EMERGENCY RADIOLOGY SPECIAL FEATURE: REVIEW ARTICLE

The role of interventional radiology in abdominopelvic trauma

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ABSTRACT

The management of trauma patients has evolved in recent decades owing to increasing availability of advanced imaging modalities such as CT. Nowadays, CT has replaced the diagnostic function of angiography. The latter is considered when a therapeutic option is hypothesized. Arterial embolization is a life-saving procedure in abdominopelvic haemorrhagic patients, reducing relevant mortality rates and ensuring haemodynamic stabilization of the patient. Percutaneous transarterial embolization has been shown to be effective for controlling ongoing bleeding for patients with high-grade abdominopelvic injuries, thereby reducing the failure rate of non-operative management, preserving maximal organ function. Surgery is not always the optimal solution for stabilization of a patient with polytrauma. Mini-invasivity and repeatability may be considered as relevant advantages. We review technical considerations, efficacy and complication rates of hepatic, splenic, renal and pelvic embolization to extrapolate current evidence about transarterial embolization in traumatic patients.

INTRODUCTION

Injuries are the third leading cause of death across all ages.[1] Active bleeding is the most common cause of death among trauma patients. While surgery is often considered the definitive treatment for bleeding control, it may not always be the optimal solution for stabilization of a patient with polytrauma. Specifically, arterial haemorrhage arising from pelvic fractures[1–3] and solid organ injuries[4–6] is amenable to management with angiography and embolization.

Abdominopelvic injuries present a challenge for the emergency department. A multidisciplinary team, comprising an orthopaedic trauma surgeon, a general surgeon, an anaesthesiologist, a radiologist and an interventional radiologist, evaluates each case.

All the protocols[5] reported in literature are based on the "damage control orthopaedics (DCO)";[3,6] therefore any intervention, as rapid as possible, should be focused on haemorrhage control and on other life-saving measures. The arterial inflow arrest, pelvic sling and external fixation devices for pelvic fractures, direct surgical haemostasis, angiography and embolization represent treatment options that should be considered for the emergency haemostasis of abdominopelvic traumas.[4,5] External devices, easily applied, can be used effectively.[3–6]

Owing to the lack of randomized trials evaluating the efficacy of arterial embolization in the trauma setting, the Eastern Association for the Surgery of Trauma guidelines offered Level 2 recommendations for angiography and embolization as a first-line treatment of liver injuries "for a patient who is a transient responder to resuscitation as an adjunct to potential operative intervention".[7]

Several studies[8,9] have demonstrated a valuable role for angiography and embolization in these settings.

The purpose of this study was to evaluate and review indications, techniques, results, complications and future developments in utilization of angiography and embolization for abdominopelvic traumatic patients.

MATERIALS AND METHODS

A review of international literature on abdominopelvic traumatic lesions, pelvic ring fractures and angioembolization was carried out through PubMed with the following medical subject heading: "blunt abdominal/liver/spleen/

Table 1. Authors, patients and their traumatic characteristics, embolic agent used, number of sessions, technical and clinical successes, cases of rebleedings, complications and mortality rates

Authors	Number of patients	Trauma	AAST (grade)	Associated lesions	ISS [range (media)]	Number of sessions	Embolic agent	Technical success (%)	Clinical success (%)	Rebleeding	Complication and mortality
Kozar et al[13]	12	NS	IV: 8 V: 4	NS	NS	NS	NS	100	100	NS	NS
Laopaiboon et al[14]	9	NS	NS	NS	NS	10	Gelfoam Coils PVA	100	88.8	1	0
Monnin et al[15]	14	NS	III: 2 IV: 9 V: 3	NS	11.94	NS	Gelfoam PVA Coils	100	85.72	0	0 related to TAE; 1 died of complications of transfusion; 2 gallbladder infarction
Misselbeck et al[16]	58	NS	NS	NS	NS	NS	Gelfoam Coils	100	98.3	NS	9 complications (3 surgery, remaining conservative); 9 died: 1 died of liver failure; 8 died of concomitant trauma
Letoublon et al[17]	13	NS	III: 6 IV: 7	NS	NS	13	NS	100	100	0	1 died of complications 0 for TAE
Wang et al[18]	8	NS	III: 3 IV:3 V: 2	NS	9–43 29	5	Gelfoam Coils	73	50	1	2 died (1 died of concomitant trauma; 1 died of uncontrolled haemorrhage)
Ochiai et al[19]	134	NS	NS	NS	NS	NS	NS	100	95.5	NS	14 died: 8 died of concomitant trauma; 6 died of uncontrolled haemorrhage
Mohan et al[20]	6	NS	III: 3 IV: 2 V: 1	NS	NS	15	PVA Coils	NS	93	1	0
Kong et al[21]	70	NS	II: 13 III: 25 IV: 23 V: 9	NS	NS	NS	Coils	100	100	NS	19 complications related to TAE
Lee et al[22]	48	NS	II: 5 III: 14 IV: 25 V: 4	NS	NS	52	Gelfoam Coils	81.2	NS	NS	5 died (2 died of liver infections; 3 died of associated trauma); 0 TAE related complications

AAST, American Association for the Surgery of Trauma; ISS, Injury Severity Score; NS, not specified; PVA, polyvinyl alcohol; TAE, transarterial embolization.

renal trauma", "retroperitoneal bleeding/trauma", "pelvic fractures/injury/trauma/bleeding" and "transarterial embolization/interventional radiology".

All titles and abstracts of studies identified in the initial search were screened to identify those reporting on patients with traumatic lesions of solid organs or pelvic bleeding undergoing transarterial embolization (TAE) as one of the initial life-saving interventions. We identified additional studies through hand searches of bibliographies from primary studies, review articles and key journals. Case reports, small series revisions and articles that contained data reported previously were excluded and only articles in the English language or published after 2002 were included. Articles were considered eligible for inclusion in the present review if at least one outcome of interest was described; if articles dealing with traumatic and non-traumatic causes of bleeding, traumatic patients were extracted.

The following variables were extracted, where available, from the included articles: number of patients; trauma and its grading on the basis of American Association for the Surgery of Trauma Organ Injury (AAST),[10,11] associated lesions, injury severity score (ISS),[12] number of sessions of treatment, embolic agent used, technical success, clinical success, rebleeding rate, complication and mortality rate. Data are reported as described in the studies: authors sometimes reported a range and/or a median value and sometimes reported a rate and/or a value.

Before extracting data from the eligible studies, clear definitions of all outcomes of interest were established. Efficacy rate of TAE was defined as the frequency of successful embolizations in each study. Successful embolization was defined as cessation of contrast medium extravasation in post-TAE imaging without any need for further intervention (repeat TAE or surgical approach), as clearly mentioned in each manuscript. Mortality was defined as early patients' death before discharge, with the following causes: persistent haemorrhage, concomitant trauma and complications (adult respiratory distress syndrome, multiple organ failure, sepsis). Mortality due to all above causes was defined as overall mortality. Angio-related complications were those associated with the angiography and embolization procedures, such as major puncture site complications (haematoma, infection, femoral artery dissection, aneurysm or pseudoaneurysm formation, a–v fistula, leg ischaemia); gluteal muscle, bladder or intestinal necrosis; liver or renal failure, ischaemia of the gallbladder, abscesses of large necrotic areas (hepatic, splenic or retroperitoneal), major allergic reactions.

RESULTS
Liver injuries
We selected a total of 10 studies,[13–22] involving a total of 360 patients (Table 1).

Mechanism of injury was not specified in all studies,[13–22] even if motor vehicle accident was the most frequent cause[13–22] (Figure 1a–c).

Figure 1. Arterial phase of contrast-enhanced CT revealed an extensive active bleed (a); selective angiogram confirmed bleed (b); final angiogram performed after embolization with sponge and coils (c).
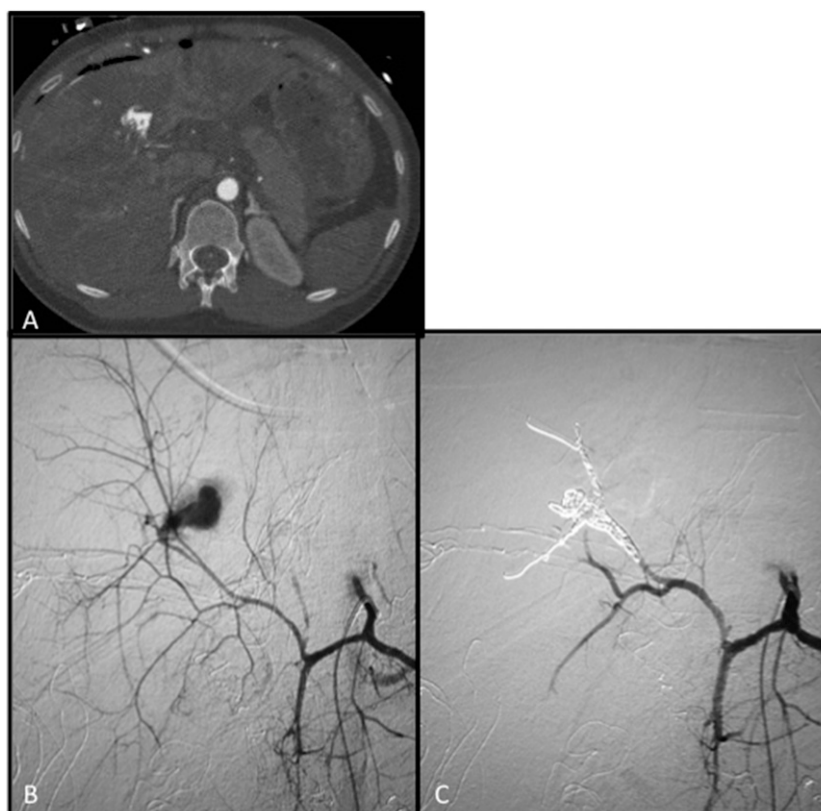
The AAST grade of liver injury was reported in almost all the studies,[13,15,17,20–22] in particular in a total of 172 patients, as reported below, 18 Grade II, 53 Grade III, 77 Grade IV, 23 Grade V injuries.

Mean ISS was reported in only two studies[15,18] having an overall mean value of 20.47. Associated lesions were not specified;[13–22] authors often reported multiple associated injuries.

In almost all the studies,[14–16,18,20–22] materials used to embolize were coils, gelfoam and polyvinyl alcohol particles (PVA). The choice of the materials used to embolize was based on the operator's preference and expertise (Figure 2a–c).

Technical success was reported in nine studies,[13–19,21,22] with a mean value of 94.9%; distributed as follows: 100% ($n = 7$); 81.2% ($n = 1$); and 73% ($n = 1$).

Clinical success was reported in nine studies,[13–21] with a mean value of 79.8% in particular: 100% ($n = 3$); 98.3% ($n = 1$); 95.5% ($n = 1$); 93% ($n = 1$); 88.8% ($n = 1$); 85.7% ($n = 1$); and 50% ($n = 1$).

Rebleeding rate was another data mostly not reported.[13,16,19,21,22] In some cases, when reported,[14,15,17,18,20] a second transarterial embolization was performed.

Complications were reported in nine studies.[14–22] Complications have been described differently; on the basis of the definitions of the present review, complications related to embolization were gallbladder infarction, hepatic necrosis, liver abscess described by Kong et al.[21] Monnin et al[15] registered two cases of gallbladder infarction but they did not attribute it to embolization.

Most of the complications described were managed conservatively; cholecystectomy was performed when necessary.[15] Misselbeck et al[16] described nine complications after TAE (three managed operatively) and in total they described only one death related to liver failure.

The overall mortality rate was usually related to concomitant trauma or to uncontrolled haemorrhage (Table 1).[15–19,22] Embolization was never described as a direct cause of death, it may be considered as a co-factor (for example, the death described by Misselbeck et al[16] for liver failure or the two deaths for liver infections reported by Lee et al[22]).

Spleen injuries

We identified 20 studies,[23–42] involving a total of 939 patients who underwent splenic angioembolization (SAE) for traumatic lesions (Table 2). All 20 studies that were included were retrospective cohort studies.

All included patients sustained blunt mechanism of injury, and the overall mean America Association for the Surgery of Trauma Organ Injury (AAST)–Organ Injury Scale (OIS)[6,8] AAST-OIS grade of splenic injuries was 3.65. In the table, mean value is indicated because most of the studies reported it.

SAE could be distal (selective), proximal (splenic artery) or combined.[43] Proximal embolization was performed significantly more often than distal embolization (601 patients *vs* 144 patients; 64% *vs* 15.33%).[23–25,27–40] A combination of both techniques was applied in only 30 patients (3.19%).[23–25,27–40] In 164 patients (17.35%), SAE procedure was not described in detail (three studies)[26,41,42] (Figure 3a–e).

Embolic agents used were coils or gelatine particles in 417 patients (11 studies), vascular plugs in 13 patients (1 study[35]), coils or PVA particles in 1 study (13 patients[25]) (Figure 4a–d).

Technical success was described in seven studies, with a mean value of 93.3%, with complete exclusion of the lesion.[27–30,33,40] Clinical success was reported in 19 studies.[23–41]

In some studies,[26,27] the effectiveness of SAE could be masked when the outcomes of patients treated with observational management and SAE are combined in terms of non-operative management. Average rate is 84.6%.

Figure 2. Initial arteriography revealed a little pseudoaneurysm (PSA) (arrow) (a); PSA was embolized with a microcoil (arrow) deployed proximally on the basis of the tortuosity of the vessel (b); final angiogram confirmed complete embolization (c).
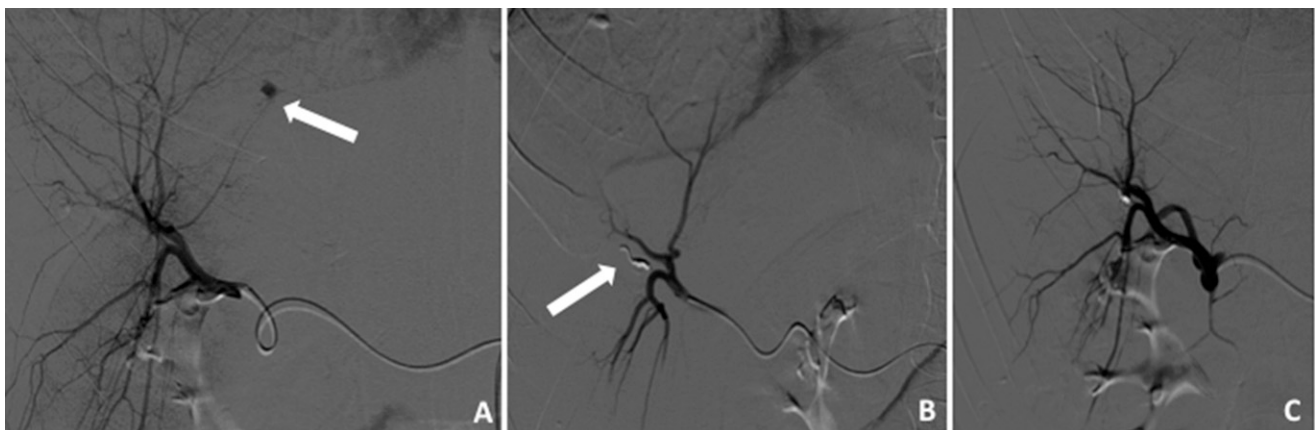
Table 2. Authors, patients and their traumatic characteristics, embolic agent used, number of sessions, technical and clinical successes, cases of rebleedings, complications and mortality rates

| Authors	Number of patients	Trauma	AAST (grade)	Associated lesions	ISS	Number of sessions/ proximal–distal SAE	Embolic agent (if indicated)	Technical success (%)	Clinical success (%)	Rebleeding	Complications and mortality
Hagiwara et al[23]	15	NS	4	NS	33	9 proximal embolization 1 distal 5 combined	Coils/gelatine particles	100	100	0	0%
Liu et al[24]	6	NS	3.7	NS	NS	6 distal	Coils/gelatine particles	NS	83.3	1	1 splenectomy
Dent et al[25]	13	NS	3.7	NS	26	13 distal	Coils/particles	NS	92.3	1	0%
Wahl et al[26]	24	NS	3.8	NS	27	NS	NS	NS	98 (NOM)	NS	0%
Haan et al[27]	140	NS	3.5	NS	20	83 proximal 48 distal 9 combined	NS	91.3	90 (NOM)	3	5 splenectomy (3 abscesses and 2 missed diaphragmatic injuries) 3 coils migration
Bessoud et al[28]	37	NS	3.7	NS	29	37 proximal	Coils	100	97.3	1	1 splenectomy
Cooney et al[29]	9	NS	3.1	NS	24	6 proximal 3 distal	Coils/gelatine particles	89	66.7	1	2 delayed splenic infarction mortality 0%
Smith et al[30]	41	NS	3.1	NS	NS	27 proximal 9 distal 5 combined	Coils/gelatine particles	73	73	9	3 splenectomy 1 femoral artery dissection 1 femoral arteriovenous fistula 1 splenic artery dissection 1 splenic abscess
Gaarder et al[31]	27	NS	3.5	NS	31	21 proximal 2 distal 4 combined	Coils/gelatine particles	NS	92.3	1	0%
Haan et al[32]	130	NS	NS	NS	24.8	130 proximal	NS	NS	95	27 persistant PSA 5 new PSA	2 splenectomy 1 splenorrhaphy
Wei et al[33]	51	NS	3.8	NS	29	14 proximal 37 distal	NS	100	98	NS	1 splenectomy (for abscess)
Duchesne et al[34]	76	NS	2.9	NS	29	76 proximal	Coils/gelatine particles	NS	71	22	NS

(Continued)

Table 2. (Continued)

Authors	Number of patients	Trauma	AAST (grade)	Associated lesions	ISS	Number of sessions/ proximal–distal SAE	Embolic agent (if indicated)	Technical success (%)	Clinical success (%)	Rebleeding	Complications and mortality
Widlus et al[35]	13	NS	3.7	NS	NS	13 proximal	Amplatzer vascular plug	NS	84.6	NS	0%
Wu et al[36]	21	NS	3.4	NS	26	3 proximal 16 distal 2 combined	Coils/gelatine particles	NS	76.2	4	NS
Kaseje et al[37]	11	NS	4.4	NS	27	8 proximal 3 distal	NS	NS	81.9	2	NS
Sabe et al[38]	156	NS	3.5	NS	20.1	156 proximal	Coils	NS	92.3	12	9 splenectomy 3 splenorrhaphy
Ekeh et al[39]	15	NS	3.5	NS	24	10 proximal 1 distal 4 combined	Coils/gelatine particles	NS	93.3	2	2 splenectomy
Franco et al[40]	14	NS	3.1	NS	18.5	8 proximal 6 distal	Coils/1 gelatine particles	100	92.9	1	1 splenectomy
Chen et al[41]	11	NS	4	NS	14	NS		NS	100	NS	0%
Rosati et al[42]	129	NS	NS	NS	29.1 ± 1.0	NS	NS	NS	NS	NS	3.9%

AAST, American Association for the Surgery of Trauma; ISS, Injury Severity Score; NOM, non-operative management; NS, not specified; PSA, pseudoaneurysm; PVA, polyvinyl alcohol; SAE, splenic arterial embolization.

Figure 3. Contrast-enhanced CT revealed splenic haematoma with active bleeding (a); selective angiogram confirmed active bleeding (b); angiogram performed after embolization with coils (c); ultrasound performed during follow-up showed a subcapsular ipoanechoic area (d) corresponding with an infarct area at contrast-enhanced ultrasound (CEUS) (e).
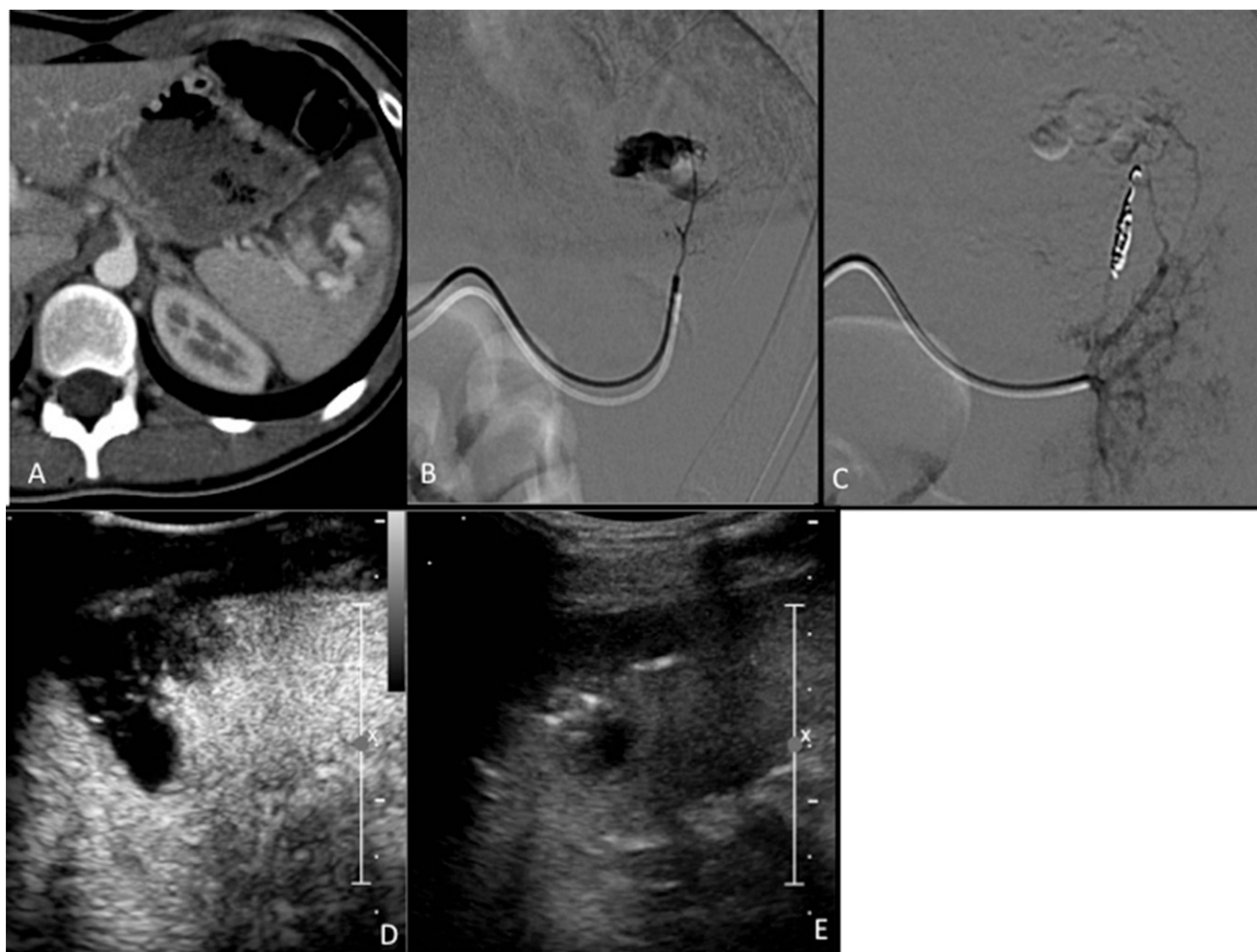
In 60 cases (6.38%), bleeding recurrence was observed;[24,25,27–32,34,36–40] Haan et al[32] observed 27 persistent splenic pseudoaneurysm (PSA) and 5 new splenic PSA after first coil embolization. In a total of 25 patients,[32] splenectomy was required (splenectomy was required for infectious complications in 4 patients), and in 4 patients, splenic angiography was performed again,[32] with a mean SAE failure rate of 14.67% and clinical success ranged from 67.6% to 100% (mean 84.33%). Other complications described were splenic abscess, delayed splenic infarction, splenic artery dissection, femoral artery dissection and femoral arteriovenous fistula, coils migration (Table 2).[27,30,33,42]

Smith et al[30] failed non-operative/SAE management in 27% of patients. None of the patients ($n = 9$) with low-grade injury (I, II) and mild or absent haemoperitoneum failed transarterial embolization, whereas 10 of the 23 patients (43%) with high-grade injury (III, IV, V) and moderate or large haemoperitoneum failed.

Renal injuries
We selected a total of 20 studies,[44–63] involving a total of 306 patients (Table 3) (Figure 5a–c).

Mechanism of injury was not specified in three studies.[54,55,59] When reported,[44–53,56–58,60–63] the cause was blunt renal trauma (majority caused by motor vehicle accidents) in 87.4% of the cases and penetrating injuries (gunshot or stab wounds) in 12.6% of the cases.

The AAST grade of renal injury was reported in almost all the studies as reported below: 9.1% Grade II injuries, 18.2% Grade III, 50.48% Grade IV, 22.59% Grade V injuries.

Mean ISS was reported in only eight studies,[50–52,55,58–61] having an overall mean value of 23.37. The most frequently associated lesions were pelvic bleeding in 23.4% of the reported cases, thorax injuries in 23.4% of the cases, spleen injuries in 21.2%, liver injuries in 17% and central nervous system injuries in 14.8%.

In half of the studies,[48,50,54,55,57–60] there were no reported data on the materials used to embolize. However, in the studies[44–47,49,51–53,56,61–63] that reported embolic materials they were distributed as follows: 47.8% coils, 21.7% coils and

Figure 4. CT revealed voluminous splenic haematoma with arterial bleeding in the context (a); selective angiography of the intrasplenic bleeder (b); complete embolization with ethylene vinyl alcohol copolymer (c); final angiogram showed complete embolization of the bleed (d).

gelfoam combined, 18.4% only gelfoam, 6.5% glue, 3% Onyx, 2% PVA. The choice of the materials used to embolize was based on the operator's preference and expertise (Figure 6a–e).

Technical success was 96.2%. Clinical success was 90.92%. Rebleeding rate was mostly reported,[44–48,50–58,60–63] having an overall rate of 25.6%. The overall mortality rate was 8.5%.[44–48,50–56,58,61–63]

Pelvic injuries
We selected a total of 13 studies,[3,64–75] involving a total of 627 patients (Table 4) (Figure 7a–e).

Mechanism of injury was not always reported.[65,67–69,72–75] When reported,[3,64,66,68,70,71,73,74] the major cause was motor vehicle accidents; pedestrian accidents, crushs, falls, train accidents and stabbings were the less frequently reported causes.[3,64,66,68,70,71,73,74] The AAST grade was not specified;[3,64–75] in some studies,[66,68–70] patients were haemodynamically unstable. Haemodynamic instability was defined as systolic arterial pressure <90 mmHg after an additional infusion of normal saline (generally 500–1000 ml) and a continuous infusion of dopamine was started.[1,10,12] In most cases, thoracic and abdominal bleeding, cardiac tamponade and pneumothorax tension were investigated simultaneously to pelvic haemorrhages.[64,67–75] Laparotomy was indicated by concomitant haemodynamic instability and progressive abdominal effusion or

by the existence of a pneumoperitoneum. The most frequently associated lesions were multiple lesions, in particular involving abdominal organs.[64,67–75]

In the case of combined intraperitoneal and retroperitoneal bleeding, the attending physician could choose pelvic angiography or exploratory laparotomy as the first-line treatment.[76]

Mean ISS was reported in 11 studies;[65–69,71–75] in most of them, a mean value or a range is reported.[65–67,69,71–75]

In most studies,[65,66,68,69,71–75] there were no reported data on the materials used to embolize. However, in the studies[3,64,67,70] that reported embolic materials they were coils, gelfoam, coils and gelfoam combined, particles and plug[3,64,67,70] (Figure 8a–e). The choice of the materials used to embolize was based on the operator's preference and expertise. Technical success was reported in 11 studies;[3,68–75] the overall rate is 98.9%.

Clinical success was reported in 10 studies;[3,64,67–73,75] the overall rate is 91.75%. Rebleeding rate was reported in 10 studies,[3,64,67–73,75] having an overall rate of 9.7%. Among the cases of rebleedings, some were from new sites or from controlateral sites.[72,75]

The overall mortality rate was 15.3%;[3,64–75] however, none described deaths related to the procedure of embolization

Table 3. Authors, patients and their traumatic characteristics, embolic agent used, number of sessions, technical and clinical successes, cases of rebleedings, complications and mortality rates

| Authors	Number of patients	Trauma	AAST (grade)	Associated lesions	ISS	Number of sessions	Embolic agent	Technical success (%)	Clinical success (%)	Rebleeding	Mortality
Dinkel et al[44]	9	5 traffic accidents 1 gunshot wound 3 falls	III: 5 IV: 1 V: 3	1 spleen + bladder 1 liver + pancreas + biliary tract	NS	9	7 microcoils 2 PVA particles	100	100	0	0
Chatziioannou et al[45]	2	Blunt trauma	4	NS	NS	2	Coils	100	100	0	0
Sofocleous et al[46]	22	11 accidents 10 penetrating injury 1 fall	IV: 17 V: 5	2 liver 2 spleen 4 colon 1 RP bleeding 2 thorax 1 CNS	NS	24	9 microcoils 9 coils 3 gelfoam 1 gelfoam and PVA	91	82	2	3 (1 for CNS injury)
Nicola et al[47]	2	1 traffic accident 1 stab injury	IV	NS	NS	2	Coils	100	100	0	0
Breyer et al[48]	16	5 traffic accidents 4 falls 6 penetrating injuries	V: 5 III–IV: 11	NS	NS	NS	NS	81	63	6	12.5% (n = 2)
Mohsen et al[49]	19	15 blunt renal trauma 4 penetrating trauma	NS	NS	NS	NS	Coils PVA	88	NS	NS	NS
Chow et al[50]	18	79.9% traffic accidents 15.8% falls 2.6% assault 2.6% sport	IV–V (100%)	36.8% liver 36.3% spleen 36.8% retroperitoneal haemorrhage 39.5 bone injury	29.5 SD 14.2	18	NS	94.4	88	5.4%	5.4%
Morita et al[51]	17	9 traffic accident 4 falls 2 violence 2 sports injuries	NS	8 thorax injuries 2 pelvic fractures 4 head injury	24	17	10 gelfoam 3 coils 4 coils and gelfoam	100	100	0	0
Kiankhooy et al[52]	3	2 accidents 1 fall	IV	1 liver	22.4 ± 10.0	3	Coils	100	100	0	0
Eassa et al[53]	2	1 traffic accident 1 fall	V	NS	NS	2	Coils	100	100	0	0
Brewer et al[54]	9	NS	V	Abdominal organ injury (100%)	NS	9	NS	100	100	0	0

(Continued)

Table 3. (Continued)

Authors	Number of patients	Trauma	AAST (grade)	Associated lesions	ISS	Number of sessions	Embolic agent	Technical success (%)	Clinical success (%)	Rebleeding	Mortality
Menaker et al[55]	22	NS	II: 2 III: 2 IV: 17 V: 1	6 patients with multiple lesions	28.2 ± 10.7	22	NS	100	83.8	6 (27.2)	1 (4.5%)
Müller-Willeter et al[56]	3 (1 both kidneys)	2 falls 1 motor vehicle accident	IV	1 pneumothorax + pulmonary contusion + humerus and hip fracture 1 both kidneys + liver	NS	3	Onyx	100	100	0	0
Hotaling et al[57]	77	87.9% blunt trauma	IV: 36 V: 12 III: 12 II: 17	NS	NS	87	NS	87	22.7	88.3%	NS
van der Vlies et al[58]	6	84% high energy	III: 1 IV: 2 IV: 3	NS	17	6	NS	100	100	0	0
Lin et al[59]	22	NS	NS	Multiple	20.9	28	NS	100	95.5	6	0% mortality 1 nephrectomy
Van der Wilden et al[60]	25	Majority accidents	IV–V	Multiple	22.7	27	NS	100	92	2	NS
Saour et al[61]	10	7 motor vehicle accidents 3 falls	III: 1 IV: 4 V: 5	1 liver 1 pelvic bleeding (TAE for both)	20.5 (4–66)	10	6 microcoils 4 spongocoel	90	90	10%	10%
Rao et al[62]	16	13 traffic accidents 2 falls 1 assault	III: 12 IV: 3 V: 1	2 pelvic bleeding 1 liver 3 cerebral trauma 1 haemothorax	NS	NS	Coils and gelatin sponge	94	100	0	6% (CNS trauma)
An et al[63]	6	Blunt trauma	III	NS	NS	6	Glue	100	100	0	0

AAST, American Association for the Surgery of Trauma; CNS, central nervous system; ISS, Injury Severity Score; NS, not specified; PVA, polyvinyl alcohol; TAE, transarterial embolization.

Figure 5. Contrast-enhanced CT showed renal haematoma with active arterial bleeding in the context (a); selective angiogram confirmed active bleeding (b); angiogram performed at the end of embolization with ethylene vinyl alcohol copolymer (c).
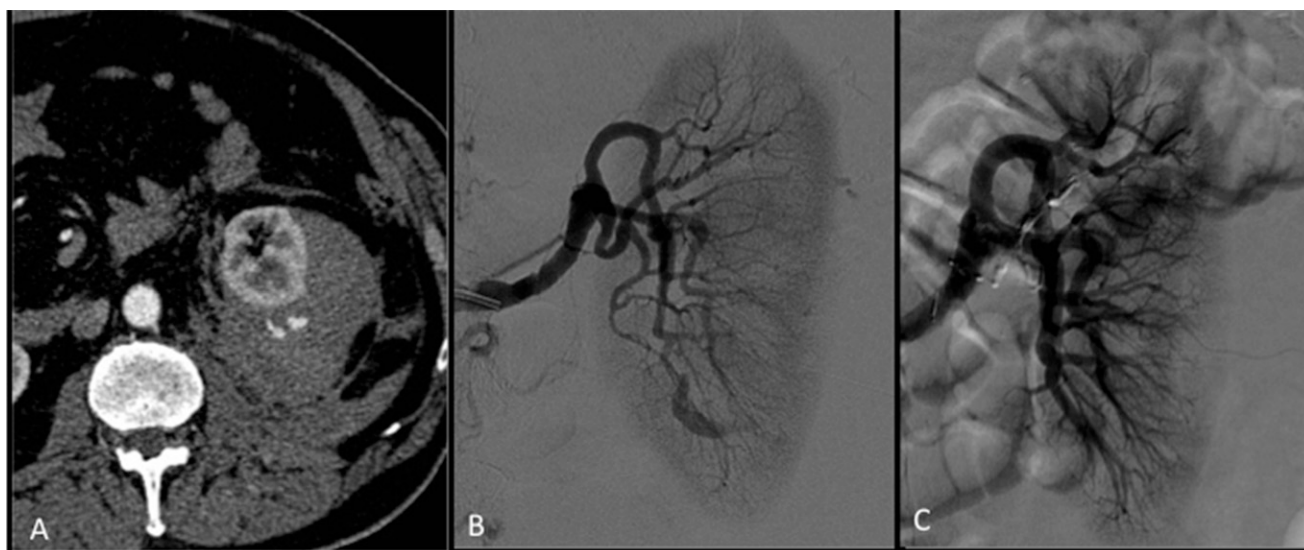
(Table 4); Sarin et al[65] did not indicate the cause of deaths registered.

DISCUSSION

The main purpose of the present review was to evaluate and analyse indications, techniques, results, complications and future developments of arterial embolization in abdominopelvic haemorrhages.

In the last years,[77] a significant decreasing utilization for angiography was registered. Improved patient selection for angiography may have been a factor contributing to decreased use.

Figure 6. CT showed renal haematoma with two little arterial bleeds in the context: axial view (a) and coronal MIP view (b); selective angiogram of the left kidney confirmed the two little bleeds (white arrows) (c); the upper bleed was embolized with ethylene vinyl alcohol copolymer (black arrow) and superselective angiogram confirmed second bleed (white arrow) (d); both bleeds were embolized with ethylene vinyl alcohol copolymer (arrows) (e).
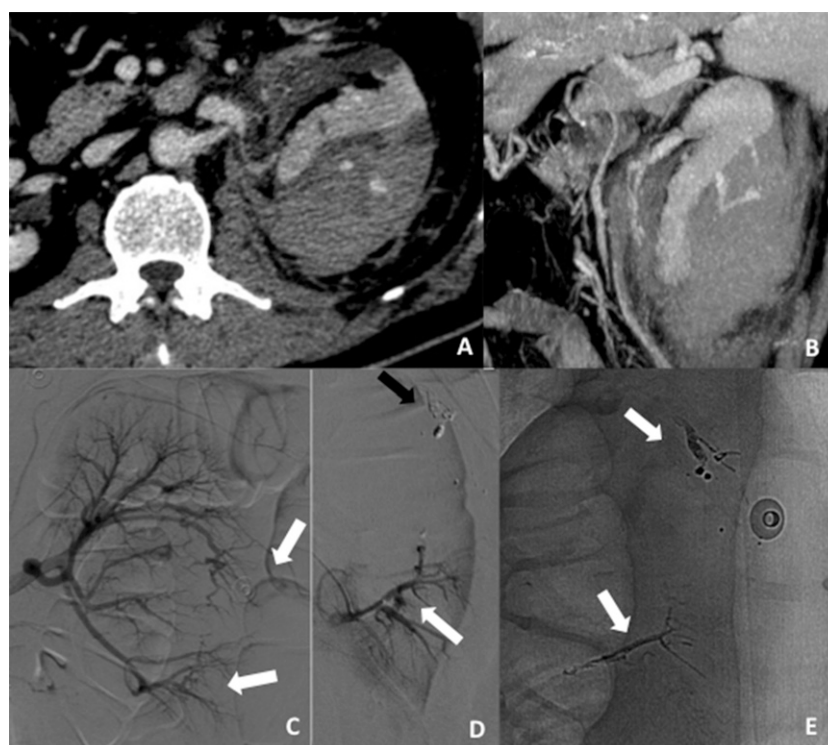
Table 4. Authors, patients and their traumatic characteristics, embolic agent used, number of sessions, technical and clinical successes, cases of rebleedings, complications and mortality rates

Authors	Number of patients	Trauma	AAST (grade)	Associated lesions	ISS	Number of sessions	Embolic agent	Technical success (%)	Clinical success (%)	Rebleeding	Mortality
Sofocleous et al[64]	11	7 MVA 3 stabbing 1 fall	NS	1 subdural haematoma 1 PNX 1 splenectomy 1 laparatomy (no findings)	NS	13 (in 1 patient PSA 4 days after first AE)	6 coils 4 gelfoam 1 particle + gelfoam	11/11 (100)	1, (91) retroperitoneal abscess 4 days after AE, treated percutaneously	1	3 deaths during FU, not related to procedure
Sarin et al[65]	37	NS	NS	NS	35.16 ± 2.67	NS	NS	NS	NS	NS	13 (cause NS)
Fangio et al[66]	25	MVA Pedestrian accident Crush	Unstable	NS	39 ± 11	NS	NS	24/25 (96)	NS	NS	9 (not related to procedure)
Shapiro et al[67]	31	NS	NS	3 abdominal haemorrhage	29 ± 6	NS	Gelfoam Coils Both	NS	NS	7	4
Sadri et al[68]	5	NS	Unstable	Multiple (NS)	≥20	5	NS	100	100	0	1 (<12 h × shock)
Tötterman et al[69]	31	NS	Unstable	Multiple	17–66	31	NS	100	100 (3 gluteal necrosis)	0	5 (2 MOF, 2 thor tr; 1 head injury)
Akpinar, et al[70]	2	1 MVA 1 train	Unstable	3 spleen 2 bowel 1 liver 3 AMSorIA	NS	NS	2 coils	100	50	1	Died 1 and 4 days after
Verbeek et al[71]	48	MVA Pedestrian accident Crush	NS	Multiple	42 ± 16	53	NS	46/48 (95.8)	46/48 (95.8)	5	2 died for haemorrhage
Fang et al[72]	140	NS	NS	28 (single TAE); 12 (repeat TAE)	29 ± 13 (single TAE) 32 ± 11 (repeat TAE)	166	NS	100	95	26 (7 same 10 new 9 both 8 neg)	26/140 (× associat les) 9/26 (× shock or CNS les)
Jeske et al[73]	42	NS	NS	Multiple	47–50	44	NS	100	100 (1 gluteal necrosis; 9 renal replacement)	2	1 died of haemorrhage for MOF and head trauma

(Continued)

Table 4. (Continued)

Authors	Number of patients	Trauma	AAST (grade)	Associated lesions	ISS	Number of sessions	Embolic agent	Technical success (%)	Clinical success (%)	Rebleeding	Mortality
Hauschild et al[74]	17	NS	NS	12/17	35.4 ± 9.8 (9–48)	NS	NS	100	100	NS	3 (not related to embolization)
Fu et al[75]	70 (27 bi; 43 uni)	NS	NS	NS	24.6 ± 7.0 / 15.0 ± 8.1	78	NS	95.7	100 (1 skin ulcer; 2 erectile dysfunction)	8/70 (3 controlat)	0
Ierardi et al[3]	168	101 MVA, 47 falls, 15 pedestrians	NS	Multiple	NS	171	Coils Spongocel AVP Glue	100	85.7	3	15 (4 shock hypovolemic, 3 brain; 8 blood transfusion)

AAST, American Association for the Surgery of Trauma; AE, arterial embolization; AMS, superior mesenteric artery; CNS, central nervous system; IA, iliac artery; ISS, Injury Severity Score; MVA, motor vehicle accident; NS, not specified; PSA, pseudoaneurysm; PVA, polyvinyl alcohol; TAE, transarterial embolization.

Contrast-enhanced CT has revolutionized the diagnosis, management and treatment of trauma patients, demonstrating most of the lesions in a single examination.

Whole body contrast-enhanced CT should be the first-line imaging modality in severely injured patients who respond at least partially to resuscitation.

Early whole body CT improves outcome, shortening the decision time. Its aim is to indicate whether haemostatic control is best achieved by non-operative management, interventional radiology or damage control surgery.

The Eastern Association for the Surgery of Trauma first published guidelines for the management of haemorrhage in patients with pelvic fractures in 2001.[78]

The same group published the first set of guidelines for the management of hepatic injuries in 2003; an update in 2012 gave similar recommendations for the role of angiography.[7] In the same year, the same group published guidelines for non-operative management of blunt splenic injury.[79] Four years before, Raikhlin et al[80] had already reviewed literature about splenic embolization focusing to its technique (proximal, distal, combined), its efficacy and safety and residual splenic immunological function and risk of infection.

In 2004, Santucci et al[9] published a consensus document on renal injury. One year later, Lynch et al[81] published the European Association of Urology guidelines on urological trauma (update 2009).

In 2012, Cardiovascular and Interventional Radiology Society of Europe published guidelines for endovascular treatment of traumatic haemorrhage[76] on the basis of those proposed by Oxford Centre for Evidence-based Medicine. Interventional radiology and imaging play an important role in severely traumatic patients, as this document shows.

All included studies were case series: a clearly defined protocol for angiographic intervention was missing, and incomplete description of all outcomes of interest was available. Studies were clinically and methodologically heterogeneous, on the basis of different design, conduct, demographic factors, therapeutic interventions, resuscitation data and outcomes, as consequence bias in the results are inevitable. Moreover, some studies include haemorrhages with different causes, and we extrapolated traumatic patients and data about procedures, results, outcomes and complications; possible errors of interpolation and/or interpretation should be considered.

The lack of randomized control trials does not allow one treatment method to be stably superior over the other. However, the review of case series about abdominopelvic traumatic lesions of the last 13 years confirmed TAE as a highly effective technique in controlling life-threatening haemorrhages.

Efficacy rate was based on three substantive criteria: cessation of contrast extravasation on post-TAE angiography; improvement

Figure 7. Arterial (a) and venous (b) phases of contrast-enhanced CT in multiple pelvic fractures revealed active bleed; selective (c) and superselective (d) angiogram confirmed multiple active bleeds, embolized with ethylene vinyl alcohol copolymer (e).

of patients' haemodynamics; and avoidance of further interventions to control exsanguination from the districts examined (no further TAE or urgent laparatomy/pelvic packing). Technical success, clinical success and rebleeding rates resulted high in all the districts considered, in particular ranged from 93.3% to 98.9% (splenic and pelvic embolization, respectively), from 79.8% to 91.75% (liver and pelvic embolization, respectively) and from 6.38% to 25.6% (splenic and renal embolization, respectively). Most of the studies[16,18,48,62,72,73] recorded high percentages of other arterial bleeding sites than the ones initially embolized, probably for the profuse vasoconstriction during the initial shock state that had obscured arterial bleeding sites during the primary angiographic procedure. It is unclear whether an open approach (instead of TAE) could have resulted in a more efficacious haemorrhage control with less complications in recurrent bleeding, either from the primarily embolized site or from new arterial bleeding sites.

Figure 8. CT showed a voluminous pseudoaneurysm (a); coronal MIP reconstruction revealed the afferent vessel (b); selective angiogram confirmed the pseudoaneurysm (c); final angiography confirmed complete embolization (d); embolization was performed with 2 amplatzer vascular plug (arrows) (e).

Overall mortality can be attributed to massive uncontrolled haemorrhage; concomitant trauma; lethal complications (adult respiratory distress syndrome, multiple organ failure, sepsis). Our data about overall mortality are heterogeneous therefore an overall value cannot be given. Deaths related to the procedure of embolization are not reported; furthermore, some authors[65] did not indicate the cause of deaths registered. Other authors attributed mortality to concomitant trauma and/or to systemic complications; many factors should be considered (polytrauma situation and ISS, and indirect blood loss and concomitant transfusions).[3,82] Timing of TAE could be another important factor but we did not analyse it because very few studies reported mortality (or efficacy rate) with respect to timing of TAE.

Few studies provided data on angio-related complications. Complications should be divided in that of arterial access (haematoma, femoral artery arteriovenous fistula, pseudoaneurysm, etc) and of the artery affected (dissection, rupture, etc) and that are consequent of the embolization (infarction, necrosis, abscess, etc).

The latter were described in all districts; some of them may be easily managed; an example may be cholecystectomy after gallbladder infarction; others, like liver or splenic abscesses are more severe. In these patients, the initial extent of haemorrhagic damage should be considered before to attribute abscess, necrosis and organ failure (in the case of liver) to TAE. These data are not available but sometimes only deductible from the entity of trauma (when reported) and consequently it can not be trusted.

Non-target embolization was described only in a series of the (Table 2).[27] Muscle necrosis was described in pelvic embolization, but it is unknown if another approach would have avoided this complication.

CONCLUSION

In conclusion, TAE seems to represent effective acute interventions for arterial haemorrhage control in the context of abdominopelvic trauma and could potentially reduce relevant mortality rates. Haemodynamic stabilization of the patient should be considered the main purpose of TAE.

The necessity of a subsequent surgical revision depends on several factors, in most cases not dependent on unsuccessful TAE, as the present review demonstrated. Only randomized control trials could confirm the data reported. Nevertheless, randomized trials are very difficult to perform in emergency settings.

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