Predictors of Mortality for Upper Extremity Penetrating Vascular Injuries

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Background: Our objective was to determine risk factors and operative outcomes for patients with upper extremity penetrating vascular injuries (UEPVIs).
Methods: A retrospective review was performed of all adult UEPVI patients presenting to a level I trauma center between 1986 and 2019. Statistical analyses were performed to determine the independent predictors of mortality and hospital length of stay (LOS) among patients who underwent operative repair.
Results: Among 481 UEPVI patients, the majority were male (87%), Caucasian (52%), and uninsured/underinsured (52%). Over half of injuries were caused by violent means and required surgery. Female patients had a higher injury severity score (ISS) (mean 9.55 vs 6.77, $P = 0.02$), were more likely to proceed urgently to the operating room (40.6% vs. 24.2%,$P = 0.02$),but had a lower mortality(1.6% vs. 4.8%,$P = 0.009$) compared to male patients. 43 (0.9%) of patients suffered amputation and 213 (44%) of patients ultimately underwent operative repair; odds ratio of mortality with an operation among all patients was 0.20 ($P = 0.011$, 95% confidence interval [CI]: 0.058−0.687). Among operative patients, only ISS was significant predictor of longer LOS (standardized coefficient = 0.47, 95% CI: 0.76−1.36, $P < 0.001$).
Conclusions: This retrospective analysis demonstrates that the majority of UEPVI are incurred by men and associated with violence. Operative intervention was protective with regards to mortality. Among operative patients, increased age and ISS were predictive of longer LOS.

INTRODUCTION

Trauma is the leading cause of death for patients aged 1−45 and ranks as the fourth leading cause of death among all combined age groups. The rising prevalence as well as high morbidity and mortality associated with penetrating injuries have been previously noted.[1]

Upper extremity penetrating vascular injuries (UEPVIs) represent a small proportion of traumatic injuries. According to a review of all vascular injuries from the National Trauma Database between 2002 and 2006, about 1.6% of adult and 0.6% of pediatric trauma patients presented with a vascular injury.[2] Half of these vascular injuries among adults were penetrating, roughly evenly distributed throughout different regions of the body.[2] Fractures represent the most common upper extremity injury.[3] Upper extremity vascular injuries are relatively rare—representing 1% of all traumatic injuries, and 20% of vascular injuries.[4−6] The epidemiologic profile of UEPVI compared to other types of vascular injuries is relatively unknown.[7] Mortality has been reported to range between 2 and 3% for both adult and pediatric patients.[2,8] Morbidity—in particular amputation rate—is relatively unknown.

UEPVI can pose a diagnostic and therapeutic challenge to trauma surgeons.[9−12] Perhaps, due to their rarity, their epidemiologic risk factors are not

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well characterized and as a result diagnosis can be delayed.[13–17] Concomitant injuries often occur with upper extremity vascular injuries leading to significant morbidity, extended hospitalizations and cost; however, optimal treatment algorithms are not well established to manage these complex injuries.[18–20] Mortality, morbidity and risk factors for UEPVI are also not well defined.[21] The goal of this study was to characterize the presentation, management and outcomes of UEPVI and determine risk factors for mortality and morbidity, especially length of stay (LOS) and amputation.

METHODS

After institutional review board approval was obtained, a retrospective review of all adult (age ≥18) UEPVI patients presenting to a single American College of Surgeons and state of Florida designated level I trauma center between 1986 and 2019 was performed. The trauma center has 24/7 availability of both vascular surgeons and acute care surgeons competent with repairs above the elbow. All repairs performed during the study period were open and not endovascular. Both arterial and venous injuries ranging from subclavian to ulnar and radial anatomical distribution were included; concomitant bone/nerve injuries were also analyzed. Retrospectively calculated injury severity score (ISS), diagnostics and surgical operations coded based on current procedural terminology code were reviewed. Amputation was defined as any significant injury resulting in loss of limb. Statistical Package for Social Sciences (SPSS) Statistical Software version 28 was used to perform statistical analysis. Chi-square analysis was performed to compare demographics, presentation and treatment outcome differences. Multivariate logistic and linear regression analyses were used to determine independent predictors of mortality, amputation rate and hospital LOS among operative patients using the covariates race, age, gender, insurance status, ISS, mechanism of injury, and emergency department (ED) disposition.

RESULTS

Demographics, patterns of injury, diagnostics, treatment and outcomes for 481 total patients presenting with UEPVI to a single level I trauma center are presented in Table I. The majority (87%) of patients was male and Caucasian (51%). The average age was 35 and the majority of patients were uninsured or had Medicaid or other government insurance (52%). The majority of injuries were caused by assault or self-inflicted (52%) and were incurred by gunshot wound (23%) or stab wound (20%). A large percentage of patients required emergent repair including 24% who were transferred directly to the operating room (OR) from the ED. Injuries resulted in amputation in 43 (8.9%) of patients. Women compared to men were more likely to suffer self-inflicted injuries (20% vs. 9.4%, $P = 0.0108$). The majority of patients did not have documented bone and/or nerve concomitant injury (53%); 213 (44%) underwent surgical repair of their vascular injuries. The most common vascular procedures performed were primary repair of an arterial injury (31%) or distal arterial ligation (21%). On bivariate analysis, female patients had a higher ISS (mean 9.55 compared to 6.77, $P = 0.02$), were more likely to have injuries to more distal vessels ($P < 0.001$), were more likely to go to the OR (40.6% compared to 24.2%, $P = 0.02$), and had a higher rate of arterial ligation (31% compared to 20%) but had a lower mortality (1.6% compared to 4.8%, $P = 0.009$) compared to male patients. Odds ratio of mortality with an operation among all patients was 0.20 ($P = 0.011$, 95% confidence interval [CI]: 0.058–0.687).

Table II demonstrates the multivariate logistic regression for mortality among operative patients; no variables significantly affected survival. Table III reflects the multivariate linear regression for hospital LOS among operative patients. Increased age and ISS were associated with longer LOS, respectively ($r = 0.148$, 95% CI 0.02–0.28, $P = 0.029$) ($r = 0.47$, 95% CI 0.75–1.36, $P < 0.001$). Table IV shows multivariate logistic regression for amputation rate among operative patients; no variables significantly affected amputation rate among operative patients.

DISCUSSION

UEPVI and their outcomes have been limited to small retrospective and few prospective studies.[6,21] Our retrospective review from a single center level I trauma center is one of the larger retrospective reviews of UEPVI documented in the literature and demonstrates that the majority of UEPVI were incurred by Caucasian men often who are uninsured/underinsured and often by violent means with a mortality rate of 4% and amputation rate of 9%.

Although the majority of UEPVI were incurred by men, there were important differences in presentation and outcomes between male and female patients. Female patients had a higher mean ISS

Table I. Demographics, patterns of injury, evaluation, treatment, and outcomes

Variable	Female ($n = 64$) (13)	Male ($n = 417$) (87)	*P* value
Race			**0.035**
Not defined	1 (2)	7 (1.7)	
Native American	0	1 (0.2)	
Asian	1 (1.6)	2 (0.5)	
African-American	29 (45.2)	171 (41)	
Other race	0	23 (5.5)	
Caucasian	33 (51.6)	213 (51.1)	
Age (mean ± SD)	35.9 (± 15.09)	35.0 (± 13.72)	0.671
Insurance			0.407
Uninsured	8 (12.5)	80 (19.2)	
Medicaid/other gov	24 (37.5)	137 (32.9)	
Medicare	3 (4.7)	21 (5)	
Private	17 (26.6)	79 (18.9)	
Unknown	12 (18.8)	100 (24.0)	
Mechanism			**< 0.001**
GSW	9 (14.1)	104 (24.9)	
SW	9 (14.1)	87 (20.9)	
Self-inflicted laceration/cutting	6 (9.4)	21 (5.0)	
Fall	3 (4.7)	17 (4.1)	
Sport/work related	8 (12.5)	40 (9.6)	
Glass	9 (14.1)	23 (5.5)	
Injured by animal	3 (4.7)	4 (1.0)	
Other/unknown	11 (17.2)	70 (16.8)	
Mechanism type			**< 0.001**
Assault	19 (29.7)	209 (50.1)	
Suicide/self-inflicted	7 (10.9)	21 (5)	
Accident	27 (42.2)	117 (28.1)	
Unknown	11 (27.2)	70 (16.8)	
GCS (mean ± SD)	13.94 (± 2.56)	14.03 (± 2.97)	0.963
ISS			
(Mean ± SD)	9.55 (± 8.80)	6.77 (± 4.90)	**0.024**
Median			0.235
IQR			
Extremity AIS (mean ± SD)	2.02 (± 0.84)	2.16 (± 0.83)	0.701
Other injuries			0.57
None	32 (50)	223 (53.5)	
Bone	6 (9.4)	38 (7.9)	
Nerve	15 (23.4)	110 (26.4)	
Bone + nerve	11 (17.2)	46 (11.0)	
Injury			**< 0.001**
Subclavian	1 (1.6)	26 (6.7)	
Axillary	1 (1.6)	16 (4.1)	
Brachial	9 (14.3)	93 (23.8)	
Radial	16 (25.4)	109 (27.9)	
Ulnar	12 (19)	64 (16.4)	
Digital/hand	7 (11)	36 (9.2)	
Amputation	12 (18.8)	31 (7.4)	
Unknown	13 (21)	62 (15.8)	
Procedures			1.00
Ligation	20 (31.2)	82 (19.7)	
Repair artery	17 (26.6)	130 (31.2)	
Repair vein	4 (6.3)	26 (6.2)	
Reconstruction with anastomosis/bypass/graft	2 (3.1)	44 (10.6)	
Unknown/none	32 (50)	161 (39)	

(*Continued*)

Table I. Continued

Variable	Female ($n = 64$) (13)	Male ($n = 417$) (87)	*P* value
ED disposition			
Direct transfer to OR	26 (40.6)	101 (24.2)	
Other	38 (59.4)	316 (75.77)	**0.024**
Operation			
No	38 (59)	230 (55.2)	
Yes	26 (40.6)	187 (44.8)	0.550
Outcomes			
Mortality	1 (1.6)	20 (4.8)	**0.009**
Length of stay	5.38 (10.27)	5.08 (12.61)	0.541

P values that are significant have been bolded.
GCS, Glascow coma scale; SD, standard deviation; ISS, injury severity score; AIS, abbreviated injury score; GSW, gun-shot wound; SW, stab wound.

Table II. Multivariate logistic regression—mortality among operative patients

Variable	Odds ratio	95% CI	*P* value
Race			
Caucasian	Ref		
African-American/Other	0	0	0.993
Age	0.73	0−2.36 E+94	0.998
Gender			
Male	Ref		
Female	1.38 E+29	0	0.99
Insurance			
Uninsured/underinsured	Ref		
Private/Medicare	37.85	0	0.999
ISS	53.42	1−1.77 E+205	0.99
Mechanism of injury			
Stab wound/Other	Ref		
GSW	7,209.58	0	0.997
ED disposition			
Other	Ref		
Direct transfer to OR	13,681,791.8	0	0.996
Procedure			
Unknown	Ref		
Ligation of artery/vein	Ref		
Repair of artery/vein	6,279.72	0	0.998

(9.55 vs. 6.77, $P = 0.024$), had a higher rate of amputations (18.8 vs. 7.4%, $P < 0.001$), and were more likely to urgently go to the OR compared to male patients (40.6% vs. 24.2%, $P = 0.024$) even though they had a lower mortality (1.6 vs. 4.8%, $P = 0.009$). It is unclear the exact mechanism underlying these differences between male and female patients and warrants further investigation. It was also noted that female patients had a higher rate of more distal arterial injuries (ulnar: 19 vs. 16.4%, digital/hand: 11 vs. 9.2%, $P < 0.001$) and arterial ligation (31.2% vs. 16.4%, $P = 1.00$) in addition to amputations compared to male patients. The diagnostic and treatment challenge and increased morbidity and mortality of more proximal upper extremity arterial injuries has been previously noted in smaller cohort studies in the literature as they may often present without hard signs of vascular injury.[15,22−30] Although ISS has its limitations in terms of predicting mortality, the disparity between male and female patients' ISS and mortality could also be explained by the differences in arterial injury location.[31−33] Because they may not present with hard signs of vascular injuries, more proximal arterial injuries may be more difficult to diagnose and could result in an inaccurate initial ISS and delayed diagnosis and treatment and potentially an increased mortality as a result. Operative repair among our

Table III. Multivariate linear regression–hospital LOS among operative patients

Variable	Unstandardized coefficient	Standardized coefficient	95% CI	*P* value
Race				
Caucasian	Ref	Ref		
African-American/Other	−2.55	−0.09	−6.39−1.29	0.19
Age	0.148	0.14	0.02−0.28	**0.029**
Gender				
Male	Ref	Ref		
Female	−0.12	−0.003	−5.65−5.41	0.97
Insurance				
Uninsured/underinsured	Ref	Ref		
Private/Medicare	2.45	0.08	−1.20−6.10	0.19
ISS	1.06	0.47	0.76−1.36	**<0.001**
Mechanism of injury				
Stab wound/Other	Ref	Ref		
GSW	0.42	0.01	−5.63−6.47	0.89
ED dispo				
Other	Ref	Ref		
Direct transfer to OR	−3.35	−0.11	−7.35−0.65	0.10
Procedure				
Unknown	Ref	Ref		
Ligation of artery/vein	Ref	Ref		
Repair of artery/vein	0.99	0.03	−2.99−4.97	0.62

P values that are significant have been bolded.

Table IV. Multivariate logistic regression—amputation rate among operative patients

Variable	Odds ratio	95% CI	*P* value
Race			
Caucasian	Ref		
African-American/Other	12.96	0.11−15	0.29
Age	1.11	0.91−1.35	0.30
Gender			
Male	Ref		
Female	6.04	0.13−273.62	0.36
Insurance			
Uninsured/underinsured	Ref		
Private/Medicare	12, 112, 119	0	0.996
ISS	0.69	0.30−1.57	0.38
Mechanism of injury			
Stab wound/other	Ref		
GSW	0	0	0.998
ED dispo			
Other	Ref		
Direct transfer to OR	1.4	0.02−85.72	0.993

cohort resulted in a significant improvement in survival, demonstrating the need for expeditious diagnosis and treatment for UEPVI injuries. Our dataset was limited in capturing mechanism—in particular domestic partner violence—and did not capture concomitant injuries both of which may have contributed to ISS. Future investigations should seek to better characterize the risk factors and presentation of these injuries to aid in expeditious diagnosis and treatment.

Operative intervention was protective in terms of mortality for all UEPVI patients. Among operative

patients, higher ISS predicted longer LOS but otherwise no other factors significantly impacted mortality or morbidity. Our data suggests that expeditious diagnosis and appropriate operative management is critical for reducing mortality among these patients, regardless of other risk factors.

Our retrospective review has significant limitations. Our single institution dataset is missing significant data-points both among included variables as well as variables not able to be captured that would be useful variables to better elucidate mechanisms underlying the outcomes reviewed. For instance, details on mechanism such as domestic violence, diagnostics, and treatment methods, such as level of amputation, were not available data-points. Furthermore, as this is a retrospective review, we are limited in determining causation for the patterns observed. Moreover, as this is a single institution review, our results are limited in their generalizability to the national and/or international trauma population. The management of vascular injuries has continued to evolve to include more minimally invasive endovascular techniques which were not often available at this single institution due to limited timing, staffing, and resources.

CONCLUSION

Our retrospective analysis demonstrated that the majority of penetrating upper extremity vascular injuries are incurred by men and are associated with assaultive or self-directed violence. Operative repair was associated with improved survival. On multivariate analysis, among operative patients, increased age and ISS were associated with longer LOS. Future study is warranted to further elucidate the mechanisms that lead to increased mortality among this cohort as well as strategies aimed to prevent and aid expeditious diagnosis and treatment of these injuries among this at-risk population.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Justine Broecker: conceptualization, Formal analysis, Writing original draft, Writing – Review & Editing. **Albert Hsu:** conceptualization, Writing – Review & Editing. **Matthew Kocuba:** conceptualization, Writing – Review & Editing. **Firas Madbak:** conceptualization, Writing – Review & Editing. **Henry Veldenz:** conceptualization, Writing – Review & Editing. **David Skarupa:** conceptualization, Writing – Review & Editing. **Brian Yorkgitis:** conceptualization, Writing – Review & Editing. **Jeanette Zhang:** conceptualization, Writing – Review & Editing. **Marie Crandall:** conceptualization, Formal analysis, Writing - Review & Editing.

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