesions change greatly during the first ten days after the injury itself. Pseudoaneurysms or arteriovenous fistulae may appear or thrombose spontaneously. Secondary splenic ruptures occurring during the first week, until occasionally up to three weeks after the injury are probably due to undiagnosed or insidious traumatic arterial injuries, which rupture secondarily. This highlights the importance of a systematic routine imaging monitoring.

Indications for endovascular treatment

The purpose of splenic embolization is to improve the patient's functional prognosis (preserving their immunity), although this should not be at the cost of their overall prognosis. Surgical splenectomy is therefore used a general rule in hemodynamically unstable patients, except in very rare cases, which should be considered on an individual case basis (multisite bleeds).

The indications for embolizing splenic injuries are listed in the AAST guidelines [9].

In a patient who is hemodynamically stable, any hemorrhagic lesion identified in the arterial phase of a CT should be treated by embolization, as should any splenic artery abnormality found on CT: pseudoaneurysm (Fig. 7) arteriovenous fistula, or abrupt cutoff of a large diameter arterial branch. This last indication is more debatable as embolization of this type of lesion carries a risk of reactivating the hemorrhage by releasing spasm in the injured artery.

A further indication for treatment has emerged since 2006 with the publications by Haan et al. [10] and Gaarder et al. [11] who showed that proximal embolization of the splenic arterial trunk in hemodynamically stable patients without hemorrhagic lesions on CT could reduce the risk of secondary splenectomy. The purpose of embolization in this case is to reduce splenic vascularization pressure after occlusion, with an average reduction of 40 mmHg, which would appear to be sufficient in the majority of cases to allow traumatic vascular injuries to heal. Such preventive proximal embolization is used in patients with grade IV and V trauma (Fig. 8) of the AAST classification and in grade III trauma (Fig. 7) with a risk factor (age over 50 years old, large hemoperitoneum, concomitant traumatic injuries increasing the risk of bleeding).

Embolization technique

Firstly, the anatomy of the celiac axis should be analyzed on the pre-treatment CT. If the celiac axis is horizontal, a



Figure 7. Thirty year old man, who suffered a surfing accident. Isolated grade 3 splenic injury with hemoperitoneum. Initially refused embolization. Repeat embolization on D+5: a: CT view with enhancement: appearances of splenic pseudoaneurysm; b: CT with sagittal reconstruction. Short compression of the celiac axis by the diaphragm with horizontal path beyond that. Catheterization possible with a Cobra catheter, assembled with a flexible valve introducer; c: arteriography with injection into the inferior segmental branch: several pseudo-aneurysms present; d: repeat view after triple distal embolization with microcoils and proximal embolization with a plug and coils.

hydrophilic Cobra catheter is sufficient, whereas if it follows a descending path a tightly-curved catheter is indicated (shepherd's hook or Simmons catheter). If the celiac axis is compressed by the arcuate ligament and the compression is short, it may be corrected with a 180° curved catheter (Fig. 7), whereas if the compression is long a humeral approach may be preferable, using a multipurpose catheter.

Proximal embolization should be segmental, short and ideally between the origin of the dorsal pancreatic artery and the pancreatica magna, although these two arteries

cannot always be identified individually, and a large number of anatomical variations in pancreatic vascularization exist. In practice, the occlusion is performed in the middle part of the artery, and if catheterization is more difficult, in the proximal part. This is often the case if the splenic artery is very tortuous. Occlusion uses a type II Amplatzer plug if it is possible to connect a flexible valve introducer or a guide catheter in the artery (Fig. 7), failing which, a type IV plug with an armored wall catheter when catheterization is more difficult. Finally, if it is impossible to introduce a plug, an

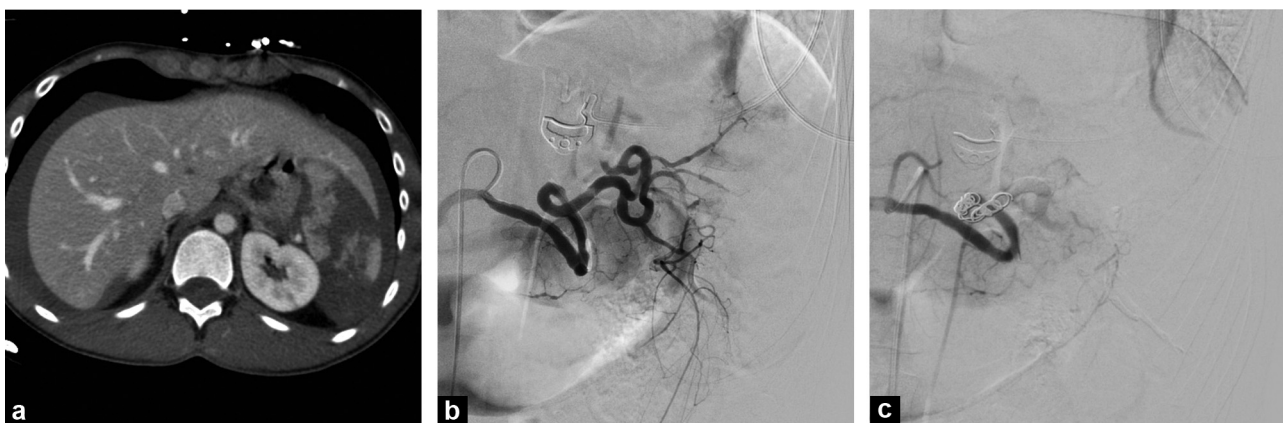


Figure 8. Twenty-eight year old man who suffered a skiing accident: grade 5 splenic injury: a: CT view after opacification: shattered spleen; b: splenic arteriography: diffuse defect on parenchography but not hemorrhagic lesions. Difficult vascular anatomy with vertical celiac axis. Proximal embolization with coils; c: repeat angiography after embolization showing proximal occlusion.

arterial trunk can be occluded with 0.035 inch rigid fibered coils, between 6 and 8 mm in diameter (Fig. 8).

Distal embolization should be very limited, as this causes necrosis. Either resorbable or non-resorbable materials can be used. Microcoils enable highly targeted (Fig. 7), precise occlusion, although do not always reach arteries with a diameter of less than 1 mm in diameter. In this situation, gelatin microfragment embolization may be useful.

Results of embolization

Embolization of hemorrhagic splenic injuries can achieve hemostasis in the site of hemorrhage in over 90% of cases [12]. Multiple procedures are rare.

Preventative embolization for splenic injuries can reduce the splenectomy rate by an average of 18% [11].

The complications of embolization are rare and mostly involve extensive splenic necrosis in the event of proximal embolization of a long arterial segment or in the elderly, together with infection, pancreatitis involving the tail of the pancreas in case of untargeted embolization of the pancreatic artery and dissection or rupture of the splenic artery during catheterization in a difficult anatomical situation. Some series have reported high rates of complications for embolization [13,14] as they included both complications specific to the technique and adverse events due to the injury or other treatments. In our experience, the risk of adverse events in splenic injuries is due only to the initial severity of the injury, patient age and co-existent traumatic injuries. These adverse events are independent of the method of treatment, either surgery, embolization or monitoring.

Organization of traumatology care

Organization of traumatology care into centers and networks is a major factor in improving care [15,16].

Within the center itself, a specialist traumatology care team combining surgeons (emergency surgeons, visceral and thoracic surgeons and orthopedic surgeons), anesthetists, intensive care physicians and interventional radiologists should be individualized. This team should continuously implement up-to-date patient management protocols, analyze operational issues through multi-disciplinary morbidity and mortality meetings and offer both in-house and external training activities.

Within the region, a traumatology network defining patient management pathways is essential, based on the centers contributing to emergency care, their technical platform and medical resources available, updating these alongside medical change and monitoring their effectiveness.

Both interventional and non-interventional radiologists should form part of these teams both locally and within the care network.

Take-home messages

- Embolization for abdominal solid organ injuries is indicated if any leakage of contrast medium is seen on an enhanced CT.

- Embolization is not indicated if a large hemoperitoneum is present, except in multisite bleeding. This decision should be taken after a multi-disciplinary discussion.
- Preventative embolization for high-grade splenic injuries with no CT signs of bleeding is a specific indication for this organ.
- Splenic parenchymal contusions may produce appearances of localized or diffuse extravasation of contrast medium, which should not be confused with true arterial leakages.
- Intrahepatic arterial hemorrhages seen peroperatively may be treated effectively by clamping the hepatic artery pedicle with a removal clamp and then transferring the patient for embolization.
- Proximal renal artery embolization is a legitimate indication which can defer or avoid hemostatic nephrectomy.
- In traumatology, temporary embolization agents should be preferred, except in specific cases.
- Embolization in traumatology may require several sessions, although this does not represent a failure of treatment.
- Organization of care into centers and networks is an essential factor in improving traumatology care. The interventional radiologist should contribute to this organization.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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