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SYSTEMATIC REVIEW / *Interventional imaging*

Clinical outcomes of primary arterial embolization in severe hepatic trauma: A systematic review

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KEYWORDS
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Abstract
Purpose: This purpose of this systematic review was to determine the safety and efficacy of arterial embolization as the primary treatment for grade III-V liver trauma, excluding the postoperative use of arterial embolization.
Material and methods: A total of 24 studies published between January 2000 and June 2018 qualified for inclusion in this study. Four of them were prospective studies and 20 were retrospective. A total of 3855 patients (mean age, 33.5 years; range: 22—52.5 years) were treated non-operatively and 659 patients (659/3855; 17.09%) with hepatic hemorrhage underwent primary arterial embolization from 2000 to 2017. Indication for arterial embolization was a contrast blush visible on computed tomography in hemodynamically stable patient in all studies.
Results: The arterial embolization success rate ranged from 80% to 97%. The most commonly reported complication was bile leak, with an incidence of 5.7%. Nineteen bilomas (2.8%) were reported in five studies with a range between 4% and 45%. Hepatic ischemia was reported in eight studies, with a mean incidence of 8.6%.

Abbreviations: CT:, computed tomography; NOM:, non-operative management; AAST:, American Association for the Surgery of Trauma; ISS:, high injury severity score.

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Conclusion Primary arterial embolization has a high success rate in patients with hepatic trauma. Complications, including biloma and hepatic ischemia, have acceptable rates in the context of a minimally-invasive procedure that allows stabilization of life-threatening, complex liver injuries.

The liver is the most often injured organ in blunt abdominal trauma [1]. Liver trauma represents the first cause of death in major abdominal trauma, with an increased prevalence during the past three decades [1,2]. High grade liver injuries can be successfully managed without surgical intervention with overall mortality rates ranging from 0 to 8% [3]. Higher mortality rates are reported for patients with high-grade injuries who require surgical management either immediately or following a failed conservative management [3].

The increased use of computed tomography (CT) and more effective resuscitation strategies has led to an increased number of relatively stable patients with severe hepatic injury [4]. The majority of patients with liver trauma were historically treated surgically with techniques including packing, hepatorrhaphy, vessel ligation and hepatic resections [5]. Urgent operative management for liver injuries in hemodynamically unstable patients remains essential. However, patients with blunt liver injuries of any American Association for the Surgery of Trauma (AAST) grade who are hemodynamically stable or who respond well to initial resuscitation, and do not have peritonitis or associated abdominal injuries requiring surgery, may be managed with non-operative management (NOM) [6]. NOM includes both watchful waiting and arterial embolization (or angioembolization). Patients with high-grade penetrating hepatic trauma are suitable candidates for NOM in centers with experience in penetrating injuries and more than 80% of isolated penetrating liver injuries can safely be managed nonoperatively [7].

NOM was initially considered for low grade hepatic injuries but, thanks to improvement in quality and accessibility of imaging and availability of new therapeutically tools such arterial embolization, watchful and waiting NOM, as well as NOM with the adjunct of arterial embolization has become a first line approach even in patients with higher grade of injury [5]. The use of NOM depends on several factors including:

- the availability of CT for precise assessment and classification of hepatic injuries [8,9];
- the role of primary arterial embolization, which has high rate of success in intra- and retroperitoneal bleeding [10—12];
- the better understanding of trauma physiopathology and its complications [13]. The success rate of NOM is generally greater than 90% [14]. Moreover, NOM is also associated with a decrease in overall mortality, abdominal complications, and transfusion requirements when compared to surgical management [15—17].

Endovascular techniques such as arterial embolization have become an important component in the treatment of adult traumatic injuries and the demonstrated success of NOM in hepatic injury, especially in pediatric trauma patients, have also contributed to this. Indications for NOM are hemodynamic stability, absence of other injuries requiring laparotomy, and prompt availability of a fully staffed operating room and surgeons [18,19]. Past contraindications to NOM, such as hemoperitoneum, associated brain damage, high grade of liver damage, number of transfusions required, high injury severity score (ISS), age above 55 years, periportal blood monitoring or active extravasation on CT, are no longer absolute contra-indications in hemodynamically stable patients [6]. Arterial embolization represents an important adjunct to NOM even in stable patient following a penetrating hepatic trauma with active extravasation of contrast material on CT [20]. To date only one systematic review has investigated the results of arterial embolization in severe hepatic trauma, but including arterial embolization as a primary treatment and as a postoperative adjunct for hemostasis [21].

The purpose of this systematic review was to determine the safety and efficacy of arterial embolization as the primary treatment for grade III-V liver trauma, excluding the postoperative use of arterial embolization.

Materials and methods

Search methods for identification of studies

A literature review with a focus on the conservative management of both blunt and penetrating liver injuries, including the use of primary arterial embolization in the treatment of liver trauma was conducted. A systematic literature search was performed using PubMed, EMBASE, MEDLINE, Google Scholar, and the Cochrane Central Register of Controlled Trials databases for studies published on the conservative management of both blunt and penetrating liver injuries and reporting the use of primary arterial embolization in the treatment of liver trauma. Database-specific search terms for ''hepatic angioembolisation'', ''liver angioembolisation'', ''conservative management'', ''non operative management'', ''liver trauma'', ''hepatic

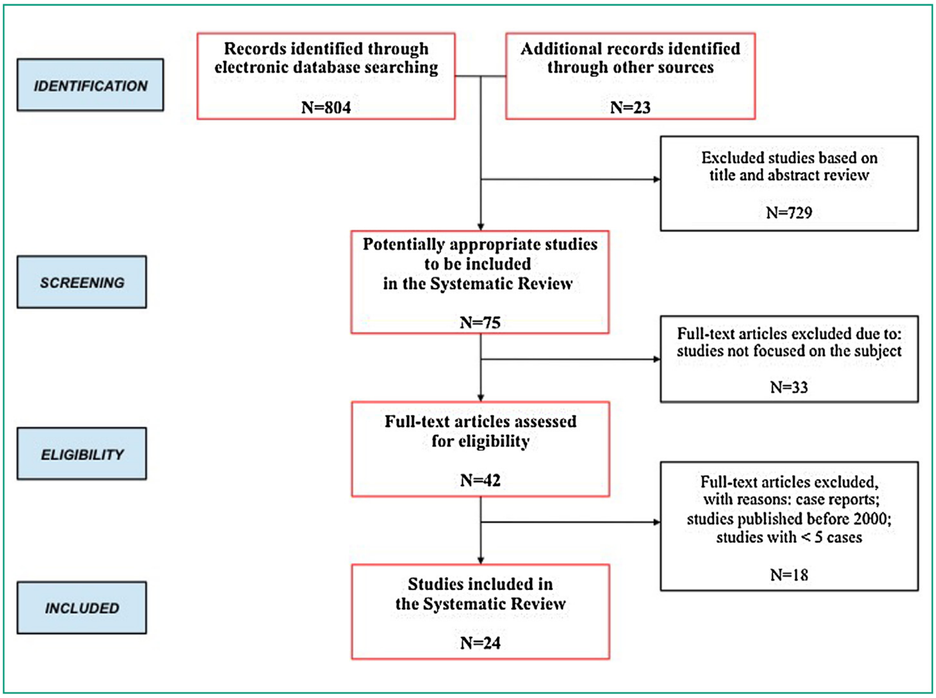

Fig. 1. PRISMA flow diagram for systematic search and selection of studies included in the systematic review.

trauma'', were combined as follows: [hepatic OR liver AND trauma AND conservative management AND angioembolisation OR angioembolization]; [hepatic OR liver AND trauma AND conservative management].

The search was then extended to related articles suggested by the databases and supplemented with articles obtained from manual searches of the reference lists of all relevant articles. When the results of a single study were reported in more than one publication, only the most recent and complete data was included in the review. Data collection was performed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Fig. 1) and the literature search was concluded in June 2018, limited to articles in English language published after 2000. This review included prospective and retrospective studies that evaluated the efficacy, safety and feasibility of primary arterial embolization in patients with traumatic hepatic injury and required intervention for hepatic hemorrhage.

The following inclusion criteria were used:

- enrolled patients had a traumatic cause (blunt or penetrating) of hepatic bleeding;
- arterial embolization was used in patients with traumatic hepatic injuries only;
- arterial embolization was the primary intervention;
- at least one outcome of interest was described (efficacy, safety and/or feasibility); and v), a liver injury grade range was reported.

Exclusion criteria included:

- case reports;
- studies with five or fewer patients;
- studies limited to pediatric patients;
- studies including patients who did not have arterial embolization as primary management (e.g., post-laparotomy);
- studies reporting arterial embolization for non-traumatic liver injury.

Only the studies that analyzed patients who underwent arterial embolization were considered for this systematic review and complications that occurred in patients treated with NOM without arterial embolization were not considered.

Types of outcome measures

Primary outcomes assessed were: mortality, efficacy of primary arterial embolization, and overall morbidity post-procedure. Specific causes of morbidity, such as bile leak, liver abscess, hepatic ischemia, gallbladder necrosis, biloma, compartment syndrome, peritonitis and, sepsis were also investigated. The AAST classification was used to characterize the severity of the liver injury as management of hepatic trauma is guided by this classification and it was used in all of the studies analyzed [22]. The efficacy of primary arterial embolization was determined by an absence of re-bleeding after the procedure with no need for further procedure (success) or persistent bleeding after primary arterial mebolization (failure).

Data extraction

Two reviewers (F.V. and M.P.) independently screened titles and abstracts to identify appropriate articles for data extraction and discordances were resolved by mutual discussion. Country and year of publication, study type, number of patients treated with primary arterial embolization, and patient demographics (age, gender, perioperative outcome, postoperative results) were extracted.

Results were tabulated then presented using descriptive statistics and dichotomous and continuous variables were reported as absolute numbers, means, percentages, ranges and ratios as appropriate. Due to the lack of comparative studies, a quantitative meta-analysis was not performed.

Results

Description of studies

A total of 804 references were initially identified. A total of 729 searches were excluded through title and abstract screening. The remaining 75 publications were considered potentially appropriated to be included in the review, and underwent full article review. A further 33 articles were excluded as they did not focus on the subject. Altogether, 42 full-text articles were assessed for eligibility then 18 publications were excluded as they were clinical case reports, were published before 2000, or were studies with less than five patients.

Ultimately, a total of 24 studies, published between January 2000 and November 2017 were included in this review [2,5,23—44]. Seven of these studies were conducted in the USA, six in Taiwan, two in France, one in the UK, one in Canada, one in Japan, one in Netherlands, one in Israel, one in India, one in Norway and two in China. Four of the studies included were prospective [2,5,23,30], and 20 were retrospective studies [24—29,31—44]. Table 1 shows the characteristics of the included studies and the demographic details regarding the enrolled patients. All patients were treated with NOM as the primary intervention following the criteria for conservative management in liver injuries.

Among the 24 studies, five included patients with penetrating liver trauma [24,30,32,35,37]; several have undergone surgery while a smaller percentage underwent arterial embolization, however the authors did not specify how many of these patients underwent arterial embolization, as well as no comparison was made between the complications in blunt and penetrating patients, considering the outcome independently from the mechanism of injury.

Indication for arterial embolization was a contrast blush visible on CT in hemodynamically stable patient in all studies (Table 2) with arterial embolization performed within 48 hours, while other indications, including failure of NOM and delayed arterial embolization for control of continued hemorrhage following damage-control laparotomy were not considered.

Patient demographics

Amongst all the included studies, a total of 3855 patients (mean age, 33.5 years; range: 22—52.5 years) were treated non-operatively and 659 patients (659/3855; 17.09%) with hepatic hemorrhage underwent primary arterial embolization from 2000 to 2017. Patients included in these studies had a liver injury between grade III and V, however only six out of 24 articles reported the exact number of patients divided per grade of injury (Table 1) [24,31,32,36,38,44].

Technique

All articles describing the arterial embolization protocol reported the use of microcatheter systems with selective and superselective embolization techniques and the most commonly used embolization materials were gelatin sponge and microcoils. Thirteen studies specified the material used in the arterial embolization procedure. Dabbs et al. described gelfoam usage in 54 patients, coil in 13 patients and both in one patient [32]. Misselbeck reported that gelfoam was used in seven of the patients with arterial embolization complications, coil was used in one patient and both materials were involved in another [33]. Mohan described 10 adults and three children who underwent arterial embolization with polyvinyl alcohol particle (PVA)/soft metal coil, and one adult underwent revascularization with a covered stent for arterial bleeding [40].

In the remaining studies, the choice of embolic agents was at the radiologist's discretion and included gelfoam suspension and/or microcoils [36,42], microcoil [30], gelatin sponge particles and stainless steel coils [23], coil [38,41], gelfoam and/or stainless steel coils or PVA particles [24], metallic coils, microcoils, tissue adhesive or mixed microcoils [27,44] and a combination of coils and PVA particles [35].

Efficacy

All outcome measures related to safety and feasibility were evaluated with detailed results reported in Tables 3 and 4. The success rate of arterial embolization ranged from 80% to 97% with 14 studies reporting 6% (40 patients) of re-bleeding average rate following early arterial embolization, or a failure of the procedure with persistent bleeding (range 3—20%) (Table 3).

Mortality

Five mortalities were reported in four studies, with an average of 0.7% and a range between 1% and 18% (Table 3). Amongst these five mortalities, four patients underwent operative intervention. The cause of death was sepsis and hemorrhagic shock in three patients [24,44], unrecognized hepatic necrosis in one patient [34] and multiorgan failure following multiple postembolization complications [31].

Morbidity

The complication rate was reported in all 24 studies and averaged 28% with a range between 5% and 93% (Tables 3 and 4). The most commonly reported complication was bile leak, reported in 9 studies with an incidence of 5.7% and a range between 3% and 71% [24,32—35,37,41,43,44].

Nineteen patients with biloma (2.8%) were reported in five studies [24,29,31,40,41], with a range between 4% and 45%. Hepatic ischemia was identified in eight studies [5,24,32,33,35,40,41,44], with a mean incidence of 8.6% and a range between 3.3% and 42%.

Liver abscess were reported in ten studies with a mean incidence of 6.8% and a range between 1% and 28% [5,24,27,28,31—33,35,41,44]. Gallbladder necrosis was

Table 1 General characteristics of studies included in the systematic review.

Authors	Year	Study type	Country	Total NOM *n*	Sex M/F ratio	Age (mean ± SD)	Total primary AE *n* (%)	Grade III trauma *n* (%)	Grade IV trauma *n* (%)	Grade V trauma *n* (%)
[23] Hagiwara et al.	2002	PCS	Japan	51	2.6/1	29.4 ± 15.1	26 (60)	≥ III	—	—
[24] Mohr et al.	2003	RCS	USA	26	2.4/1	38	11 (42)	3 (27)	7 (63)	1 (9)
[2] Velmahos et al.	2003	PCS	USA	55	NR	35 ± 17	7 (13)	≥ III	—	—
[25] Christmas et al.	2005	RCS	USA	56	NR	35 ± 15	12 (21)	≥ III	—	—
[26] Kozar et al.	2005	RCS	USA	230	2/1	31	12 (5)	≥ III	—	—
[27] Tzeng et al.	2005	RCS	Taiwan	NR	2.4/1	52.5	32 (NA)	≥ III	—	—
[28] Fang et al.	2006	RCS	Taiwan	184	2.6/1	29	8 (16)	≥ III	—	—
[29] Kozar et al.	2006	RCS	USA	35	2/1	33	20 (57)	≥ III	—	—
[30] Gaarder et al.	2007	PCS	Norway	73	1.8/1	32.4	5 (7)	≥ III	—	—
[31] Monnin et al.	2007	RCS	France	84	6/1	35	14 (17)	2 (14)	9 (64)	3 (21)
[32] Dabbs et al.	2009	RCS	USA	538	2.3/1	34.3 ±14.7	71 (13)	16 (23)	44 (62)	11 (15)
[33] Misselbeck et al.	2009	RCS	USA	707	1.5/1	32.6	31 (4)	≥ III		
[35] Saltzherr et al.	2010	RCS	Netherlands	116	2.3/1	29	23 (20)	≥ III	—	—
[34] Letoublon et al	2011	RCS	France	151	2.6/1	37	13 (9)	≥ III	—	—
[36] Wang et al.	2011	RCS	Taiwan	98	NR	22	5 (5)	2 (40)	2 (40)	1 (20)
[37] Bala et al.	2012	RCS	Israel	24	2.2/1	24.8 ±15.5	7 (29)	≥ III	—	—
[38] Huang et al.	2012	RCS	Taiwan	130	3.3/1	30	24 (18)	10 (42)	14 (58)	—
[40] Mohan et al.	2012	RCS	India	NR	3.6/1	36	14 (NA)	≥ III	—	—
[39] Van Der Wilden et al.	2012	RCS	UK	262	1/1	33	65 (25)	≥ III	—	—
[42] Lee et al.	2014	RCS	Taiwan	NR	NR	30	48 (NA)	≥ III	—	—
[41] Kong et al.	2014	RCS	China	NR	NR	36.3	70 (NA)	≥ III	—	—
[43] Yuan et al.	2014	RCS	Taiwan	288	2.9/1	34.5 ± 15.2	45 (16)	≥ III	—	—
[5] Bartens et al.	2015	PCS	Canada	396	1.3/1	38	7 (2)	≥ III	—	—
[44] Xu et al.	2017	RCS	China	351	2.4/1	38 ± 16	89 (25)	32 (36)	15 (17)	11 (12)
Total	—	23	—	3855	—	33.5	659 (17)	—	—	—

M:male; F: female; NOM: non operative management; AE: arterial embolization; NR: not reported; NA: not available; RCS: retrospective cohort study; PCS: prospective cohort study; SD: Standard deviation.

Table 2 Indication for arterial embolization.

Authors [Ref]	Indication for arterial embolization
Hagiwara et al. [23]	Extravasation of contrast medium extending within the hepatic parenchyma; Extravasation of contrast medium extending beyond the hepatic parenchyma
Mohr et al. [24]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Velmahos et al. [2]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Christmas et al. [25]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Kozar et al. [26]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Tzeng et al. [27]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Fang et al. [28]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT; patients had ongoing hemorrhage requiring more than four units of blood transfusion to maintain hemodynamic stability within 72 hours
Kozar et al. [29]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Gaarder et al. [30]	Angiography revealed ongoing bleeding, vessel truncation seen as an unsecured bleeding site, or pseudoaneurysm
Monnin et al. [31]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Dabbs et al. [32]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Misselbeck et al. [33]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Saltzherr et al. [35]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Letoublon et al. [34]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Wang et al. [36]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Bala et al. [37]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Huang et al. [38]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Mohan et al. [40]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Van Der Wilden et al. [39]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Lee et al. [42]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Kong et al. [41]	Active extravasation on contrast-enhanced CT, an episode of hypotension or a decrease in hemoglobin level during the non-operative treatment
Yuan et al. [43]	Hemodynamic stability with evidence of active hepatic extravasation on abdominal CT
Bartens et al. [5]	Hemodynamic stability evidence of active hepatic extravasation on abdominal CT; pseudoaneurysms detected on routine imaging, 24—48 hours post trauma
Xu et al. [44]	Contrast blush on initial CT, high-grade hepatic trauma of segments IV to VI, and/or decreasing hemoglobin

AE: arterial embolization; CT: computed tomography.

reported in seven studies, with a mean incidence of 3.6%, and a range between 2.2% and 25% [25,31—33,37,41,44].

Occurrence of abdominal compartment syndrome was reported in 3 studies with a mean incidence of 2% and a range between 17% and 50% [29,31,34]. Peritonitis was reported in 4 studies with a mean incidence of 1.9% and a range between 2.2% and 43% [31,34,42,44]. Occurrence of septic complications were reported in 3 studies with a mean incidence of 0.6% and a range between 3% and 17% [26,27,33].

Only two studies individualized the complication rates according to the embolic agent used [32,33]. Among 54 patients treated with gelfoam, Dabbs et al. reported 21 patients who developed hepatic necrosis (70%), while six patients (20%) developed hepatic necrosis following arterial embolization with coil [32]. Misselbeck et al. reported seven patients who underwent complications after arterial embolization with gelfoam (including one patient with gallbladder necrosis, one with hepatic failure, three with hepatic and gallbladder necrosis and liver abscess, one with liver abscess and one with hepatic necrosis and bile leak), and one patient who had gallbladder necrosis following arterial embolization with coil [33].

Discussion

Currently interventional radiologists and their support staff represent fundamental part of the trauma team involved in management of hepatic trauma where NOM, with or without the adjunct of arterial embolization, is recognized as standard of care regardless the grade of hepatic injury with a surgical intervention rate in higher grade injury remaining under 40% [21]. This systematic review analyzed 24 studies including three prospective studies and ten retrospective studies. It is, so far the largest and most up-to-date review on the role and indications of primary arterial embolization in the management of grade III-V liver injuries currently available in the literature.

In the last three decades the management of hepatic trauma has moved toward a more conservative approach, minimizing the costs and risks of surgical interventions whilst optimizing patient outcomes. This is certainly linked to several factors, including improved diagnostic imaging techniques, a more thorough understanding of the pathophysiology of liver trauma, and developments of a multidisciplinary approach involving interventional radiology.

Table 3 Primary outcomes.

Authors	Year	Total primary AE *n*	Mortality *n* (%)	Re-bleeding/Failure *n* (%)	Post-AE morbidity *n* (%)
[23] Hagiwara et al.	2002	26 (60)	—	2 (8)	2 (8)
[24] Mohr et al.	2003	11 (42)	2 (18)	—	8 (73)
[2] Velmahos et al.	2003	7 (13)	—	1 (14)	1 (14)
[25] Christmas et al.	2005	12 (21)	—	1 (8)	4 (33)
[26] Kozar et al.	2005	12 (5)	—	—	4 (33)
[27] Tzeng et al.	2005	32 (NA)	—	5 (16)	8 (25)
[28] Fang et al.	2006	8 (16)	—	—	1 (12)
[29] Kozar et al.	2006	20 (57)	—	3 (15)	12 (60)
[30] Gaarder et al.	2007	5 (7)	—	1 (20)	1 (20)
[31] Monnin et al.	2007	14 (17)	1 (7)	—	13 (93)
[32] Dabbs et al.	2009	71 (13)	—	2 (3)	43 (60)
[33] Misselbeck et al.	2009	31 (4)	—	—	9 (29)
[35] Saltzherr et al.	2010	23 (20)	—	2 (9)	1 (57)
[34] Letoublon et al	2011	13 (9)	1 (4)	—	9 (69)
[36] Wang et al.	2011	5 (5)	—	1 (20)	1 (20)
[37] Bala et al.	2012	7 (29)	—	—	6 (86)
[38] Huang et al.	2012	24 (18)	—	3 (12)	3 (12)
[40] Mohan et al.	2012	14 (NA)	—	3 (5)	4 (29)
[39] Van Der Wilden et al.	2012	65 (25)	—	1 (7)	3 (5)
[42] Lee et al.	2014	48 (NA)	—	9 (19)	9 (19)
[41] Kong et al.	2014	70 (NA)	—	—	19 (27)
[43] Yuan et al.	2014	45 (16)	—	—	7 (16)
[5] Bartens et al.	2015	7 (2)	—	—	3 (43)
[44] Xu et al.	2017	89 (25)	1 (1)	6 (7)	11 (12)
Total	—	659 (17)	5 (0.7)	40 (6)	185 (28)

AE: Arterial embolization. NA: not available

Currently, there is clear evidence supporting appropriate NOM in trauma patients whom satisfy the selection criteria for conservative treatment. The feasibility and safety of NOM in liver trauma has been demonstrated in several studies [2,3,39,45].

The most recent data demonstrates that half of patients with any grade of liver injury can be approached conservatively with a success rate up to 98.5%. However, NOM of medium/high grade blunt hepatic injuries should be considered only in institutions that can provide intensive monitoring and have an emergency operating room available immediately if required [6,26].

Arterial embolization in blunt trauma patients has been recently analyzed by Xu et al. [44]. These authors concluded that arterial embolization should be indicated in selected patients with high risk of failure of NOM, including blush on initial CT, high-grade liver trauma, and/or decreasing hemoglobin levels during NOM observation, rather than universally applied to all traumatic liver patients [44].

Indications for hepatic angiography and arterial embolization consist in blunt liver trauma of any AAST grade with contrast extravasation on CT, in hemodynamically stable patient and without other indications for laparotomy. However, different clinical protocols for arterial embolization have been reported in the literature. In a series of 138 consecutive patients with liver trauma, Gaarder et al. performed arterial embolization in the acute setting in all stable or stabilized patients with active contrast extravasation on CT scan, and angiography the next day in all grade III-V liver injuries without initial CT scan evidence of bleeding. They found that patients without signs of bleeding on initial CT examination did not require embolization [30]. Similarly, Letoublon et al. demonstrated that arterial embolization was not indicated in the absence of extravasation of contrast material on CT, even in grade IV-V injuries [30]. These results support arterial embolization in the presence of contrast extravasation on initial CT examination, irrespective of injury grade [6].

Several technical protocols for arterial embolization were reported in the different studies included in this systematic review and the variability in the technique and materials impacts the evaluation of arterial embolization efficacy, with comparisons of various materials (e.g., gelatin sponge vs. coil) representing an area of future research interest. Investigation of the association between post- arterial embolization complications and the type of material was not possible as studies did not report the technique used in every single case of NOM complication/failure. Reporting on the techniques and materials used in all patients, including failures, represents a possible future research area of interest. Xu et al. underlined the role of the type of arterial embolization [44]. These researchers showed that simple selective embolization involving the arterial branches can result in less complications and a higher success rate of NOM by comparison with combined embolization involving the extrahepatic trunk and intrahepatic branches [44].

Table 4 Specific causes of morbidity of arterial embolization.

Authors	Year	Total primary AE *n*	Bile leak *n* (%)	Liver abscess *n* (%)	Hepatic ischemia *n* (%)	Gallbladder necrosis *n* (%)	Biloma *n* (%)	Compartment syndrome *n* (%)	Peritonitis *n* (%)	Sepsis *n* (%)
[23] Hagiwara et al.	2002	26	NR	NR	NR	NR	NR	NR	NR	NR
[24] Mohr et al.	2003	11	2 (18)	1 (9)	3 (27)	NR	2 (18)	NR	NR	NR
[2] Velmahos et al.	2003	7	NR	NR	NR	NR	NR	NR	NR	NR
[25] Christmas et al.	2005	12	NR	NR	NR	3 (25)	NR	NR	NR	NR
[26] Kozar et al.	2005	12	NR	NR	NR	NR	NR	NR	NR	2 (17)
[27] Tzeng et al	2005	32	NR	2 (6)	NR	NR	NR	NR	NR	1 (3)
[28] Fang et al.	2006	8	NR	1 (12)	NR	NR	NR	NR	NR	NR
[29] Kozar et al.	2006	20	NR	NR	NR	NR	9 (45)	2 (17)	NR	NR
[30] Gaarder et al.	2007	5	NR	NR	NR	NR	NR	NR	NR	NR
[31] Monnin et al.	2007	14	NR	2 (14)	NR	2 (14)	4 (28)	7 (50)	6 (43)	NR
[32] Dabbs et al.	2009	71	14 (20)	12 (17)	30 (42)	5 (7)	NR	NR	NR	NR
[33] Misselbeck et al.	2009	31	1 (3)	4 (13)	5 (16)	6 (19)	NR	NR	NR	1 (3)
[35] Saltzherr et al	2010	23	2 (9)	5 (22)	3 (11)	NR	NR	NR	NR	NR
[34] Letoublon et al	2011	13	1 (8)	NR	NR	NR	NR	5 (38)	3 (23)	NR
[36] Wang et al.	2011	5	NR	NR	NR	NR	NR	NR	NR	NR
[37] Bala et al.	2012	7	5 (71)	NR	NR	1 (14)	NR	NR	NR	NR
[38] Huang et al.	2012	24	NR	NR	NR	NR	NR	NR	NR	NR
[40] Mohan et al.	2012	14	NR	NR	1 (7)	NR	1 (7)	NR	NR	NR
[39] Van Der Wilden et al.	2012	65	NR	NR	NR	NR	NR	NR	NR	NR
[42] Lee et al.	2014	48	NR	NR	NR	NR	NR	NR	2 (3)	NR
[41] Kong et al.	2014	70	3 (4)	9 (13)	11 (16)	5 (7)	3 (4)	NR	NR	NR
[43] Yuan et al.	2014	45	7 (15)	NR	NR	NR	NR	NR	NR	NR
[5] Bartens et al.	2015	7	NR	2 (28)	1 (14)	NR	NR	NR	NR	NR
[44] Xu et al.	2017	89	3 (3)	1 (1)	3 (3.3)	2 (2.2)	NR	NR	2 (2.2)	NR
Total	—	659	38 (5.7)	39 (6.8)	57 (8.6)	24 (3.6)	19 (2.8)	14 (2)	13 (1.9)	4 (0.6)

AE: arterial embolization; NR: not reported.

In this systematic review, the incidence of complications showed marked variability, ranging from 7% to 93%. Bile leak, hepatic ischemia and liver abscess were the most commonly observed complications, as also observed by others [3,26,32]. Biliary complications affect 3.2% of all hepatic traumas and are usually delayed with signs of systemic inflammation, jaundice, abdominal pain and sepsis. These complications are not unique to arterial embolization and are also common complications of liver trauma in both operative and conservative management [46—48]. However, liver trauma combined with ischemia caused by arterial embolization may predispose to necrosis and biliary complications [6,32]. Further studies are required to clarify how and if arterial embolization increases the rate of bile leak. This should be done by a comparison with the incidence of bile leak in patients who underwent watchful waiting. However, it may be unlikely that immediate bile leak is a result of embolization. In this regard, embolization could in theory lead to bile leak through ischemia but this would take time to develop. But to date, there is no clear data to determine the actual role of embolization in the occurrence of bile duct complications. Bala et al. reported biliary complications in 2.8 to 7.4% of patients following blunt hepatic trauma [37]. In their study, patients who were treated operatively and those who underwent embolization had higher rates of biliary complications and required additional interventions [37]. Hommes et al. reported a rate of 4% of liver related complications (including biloma and biliary peritonitis) among 94 patients successfully managed with NOM [49]. Han Xu et al. recently followed up 158 patients treated with NOM without arterial embolization and documented a morbidity of 29,7%, with 3,7% rate of biliary complications including bilioma and bile leak [44].

The treatment of liver abscess has been improved by interventional radiology techniques such as percutaneous drainage. However, a surgical approach still retains an essential role. This review shows a mean incidence of liver abscess of 6.7% and a range between 6% and 28%.

High grade hepatic injury, high ISS and need for blood transfusions, have been identified as risk factors for NOM complications and/or failure [21] and studies have shown that central hepatic damage and the use of arterial embolization are risk factors for bile leak and hepatic necrosis [50].

NOM with arterial embolization in liver trauma has an overall complication rate ranging from 12—24% in adults, and 7—10% in children [51—54], with high grade liver injuries more likely to be associated with major blood vessels and bile ducts damage [13]. Discussing the management of these complications is beyond the scope of this review, but such complications may require further minimally invasive techniques or surgical intervention.

Compartment syndrome ranged between 17% and 50% and peritonitis between 2.2% and 43% as reported by four studies, although the highest rate of compartment syndrome (50%) and of peritonitis (43%) came from the same study [31].

The mortality rate ranged from 1% to 18% in this review where all deaths involved patients with high grade injuries who underwent arterial embolization and later suffered severe from complications such as major hepatic necrosis, abdominal compartment syndrome, or sepsis.

In conclusion, primary arterial embolization is becoming an increasingly important and effective mean for the conservative treatment of hemodynamically stable patients with liver trauma. Complications may occur with variable degrees of severity thus affecting the post procedure course. However, considering the benefits of lower invasiveness, costs and resource use and compared to the risks of surgery for hepatic trauma, such complications become reasonable. Currently, there is no agreement on the timing, patient selection criteria and indication for arterial embolization in hepatic trauma and consequently, a lack of precise guidelines. However, its effectiveness and value in the treatment of posttraumatic hepatic bleeding has been demonstrated [55—57] although the level of evidence on this topic is too low to draw robust conclusion. The main bias in our study is related to the lack of comparison between patients who underwent NOM and arterial embolization with patients who underwent NOM alone. In the same time it is hard to ascertain whether the complications are due to the trauma itself or a consequence of arterial embolization. Further comparative studies are needed to amend this major bias.

Disclosure of interest

The authors declare that they have no competing interest.

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