Experience of surgical treatments for abdominal inferior vena cava injuries in a regional trauma center in Korea

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Purpose: Inferior vena cava (IVC) injuries are a rare type of traumatic abdominal injuries that are challenging to treat and have a very high mortality rate. This study described our experience with the surgical treatment of traumatic IVC injuries, and we investigated the demographics, clinical profiles, and surgical outcomes of cases at a regional trauma center.

Methods: Among the 16 patients who were treated for a traumatic IVC injury between January 2014 and March 2022, 14 underwent surgery. The surgical outcomes included overall mortality and 24-hour mortality, and we investigated the factors associated with these surgical outcomes. The 14 patients were divided into two groups according to the location of the IVC injury (retrohepatic IVC or higher vs. subhepatic IVC), and differences between the two groups were analyzed.

Results: A body mass index (BMI) >23.0 kg/m^2 (P=0.046), an elevated serum lactate level (P=0.043), and a shorter operation time (P=0.016) were associated with overall mortality. A higher BMI (P=0.050), higher serum lactate level (P=0.004), shorter operation time (P=0.005), and an injury at the retrohepatic IVC or higher level (P=0.031) were associated with 24-hour mortality. Younger age (P=0.028), higher BMI (P=0.005), more acidic pH, higher lactatemia (P=0.012), a higher hemoglobin level (P=0.012), and shorter door-to-operating room time (P=0.028) were associated with injury at the retrohepatic IVC or higher level. Patients with subhepatic IVC injuries had a high rate of direct repair (75.0%) and a significantly lower 24-hour mortality rate (37.5%, P=0.031).

Conclusions: Subhepatic IVC injuries are easy to access and are usually expected to treat with a direct repair method. Injuries at the retrohepatic IVC or higher level are difficult to treat surgically and require a systematic and multidisciplinary treatment strategy.

Keywords: Inferior vena cava; Wounds and injuries; Operative surgical procedures

INTRODUCTION

Traumatic inferior vena cava (IVC) injuries are rare among traumatic abdominal injuries, accounting for fewer than 5% of pene-trating injuries and 0.5% of blunt trauma injuries [1]. However, they are often fatal, with prehospital and in-hospital mortality rates of 30% to 50% and 20% to 66%, respectively [2].

There are various methods for treating traumatic IVC injuries,

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including surgery, vascular grafting, and even close monitoring, depending on the injury level and patient stability. Although IVC repair is the mainstay treatment, in cases where repair is challenging because of massive bleeding, difficult access to the injured site, or notable patient instability, ligation is a treatment option [3]. An atriocaval shunt can also be used to repair the retrohepatic IVC segment [4]. This variety of treatment methods illustrates the lack of consensus or guidelines, and survival rates have not significantly improved over time [5].

Currently, a higher level of injury, blunt trauma, and a lower Glasgow Coma Scale (GCS) score are associated with worse outcomes of traumatic IVC injuries [3,6–8]. However, relatively few cases of IVC injuries have been studied to identify the prognostic factors.

IVC injuries often require emergency treatment, and it can be difficult to collect data in those urgent situations. Moreover, IVC injuries are rare and information is scarce. In Korea, where the availability of authorized trauma centers is relatively recent, there have been few studies on traumatic IVC injuries, and most are case reports. Therefore, this study aimed to describe our experience with the surgical treatment of traumatic IVC injuries and to investigate the demographics, clinical profiles, and surgical outcomes of cases at a regional trauma center.

METHODS

Ethics statements
This study was reviewed and approved by the Institutional Review Board Dankook University Hospital (No. DKUH 2022-11-034). The requirement for informed consent was waived by the Institutional Review Board because this was a retrospective study and only anonymized data were used.

Description of participants
The medical records of patients admitted to a single regional trauma center for traumatic IVC injuries between January 2014 and March 2022 were retrospectively reviewed. Nineteen patients with IVC injuries were identified. Among them, one patient had an IVC contusion only, one patient had an unnamed vessel branch injured near the IVC, and one patient was transferred from another hospital after already undergoing repair. Thus, 16 patients were enrolled after the three above-mentioned patients were excluded. Of these 16 patients, two underwent medical treatment without surgery. Finally, 14 patients were enrolled for the analysis of surgical outcomes (Fig. 1). The surgical outcomes included overall mortality and 24-hour mortality. We

aimed to identify the factors associated with these surgical outcomes and the differences between patients with injuries at the retrohepatic IVC or higher level and those with injuries at the subhepatic IVC level.

Data collection
Data regarding patient demographics, injury levels, initial clinical characteristics, initial laboratory values, treatments, and surgical outcomes were collected. The demographics included age, sex, body mass index (BMI), injury mechanism, cause of injury, prehospital time, Injury Severity Score (ISS), and Abbreviated Injury Scale for each body part. Initial clinical characteristics included systolic blood pressure (SBP), heart rate per minute, mean arterial pressure (MAP), and GCS score. Initial laboratory values included pH, partial pressure of arterial oxygen, serum lactate level, hemoglobin, and international normalized ratio. Treatment data included cardiopulmonary resuscitation (CPR) in the emergency room (ER), door-to-operating room (DTO) time, main treatment methods (direct repair, ligation, atriocaval shunt, observation, and others), amount of red blood cells (RBCs) transfused within the first 24 hours, and operation time. "Others" in the main treatment methods included procedures to stop bleeding such as gauze packing, direct manual compression, and resuscitative endovascular balloon occlusion of the aorta.

If the patient was intubated on arrival, the GCS verbal score was calculated using a linear regression model as follows [9]:

Derived verbal score = −0.3756 + motor score × (0.5713) + eye score × (0.4233)

The abdominal IVC was anatomically divided into five segments as follows: (1) suprahepatic IVC, from the upper margin of the hepatic veins to the lower margin of the diaphragm; (2) retrohe-
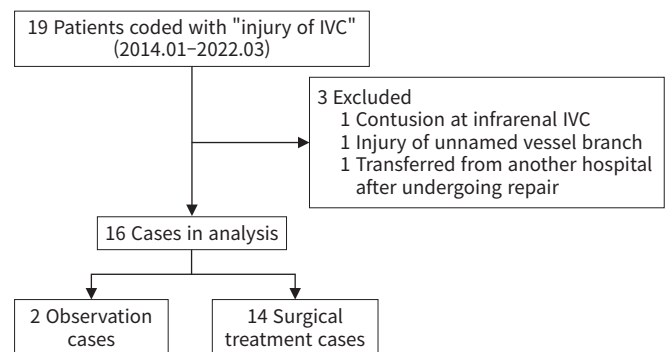

Fig. 1. Patient selection flow chart in a study of patients with traumatic inferior vena cava (IVC) injuries.

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patic IVC, which is covered by the liver; (3) suprarenal IVC, from the upper margin of the renal vessels to the lower margin of the liver; (4) juxtarenal IVC, between the bilateral renal vessels; and (5) infrarenal IVC, from the bifurcation of the common iliac veins to the lower margin of the renal vessels (Fig. 2). In this study, subhepatic IVC included the IVC segments below the retrohepatic IVC.

Statistical analysis

Categorial variables were analyzed using the Fisher exact test and continuous variables were analyzed using the Mann-Whitney U-test. Continuous variables were expressed as median values (interquartile range, IQR). Statistical significance was set at P < 0.05. Statistical analysis was conducted using R ver. 4.2.0 (R Foundation for Statistical Computing).

RESULTS

Demographics

Of the 16 patients who had traumatic IVC injury, 10 (62.5%) were male and 15 (93.8%) had blunt trauma. The most common cause of traumatic IVC injury was a car-driver traffic accident (six patients, 37.5%), followed by falls (three patients, 18.8%). The median patient age was 48 years (IQR, 40–68 years), BMI

Fig. 2. Anatomical levels of the inferior vena cava (IVC), distinguished by colors and frequency (percentage) of injuries in this study: red, suprahepatic IVC; orange, retrohepatic IVC; green, suprarenal IVC; blue, juxtarenal IVC; purple, infrarenal IVC.

was 23.4 kg/m^2 (IQR, 21.0–26.1 kg/m^2), prehospital time was 92.5 minutes (IQR, 54.0–158.0 minutes), and ISS was 34 (IQR, 25–43) (Table 1). The most common injury level was the retrohepatic IVC (six patients, 37.5%), followed by the infrarenal IVC (five patients, 31.3%), suprarenal IVC (two patients, 12.5%), juxtarenal IVC (two patients, 12.5%), and suprahepatic IVC (one patient, 6.3%) (Fig. 2).

Clinical characteristics and initial laboratory findings

During admission, the median SBP and MAP values were 86.5 mmHg (IQR, 71.8–120.8 mmHg) and 60.5 mmHg (IQR, 54.7–85.3 mmHg), respectively. Patients had a moderate loss of consciousness (median GCS, 10; IQR, 6–15). The initial laboratory data showed acidosis (median pH, 7.31; IQR, 7.24–7.37) with hyperlactatemia (median lactate, 4.3 mmol/L; IQR, 2.2–7.5 mmol/L) (Table 1).

Treatment and surgical outcomes

Of the 16 patients studied, eight (50.0%) underwent direct repair, two (12.5%) were closely monitored (observation), one (6.3%) underwent ligation, and one (6.3%) underwent an atriocaval shunt. Furthermore, four patients (25.0%) underwent other damage control surgery, and three (18.8%) underwent CPR in the ER. The median DTO time was 72.5 minutes (IQR, 55.8–109.8 minutes) and the median number of RBC units transfused within the first 24 hours was 29.0 (IQR, 19.8–40.3). Of the two patients who were closely monitored, one had a pericaval hematoma at the infrarenal IVC level and received only an injection of tranexamic acid and fluid therapy because the hemodynamics were stable. The other patient was hypotensive on arrival and had extravasation at the retrohepatic IVC level. However, the hemodynamics became stable after an initial transfusion of 2 units of RBCs. The patient was then closely monitored during hospitalization and received additional transfusions (14 units of RBCs, 7 units of fresh-frozen plasma, and 30 units of platelet concentrate) and injections of tranexamic acid. Both patients that were closely monitored, eventually survived. Of the 14 patients who underwent surgery, 11 (78.6%) did not survive, nine of whom (64.3%) died within 24 hours of admission (Table 1).

Survivors who underwent damage control surgery

The five survivors who underwent surgical treatment for traumatic IVC injury are presented in Table 2. All patients were injured at the subhepatic IVC level and successfully underwent direct repairs (venorrhaphy) in the first operation. Three patients were discharged alive and the remaining two died. One patient
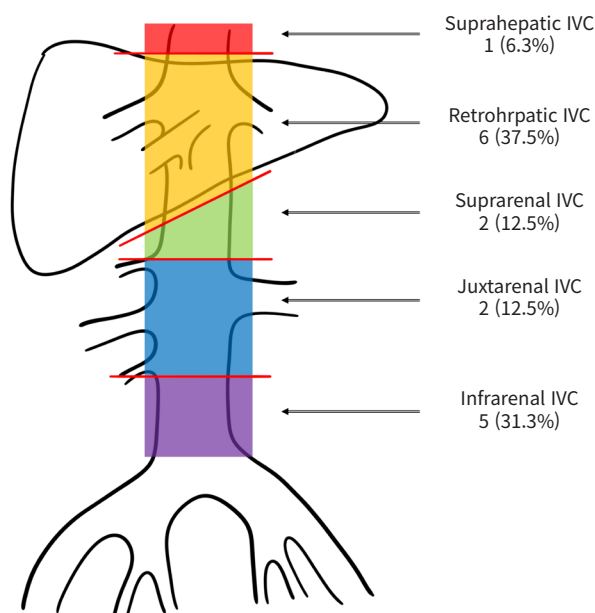
Table 1. Overall patient characteristics, treatment, and surgical outcomes

Variable	Value (n=16)
Male sex	10 (62.5)
Age (yr)	48 (40–68)
Body mass index (kg/m^2) (n=14)[a]	23.4 (21.0–26.1)
Prehospital time (min)	92.5 (54.0–158.0)
Injury mechanism (blunt)	15 (93.8)
Cause of injury	
In-car TA	6 (37.5)
Motorcycle TA	2 (12.5)
Pedestrian TA	2 (12.5)
Fall	3 (18.8)
Crash injury	2 (12.5)
Stab wound	1 (6.3)
Injury Severity Score	34 (25–43)
Abbreviated Injury Scale	
Head and neck	0 (0–0)
Chest	3 (2–3)
Abdominopelvic	4 (4–5)
Extremities and pelvis	0 (0–3)
Systolic blood pressure (mmHg)	86.5 (71.8–120.8)
Mean arterial pressure (mmHg)	60.5 (54.7–85.3)
Heart rate (beats/min)	96.0 (76.5–115.0)
Glasgow Coma Scale	10 (6–15)
pH	7.31 (7.24–7.37)
PaO$_2$ (mmHg)	119.5 (60.8–209.3)
Lactate (mmol/L)	4.3 (2.2–7.5)
Hemoglobin (g/dL)	11.8 (9.0–13.1)
International normalized ratio (n=15)[b]	1.22 (1.08–1.37)
CPR in the ER	3 (18.8)
DTO time (min)	72.5 (55.8–109.8)
Treatment method	
Direct repair	8 (50.0)
Ligation	1 (6.3)
Atriocaval shunt	1 (6.3)
Others[c]	4 (25.0)
Observation[d]	2 (12.5)
Operation time (min)	100.0 (80.5–157.5)
Transfused RBC within 24 hr (unit)	29.0 (19.8–40.3)
Surgical outcome (n=14)	
Overall mortality	11 (78.6)
24-hr Mortality	9 (64.3)

Values are presented as median (interquartile range) or number (%).
TA, traffic accident; PaO$_2$, partial pressure of arterial oxygen; CPR, cardiopulmonary resuscitation; ER, emergency room; DTO, door-to-operating room; RBC, red blood cell.
[a]Values of two patients were not available. [b]Value of one patient was not available. [c]Gauze packing, manual compression, and resuscitative endovascular balloon occlusion of the aorta. [d]Medical treatment with close monitoring.

died of severe brain injury on hospital day 11, and the other died of septic shock with pneumonia on hospital day 12.

Table 2. Clinical profiles of five patients survived after damage control surgery

Case no.	Age (yr)	Sex	BMI (kg/m^2)	IVC injury level	Injury mechanism	Prehospital time (min)	ISS	GCS	SBP (mmHg)	Lactate (mmol/L)	CPR in the ER	Operation time (min)	Treatment	HD (day)	Status
1	40	Male	22.0	Suprarenal	Crash	191	42	15	135	2.4	No	160	Venorrhaphy, diaphragm repair, perihepatic packing, TAC	19	Alive
2	74	Female	20.8	Juxtarenal	Pedestrian TA	51	30	15	73	2.3	No	200	Venorrhaphy, nephrectomy, perihepatic packing, TAC	34	Alive
3	41	Female	19.1	Infrarenal	Stab injury	23	25	6	59	2.0	No	264	Venorrhaphy, hemicolectomy with enterostomy	35	Alive
4	68	Female	21.5	Infrarenal	Car driver TA	70	43	6	140	1.3	No	117	Venorrhaphy, craniectomy	11	Dead
5	57	Male	23.3	Suprarenal	Car driver TA	55	25	6	71	4.2	No	160	Venorrhaphy, nephrectomy	12	Dead

BMI, body mass index; IVC, inferior vena cava; ISS, Injury Severity Score; GCS, Glasgow Coma Scale; SBP, systolic blood pressure; CPR, cardiopulmonary resuscitation; ER, emergency room; HD, hospital day; TAC, temporary abdominal closure; TA, traffic accident.

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Variables associated with surgical outcomes

A BMI >23.0 kg/m^2 (P=0.046), a higher serum lactate level (P=0.043), and a shorter operation time (P=0.016) were significantly associated with overall mortality (Table 3). A higher BMI (P=0.050), higher serum lactate level (P=0.004), shorter operation time (P=0.005), and injury at the retrohepatic IVC or high-er level (P=0.031) were significantly associated with 24-hour mortality in the univariate analysis (Table 3).

Comparison according to the injury level of the IVC

Younger age (P=0.028), higher BMI (P=0.005), more acidic pH (P=0.028) with higher lactatemia (P=0.012), higher hemoglo-

Table 3. Comparison between survivor and nonsurvivor groups following surgical treatment

Variable	Overall mortality		P-value	24-hr Mortality		P-value
	Survival (n=3)	Death (n=11)		Survival (n=5)	Death (n=9)	
Male sex	1 (33.3)	7 (63.6)	0.539	2 (40.0)	6 (66.7)	0.580
Age (yr)	41.0 (40.5–57.5)	48.0 (41.0–68.5)	0.815	57 (41–68)	47 (40–69)	0.841
Body mass index (kg/m^2)	20.8 (20.0–21.4)	26.1 (23.3–26.1)	0.094	21.5 (20.8–22.0)	26.1 (25.4–27.7)	0.050
≥23.0	0	7 (63.6)	0.046	1 (20.0)	6 (66.7)	0.072
Prehospital time (min)	51.0 (37.0–121.0)	93.0 (55.0–146.0)	0.436	55.0 (51.0–70.0)	130.0 (55.0–147.0)	0.317
Injury mechanism (blunt)	2 (66.7)	11 (100)	0.214	4 (80.0)	9 (100)	0.357
Injury Severity Score	30 (28–36)	34 (25–43)	0.635	30 (25–42)	34 (25–43)	0.735
Abbreviated Injury Scale						
Head and neck	0 (0–0)	0 (0–0)	0.523	0 (0–0)	0 (0–0)	0.662
Chest	3 (3–4)	3 (2–3)	0.665	3 (3–3)	3 (0–3)	0.504
Abdominopelvic	5 (5–5)	4 (4–5)	0.352	4 (4–5)	4 (4–5)	0.885
Extremities and pelvis	0 (0–0)	0 (0–3)	0.197	0 (0–0)	2 (0–3)	0.058
Systolic blood pressure (mmHg)	73.0 (66.0–104.0)	82.0 (71.0–112.5)	>0.999	107.0 (73.0–131.0)	78.0 (68.0–94.0)	0.350
Mean arterial pressure (mmHg)	59.7 (52.3–79.3)	61.3 (54.0–75.5)	>0.999	67.7 (59.7–99.0)	56.0 (52.7–64.0)	0.286
Heart rate (beats/min)	82.0 (82.0–95.5)	102.0 (71.5–131.0)	0.755	82.0 (82.0–109.0)	102.0 (72.0–130.0)	0.894
Glasgow Coma Scale	15 (11–15)	9 (6–13)	0.423	6 (6–15)	10 (7–15)	0.891
pH	7.37 (7.34–7.39)	7.27 (7.14–7.34)	0.119	7.37 (7.31–7.40)	7.27 (7.12–7.31)	0.061
PaO$_2$ (mmHg)	194.0 (125.0–239.5)	80.0 (60.5–209.5)	0.815	56.0 (56.0–194.0)	82.0 (76.0–210.0)	0.229
Lactate (mmol/L)	2.3 (2.2–2.4)	5.2 (4.3–9.9)	0.043	2.3 (2.0–2.4)	7.3 (4.9–11.6)	0.004
Hemoglobin (g/dL)	10.5 (9.5–10.7)	11.9 (8.9–13.1)	0.350	10.5 (8.5–10.8)	13.0 (9.0–13.1)	0.182
International normalized ratio	1.05 (0.99–1.14)	1.24 (1.13–1.43)	0.127	1.19 (1.05–1.22)	1.25 (1.11–1.51)	0.163
CPR in ER	0	3 (27.3)	>0.999	0	3 (33.3)	0.258
DTO time (min)	69.0 (68.0–99.0)	76.0 (51.0–101.5)	0.696	76.0 (69.0–129.0)	67.0 (50.0–85.0)	0.181
Treatment method			0.692			0.119
Direct repair	3 (100)	5 (45.5)		5 (100)	3 (33.3)	
Ligation	0	1 (9.1)		0	1 (11.1)	
Atriocaval shunt	0	1 (9.1)		0	1 (11.1)	
Others[a]	0	4 (36.4)		0	4 (44.4)	
Operation time (min)	200.0 (180.0–232.0)	90.0 (80.0–111.0)	0.016	160.0 (160.0–200.0)	82.0 (80.0–95.0)	0.005
Transfused RBC within 24 hr (unit)	40.0 (35.0–40.5)	28.0 (1.5–40.5)	0.456	36.0 (30.0–40.0)	28.0 (22.0–45.0)	0.797
IVC injury level			0.368			0.091
Suprahepatic	0	1 (9.1)		0	1 (11.1)	
Retrohepatic	0	5 (45.5)		0	5 (55.6)	
Suprarenal	1 (33.3)	1 (9.1)		2 (40.0)	0	
Juxtarenal	1 (33.3)	1 (9.1)		1 (20.0)	1 (11.1)	
Infrarenal	1 (33.3)	3 (27.3)		2 (40.0)	2 (22.2)	
Level (retrohepatic or higher)	0	6 (54.5)	0.209	0	6 (66.7)	0.031

Values are presented as number (%) or median (interquartile range).
PaO$_2$, partial pressure of arterial oxygen; CPR, cardiopulmonary resuscitation; ER, emergency room; DTO, door-to-operating room; RBC, red blood cell; IVC, inferior vena cava.
[a]Gauze packing, manual compression, and resuscitative endovascular balloon occlusion of the aorta.

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bin level (P = 0.012), and shorter DTO time (P = 0.028) were significantly associated with injury at the retrohepatic IVC or higher level (Table 4). Although not statistically significant, the MAP was lower (P = 0.081) in patients with an injury at the retrohepatic IVC or higher level, and CPR in the ER was performed more frequently in these patients (P = 0.055). All patients with injuries at the retrohepatic IVC or higher level who underwent surgical treatment died within 24 hours of admission. In contrast, patients with subhepatic IVC injuries had a high rate of direct repair (75.0%) and a significantly low 24-hour mortality rate (37.5%, P = 0.031) (Table 4).

DISCUSSION

In this study, the overall and 24-hour mortality rates after surgery were 78.6% and 64.3%, respectively. These outcomes are slightly worse than those noted in previous studies, where the overall mortality rates ranged between 20% and 70% [5,8,10–14]. The worse outcomes in this study are probably because 13 of the 14 patients who underwent surgery had blunt trauma, which is a known risk factor for mortality in traumatic IVC injury [7]. Of the nine deaths within 24 hours of admission, seven developed cardiac arrest due to massive bleeding during the operation and did not recover. For the remaining two deceased patients, the op-

Table 4. Comparison according to the injury level of IVC

Variable	Retrohepatic IVC or higher (n = 6)	Subhepatic IVC (n = 8)	P-value
Surgical outcome			
Overall mortality	6 (100)	5 (62.5)	0.209
24-hr Mortality	6 (100)	3 (37.5)	0.031
Male sex	5 (83.3)	3 (37.5)	0.138
Age (yr)	41 (33–46)	69 (53–75)	0.028
Body mass index (kg/m^2)	26.1 (26.1–28.5)	21.1 (19.6–21.9)	0.005
Prehospital time (min)	74.0 (47.5–120.8)	108.5 (54.0–198.3)	0.366
Injury mechanism (blunt)	6 (100)	7 (87.5)	>0.999
Injury Severity Score	43 (36–43)	28 (25–36)	0.101
Abbreviated Injury Scale			
Head and neck	0 (0–0)	0 (0–1)	0.244
Chest	3 (3–3)	3 (2–3)	0.518
Abdominopelvic	5 (4–5)	4 (4–4)	0.326
Extremities and pelvis	2 (0–3)	0 (0–1)	0.285
Systolic blood pressure (mmHg)	76.0 (18.5–81.0)	100.5 (71.8–121.3)	0.272
Mean arterial pressure (mmHg)	54.0 (13.2–59.8)	65.8 (58.8–99.9)	0.081
Heart rate (beats/min)	101.0 (60.3–108.0)	95.5 (79.5–130.5)	0.747
Glasgow Coma Scale	9 (4–14)	9 (6–15)	0.740
pH	7.14 (7.08–7.24)	7.34 (7.31–7.38)	0.028
PaO$_2$ (mmHg)	81.0 (77.0–178.0)	127.0 (56.0–228.0)	0.651
Lactate (mmol/L)	9.9 (5.7–13.1)	3.3 (2.2–4.5)	0.011
Hemoglobin (g/dL)	13.1 (13.0–14.1)	9.7 (8.0–11.0)	0.011
International normalized ratio	1.25 (1.10–1.25)	1.21 (1.10–1.30)	0.942
CPR in ER	3 (50.0)	0	0.055
DTO time (min)	51.0 (47.8–63.3)	80.5 (74.3–120.8)	0.028
Treatment method			0.277
Direct repair	2 (33.3)	6 (75.0)	
Ligation	0	1 (12.5)	
Atriocaval shunt	1 (16.7)	0	
Others[a]	3 (50.0)	1 (12.5)	
Operation time (min)	92.5 (82.5–102.5)	138.5 (81.5–170.0)	0.244
Transfused RBC within 24 hr (unit)	36.0 (18.8–48.8)	32.5 (26.5–37.0)	0.852

Values are presented as number (%) or median (interquartile range).
IVC, inferior vena cava; PaO$_2$, partial pressure of arterial oxygen; CPR, cardiopulmonary resuscitation; ER, emergency room; DTO, door-to-operating room; RBC, red blood cell.
[a]Gauze packing, manual compression, and resuscitative endovascular balloon occlusion of the aorta.

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erations ended with uncontrolled bleeding. Therefore, 24-hour mortality in this study indicated a failure of damage control.

Several prognostic factors associated with traumatic IVC injury have been reported. According to previous studies, a higher IVC injury level was a prognostic factor for mortality [3,8]. A recent meta-analysis revealed that blunt trauma and injury at the suprarenal or higher IVC level were prognostic factors for mortality in traumatic IVC injury [7]. It is difficult to expose the retrohepatic IVC segment as the liver is attached to the anterior surface of the IVC, and the major hepatic veins connect to this level; therefore, the mortality rate associated with a retrohepatic IVC injury can be as high as 90% [3]. Furthermore, in this study, compared to patients with injury at the subhepatic IVC, those with injury at the retrohepatic IVC or higher level showed worse 24-hour mortality rates in the univariate analysis. In a study of 16 cases, multiple logistic regression analysis revealed lower GCS scores to be an independent factor for mortality [6]. We found that higher BMI and serum lactate levels were associated with mortality. Obesity has been reported as an independent risk factor for mortality in blunt trauma patients because the kinetic energy applied to the patient is in proportion to the mass; thus, obesity may increase the energy and cause more severe injury [15]. A higher initial serum lactate level has been associated with higher injury severity and can predict massive hemorrhage in trauma patients [16]. However, because the currently available studies and this study have all had small sample sizes, further studies with a large population are required to confirm that these are prognostic factors for traumatic IVC injury.

The surgical treatments for IVC injuries vary depending on the location of the injury. In general, the first step is to expose the injured IVC segment and apply direct compression to the proximal and distal parts of the segment [1]. Direct repair can then be attempted following proximal and distal control of the injured IVC. However, when repair is difficult due to massive bleeding, ligation can be performed more quickly and easily for damage control [2]. In a study using data from the United States (2007 to 2014), excluding other-vessel injuries and severe extraperitoneal injuries, there was no difference in mortality between ligation and repair, and ligation was not an independent factor for mortality [17]. A recent meta-analysis showed that, compared with repair, ligation was associated with higher mortality. However, there was no significant difference in mortality rates for infrarenal IVC injuries [7]. Therefore, ligation appears to be a safe treatment option, particularly in infrarenal injuries. Nevertheless, we were unable to save a patient with an infrarenal IVC injury despite using ligation. For a retrohepatic IVC injury, liver mobiliza-

tion may be required to expose the segment, but massive hemorrhage from the injury site can occur with this procedure [5]. Therefore, in a retrohepatic IVC injury, without active bleeding or with only a contained hematoma, perihepatic gauze packing without mobilization should be performed [1]. However, if packing fails to control the bleeding, direct repair of the injured site may be the only way to do so. Total hepatic vascular occlusion or an atriocaval shunt can be used to achieve a clear operative field during repair. Since subhepatic and suprahepatic IVC clamping for total hepatic vascular occlusion also blocks venous return, it may cause cardiac arrest. Therefore, additional aortic clamping at the supraceliac level or a venovenous bypass may be required, although outcomes have been reported to be poor [18,19]. Alternatively, an atriocaval shunt facilitates volume resuscitation during repair by isolating the injury site and maintaining venous return through a shunt using an endotracheal tube or a chest tube. As such, it can be used in a retrohepatic IVC injury with active bleeding, a large injury site, and extreme hemodynamic instability [4,5,20]. However, the reported outcomes of using an atriocaval shunt have also been unsatisfactory due to the severity of retrohepatic IVC injuries, the complexity of the procedure, the approach to the thorax, and delays in the decision to apply the procedure [4,20]. Richardson [21] reported a mortality rate of 88% in 412 patients with atriocaval shunts. We had one case of retrohepatic IVC injury for whom total hepatic vascular occlusion and an atriocaval shunt were ineffective. The patient was a 24-year-old man who was crushed by 2,000 kg of building material. Although venorrhaphy for a retrohepatic IVC injury was performed with total hepatic vascular occlusion, bleeding through an extended supradiaphragmatic IVC injury continued. By switching to an atriocaval shunt, the extended IVC injury was confirmed and venorrhaphy was successfully performed. Unfortunately, the patient did not survive because the delay in deciding to apply the atriocaval shunt resulted in significant blood loss (57 units of RBC were transfused during the operation). However, this case confirmed that an atriocaval shunt could be a better damage control tool than total hepatic vascular occlusion for primary repair of a retrohepatic IVC or higher level injury in terms of securing the operative field during massive bleeding.

There were some limitations to this study. First, it was a retrospective study; therefore, important variables affecting surgical outcomes may have been missed. Moreover, data extracted from a review of medical records are not very reliable. Second, this was a single-center study, making it difficult to generalize the results to the overall population of patients with traumatic IVC injuries. Third, the statistical power of this study was weak because the

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sample size was small (14 to 16 patients).

Subhepatic IVC injuries, which are easy to access, can be usually treated with a direct repair method. A systematic and multidisciplinary treatment strategy is required to deal with injuries at the retrohepatic IVC or higher level that are difficult to treat surgically. Since IVC injuries that require surgical treatment are rare, simulation training may be necessary to master the surgical skills needed for the complex damage control techniques (e.g., atriocaval shunt or ligation) and to understand their correct indications. This study described 14 cases in which surgical treatment was performed for IVC injury over a period of 9 years at a single institution. For a more comprehensive analysis, further studies are needed with larger populations and the participation of multiple centers.

NOTES

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