Use of covered stent grafts as treatment of traumatic venous injury to the inferior vena cava and iliac veins: A systematic review

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ABSTRACT

Objective: Venous injury to the inferior vena cava or iliac veins is rare but can result in high mortality rates. Traditional treatment by repair or ligation can be technically demanding. A relatively new treatment modality is the use of a covered stent to cover the venous defect. The aim of the present systematic review was to assess the techniques, results, and challenges of covered stent graft repair of traumatic injury to the inferior vena cava and iliac veins.

Methods: The PubMed (Medline) and Embase databases were systematically searched up to September 2020 by two of us (R.R.S. and D.D.) independently for studies reporting on covered stenting of the inferior vena cava or iliac veins after traumatic or iatrogenic injury. A methodologic quality assessment was performed using the modified Newcastle-Ottawa scale. Data were extracted for the following parameters: first author, year of publication, study design, number of patients, type and diameter of the stent graft, hemostatic success, complications, mortality, postoperative medication, follow-up type and duration, and venous segment patency. The main outcome was clinical success of the intervention, defined as direct hemostasis, with control of hemorrhage, hemodynamic recovery, and absence of contrast extravasation.

Results: From the initial search, which yielded 1884 records, a total of 28 studies were identified for analysis. All reports consisted of case reports, except for one retrospective cohort study and one case series. A total of 35 patients had been treated with various covered stent grafts, predominantly thoracic or abdominal aortic endografts. In all patients, the treatment was technically successful. The 30-day mortality rate for the entire series was 2.9%. Three perioperative complications were described: one immediate stent occlusion, one partial thrombosis, and one pulmonary embolism. Additional in-stent thrombus formation was seen during follow-up in three patients, leading to one stent graft occlusion (asymptomatic). The postoperative anticoagulation strategy was highly heterogeneous. The median follow-up was 3 months (range, 0.1-84 months). However, follow-up with imaging studies was not performed in all cases.

Conclusions: In selected cases of injury to the inferior vena cava and iliac veins, covered stent grafts can be successful for urgent hemostasis with good short-term results. Data on long-term follow-up are very limited. (J Vasc Surg Venous Lymphat Disord 2021;9:1577-87.)

Keywords: Hemorrhage; Iliac vein; Inferior vena cava; Injury; Stents

Vascular injury occurs in major trauma in civilians in 4.4% and ≤15% in military conflicts.[1,2] Vessels of any size and location can be affected by sharp or blunt traumatic forces. An inferior vena cava (IVC) injury is rare and encountered in ~5% of trauma laparotomy series, with a mortality rate of ≤50%.[3] Trauma to the iliac vessels comprises only 1.8% to 6.5% of all vascular injuries.[4] A combined arterial and venous injury is common but an isolated vein injury can also occur, with mortality rates of ≤25%.[5] In addition to trauma, the iliac veins and IVC can be injured during various surgical procedures such as lumbar spine surgery.[6] Especially for such iatrogenic injuries, quick surgical intervention is required because no retroperitoneal tamponade can prevent exsanguination. Traditionally, venous injury was treated by ligation; however, recently, venous injuries have been treated with repair to preserve vessel patency.[7] These type of repairs are time-consuming and technically demanding, and the mortality and morbidity have remained high. In an attempt to reduce the surgical morbidity to trauma patients, endovascular techniques have been increasingly used in the treatment of vascular trauma.[8] In blunt aortic repair, endovascular treatment of blunt aortic trauma has decreased the mortality significantly in previous years.[9] Recently, other (peripheral) injured arterial segments have also been treated with covered stent grafts, with good mid-term results.[10,11] A venous injury to the IVC

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or iliac veins is a different entity compared with injuries to the high flow arterial system. However, such endovascular repair has similar theoretical benefits. A "simple" endovascular hemostatic technique with a covered stent would have advantages compared with the time-consuming open surgical approach. However, at present, no covered stent grafts are commercially available for venous implementation. Nevertheless, reports of the off-label use of covered arterial stent grafts in venous injuries have been increasing. Thus, we reviewed the technical feasibility, challenges, and complication of this novel, but promising, technique.

METHODS

The present review was registered in the International Prospective Register for Systematic Reviews (PROSPERO registration no. CRD42020162912). The results are presented in accordance with the PRISMA (preferred reporting items for systematic reviews and meta-analyses) guidelines.[12]

Literature search. A systematic search was independently performed by two of us (R.R.S. and D.D.) using Medline (via PubMed) and Embase for all studies reported in English up to September 2020 without publication date restrictions. The search algorithm included the following terms: endovascular OR stent(s) AND vein(s) OR venous AND wounds and injuries (MeSH) OR wounds OR injuries OR bleeding OR hemorrhage NOT heart (MeSH) OR coronary AND humans. An additional search was performed in the Cochrane library. The literature search strategy is presented in the Supplementary Fig (online only).

Two of us (R.R.S. and D.D.) independently screened the titles and abstracts. After inclusion based on the abstract screening, the full text was carefully read before inclusion in the analysis. In the case of discrepancy or uncertainty, a third author (B.M.E.M.) was consulted to resolve the issue.

Criteria of eligibility. All observational and interventional studies, including case series, case control studies, cohort studies, clinical trials, and case reports, were screened for relevance. The condition studied was a traumatic and iatrogenic venous injury to the IVC or iliac veins in adults (aged >18 years). The treatment for this condition had to consist of the use of one or more covered stent grafts. Spontaneous venous rupture, venous dissection, and arteriovenous fistulas were excluded from the present study. Cases of venous injury treated with embolization, uncovered stents, or an occlusion balloon were also excluded from the present analysis.

Data extraction. Two of us (R.R.S. and D.D.) extracted the following data from each study: first author, year of publication, study design, number of patients, type and diameter of stent graft, hemostatic success, complications, mortality, postoperative medication, follow-up type and duration, and venous segment patency.

The main outcome was clinical success of the intervention, defined as direct hemostasis, with control of hemorrhage, hemodynamic recovery, and the absence of contrast extravasation. The additional outcomes of interest were mortality, reoperation rate, persistent hemorrhage, additional stenting, graft thrombosis, deep vein thrombosis, and pulmonary embolization at follow-up.

Data synthesis and analysis. Data were collected using SPSS statistic software, version 26 (IBM Corp, Armonk, NY). Nominal values are reported as percentages and continuous values as the median and range.

The methodologic quality assessment for each study was performed using the modified Newcastle-Ottawa scale with only four domains: selection, ascertainment, causality, and reporting. An overall judgement of the method is reported (ie, poor, fair, good) instead of reporting the results of the assessment as a sum of the eight binary responses.[13]

RESULTS

Study selection. The search in PubMed (Medline) and Embase yielded a total of 3740 results. After removal of the duplicates, 1844 records were identified for screening of the titles and abstracts. Of these 1844 reports, 28 were selected for full text analysis. An additional four reports were excluded: one study had described venous injury treatment with a bare metal stent, one had reported a spontaneous venous rupture, one had described a patient aged <18 years, and one case report had described a traumatic venous dissection.[14-17] After scrutinizing all the references, we were able to add three additional studies from the cross references and a report from our own hospital. The flow chart illustrates the study selection process (Fig 1).

Study characteristics. The 28 included studies were reported from 2001 to 2020. These reports consisted of 26 case reports,[14,18-42] 1 case series,[43] and 1 retrospective cohort study.[44] A summary of the most important study characteristics of the included studies and the methodologic scores is provided in Table I. The overall methodologic quality of the studies using the modified New-Ottawa scale was fair. Most of the studies were case reports without defined criteria for the selection of patients. Two studies had reported the entire experience of a center during a specific period. The overall reporting of the other three domains (ascertainment, causality, and reporting) was good. The number of patients per study ranged from one to three.

Patient characteristics. The treatment of an IVC or iliac vein injury with a covered stent was described for 35 patients. Of the 35 patients, 17 were men (48.5%) and 18

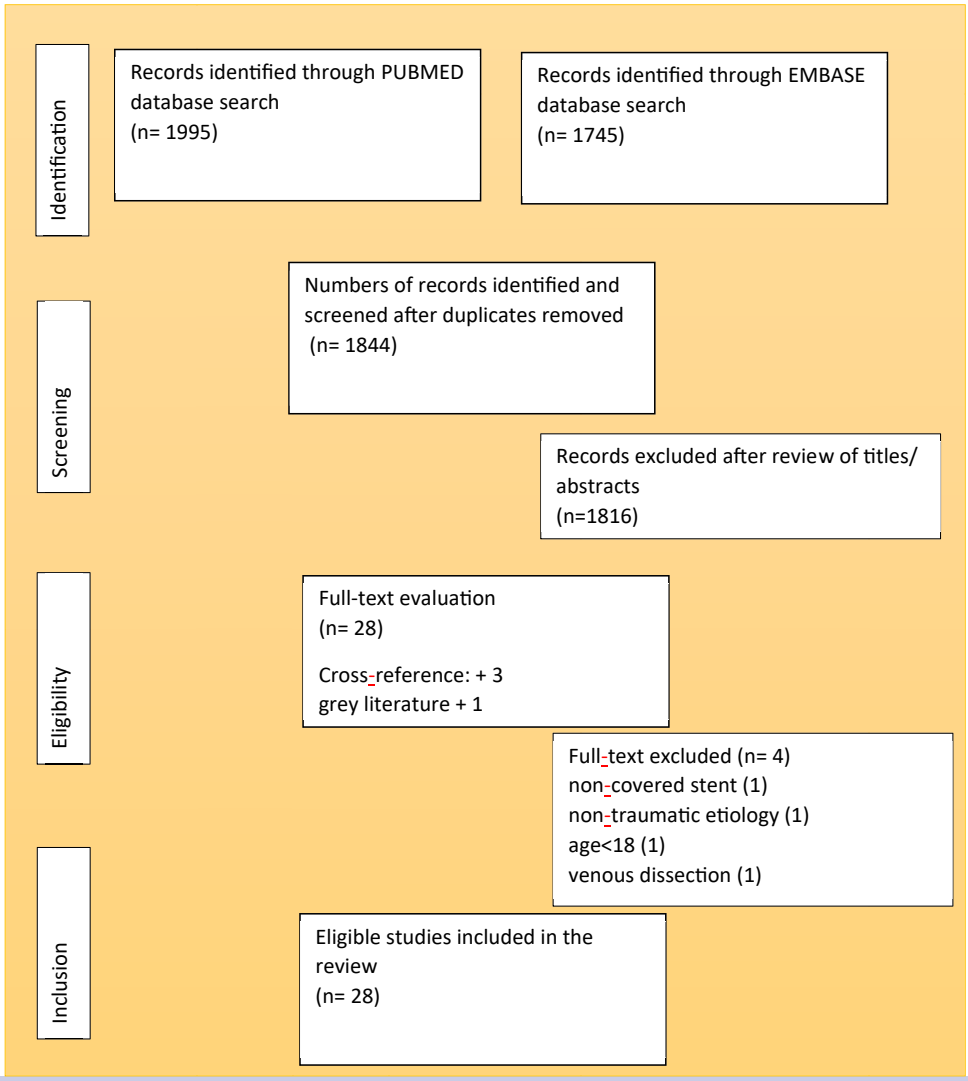

Fig 1. Flow chart illustrating the study selection process.

were women (51.5%), with a mean age of 50 years (range, 18-86 years). The cause of injury was traumatic for 15 patients (13 blunt and 2 sharp) and iatrogenic in 20 patients.

Injury etiology and location. In the 15 traumatic cases, motor vehicle collision and blunt trauma accounted for 13 cases. The other two had been caused by gunshot wounds or stab wounds combined with a fall from a height. Most of the iatrogenic injuries had occurred during a lumbar vertebrae operation (n = 11). In 9 of these 11 cases, the bleeding had occurred during an anterior approach to the lumbar spine. Six had occurred during revision procedures of previous lumbar spine surgery. Other iatrogenic causes were percutaneous venous intervention (n = 2), sarcoma resection (n = 1), endoscopic adrenalectomy (n = 1), iliocaval thrombolysis (n = 1), IVC filter removal (n = 1), laparoscopic trocar placement (n = 1), redo aorta bi-iliac aneurysm surgery (n = 1), and hip arthroplasty (n = 1). The injuries were treated in the juxtahepatic IVC (n = 8), infrarenal IVC (n = 5), iliocaval bifurcation (n = 6), common iliac vein (n = 10), and external iliac vein (n = 6). The left common iliac vein was injured in six cases, the right common iliac vein in two, and no side was reported in two cases. The left external iliac vein was affected in five patients and the right external iliac vein in one patient. A postoperative computed tomography (CT) scan of a thoracic endovascular aortic repair stent graft placed in an external iliac vein injury is shown in Fig 2.

Clinical presentation and detection method. The clinical presentation of the venous injury was hypotension or shock in 17 patients (48%), noncontrollable hemorrhage during surgery in 14 (40%), abdominal flank or hip pain in 2 (6%), swelling of the leg with an absence of pulse in 1 (3%), and asymptomatic with an incidental finding on CT in 1 patient (3%). Shock was the predominant presentation of the trauma patients (13 of 15), and perioperative noncontrollable hemorrhage was the most common in the iatrogenic patients (14 of 20). The investigators had

Table I. Studies reporting covered stent graft repair for injuries to inferior vena cava and iliac veins

Investigator	Journal	Location	*Study* type	Injury *etiology*	Covered stent cases, *No.*	*Methodologic quality*[a]				
						Overall	Selection	Ascertainment	Causality	Reporting
Uppot et al,[18] *2001*	AJR Am J Roentgenol	USA	Case report	Trauma	1/1	Fair	–	+	–	–
Watarida et al,[19] *2002*	J Endovasc Ther	Japan	Case report	Trauma	1/1	Fair	–	+	+	+
Erzurum et al,[20] *2003*	J Vasc Surg	USA	Case report	Iatrogenic	1/1	Fair	–	+	+	+
Zieber et al,[14] *2004*	J Vasc Interv Radiol	USA	Case report	Trauma	1/2	Fair	–	+	+	+
Castelli et al,[21] *2005*	Eur J Cardiothorac	Italy	Case report	Trauma	1/1	Fair	–	+	+	+
Mahendran et al,[41] *2005*	EJVES Extra	Ireland	Case report	Iatrogenic	1/2	Fair	–	+	+	+
de Naeyer et al,[22] *2005*	J Vasc Surg	Belgium	Case report	Iatrogenic	1/1	Fair	–	+	+	+
Kataoka et al,[44] *2005*	J Trauma	Japan	Retrospective cohort	Trauma	3/73	Good	+	+	–	+
Sam et al,[23] *2006*	J Vasc Surg	USA	Case report	Trauma	1/1	Fair	–	+	+	+
Schneider et al,[24] *2006*	J Vasc Surg	USA	Case report	Iatrogenic	1/1	Fair	–	+	–	+
Hommes et al,[25] *2009*	J Trauma	Netherlands	Case report	Trauma	1/1	Fair	–	+	+	+
Adams et al,[26] *2012*	Ann Vasc Surg	USA	Case report	Iatrogenic	2/2	Fair	–	+	+	+
Zahradnik et al,[27] *2012*	Ann Vasc Surg	USA	Case report	Iatrogenic	2/2	Fair	–	+	+	+
Filippini et al,[28] *2013*	Eur J Cardiothorac	France	Case report	Trauma	1/1	Fair	–	+	+	+
Merchant et al,[29] *2013*	J Vasc Interv Radiol	USA	Case report	Trauma	1/2	Fair	–	+	–	+
Piffaretti et al,[30] *2013*	Endovasc Today	Italy	Case report	Trauma	1/1	Fair	–	+	+	+
Briggs et al,[31] *2014*	Ann Vasc Surg	USA	Case report	Iatrogenic	1/1	Fair	–	+	+	+
Chou et al,[32] *2016*	Ann Vasc Surg	USA	Case report	Iatrogenic	1/1	Fair	–	+	–	+
Bonasso et al,[43] *2017*	Ann Vasc Surg	USA	Case series	Iatrogenic	3/3	Good	+	+	+	+
Saito et al,[33] *2017*	J Orthop Sci	Japan	Case report	Iatrogenic	1/1	Fair	–	+	–	+
Ginjupalli et al,[34] *2018*	Methodist Debakey Cardiovasc J	USA	Case report	Iatrogenic	1/1	Fair	–	+	+	+
Marsala et al,[35] *2018*	J Vasc Interv Radiol	USA	Case report	Iatrogenic	1/1	Fair	–	+	+	+
Matteo et al,[36] *2018*	Cureus	USA	Case report	Iatrogenic	1/1	Fair	–	+	–	–
El Khoury et al,[38] *2018*	J Vasc Surg Venous Lymphat Disord	USA	Case report	Trauma	1/1	Fair	–	+	+	+
Braun et al,[37] *2019*	J Vasc Interv Radiol	USA	Case report	Iatrogenic	1/1	Fair	–	+	+	+
Frenk et al,[39] *2019*	J Vasc Interv Radiol	USA	Case report	Iatrogenic	1/1	Fair	–	+	+	+
Tariq et al,[40] *2019*	J Vasc Interv Radiol	USA	Case report	Trauma	1/1	Fair	–	+	+	+

Table I. Continued.

Investigator	Journal	Location	Study type	Injury etiology	Covered stent cases, No.	Methodologic quality[a]				
						Overall	Selection	Ascertainment	Causality	Reporting
Demir et al,[42] 2020	J Vasc Surg Venous Lymphat Disord	Nether lands	Case report	Iatrogenic	2/2	Fair	–	+	+	+

[a]Methodologic quality stated as poor, fair, or good using the modified Newcastle-Ottawa scale on four domains: selection, ascertainment, causality, and reporting.

predominantly used intravenous (IV) contrast-enhanced CT (37%) or direct venography (49%) as the detection method of the injury. In five patients, both arterial and venous angiography was used to rule out an additional arterial injury (14%). For the patients with trauma, CT was used more often to detect the injury (9 of 14 patients), followed by venography combined with arterial angiography (4 of 14 patients). For the patients with iatrogenic injury, direct venography was used most often to detect the location of the hemorrhage (16 of 20 patients).

Stent graft type and diameter. The 35 patients were treated with abdominal aortic grafts (n = 14), thoracic aortic grafts (n = 4), self-expanding covered stents (n = 7), a combination of an aortic graft with self-expanding covered stents (n = 4), and a balloon-expandable covered stent and a custom-made covered stent (n = 1). For four patients, no precise description was reported.

The abdominal aortic grafts consisted of abdominal aortic extensions (cuffs), iliac extensions, iliac limbs, and a complete aortic bifurcation graft. The thoracic aortic stent grafts were commercially available grafts for aneurysm repair. The self-expanding stents consisted of large-size arterial covered stent grafts. The balloon expandable stent was a covered CP stent (NuMED, Aubrey, Tex). The custom-made covered stent graft was composed of two Gianturco Z stents (Cook Medical, Bloomington, Ind) covered with a Dacron tube. A detailed description of the type of stent and manufacturer is provided in Tables II and III.

In the 35 patients, a total of 56 covered stent grafts were used. Of the 35 patients, 18 were treated with one, 13 patients with two, and 4 with three stent grafts. If multiple stents were used (n = 17), they were used in overlapping fashion (n = 12), a kissing configuration (n = 3), a bifurcated configuration (n = 1) or as one large stent in the IVC with overlapping kissing stents in the common iliac veins (n = 1). In 7 of these 17 patients, an additional stent graft was placed because of persistent leakage. In six patients, extra overlap was created, and in one patient, an additional stent was placed in kissing configuration in the contralateral common iliac vein.

A total of 24 grafts were placed in the IVC, with a median diameter of 28 mm (range, 13-44 mm). In the common iliac vein, 24 stent grafts were used/ with a median diameter of 16 mm (range, 10-28 mm). Eight stent grafts were placed in the external iliac vein, with a median diameter of 13.5 mm (range, 10-28 mm). In eight reports, the investigators had described how sizing had been performed. In five of these studies, perioperative venography was used to measure the diameter, with a catheter or sheath as a reference. In the others, a preoperative CT scan or intravascular ultrasound was used, and in one, a previously placed uncovered stent (measured on intravascular ultrasound) served as the reference diameter. The length of the individual stent grafts was described for 44 endografts, with a mean length of 74 mm (range, 29-158 mm). Because of the various configurations (single stent, kissing, overlapping) used, the coverage length and sealing zone could not be adequately reported.

Systemic heparinization during stent graft placement was discussed in three cases. In one case, heparin (5000 U) was administered. However, two investigators specifically stated that heparin should not be used for patients with coexisting traumatic injuries.

Technical success and complications. Direct hemostasis, after initial stent placement, was present in 27 of the 35 patients. In the other patients, hemostasis was achieved with a subsequently placed stent graft (n = 7) or temporary balloon occlusion (n = 1). In all 35 patients, hemostasis had been achieved at the end of the intervention (100% success rate). Device implementation-related complications were reported in three patients and consisted of immediate thrombus formation in two and embolization in one. One stent graft thrombosis was treated with an AngioJet (Boston Scientific, Marlborough, Mass) and an IVC filter. The other thrombosis was left untreated with IVC filter placement. Embolization had occurred in one patient treated for cement perforation into the IVC during spinal surgery, which had resulted in asymptomatic embolization of particles of cement into the pulmonary circulation. One death was reported after a post-traumatic injury on the second postoperative day

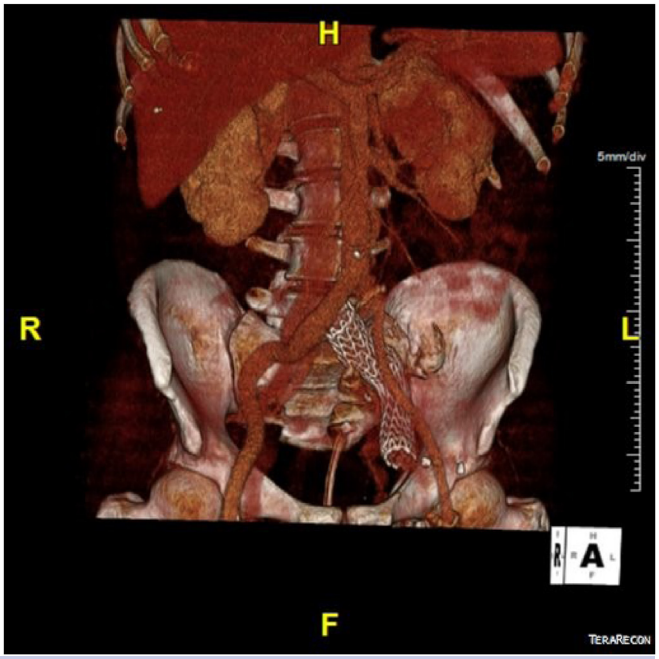

Fig 2. Postoperative computed tomography (CT) scan of a thoracic stent graft placed in an injured external iliac vein. The patient provided written informed consent for the publication of the image.

of coexisting intracerebral injuries (30-day mortality rate, 2.9%).

Follow-up and medication. Follow-up data were reported for 32 patients (91%). Follow-up was performed with clinical parameters (n = 11), CT scan (n = 12), ultrasound (n = 7), CT combined with ultrasound (n = 1), or venography (n = 1). The median follow-up period was 3 months (range, 0.1-84 months). For 21 patients, imaging studies were used to detect the patency of the stent grafts, and the median imaging follow-up period was 6 months (range, 0.07-84 months). For 17 of these 21 patients, imaging surveillance was >30 days. The stent graft with immediate thrombosis had remained partially occluded at that follow-up examination. In the other 16 patients, three additional asymptomatic events were reported: one thrombosis was detected at 12 months (IVC stent), one mural thrombus was detected at 18 months (IVC stent), and one case of 50% stenosis due to thrombus was detected at a 6-week follow-up scan (juxtahepatic IVC). The investigators of the latter case suggested that discontinuation of a vitamin K antagonist might have caused the stenosis. For three patients, no data regarding follow-up were reported. Clinical signs of graft thrombosis during follow-up were present in the one patient with immediate partial graft thrombosis.

Data on postoperative antithrombotic treatment were reported for 20 of the 35 patients. The type of medication was highly heterogeneous. The treatment regimens included a vitamin K antagonist (n = 8), direct oral anticoagulant agents (n = 3), clopidogrel (n = 2), dual antiplatelet therapy (n = 2), acetylsalicylic acid (n = 1), a vitamin K antagonist combined with acetylsalicylic acid (n = 1), prophylactic heparin (n = 1), and no anticoagulation therapy (n = 2). The data were missing for 15 patients. The duration of the antithrombotic therapy was described for 10 patients and ranged from 2 months to indefinitely.

DISCUSSION

Uncontrollable venous bleeding from the IVC or iliac veins poses a serious life-threatening condition for which urgent surgical attention is required. A relatively new alternative to open surgery is placement of a covered stent graft over the venous injury. The present review aimed to collect all available data on the use of covered stents for bleeding in the IVC and iliac veins.

The patients treated with a covered stent graft in the present series had either been injured through trauma or had experienced iatrogenic injury during surgery. In the present series, blunt forces accounted for most of the traumatic venous injuries, in contrast to other series in which penetrating injury accounted for most traumatic vascular injury.[1,45] Possibly, the tendency is greater to treat penetrating venous injury by open repair than with a stent graft. In the iatrogenic cases in our series, lumbar spine surgery was the predominant cause of uncontrollable hemorrhage treated with a covered stent. In another recent, large retrospective report, however, general surgery and endovascular procedures were more often the cause of abdominopelvic vascular injury.[46] It is possible that the relative inaccessibility of this iliac venous segment during lumbar spine surgery made the use of a covered stent graft more appealing than open repair. Furthermore, the data from the present cohort revealed that most venous injuries were encountered during anterior and/or revision lumbar spine surgery. Therefore, it could be argued that in these cases, the assistance of a vascular surgeon for lumbar access might be advisable.

In the detection of the injury, most investigators chose to use IV contrast-enhanced CT as the detection method of choice in the case of traumatic venous injury. CT scans are increasingly being used in the multiple trauma setting because they can detect diverse type of injuries. Additionally, IV contrast-enhanced CT has an important role in the differentiation between arterial and venous extravasation in abdominopelvic trauma.[47] In the cases of iatrogenic bleeding, many investigators chose to directly perform venography because the venous source of the bleeding was known and direct hemostatic treatment could be performed.

Several different stent grafts were used in the present series, ranging from thoracic and abdominal aortic grafts to large covered stents originally indicated for arterial implementation. No advice can be given regarding

Table II. Studies reporting covered stent graft repair for iatrogenic injuries to inferior vena cava and iliac veins

Investigator	Injured *vein*	Gender; *age, years*	Etiology	Device	Type	Technical success	Follow-up	Anticoagulation *therapy*	Outcome	Patency on imaging
Erzurum et al,[20] 2003	Juxtahepatic IVC	F; 37	Leiomyosarcoma resection	Aneurx (Medtronic)	Abdominal aortic extension	Yes	6 months	NR	Alive	NR
de Naeyer et al,[22] 2005	Infrarenal IVC	F; 51	Lumbar vertebrae operation	Talent (Medtronic)	Thoracic aortic	Yes	18 months	Vitamin K antagonist	Alive	Patent (with mural thrombus)
Schneider et al,[24] 2006	Iliocaval bifurcation	F; 61	Lumbar vertebrae operation	Aneurx (Medtronic)	Iliac extension	Yes	10 days	Vitamin K antagonist	Alive	Patent
Adams et al,[26] 2012	External iliac vein	F; 41	Venous stent placement	Viabahn (Gore)	SE stent	Yes	NR	Vitamin K antagonist	Alive	NR
	External iliac vein	F; 52	Venous stent placement	Viabahn (Gore)	SE stent	Yes	6 months	NR	Alive	Patent
Zahradnik et al,[27] 2012	Common iliac vein	M; 86	Lumbar vertebrae operation	Viabahn (Gore)	SE stent	Yes[a]	1 month	Clopidogrel	Alive	Patent
	Common iliac vein	M; 36	Lumbar vertebrae operation	Zenith (Cook)	Iliac extension	Yes	3 months	Clopidogrel	Alive	NR
Briggs et al,[31] 2014	Juxtahepatic IVC	F; 46	Retroperitoneoscopic adrenalectomy	Talent (Medtronic)	Thoracic aortic	Yes[a]	13 months	Vitamin K antagonist	Alive	Patent
Chou et al,[32] 2016	Iliocaval bifurcation	F; 61	Lumbar vertebrae operation	Excluder (Gore)	Abdominal aortic extension + iliac extension	Yes[a]	6 days	Dual antiplatelet	Alive	Patent
Bonasso et al,[43] 2017	Iliocaval bifurcation	F; 59	Lumbar vertebrae operation	NS	Iliac limb + thoracic aortic	Yes[a]	3 months	NR	Alive	NR
	Iliocaval bifurcation	M; 56	Lumbar vertebrae operation	NS	Iliac limb + thoracic aortic	Yes[a]	4 months	NR	Alive	Patent
	Common iliac vein	F; 54	Lumbar vertebrae operation	NS	Iliac limb	Yes	NR	None	Alive	NR
Saito et al,[33] 2017	Common iliac vein	F; 63	Lumbar vertebrae operation	NS	NS	Yes	14 days	NR	Alive	NR
Ginjupalli et al,[34] 2018	Common iliac vein	M; 51	Iliocaval thrombolysis	Endurant (Medtronic)	Iliac extension	Yes	2 months	DOAC	Alive	NR
Marsala et al,[35] 2018	Infrarenal IVC	F; 72	IVC filter removal	Excluder (Gore) and CTAG (Gore)	Abdominal aortic extension + thoracic aortic	Yes[a]	12 months	NR	Alive	Patent at 3 months; occlusion at 12 months
Matteo et al,[36] 2018	Infrarenal IVC	M; 70	Laparoscopic trocar placement	Excluder (Gore) and Viabahn (Gore)	Abdominal aortic extension + SE stent	Yes[b]	NR	NR	Alive	NR
Braun et al,[37] 2019	External iliac vein	F; 50	Hip arthroplasty	Viabahn (Gore)	SE stent	Yes	7 years	Vitamin K antagonist	Alive	Patent
Frenk et al,[39] 2019	Infrarenal IVC	M; 72	Lumbar vertebrae operation	Endurant (Medtronic)	Abdominal aortic extension	Yes	1 month	Dual antiplatelet	Alive	Patent
Demir et al,[42] 2020	Common iliac vein	M; 48	Lumbar vertebrae operation	Valiant (Medtronic)	Thoracic aortic	Yes	6 months	DOAC	Alive	Immediate partial thrombosis + IVC filter
	External iliac vein	M; 61	Redo aorta bifurcation reconstruction	CTAG (Gore)	Thoracic aortic	Yes	12 months	DOAC	Alive	Patent

DOAC, Direct oral anticoagulant; *F,* female; *IVC,* inferior vena cava; *M,* male; *NR,* not reported; *NS,* not specified; *SE,* self-expandable.
[a]Initial stent placement showed leakage, and successful additional stent placement was performed.
[b]Initial occlusion treated with suction of thrombosis and an IVC filter.

which type of stent graft performed best from these data. We could speculate that an ideal covered stent for this indication would be resorbable after hemostasis has been achieved. Furthermore, these grafts should be flexible and compliant to compression, especially in the iliac vein. For the prevention of early stent graft

Table III. Studies reporting covered stent graft repair in post-traumatic injuries to IVC and iliac veins

Investigator	Injured *vein*	Gender; age	Etiology	Device	Type	Technical success	Follow-up	Anticoagulation *therapy*	Outcome	Patency on imaging
Uppot et al,[18] 2001	Common iliac vein	M; 18	MVC	SMART (Cordis)	SE stent	Yes[a]	NR	NR	Alive	NR
Watarida et al,[19] 2002	Juxtahepatic IVC	M; 62	MVC	Z stents + Dacron	Self-made	Yes	16 months	Vitamin K antagonist	Alive	Patent
Zieber et al,[14] 2004	External iliac vein	M; 44	MVC	Wallgraft (Boston Scientific)	SE stent	Yes	9 months	NR	Alive	Patent at 10 days; NR at 9 months
Castelli *et al*,[21] 2005	Iliocaval bifurcation	F; 65	MVC	Excluder (Gore)	Abdominal bifurcation graft	Yes	2 days	None	Death from intracerebral injury	NR
Mahendran et al,[41] 2005	Iliocaval bifurcation	F; 66	MVC	Jomed (Jomed)	SE stent	Yes	6 months	Vitamin K antagonist	Alive	Patent
Kataoka et al,[44] 2005	Common iliac vein	M; 22	Blunt trauma	NS	NS	Yes	7 days	NR	Alive	NR
	Common iliac vein	F; 81	Blunt trauma	NS	NS	Yes	7 days	NR	Alive	NR
	Common iliac vein	F; 45	Blunt trauma	NS	NS	Yes	7 days	NR	Alive	NR
Sam et al,[23] 2006	Infrarenal IVC	M; 62	Blunt trauma	Excluder (Gore)	Abdominal aortic extension	Yes[a]	14 months	Vitamin K antagonist	Alive	Patent
Hommes et al,[25] 2009	Juxtahepatic IVC	F; 29	Stab wound and fall from height	Excluder (Gore)	Abdominal aortic extension	Yes	2 months	NR	Alive	Patent at 1 week; NR at 2 months
Filippini et al,[28] 2013	Juxtahepatic IVC	M; 25	MVC	Covered CP (NuMED)	BE stent	Yes	15 months	Acetylsalicylic acid	Alive	Patent
Merchant et al,[29] 2013	External iliac vein	M; 47	MVC	Excluder (Gore)	Iliac limb	Yes	16 days	NR	Alive	NR
Piffaretti et al,[30] 2013	Juxtahepatic IVC	M; 23	MVC	Zenith (Cook)	Abdominal aortic extension	Yes	12 months	NR	Alive	Patent
El Khoury et al,[38] 2018	Juxtahepatic IVC	M; 22	Gunshot wounds	Endurant (Medtronic)	Abdominal aortic extension + iliac extension	Yes	2 months	Prophylactic heparin	Alive	Patent
Tariq et al,[40] 2019	Juxtahepatic IVC	F; 27	MVC	Endurant (Medtronic)	Iliac extension + iliac limb	Yes	2 months	Vitamin K antagonist + acetylsalicylic acid	Alive	Patent (with mural thrombus)

BE, Balloon-expandable; *F,* female; *IVC,* inferior vena cava; *M,* male; *MVC,* motor vehicle collision; *NR,* not reported; *NS,* not specified; *SE,* self-expandable.
[a]Initial stent placement showed leakage, and successful additional stent placement or balloon occlusion was performed.

thrombosis in this low flow system, polytetrafluoroethylene might perform better than Dacron. A heparin coating could also be favorable because the stent struts should preferably be positioned on the outside of the fabric. A reversed tapered design could accommodate diameter changes from the external to common iliac vein or from the common iliac vein to the IVC and reduce the infolding of fabric. However, no such specific stent graft is currently available commercially, and we suspect this application is too rare for the development of a specific stent graft. Therefore, using a stent graft available in stock that resembles the stated properties as much as possible would seem advisable. In general, a thoracic or abdominal aortic stent graft would seem adequate with respect to the length and diameter. The diameter of the venous system is significantly larger than that of the arterial system. Furthermore, the IVC is highly subject to diameter changes during volume resuscitation.[48] Thus, on preresuscitation imaging studies, one should be aware of this effect. The use of the long-axis measurement (of the oval-shaped IVC) will result in the least underestimation of its true diameter. In a model for a temporary shunt for juxtahepatic IVC injury, the mean diameter of the juxtahepatic and retrohepatic IVC was 28 mm and, at the level of the renal veins, was 23 mm.[49] However, this model was constructed using data from 120 CT scans in a Chinese population; thus, the diameters could be slightly larger in whites. The

recommended stent diameter for stenotic or occlusive venous disease in the common iliac vein, external iliac vein, and femoral vein is 16, 14, and 12 mm, respectively.[50] These diameters correlate with the median diameters found in our review, in which the stent grafts used for the IVC had a median diameter of 28 mm, the common iliac vein stent grafts had a median diameter of 16 mm, and the external iliac vein stent grafts, a median diameter of 13.5 mm. The reported mean stent graft length was 74 mm in the present series. However, if two or more stents had been used, neither the total coverage length nor overlap had been reported. Concerning sizing, our advice would be to oversize the diameter by 20% to 25% and to aim for a 30-mm sealing zone on both sides of the injury to obtain adequate hemostasis and prevent the need for additional stent graft placement. We would use this 30-mm sealing zone (longer than for arterial use) because an injured vein is more susceptible to tearing and is more compliant to dilatation, which could compromise stent sealing capacities.

A balance should be found between using a stent or stents long enough to create an adequate seal and keeping the length of the thrombogenic fabric to a minimum. However, no relation between the stent length and thrombus formation was identified in the present series.

Stent graft implementation for venous injury was technically successful for hemostasis in all reported cases, and few adverse events were reported. The incidence of direct (n = 2) or late in-stent thrombosis was low when considering the placement of non–venous-designed stent grafts in the low-flow venous system. Whether the use of perioperative heparin could prevent early graft thrombosis is uncertain because only three investigators had reported these data. The use of heparin should be considered on a case-by-case basis because a fine line exists between thrombus formation and the occurrence of persistent hemorrhage. An IVC filter was implemented in three cases only. In selected cases, such as when in-stent thrombus formation is present or anticoagulant treatment is contraindicated, placement of an IVC filter can be considered. However, no data are available to support the use of general prophylactic placement of an IVC filter.

During follow-up, only one patient showed clinical signs of deep vein thrombosis. Antithrombotic or anticoagulant treatment in this phase of treatment would seem advisable for the prevention of thrombus formation. However, owing to the highly heterogeneous antithrombotic regimens and durations of treatment used, the preferred type and dosage of treatment remains unclear. For our own patients, we chose to prescribe anticoagulant treatment, instead of antiplatelet treatment, subsequent to the 2018 Delphi statement of the use of antithrombotic agents after deep venous stenting. This consensus was originally designed for antithrombotic treatment after deep venous (noncovered) stenting of stenotic lesions but could be extrapolated to covered venous stenting for trauma.[51] The present review focused on the endovascular treatment of pelvic venous injury; therefore, no clear conclusions can be made regarding whether endovascular treatment performs better than open ligation or repair. The 30-day mortality in the present review was 2.9% compared with a reported mortality rate of 25.5% after iliac vein and 16% to 23% after IVC repair or ligation.[5] However, the mortality rate from the present series might have been low owing to reporting case selection and the predominant iatrogenic etiology of the injuries (20 of 35). The mortality rate for the described cohort is, therefore, difficult to compare to that of abdominopelvic trauma patients who often have multisystemic injuries.

One retrospective cohort study of traumatic injury, included in the present review, described both open packing and endovascular treatment. Covered stent grafts were used in three patients with no mortality.[44] However, retroperitoneal packing was used for four patients, with 50% mortality.[44]

Endovascular exclusion of a venous injury can be performed through a bilateral percutaneous femoral venous access using large sheaths to allow for occlusion balloon placement, venography, and large stent placement. From a technical viewpoint, covered stenting of the juxtahepatic and retrohepatic IVC is appealing owing to the relative surgical inaccessibility. However, special attention must be given to preserve the outflow of the renal and hepatic veins. Outflow obstruction of the hepatic veins can have catastrophic outcomes.[52] Some investigators have addressed this issue by constructing a custom-made fenestrated graft or simultaneously stenting the hepatic outflow.[19,40] Treating the iliocaval confluence was usually performed using kissing stent grafts or a large stent in the IVC and two kissing stents in the common iliac veins. No adverse events were described when blocking the outflow of the internal iliac vein. However, the follow-up period might not have been adequate nor long enough to report this.

Study limitations. Several limitations should be considered when interpreting the results of the present review. First, and most importantly, nearly all 35 patients had been presented in case reports. Although the reporting of the treatment and outcomes was clear, none of these case reports had described how the process of patient selection was performed. Especially when interpreting the short-term high success rates and few complications, this type of selection bias should be considered seriously. Second, any solid conclusions on the long-term effectiveness of this treatment would be difficult. The reported follow-up period was relatively short, the factors involved in anticoagulant and antithrombotic treatment

were heterogeneous, and data on long-term imaging studies of the stent grafts were limited.

CONCLUSIONS

In selected cases of injury to the IVC and iliac veins, the use of covered stent grafts can be successful for urgent hemostasis with good short-term results. However, data on long-term follow-up are very limited. Because of the less invasive nature, endovascular treatment can be considered an alternative to open repair in technically demanding cases. Correct sizing and knowledge of the venous anatomy and endovascular materials are imperative.

AUTHOR CONTRIBUTIONS

Conception and design: GS, BM
Analysis and interpretation: RS, DD, JvL, BM
Data collection: RS, DD
Writing the article: RS, DD
Critical revision of the article: JvL, GS, BM
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Supplementary Fig (online only). Literature search strategy.