Impact of inferior vena cava ligation on mortality in trauma patients

Saskya Byerly, MD,[a] Vincent Cheng, MD,[b] Anastasia Plotkin, MD,[c] Kazuhide Matsushima, MD,[d] Kenji Inaba, MD,[d] *and* Gregory A. Magee, MD, MSc,[c] *Miami, Fla; and Los Angeles, Calif*

ABSTRACT

Objective: Inferior vena cava (IVC) injuries are potentially lethal and require prompt intervention. Repair of complex IVC injuries may require the use of a prosthetic graft or a complicated panel or spiral vein graft reconstruction to avoid the need for ligation. Collateral venous drainage may be sufficient to allow acceptable results from IVC ligation; however, previous studies have suffered from low numbers and have differing results. The aims of this study were to assess the outcomes of isolated IVC injuries overall and to compare IVC ligation with repair.

Methods: Patients in the National Trauma Data Bank from 2007 to 2014 with an IVC injury were evaluated. Isolated IVC injury was defined as patients with nonvascular Abbreviated Injury Scale scores <4 and no other named vascular injury. The primary outcome was mortality; secondary outcomes were in-hospital amputation-free survival, major lower extremity amputation, lower extremity compartment syndrome, acute kidney injury (AKI), deep venous thrombosis (DVT), and pulmonary embolism (PE).

Results: Overall, 1075 (0.018%) patients had IVC injuries and 443 met inclusion criteria. On univariate analysis, in comparing IVC ligation and primary repair, ligation was not associated with mortality (23% vs 16%; $P = .102$) but was associated with blunt mechanism (22% vs 11%; $P = .009$), higher fasciotomy rate (11% vs 0%; $P < .001$), trend toward lower in-hospital amputation-free survival (76% vs 84.4%, $P = .056$), and higher rates of AKI (9% vs 4%; $P = .060$) and PE (3% vs 1%, $P = .087$). Similarly, major lower extremity amputation, compartment syndrome, and DVT were not different between groups. IVC ligation was not independently associated with mortality (adjusted odds ratio [AOR], 1.54; $P = .197$), in-hospital amputation-free survival (AOR, 0.61; $P = .141$), major amputation (AOR, Inf; $P = .99$), lower extremity compartment syndrome (AOR, 0.82; $P = .827$), or PE (AOR, 6.72; $P = .052$), but it was independently associated with fasciotomy (AOR, 31.4; $P = .002$), AKI (AOR, 2.7; $P = .048$), and DVT (AOR, 2.3; $P = .021$).

Conclusions: IVC ligation was not independently associated with mortality or lower extremity amputation, but it was associated with AKI and need for fasciotomy. (J Vasc Surg: Venous and Lym Dis 2019;7:793-800.)

Keywords: IVC; Trauma; Repair; Ligation

Inferior vena cava (IVC) injuries require prompt intervention as mortality rates range from 20% to 100%.[1-10] These injuries are more commonly reported after penetrating trauma.[3,9] In addition, complications of venous thromboembolism (VTE) are a theoretical concern as a result of stasis-induced vein wall injury and enhanced tissue factor expression in endothelial cells and leukocytes, which has been demonstrated in laboratory models by Zhou et al.[11] Whereas primary repair is the preferred treatment, this may not always be practical because of acidosis, coagulopathy, hypothermia, or other life-threatening injuries. In damage control circumstances, IVC ligation can be performed out of necessity as it is faster and less complex than repair. In large, destructive injuries, the IVC may not be easily repairable without causing significant stenosis, in which case some operators may prefer ligation to a more challenging reconstruction. Shunting is another option for experienced surgeons as an alternative to ligation in such situations and can allow delayed repair or reconstruction.

IVC ligation is not unique to trauma as it was used historically for prevention of pulmonary embolism (PE) as well as for oncologic resection of urologic cancers.[12,13] Whereas early studies found that IVC ligation had a high morbidity and mortality, resulting in abandonment of the procedure for newer techniques such as IVC filter placement, this operation may be less morbid in the modern era with improvements in critical care. Previous studies evaluating IVC ligation vs repair have been small and retrospective in nature. A few studies evaluating statewide[14] and nationwide databases[15] demonstrated

From the Division of Trauma and Critical Care, Department of Surgery, University of Miami, Jackson Memorial Hospital Ryder Trauma Center, Miami[a]; and the Department of Surgery, LAC + USC Medical Center,[b] Division of Vascular Surgery and Endovascular Therapy, Department of Surgery, Keck School of Medicine of USC,[c] and Division of Trauma, Emergency Surgery and Surgical Critical Care, Department of Surgery, LAC + USC Medical Center,[d] University of Southern California, Los Angeles.

Author conflict of interest: none.

Presented at the One-hundred and fourth Clinical Congress of the American College of Surgeons, Boston, Mass, October 21-25, 2018.

Correspondence: Gregory A. Magee, MD, MSc, Assistant Professor of Surgery, Division of Vascular Surgery and Endovascular Therapy, Department of Surgery, Keck School of Medicine of USC, University of Southern California, 1520 San Pablo St, Ste 4300, Los Angeles, CA 90033 (e-mail: gregory.magee@med.usc.edu).

The editors and reviewers of this article have no relevant financial relationships to disclose per the Journal policy that requires reviewers to decline review of any manuscript for which they may have a conflict of interest.

2213-333X

https://doi.org/10.1016/j.jvsv.2019.06.013

no difference in mortality or VTE, but these studies were confounded by concomitant injuries. IVC injuries are frequently associated with other major injuries that contribute to increased mortality, and we wanted to evaluate the specific impact of IVC ligation on mortality and morbidity alone. We have previously demonstrated that ligation of iliac vein injuries is associated with increased mortality compared with repair, so we wanted to evaluate whether IVC ligation had similar results.[16]

The purpose of this study was to analyze isolated traumatic IVC injuries from a national, multicenter registry. We hypothesized that IVC ligation would not be associated with mortality compared with repair but that it would be associated with higher rates of acute kidney injury (AKI), lower extremity compartment syndrome, amputation, deep venous thrombosis (DVT), PE, and need for fasciotomy.

ARTICLE HIGHLIGHTS

- **Type of Research:** Retrospective analysis of data from the National Trauma Data Bank
- **Key Findings:** In 443 patients with isolated inferior vena cava (IVC) injury, IVC ligation was not independently associated with mortality, in-hospital amputation-free survival, major amputation, lower extremity compartment syndrome, or pulmonary embolism, but it was independently associated with fasciotomy (adjusted odds ratio [AOR], 31.4; $P = .002$), acute kidney injury (AOR, 2.7; $P = .048$), and deep venous thrombosis (AOR, 2.3; $P = .021$).
- **Take Home Message:** IVC ligation for traumatic injury was not independently associated with mortality or lower extremity amputation, but it was associated with acute kidney injury and need for fasciotomy.

METHODS

Study population. This is a National Trauma Data Bank (NTDB) analysis of all patients from 2007 to 2014 sustaining an IVC injury. All data provided by the NTDB are deidentified and in strict compliance with the Health Insurance Portability and Accountability Act of 1996. This public data set is not considered human subjects research, and Institutional Review Board review was waived and informed consent was not obtained. The NTDB typically does not include vessel-specific ligation and repair codes; therefore, we restricted the patient population to isolated IVC injuries. The procedure code for vena cava ligation (38.7) was used to define patients with IVC ligation. Patients were inferred to have IVC repair if they had an IVC injury code (421802, 421904, 421806, 421808, 421899, 521202, 521204, 521206, 521299) and vessel repair code (38.07, 38.17, 38.37, 38.47, 39.30, 30.32, 39.56, 39.57, and 39.58) with no other named vascular injury. Patients were excluded from the study if they had any of the following criteria: dead in the field or on arrival, age <18 years, Abbreviated Injury Scale (AIS) score >3 for body part other than abdomen, any vascular injury other than IVC, or absence of repair or ligation code. The population was divided into two study arms: IVC injury repair and IVC injury ligation.

Study design. The patient's age, sex, initial systolic blood pressure (SBP), heart rate, Glasgow Coma Scale (GCS) score, AIS score (head, chest, abdomen, extremity), Injury Severity Score (ISS), mechanism, blood product administration, IVC ligation or repair, complications, and outcomes were abstracted from the database. The NTDB does not provide details about the type of vascular repair (eg, venorrhaphy, graft), so all types of repair were compared against ligation.

The primary outcome was in-hospital mortality. Secondary outcomes included in-hospital amputation-free survival, major lower extremity amputation, lower extremity compartment syndrome, AKI, VTE, and PE.

Statistical analysis. Differences between IVC ligation and IVC repair patients were investigated using χ^2 test or Fisher exact test for categorical variables and Mann-Whitney U test for continuous variables. P values <.05 were considered statistically significant, and final adjusted odds ratio (AOR) with 95% confidence interval was calculated. Given that the NTDB does not record information about IVC injury site, level of injury, or size of defect, we thought that propensity matching would not be able to appropriately match patients. Instead, multivariate logistic regression using all clinically significant predictors by enter method was used to identify independent predictors of mortality, in-hospital amputation-free survival, major lower extremity amputation, extremity compartment syndrome, fasciotomy, AKI, VTE, and PE. Statistical analysis was performed using SPSS 20 for Mac (IBM Corp, Armonk, NY).

RESULTS

During the study period, 5937 trauma patients sustained an IVC injury, of whom 443 patients were eligible for analysis after exclusion criteria were applied. Of these, 104 (23.5%) had IVC ligation and 339 (76.5%) had IVC repair (Fig). Penetrating mechanism was found in 377 (85%), with 62% specifically due to gunshot wound and 23% due to stab wounds. Motor vehicle accident was the third most common mechanism (10%).

The study population was predominantly made up of men (85%), with a median age of 29 years (interquartile range [IQR], 22-39 years). For the IVC ligation patients, median age was 29 years (IQR, 22-42 years), 79% were men, and median ISS was 17 (IQR, 10-22). IVC ligation patients had a higher heart rate (104 vs 96; $P = .013$) and higher external AIS score (2 vs 1; $P = .016$) compared with IVC repair patients. The rate of shock (SBP <90 mm Hg) was 19 (18%) in the ligation group vs

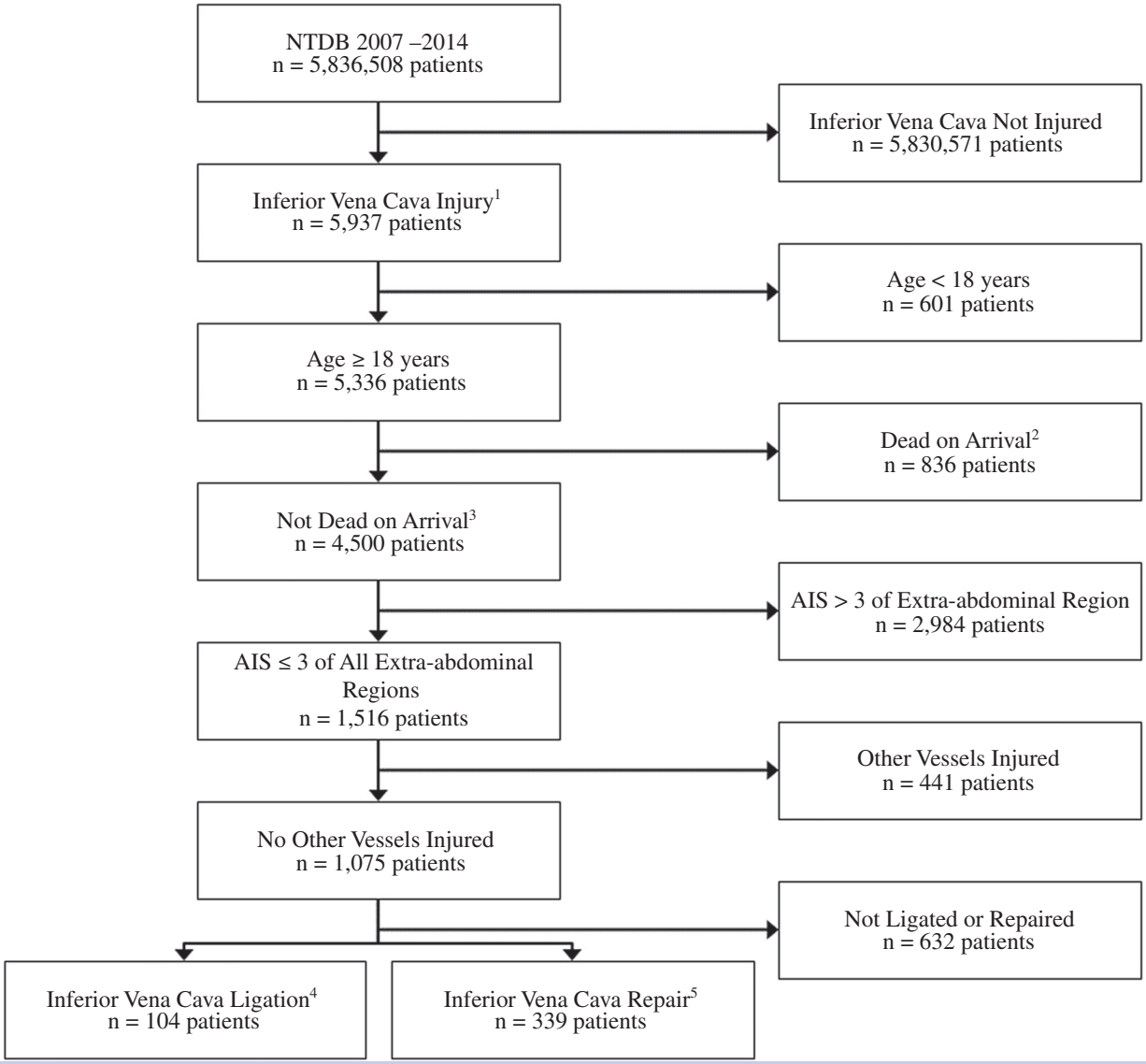

Fig. Inclusion and exclusion flow chart.[1] Includes abdominal inferior vena cava (IVC) Abbreviated Injury Scale (*AIS*) codes (521202, 521204, 521206, and 521299) and thoracic IVC AIS codes (421802, 421804, 421806, 421808, and 421899).[2] No signs of life at arrival (n = 343 patients); died after failed resuscitation attempt (failure to respond within 15 minutes; n = 105 patients); died in emergency department (other than failed resuscitation attempt; n = 288 patients); declared dead on arrival with minimal or no resuscitation attempt (n = 100 patients).[3] Includes patients with unavailable signs of life data.[4] IVC ligation procedure codes: 38.7.[5] IVC repair procedure codes: 38.07, 38.17, 38.37, 38.47, 39.30, 39.32, 39.56, 39.57, and 39.58. *NTDB*, National Trauma Data Bank.

58 (17%) in the repair group. In IVC ligation patients, IVC injury was more commonly due to blunt trauma (22% vs 11%; $P = .009$), secondary to fall (4% vs 0%; $P = .012$), or motor vehicle related (17% vs 8%; $P = .016$) compared with IVC repair patients. Overall, 39% of blunt trauma patients compared with only 20.7% of penetrating trauma patients underwent IVC ligation. Furthermore, 8.7% of stab wounds, 25% of gunshot wounds, 39% of motor vehicle accidents, and 80% of falls were treated by IVC ligation (Table I).

Mortality was not statistically significantly different between ligation and repair cohorts on univariate analysis (23% vs 16%; $P = .102$). Similarly, major lower extremity amputation, compartment syndrome, and VTE were not different between groups. IVC ligation patients had a higher rate of fasciotomy (11% vs 0%; $P < .001$), and they trended toward lower in-hospital amputation-free survival (76% vs 84.4%; $P = .056$) and higher AKI (9% vs 4%; $P = .060$) and PE (3% vs 1%; $P = .087$; Table I).

Table I. Univariate analysis by inferior vena cava (*IVC*) procedure

	All patients (N = 443)	IVC ligation (n = 104)	IVC repair (n = 339)	*P* value
Demographics				
Age, years	29 (22-39)	29 (22-42)	29 (23-39)	.590
Male sex	372 (85)	82 (79)	290 (86)	.087
ISS	16 (10-20)	17 (10-22)	16 (10-20)	.175
SBP, mm Hg	118 (95-136)	119 (92-132)	117 (95-137)	.565
Pulse	98 (82-114)	104 (85-120)	96 (80-111)	**.013**
GCS score	15 (14-15)	15 (13-15)	15 (14-15)	.336
AIS score				
Abdomen	3 (3-4)	3 (3-4)	3 (3-4)	.719
External	1 (1-1)	1 (1-1)	1 (1-1)	>.999
Face	1 (1-2)	2 (1-2)	1 (1-1)	**.016**
Head	2 (1-3)	2 (1-3)	2 (1-3)	.742
Lower extremity	2 (1-3)	2 (1-3)	2 (1-3)	.722
Neck	2 (1-2)	1 (1-1)	2 (1-3)	.134
Spine	2 (2-2)	2 (2-2)	2 (2-2)	.692
Thorax	3 (2-4)	3 (2-3)	3 (3-4)	.164
Upper extremity	1 (1-2)	1 (1-1)	1 (1-2)	.327
Mechanism, general				
Blunt	61 (14)	23 (22)	38 (11)	**.009**
Penetrating	377 (85)	78 (75)	299 (88)	**.002**
Mechanism, specific				
Fall	5 (1)	4 (4)	1 (0)	**.012**
Motor vehicle related	46 (10)	18 (17)	28 (8)	**.016**
Gunshot wound	274 (62)	69 (66)	205 (60)	.301
Stab wound	103 (23)	9 (9)	94 (28)	**<.001**
Strike	4 (1)	0 (0)	4 (1)	.577
Outcomes				
Mortality	76 (17)	24 (23)	52 (16)	.102
In-hospital amputation-free survival[a]	360 (82.4)	79 (76.0)	281 (84.4)	.056
Amputation[a]	1 (0)	1 (1)	0 (0)	.235
Compartment syndrome	8 (2)	3 (3)	5 (1)	.398
Fasciotomy	12 (3)	11 (11)	1 (0)	**<.001**
AKI	21 (5)	9 (9)	12 (4)	.060
DVT	46 (10)	17 (16)	29 (9)	**.028**
PE	5 (1)	3 (3)	2 (1)	.087

AIS, Abbreviated Injury Scale; *AKI*, acute kidney injury; *DVT*, deep venous thrombosis; *GCS*, Glasgow Coma Scale; *ISS*, Injury Severity Score; *PE*, pulmonary embolism; *SBP*, systolic blood pressure.
Continuous variables are expressed as median (interquartile range); *P* value is calculated with Mann-Whitney *U* test. Categorical variables are expressed as patients (%); *P* value is calculated with Fisher exact test. Boldface *P* values considered statistically significant ($P < .05$).
[a]Amputation at the level of below the knee or higher procedure codes: 84.15, 84.16, 84.17, and 84.18.

IVC ligation was not independently associated with mortality (AOR, 1.54; $P = .197$), in-hospital amputation-free survival (AOR, 0.61; $P = .141$), major amputation (AOR, Inf; $P = .99$), lower extremity compartment syndrome (AOR, 0.82; $P = .827$), or PE (AOR, 6.72; $P = .052$). IVC ligation was independently associated with fasciotomy (AOR, 31.4; $P = .002$), AKI (AOR, 2.7; $P = .048$), and VTE (AOR, 2.3; $P = .021$; Tables II-IX). Variables independently associated with mortality included older age (AOR, 1.03; $P = .012$), SBP <90 mm Hg (AOR, 3.7; $P < .001$), higher pulse (AOR, 1.01; $P = .014$), lower GCS score (AOR, 0.86; $P < .001$), and higher ISS (AOR, 1.05; $P < .001$). Factors independently associated with in-hospital amputation-free survival included younger age (AOR, 0.97; $P = .013$), SBP ≥90 mm Hg (AOR, 0.27; $P < .001$), lower pulse (AOR, 0.99; $P = .01$), higher GCS score (AOR, 1.16; $P < .001$), and lower ISS (AOR, 0.95; $P = .007$).

Table II. Logistic regression of mortality in patients with isolated inferior vena cava (*IVC*) injury

	Mortality		
	Odds ratio	95% Confidence interval	*P* value
IVC ligation	1.544	0.799-2.984	.197
Male sex	0.776	0.346-1.737	.537
Age	1.028	1.006-1.051	**.012**
SBP <90 mm Hg	3.702	1.91-7.175	**<.001**
Pulse	1.013	1.003-1.024	**.014**
GCS score	0.860	0.807-0.917	**<.001**
ISS	1.050	1.011-1.091	**.012**
Blunt injury	1.196	0.205-6.982	.843
Penetrating injury	1.471	0.271-7.997	.655

GCS, Glasgow Coma Scale; *ISS*, Injury Severity Score; *SBP*, systolic blood pressure.
Boldface *P* values considered statistically significant ($P < .05$).

Table IV. Logistic regression of amputation in patients with isolated inferior vena cava (*IVC*) injury

	Amputation		
	Odds ratio	95% Confidence interval	*P* value
IVC ligation	>9999.999	<0.001-<0.001	.987
Male sex	0.001	<0.001-<0.001	.998
Age	0.690	<0.001->9999.999	.992
SBP <90 mm Hg	0.000	<0.001-<0.001	.994
Pulse	1.566	<0.001->9999.999	.989
GCS score	0.287	<0.001->9999.999	.995
ISS	6.171	<0.001->9999.999	.986
Blunt injury	0.000	<0.001-<0.001	1
Penetrating injury	0.000	<0.001-<0.001	.998

GCS, Glasgow Coma Scale; *ISS*, Injury Severity Score; *SBP*, systolic blood pressure.

DISCUSSION

Our study aimed to evaluate the consequences of repair vs ligation in isolated IVC injuries to provide insight into consequences directly attributable to the IVC treatment technique. After an extensive literature search, we have not found any previous studies that evaluate isolated IVC injuries in trauma patients. Reports of mortality in IVC injuries and their treatment have varied in the literature. In the 1940s, IVC injuries were reported to have 100% mortality, but mortality has improved as techniques in vascular exposure and repair were refined.[17] This trend was later interrupted, probably because of improved transport times by emergency medical services, preventing patient selection as observed in the commentary of Burch et al by EE Moore.[18] When used historically for prevention of PE, IVC ligation had an associated mortality of 4% to 20%.[12] More recent reports for traumatic IVC injury have mortality rates of 20% to 87%,[1-10] which is comparable to the 23% mortality observed in our cohort of isolated IVC injuries. Moreover, a previous study evaluating propensity score-matched IVC injuries treated with ligation vs repair found that IVC ligation was associated with higher complication rates of extremity compartment syndrome, pneumonia, and PE and longer hospital length of stay but had no difference in mortality compared with IVC repair.[15] This is consistent with the findings in our study. Surprisingly, despite the internal bias for ligation of more complex injuries, there was no difference in mortality between the two groups. Roughly a quarter of patients in our cohort

Table III. Logistic regression of amputation free survival in patients with isolated inferior vena cava (*IVC*) injury

	Amputation-free survival		
	Odds ratio	95 Confidence interval	*P* value
IVC ligation	0.611	0.317-1.177	.141
Male sex	1.387	0.624-3.081	.422
Age	0.972	0.951-0.994	**.013**
SBP <90 mm Hg	0.273	0.140-0.532	**<.001**
Pulse	0.986	0.976-0.997	**.01**
GCS score	1.163	1.091-1.241	**<.001**
ISS	0.949	0.914-0.986	**.007**
Blunt injury	0.799	0.137-4.664	.803
Penetrating injury	0.696	0.128-3.794	.675

GCS, Glasgow Coma Scale; *ISS*, Injury Severity Score; *SBP*, systolic blood pressure.
Boldface *P* values considered statistically significant ($P < .05$).

Table V. Logistic regression of extremity compartment syndrome in patients with isolated inferior vena cava (*IVC*) injury

	Compartment syndrome		
	Odds ratio	95% Confidence interval	*P* value
IVC ligation	0.821	0.139-4.842	.827
Male sex	0.553	0.095-3.200	.508
Age	0.984	0.92-1.054	.649
SBP <90 mm Hg	0.859	0.09-8.181	.895
Pulse	1.031	1.002-1.061	**.036**
GCS score	488000.435	<0.001-<0.001	.987
ISS	0.987	0.886-1.099	.813
Blunt injury	3.356	0.029-384.973	.617
Penetrating injury	0.820	0.007-96.495	.935

GCS, Glasgow Coma Scale; *ISS*, Injury Severity Score; *SBP*, systolic blood pressure.
Boldface *P* values considered statistically significant ($P < .05$).

Table VI. Logistic regression of fasciotomy in patients with isolated inferior vena cava (*IVC*) injury

	Fasciotomy		
	Odds ratio	95% Confidence interval	*P* value
IVC ligation	31.353	3.696-266.003	**.002**
Male sex	1.658	0.22-12.526	.624
Age	1.022	0.966-1.081	.444
SBP <90 mm Hg	0.670	0.064-6.962	.737
Pulse	1.026	1.000-1.052	.05
GCS score	1.377	0.798-2.378	.251
ISS	1.065	0.996-1.140	.066
Blunt injury	2.980	0-40829.472	.822
Penetrating injury	4.435	0-60650.311	.759

GCS, Glasgow Coma Scale; *ISS*, Injury Severity Score; *SBP*, systolic blood pressure.
Boldface *P* values considered statistically significant ($P < .05$).

Table VIII. Logistic regression of deep venous thrombosis (*DVT*) in patients with isolated inferior vena cava (*IVC*) injury

	DVT		
	Odds ratio	95% Confidence interval	*P* value
IVC ligation	2.315	1.136-4.714	**.021**
Male sex	1.599	0.567-4.508	.375
Age	1.019	0.995-1.044	.130
SBP <90 mm Hg	0.739	0.271-2.012	.554
Pulse	0.996	0.982-1.009	.535
GCS score	1.082	0.961-1.218	.194
ISS	0.996	0.953-1.041	.865
Blunt injury	1.172	0.890-15.480	.904
Penetrating injury	2.748	0.210-35.994	.441

GCS, Glasgow Coma Scale; *ISS*, Injury Severity Score; *SBP*, systolic blood pressure.
Boldface *P* values considered statistically significant ($P < .05$).

underwent ligation (23.4% [104/443]) as opposed to repair, which is similar to the findings in other studies.[4,14] As with other studies, IVC injury in our cohort was more commonly due to penetrating trauma,[3,4,7,9] and IVC ligation was performed more frequently in patients with IVC injury from blunt mechanism. This pattern is presumably in part due to more destructive injuries with more concomitant injuries that occur during blunt trauma.

Interestingly, the lower extremity amputation rate was very low (1% vs 0%) in IVC ligation compared with repair. This is possibly due to our exclusion criteria, which rendered a cohort of isolated IVC injuries rather than including concomitant injuries. Unlike the findings of Matsumoto et al,[15] our study found that there was no difference in compartment syndrome between ligation and repair groups, but we did see a significantly higher rate of fasciotomy in the IVC ligation group. Two possible reasons for this finding are that fasciotomies were performed prophylactically to effectively prevent the development of subsequent compartment syndrome and the lack of concomitant major lower extremity injuries inherent in the study design was protective of the development of lower extremity compartment syndrome. The NTDB does not differentiate prophylactic vs therapeutic indications for fasciotomy or the timing of the fasciotomy relative to the index operation, so definitive explanations are lacking. The database reports that fasciotomies were performed for clinical suspicion of developing extremity compartment syndrome (firm and incompressible lower extremities, intraoperative compartment pressure of 25-30 mm Hg, combined arterial and venous injuries, arterial injuries >6 hours,

Table VII. Logistic regression of acute kidney injury (*AKI*) in patients with isolated inferior vena cava (*IVC*) injury

	AKI		
	Odds ratio	95% Confidence interval	*P* value
IVC ligation	2.737	1.009-7.424	**.048**
Male sex	1.035	0.301-3.561	.957
Age	1.032	1.000-1.065	.052
SBP <90 mm Hg	1.990	0.647-6.12	.23
Pulse	1.018	1.001-1.036	**.039**
GCS score	1.225	0.951-1.578	.116
ISS	0.992	0.930-1.059	.817
Blunt injury	19.258	1.64-226.131	**.019**
Penetrating injury	14.287	0.968-210.8	.053

GCS, Glasgow Coma Scale; *ISS*, Injury Severity Score; *SBP*, systolic blood pressure.
Boldface *P* values considered statistically significant ($P < .05$).

Table IX. Logistic regression of pulmonary embolism (*PE*) in patients with isolated inferior vena cava (*IVC*) injury

	PE		
	Odds ratio	95% Confidence interval	*P* value
IVC ligation	6.720	0.984-45.885	.052
Male sex	>9999.999	<0.001-<0.001	.997
Age	0.956	0.864-1.059	.389
SBP <90 mm Hg	0.000	<0.001-<0.001	.997
Pulse	0.958	0.909-1.01	.115
GCS score	0.983	0.702-1.376	.92
ISS	0.947	0.814-1.100	.475
Blunt injury	3.610	0.002-7667.746	.743
Penetrating injury	1.249	0.001-2528.993	.954

GCS, Glasgow Coma Scale; *ISS*, Injury Severity Score; *SBP*, systolic blood pressure.

crush-type injuries) but also at the discretion of the attending physician.[4] Although potentially morbid, AKI, DVT, and fasciotomy are medically treatable with appropriate intensive care unit and wound care. Furthermore, we found IVC ligation to be an independent predictor of AKI despite accounting for preoperative vital signs and blood loss. This may be due to some patients' receiving ligation of the suprarenal IVC; however, this data set does not distinguish the level of ligation.

Reported rates of DVT and PE after IVC injury range from 2% to 19% and 0.4% to 29%, respectively.[14,15,18] The wide variation of these rates is likely to be related to different practice patterns in screening, anticoagulation, and demographic differences. Patients with nontraumatic IVC resection and reconstruction for malignant disease may have higher rates of perioperative VTE (22%), isolated DVT (9%), and PE (12%),[19] although this is not uniformly described.[20] The DVT and PE rates in our study were 10% and 1%, with DVT (16% vs 9%; $P = .028$) and PE rates (3% vs 1%; $P = .087$) not significantly different between ligation and repair groups, but this study was underpowered to analyze this outcome.

This study has several limitations including bias due to its retrospective design. We would expect this database to be biased toward more favorable outcomes in the repair group, given that surgeon selection would dictate that more unstable patients with detrimental physiology and less accessible IVC injuries would preferentially have ligation, whereas more stable patients with less complex and more easily accessible IVC injuries would undergo IVC repair. This database is useful to evaluate the epidemiology of IVC injuries because of the large number of patients from all types of hospitals in every region of the United States and Canada. However, the database lacks sufficient anatomic detail in injury coding for more granular analysis. Shunting is also not captured in this database, which may be a useful third option that surgeons can employ in unstable patients. In addition, the consequences of interposition graft vs lateral venorrhaphy may differ, but these were evaluated together in this study. Importantly, this analysis is limited to short-term outcomes because long-term outcomes like IVC patency, duration of dialysis, and long-term survival are not captured by this database. Therefore, this study is more useful for hypothesis generation and for planning of future studies but is not ideal for definitive conclusions about causality. As such, these data should not be interpreted to claim that IVC repair is no better than ligation but rather that IVC ligation is commonly performed and is a reasonable strategy to use when necessary. On the contrary, we recommend repair when it is practical and ligation only when necessary when the patient is in extremis. In practice, shunting the IVC with a chest tube with delayed reconstruction is a useful alternative to ligation as it can decrease swelling and improve venous return. Meta-analyses of the previously published data would provide further insight into the relationship of the severity of injury, anatomic level of ligation, degree of postoperative AKI, and VTE occurrence. Multicenter prospective studies are warranted to evaluate enough patients and to obtain the granular data necessary to inform intraoperative decision-making in deciding between repair and ligation.

CONCLUSIONS

IVC ligation was not independently associated with mortality, major lower extremity amputation, or in-hospital amputation-free survival, but it was associated with AKI, DVT, and fasciotomy. These findings lend support to the concept that IVC ligation is reasonable in a damage control scenario.

AUTHOR CONTRIBUTIONS

Conception and design: SB, VC, KM, GM
Analysis and interpretation: SB, VC, AP, KM, KI, GM
Data collection: VC
Writing the article: SB, GM
Critical revision of the article: SB, VC, AP, KM, KI, GM
Final approval of the article: SB, VC, AP, KM, KI, GM
Statistical analysis: SB
Obtained funding: Not applicable
Overall responsibility: GM

REFERENCES

1. Buckman RF, Pathak AS, Badellino MM, Bradley KM, Miraliakbari R, Badellino MM, et al. Injuries of the inferior vena cava. Surg Clin North Am 2001;71:1431-47.
2. Maciel JD, Plurad D, Gifford E, deVirgilio C, Koopmann M, Neville A, et al. Predictors of mortality in patients with penetrating inferior vena cava injuries surviving to the operating room. Am Surg 2015;81:1000-4.
3. Cudworth M, Fulle A, Ramos JP, Arriagada I. GCS as a predictor of mortality in patients with traumatic inferior vena cava injuries: a retrospective review of 16 cases. World J Emerg Surg 2013;8:59.
4. Sullivan PS, Dente CJ, Patel S, Carmichael M, Srinivasan JK, Wyrzykowski AD, et al. Outcome of ligation of the inferior vena cava in the modern era. Am J Surg 2010;199:500-6.
5. Rosengart MR, Smith DR, Melton SM, May AK, Rue LW 3rd. Prognostic factors in patients with inferior vena cava injuries. Am Surg 1999;65:846-9.
6. Porter JM, Ivatury RR, Islam SZ, Vinzons A, Stahl WM. Inferior vena cava injuries: noninvasive follow-up of venorrhaphy. J Trauma 1997;42:913-8.
7. Surgeon TA, Kuehne J, Frankhouse J, Modrall G, Golshani S, Aziz I, et al. Determinants of survival after inferior vena cava trauma. Am Surg 1999;65:976-81.
8. van Rooyen PL, Karusseit VO, Mokoena T. Inferior vena cava injuries: a case series and review of the South African experience. Injury 2018;46:71-5.
9. Bricker DL, Morton JR, Okies JE, Beall ACJ. Surgical management of injuries to the vena cava: changing patterns of injury and newer techniques of repair. J Trauma 1971;11:725-35.
10. Asensio JA, Chahwan S, Hanpeter D, Demetriades D, Forno W, Gambaro E, et al. Operative management and outcome of 302 abdominal vascular injuries. Am J Surg 2000;180:524-8.

11. Zhou J, May L, Liao P, Gross PL, Weitz JI. Inferior vena cava ligation rapidly induces tissue factor expression and venous thrombosis in rats. Arterioscler Thromb Vasc Biol 2009;29:863-9.
12. Ochsner A, Ochsner JL, Sanders HS. Prevention of pulmonary embolism by caval ligation. Ann Surg 1970;171:923-38.
13. Beck SD, Lalka SG, Donohue JP. Long-term results after inferior vena caval resection during retroperitoneal lymphadenectomy for metastatic germ cell cancer. J Vasc Surg 1998;28:808-14.
14. Singer MB, Hadjibashi AA, Bukur M, Ley EJ, Mirocha J, Malinoski DJ, et al. Incidence of venous thromboembolism after inferior vena cava injury. J Surg Res 2012;177:306-9.
15. Matsumoto S, Jung K, Smith A, Coimbra R. Management of IVC injury: repair or ligation? A propensity score matching analysis using the National Trauma Data Bank. J Am Coll Surg 2018;226:752-9.e2.
16. Magee GA, Cho J, Matsushima K, Strumwasser A, Inaba K, Jazaeri O, et al. Isolated iliac vascular injuries and outcome of repair versus ligation of isolated iliac vein injury. J Vasc Surg 2018;67:254-61.
17. Graham JM, Mattox KL, Beall ACJ, DeBakey ME. Traumatic injuries of the inferior vena cava. Arch Surg 1978;113:413-8.
18. Burch JM, Feliciano DV, Mattox KL, Edelman M. Injuries of the inferior vena cava. Am J Surg 1988;156:548-52.
19. Hicks CW, Glebova NO, Piazza KM, Orion K, Pierorazio PM, Lum W, et al. Risk of venous thromboembolic events following inferior vena cava resection and reconstruction. J Vasc Surg 2016;63:1004-10.
20. Quinones-Baldrich WJ, Farley S. Techniques for inferior vena cava resection and reconstruction for retroperitoneal tumor excision. J Vasc Surg Venous Lymphat Disord 2013;1:84-9.

Submitted Apr 7, 2019; accepted Jun 9, 2019.