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14. ABSTRACT

Objective: To determine the impact of the widespread use of fasciotomies on a mortality, delayed amputation, fasciotomy related morbidities, and fasciotomy wound management.

Specific Aims: 1) Identify patients that received fasciotomies and characterize the data relating to demographics, mortality, primary injury, complications, return-to-duty, long-term disabilities; 2) determine the incidence of morbidities associated with fasciotomy; 3) assess the impact of fasciotomy on delayed amputation; and 4) characterize fasciotomy wound management.

Study Design: This proposal will involve a retrospective analysis of large patient cohort of US Service members included in the GWOTVII database as having sustained wartime LEVI with and without fasciotomy in the wars in Afghanistan and Iraq. The GWOTVII database will be used to initially identify patients and will then be used to provide demographic information and data on injury characteristics, complications, other injures, and limb salvage information. Information regarding fasciotomy wound management and iatrogenic complications of fasciotomy will be obtained from individual patient records. Information specific for return to duty and long-term disability will be obtained from the Physical Evaluation Board Liaison Office for each branch of service.

15. SUBJECT TERMS
acute compartment syndrome; amputation; combat casualty care; extremity trauma; fasciotomy; fracture; limb salvage; military trauma; tourniquet; vascular injury; vascular repair

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1. INTRODUCTION:

The majority of battlefield injures involve the extremities and encompasses either isolated or a combination of vascular injury, penetrating trauma, crush, blunt trauma, burns, and fractures. Each of these injuries places the wounded Service members at risk for developing acute extremity compartment syndrome (ACS). Under far forward surgical conditions the policy is to manage these at-risk patients with prophylactic fasciotomies. A recent study from our Institution found that 19% of all casualties had undergone fasciotomy, making fasciotomy one of the most common surgical procedures performed among war casualties. Fasciotomy is known to have a number of morbidities and post-procedural wound management is difficult and resource demanding. The overall goal of this project is to determine the impact of the widespread use of fasciotomies on a number of considerations critical for assessing current medical/surgical practices, management guidelines and medical needs, as well as future research direction.

2. KEYWORDS:

acute compartment syndrome; amputation; combat casualty care; extremity trauma; fasciotomy; fracture; limb salvage; military trauma; tourniquet; vascular injury; vascular repair

3. ACCOMPLISHMENTS:

What were the major goals of the project?

The major goals of this project were to address the following Specific Aims:

Aim 1A: Determine mortality rate among those with fasciotomy

Aim 1B: Compare mortality rate between those with fasciotomy to matched Service Member with extremity vascular injury without fasciotomy

Aim 2A: Determine short- and long-term impact of fasciotomy on variables related to: wound characteristics (e.g. infection, closure, tethering); functional outcomes (e.g. foot drop, motor dysfunction, loss of sensation); vascular dysfunction (limb swelling, deep vein thrombosis)

Aim 2B: Compare short- and long-term impact of functional outcomes (e.g. foot drop, motor dysfunction, loss of sensation); vascular dysfunction (limb swelling, deep vein thrombosis) between those with fasciotomy to matched Service Member with extremity vascular injury without fasciotomy

Aim 3A: Determine delayed amputation rate among those with fasciotomy

Aim 3B: Compare delayed amputation rate between those with fasciotomy to matched Service Member with extremity vascular injury without fasciotomy

Aim 4A: Determine key measurements such as ISS, MESS in those with fasciotomy

Aim 4B: Compare key measurements such as ISS, MESS in those with fasciotomy to matched Service Member with extremity vascular injury without fasciotomy

Aim 5: Determine reason fasciotomy was performed, i.e., prophylactic versus treatment of diagnosed ECS

Aim 6: Determine the relationship between fasciotomy rate and ischemia time, i.e., the time between injury and revascularization (early (<1h,) mid (1-3hr) and late (>3hr) and fasciotomy rate

Aim 7: Determine the distribution of minor and major vascular injuries, and other extremity injury and severity, e.g. bone fracture

Aim 8: In subset with complete patient records (estimated 200 patients):

A. Determine time to definitive fasciotomy wound closure
B. Number of surgeries required for fasciotomy wound closure
C. Use of vacuum assisted closure (Wound VAC) for wound management

What was accomplished under these goals?

All the goals of this project were met. The following details the Methods, Results, and Major Findings and Recommendations.

Methods

This retrospective cohort study was performed using data from the Fasciotomy and Vascular Injury Outcomes (FaVIO) database, a vascular injury limb salvage database with patients compiled from the Department of Defense Trauma Registry (DoDTR). It also includes patient information that was obtained from: the Medical Evaluation Board (MEB); the Physical Evaluation Board (PEB); the Theater Medical Data Store (TMDS) database; the Transportation Command (TRANSCOM) Regulating and Command and Control Evacuation System (TRAC2ES) information system; the Patient Administration Systems and Biostatistics Activity (PASBA) database; the Web Interface for Scanned Patient Records (WISPR); and the Defense Enrollment Eligibility Reporting System (DEERS) database. The FaVIO database includes limbs having sustained lower extremity arterial, venous, or combined vascular injuries (iliac through tibial) between 2004 and 2012 and which underwent at least one vascular limb salvage procedure in the Iraq or Afghanistan theaters of operations. Data regarding the surgical management of lower extremity injuries and follow-up data regarding limb complications and outcomes were obtained from review of Department of Defense electronic clinical records. Follow-up data are available from the time of injury until the limb underwent amputation or the casualty died or was discharged from military service. Casualties sustaining traumatic amputations and those with vascular injuries managed with amputation at the initial operation are excluded, as are limbs with only superficial venous and unnamed arterial branch injuries. Data in FaVIO are included on a limb (rather than patient) basis and, in the event of bilateral lower extremity vascular injuries, the more severely injured limb is included. Demographics, injury mechanism, and some initial care variables were collected. Global injury burden was assessed using the Injury Severity Score (ISS) as reported in the source databases. Limb injury severity was assessed using the Abbreviated Injury Scale (AIS) and subscales as reported in the source databases.[1] The Mangled Extremity Severity Score (MESS) was calculated based on the available injury data.[2,3]

The exposure of interest was lower extremity fasciotomy performed after the initial vascular limb salvage procedure with follow-up for non-fasciotomy extremities beginning upon completion of the limb salvage procedure. The primary outcome was surgical amputation at any time between the initial surgical limb salvage attempt and military discharge. Patients who did not survive until the median time to fasciotomy were excluded as these patients potentially did not survive long enough to receive the primary outcome of interest. Secondary outcomes were mortality and limb complications. Limb related complications were defined as documented infection, motor loss, contracture, foot drop, edema, or deep vein thrombosis localized to the study limb. Each of these were further characterized by the location in the affected limb and the time from injury to development of the complication. For each model with complication as an outcome variable, patients who did not survive or had an amputation before the median time to the specified complication were excluded from the specified individual analysis as these patients potentially did not have enough follow-up time to be diagnosed with the specified complication.

To adjust the study groups based on injury severity and pre-hospital care, the following eight factors, likely to be visible to providers at time of initial assessment, were included as covariates: mangled extremity severity score (greater or less than 7), tourniquet use, lower extremity fracture (open, closed, none), burn injury to the lower extremity, most proximal arterial injury or venous injury site (iliac, femoral, popliteal, tibial, isolated venous injury), multiple arterial injury sites, mechanism of injury (blast, penetrating, blunt or crush), and isolated extremity injury. Isolated extremity injury meant no AIS in non-extremity body regions.

For the primary and secondary analyses, multiple multivariable logistic regression were used to adjust the association of fasciotomy with the outcome variable of interest by the covariates: mangled extremity severity score, tourniquet use, lower extremity fracture, burn injury to the lower extremity, most proximal arterial injury or venous injury site, multiple arterial injury sites, mechanism of injury, and isolated extremity injury. The outcome variable was amputation within 30 days of the initial limb salvage operation. A sensitivity analysis of a sub-group of patients including only those with an arterial injury which underwent arterial reconstruction (as opposed to ligation) was performed. This group was felt to be at highest risk for reperfusion-related consequences and therefore would derive the most benefit from early fasciotomy. Another pre-specified sensitivity analysis was designed to align follow-up time between the study groups. In this model, the delayed-entry approach adjusted the Cox model for left truncation among patients who received a fasciotomy with those who did not receive a fasciotomy with fasciotomy was modeled as a time-dependent covariate. The final Cox model met the proportional hazards assumption based on Schoenfeld residuals and log-log plots.

Statistical analysis was performed using SAS version 9.4 (SAS Institute Inc) and Stata version 15.1 (StataCorp). Chi-square or Fisher's exact test and student t-test or Wilcoxon-Mann-Whitney test was used where appropriate. Statistical significance was defined at a P-value of less than 0.05.

Results

A search of the FaVIO database resulted in 515 limbs meeting inclusion criteria (**Figure 1**).

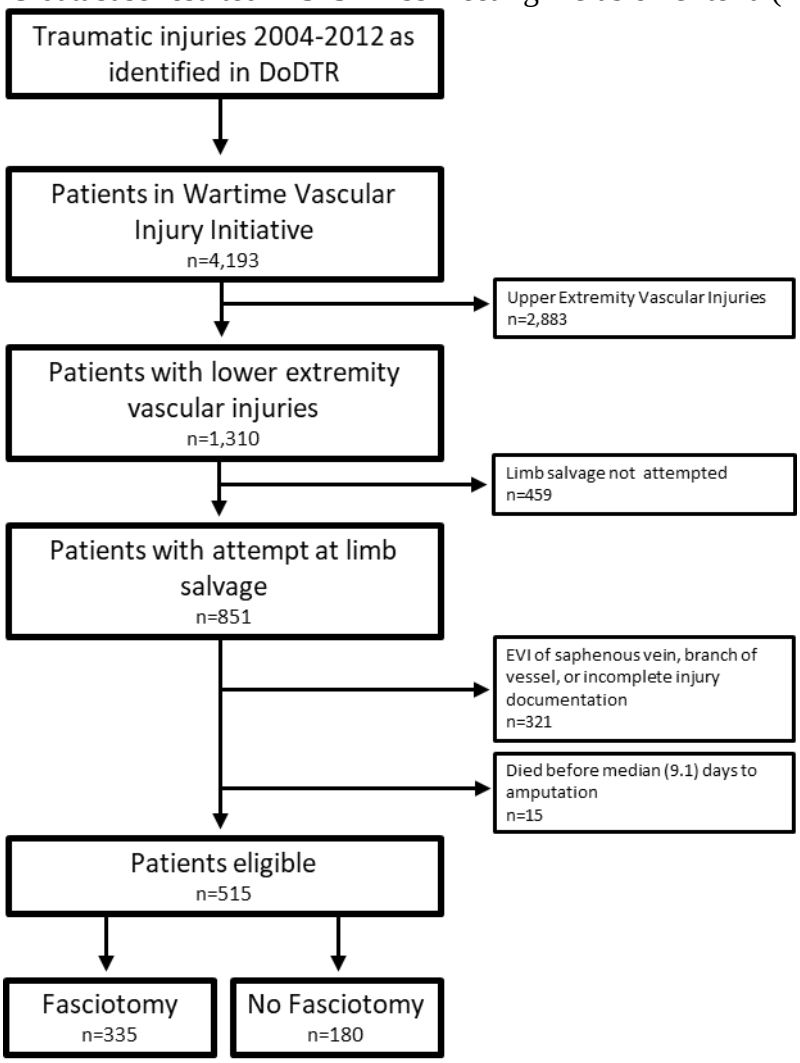

Figure 1. Flow diagram of patients (n=515) by study eligibility

Of these, 335 (65.0%) underwent fasciotomy (fasciotomy group) and 180 (35.0%) did not (no fasciotomy group), with fasciotomy proportion ranging from 50-73% throughout the course of the study time frame, with the number of fasciotomies ranged between 25-91 (**Figure 2**). Fasciotomy was performed a median of 7.7 (IQR 4.9-15.5) hours from the time of injury in the 333 fasciotomy recipients with injury timing data. A total of 212 fasciotomy recipients had adequate timing data to determine the temporal relationship between fasciotomy and the initial surgical procedure, with 174 fasciotomies (82%) performed within 30 minutes of the initial vascular procedure. Of the remaining 38 delayed (> 30 minutes) fasciotomies, those performed at Role II were a median of 3.6 hours following the initial procedure (IQR 1.0-9.5 hours) and those performed at Role III 6.4 hours (IQR 3.3-18.9). Fasciotomy was almost universally performed prior to evacuation out of the combat theater, with only 7 (2.1%) performed at the Role 4 facility in Germany, a median of 24.2 (IQR 7.0-30.9) hours following the initial procedure. Diagnosis of compartment syndrome or documentation of clinical findings suspicious for elevated compartment pressure (tense or firm compartments, edematous or ischemic muscle) was present in only 127 (24.6%) of the 515 included limbs, and 122 (36%) of limbs undergoing fasciotomy.

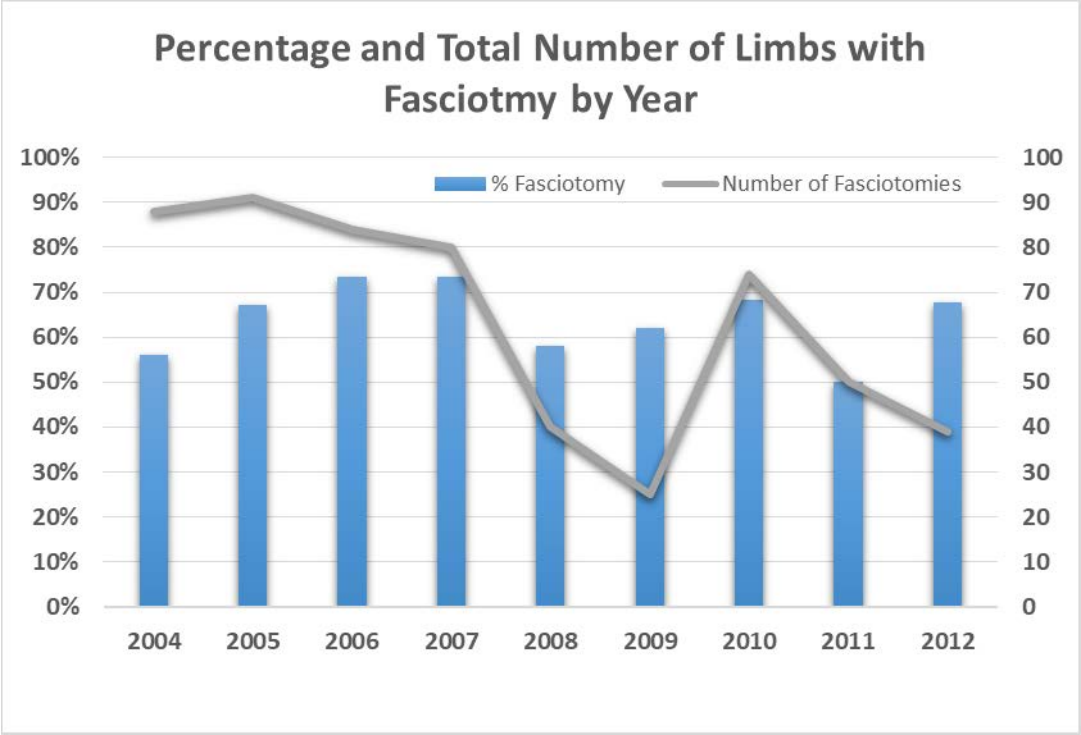

Figure 2. The relative and absolute distribution of casualties that sustained LEVI that received a fasciotomy by year of the study period

Both fasciotomy and no fasciotomy groups consisted of predominantly young (median age 24 years) males (> 99%). Two-thirds of the injuries in each group occurred in Afghanistan. Among the services, majority of the injuries occurred among Soldiers, followed by Marines, Sailor, and Airmen. Most limbs were injured by a blast mechanism (69.3%), with the most common cause being explosion of an improvised explosive device. The distribution of injury mechanism did not differ between groups ($P = 0.25$). Global injury burden was similar between the two groups with median ISS of 14 (IQR 10- 21) and 13 (IQR 10-19) for fasciotomy and non-fasciotomy, respectively. A greater proportion of limbs undergoing fasciotomy had tourniquets placed in the field (58% versus 46%, $P = 0.01$) and tourniquet times were longer in the fasciotomy group; a median of 62 (IQR 45-90) versus 50 (IQR 37-65) minutes, $P < 0.01$). **(Table 1)**

Table 1. Demographic and characteristics for 515 study patients with and without fasciotomy

	Fasciotomy, n=335	No fasciotomy, n=180	p-value
Age, median(IQR)	24 (21, 29)	24 (22, 28)	0.85
Male, n(%)	332 (99.1)	179 (99.4)	1.00
Theatre of operation, n(%)			0.38
Operation Enduring Freedom	234 (70.0)	119 (66.1)	
Operation Iraqi Freedom	101 (30.2)	61 (33.9)	
Service			
Army	250	125	
Navy	13	8	
Air Force	9	3	
Marines	113	50	
Mechanism of Injury, n(%)			0.25
Blast	224 (66.9)	133 (73.9)	
Penetrating	105 (31.3)	45 (25.0)	
Blunt or crush	6 (1.8)	2 (1.1)	
Burn to lower extremity, n(%)	14 (4.2)	4 (2.2)	0.25
Injury severity score, median(IQR)	14 (10, 21)	13 (10, 19)	0.15
First role of care, n(%)			0.26
Role II	172 (51.3)	83 (46.1)	
Role III	163 (48.7)	97 (53.9)	
Hours to fasciotomy from point of injury			
No. of patients without missing data	333	---	
Value, median(IQR)	7.7 (4.9, 15.5)	---	
Role of care of fasciotomy occurrence, n(%)			
Role II	91 (27.2)	---	
Role III	237 (70.8)	---	
Role IV	7 (2.1)	---	
Tourniquet use, n(%)	194 (57.9)	82 (45.6)	0.01
No. of patients without missing data	143	65	
Time of tourniquet use, median(IQR)	62 (45, 90)	50 (37, 65)	<0.01

Limb injury severity was modestly greater among those undergoing fasciotomy, with extremity Abbreviated Injury Scale scores distributed towards more severe limb injury. A higher proportion of fasciotomy limbs had fractures along with the vascular injury (94% versus 60%). Fasciotomy limbs demonstrated increased vascular injury complexity, with relatively more multiple-level arterial injuries (6.9% versus 1.7%), popliteal arterial injuries (19% versus 7.8%), combined arterial and venous injuries (39% versus 27%) and fewer isolated venous injuries (12% versus 23%). Ligation as a vascular treatment was used more frequently in limbs not undergoing fasciotomy (46% versus 36%). Fasciotomy limbs were more likely to have undergone shunting as an initial vascular procedure and more likely to have a vein graft as the final vascular reconstruction as opposed to a procedure of lesser magnitude. (**Table 2**)

Table 2. Injury site, type, severity, and associated injuries for 515 study patients with and without fasciotomy

	Fasciotomy, n=335	No fasciotomy, n=180	p-value
Most Proximal Arterial injury or Venous injury site, n(%)			<0.01
Iliac	7 (2.1)	11 (6.1)	
Femoral	104 (31.0)	49 (27.2)	
Popliteal	63 (18.8)	14 (7.8)	
Tibial	121 (36.1)	64 (35.6)	
Isolated Venous Injury	40 (11.9)	42 (23.3)	
Combined venous and arterial injury, n(%)	129 (38.5)	48 (26.7)	<0.01
Multiple arterial injury, n(%)	23 (6.9)	3 (1.7)	0.01
Shunt as Most Proximal Initial Vascular Procedure, n(%)	67 (20.0)	15 (8.3)	<0.01
Most Proximal Final Reconstruction, n(%)			<0.01
Ligation	121 (36.1)	83 (46.1)	
Vein Graft	138 (41.2)	36 (20.0)	
Suture/primary repair	30 (9.0)	35 (19.4)	
Other	24 (7.2)	12 (6.7)	
Thrombectomy	12 (3.6)	3 (1.7)	
Patch	5 (1.5)	8 (4.4)	
Other repair (add to suture)	5 (1.5)	3 (1.7)	
Isolated extremity injury, n(%)	42 (12.5)	25 (13.9)	0.67
Injury severity score, median(IQR)	14 (10, 21)	13 (10, 19)	0.15
Mangled extremity severity score > 7, n(%)	43 (12.8)	20 (11.1)	0.57
Abbreviated injury scale, median(IQR)			
Extremity	3 (3, 4)	3 (3, 3)	0.02
Fractures, n(%)			
Femur	84 (25.1)	23 (12.8)	<0.01
Open	62 (18.5)	14 (7.8)	0.00
Patella	21 (6.3)	4 (2.2)	0.05
Tibia	114 (34.0)	45 (25.0)	0.03
Open	101 (30.2)	38 (21.1)	0.03
Fibula	97 (29.0)	36 (20.0)	0.03
Open	83 (24.8)	30 (16.7)	0.03

Overall, 111 limbs (22%) underwent amputation following the initial limb salvage attempt with no difference in limb loss rate between the groups on univariate analysis (22% fasciotomy vs. 21% no fasciotomy, P = 0.69). Limb-specific complications were significantly more common in the fasciotomy group (72% versus 47%, P < 0.01) and initial hospitalizations were longer for these casualties (median 37 (IQR 24-60) versus 25 (13-49) days, p<0.01). Six (1.8%) fasciotomy and three (1.7%) no fasciotomy patients died. Only fourteen percent of casualties returned to military duty, with no difference in rate between the groups. **(Table 3)**

Table 3. Complications and outcomes for 515 study patients with and without fasciotomy

	Fasciotomy, n=335	No fasciotomy, n=180	p-value
Amputation, n(%)	74 (22.1)	37 (20.6)	0.69
Complications, n(%)			
Any limb complication	242 (72.2)	84 (46.7)	<0.01
Infection	113 (33.7)	32 (17.8)	<0.01
Motor loss	42 (12.5)	7 (3.9)	<0.01
Contracture	29 (8.7)	3 (1.7)	<0.01
Foot Drop	92 (27.5)	22 (12.2)	<0.01
Edema	158 (47.2)	48 (26.7)	<0.01
Deep vein thrombosis	40 (11.9)	17 (9.4)	0.39
Military status, n(%)			0.69
Mortality	6 (1.8)	3 (1.7)	
Return to duty	47 (14.0)	27 (15.0)	
Separation or medical retirement from service	273 (81.5)	148 (82.2)	
Unknown	9 (2.7)	2 (1.1)	
Initial hospitalization days			
No. of patients without missing data	329	174	
Value, median(IQR)	37 (24, 60)	24.5 (13, 49)	<0.01

Revision of the fasciotomy was performed in 58 (17%) of cases, with no noted difference in amputation or limb outcomes. Fasciotomies were closed in 272 limbs, with 43% requiring multiple closure procedures. The most commonly performed definitive closure procedure was a skin graft, used in 43% of fasciotomy recipients. Delayed primary closure was performed in 24% and flap closure in 2.2%. Almost two-thirds of fasciotomies remained open one week following the initial procedure. (**Table 4**). However, over 200 limbs underwent fasciotomy without documentation of findings suspicious for a developing compartment syndrome.

Table 4. Treatment and management of 272 fasciotomy patients who survived to fasciotomy closure or did not have an amputation

	Patients
Fasciotomy closure method, n(%)	
Skin graft	118 (43.4)
Delayed primary closure or suture closure	66 (24.3)
Flap	6 (2.2)
Other	82 (30.1)
Number of operations to close, n(%)	
missing	63 (23.2)
Single	92 (33.8)
Multiple	117 (43.0)
Days to closure, n(%)	
missing	70 (25.7)
0	1 (0.4)
1-6	29 (10.7)
7+	172 (63.2)

In the adjusted multivariable logistic regression model including all 515 study limbs, fasciotomy status was not significantly associated with amputation (P = 0.46) or mortality (P = 0.49). The adjusted odds ratio (OR) for amputation was 0.8 (95% CI 0.5-1.4) for fasciotomy limbs (74 amputations among 335) versus no fasciotomy (37 amputations among 180) and the OR for mortality was 1.7 (95% CI 0.4-8.1) in fasciotomy recipients (6 deaths among 335) versus no fasciotomy (3 deaths among 180, **Table 5**). The sensitivity analysis of the high-risk arterial injury group also demonstrated no association between fasciotomy and amputation with an adjusted OR of 0.8 (0.4-1.7, P = 0.57). There were 306 fasciotomy recipients with time data adequate for the pre-specified sensitivity analysis designed to align follow-up time and account for the timing of the fasciotomy. The odds of amputation were similar between these 306 patients with timing data compared to the 209 patients without timing data (adjusted OR 1.3, 95% CI 0.7-2.4, P = 0.40). In time-adjusted analysis, amputation remained unassociated with fasciotomy regardless of the timing of the procedure in relation to the initial limb salvage operation (P = 0.34). The adjusted hazard ratio for amputation was 0.7 (95% CI 0.4-1.4) in fasciotomy recipients (40 amputations among 212) versus non-recipients (17 amputations among 94, P = 0.34).

Table 5. Adjusted[a] odds ratio (OR) and 95% confidence interval (CI) of outcome for fasciotomy patients versus non-fasciotomy patients

Outcome	Exclusion based on median time of outcome	n	OR (95% CI)	p-value
Amputation	Death before 9.1 days	515	0.8 (0.5-1.4)	0.46
Mortality	n/a	515	1.7 (0.4-8.1)	0.49
Infection	Death or amputation before 29 days	431	2.2 (1.3-3.6)	<0.01
Motor loss	Death or amputation before 71 days	417	3.5 (1.4-8.6)	0.01
Contracture	Death or amputation before 199 days	410	4.7 (1.3-17.0)	0.02
Footdrop	Death or amputation before 113 days	415	2.4 (1.4-4.2)	<0.01
Edema	Death or amputation before 46 days	425	2.5 (1.6-4.0)	<0.01
Deep vein thrombosis	Death or amputation before 12 day	429	1.8 (0.9-3.7)	0.11

[a]Adjusted for mangled extremity severity score, tourniquet use, lower extremity fracture, burn injury to the lower extremity, most proximal arterial injury or venous injury site, multiple arterial injury sites, mechanism of injury, isolated extremity injury

The number of limbs included in the multiple multivariable models for individual limb-specific complications ranged from 410 to 431. The proportion of limbs excluded for each complication was similar between the fasciotomy and no fasciotomy groups. The odds of complications were significantly higher in fasciotomy limbs for infection (P < 0.01), motor loss (P = 0.01), contracture (P = 0.02), foot drop (P < 0.01), and edema (P < 0.01). The adjusted OR's for complications ranged from 2.2 to 4.7 times higher for fasciotomy recipients (**Table 5**).

Major Findings

- Fasciotomy was not associated with increased mortality even following correction for the more severe injuries seen among fasciotomy limbs.
- Fasciotomy was not associated with improved limb salvage but was associated with the development of limb complications. Even following correction for the more severe injuries seen among fasciotomy limbs, fasciotomy failed to demonstrate a protective effect on limb salvage, nor did it have such an effect in an isolated analysis of high-risk limbs undergoing arterial reconstruction.
- The early timing of a large majority of the procedures and the relative paucity of documented compartment syndrome or findings suspicious for its development suggest that most fasciotomies were performed immediately prior to or following revascularization and prior to the development of significant intracompartmental pressure elevation.

- In this analysis, limbs considered to be at lower risk for developing compartment syndrome were less likely to have undergone fasciotomy. The differences between this and the fasciotomy group include higher rates of iliac level and isolated venous injuries and of vascular ligation (as opposed to revascularization), less use of vascular shunts, and lower incidences of fractures, multiple arterial injuries, and combined arterial and venous injuries. Many of these differences between fasciotomy and no fasciotomy limbs have been seen in civilian trauma practice as well. [10]
- Fasciotomy is not a critical factor in determining eventual limb salvage in military lower extremity arterial injuries.
- Fasciotomy was strongly associated with a number of limb-specific complications including infection, neurologic dysfunction, and contracture. While some of the additional limb morbidity with fasciotomy may be attributable to greater injury severity, the significance in differential morbidity persisted following adjustment for many aspects of limb injury severity.
- Increased morbidity in limbs undergoing fasciotomy is likely the result of the significant additional wound burden incurred by the skin and fascial/muscular incisions required for complete fasciotomy. The clinical impact of this additional burden is evident in the nearly two weeks' additional initial hospital length of stay observed in the fasciotomy group. Additionally, most fasciotomies required multiple procedures and over a week for closure. Though the additional morbidity incurred by the fasciotomy group did not predispose to amputation, these data make it clear that fasciotomy is not a benign procedure and suggest that the decision to perform it should be made after careful consideration of the procedure's risks balanced against the potential for the development of compartment syndrome.
- Only about a quarter of the limbs in this cohort had documented compartment syndrome or findings suspicious for the conditions that may produce it and nearly all of these limbs underwent fasciotomy, presumably the procedure which uncovered those findings. The fasciotomies performed in these limbs can be thought to have prevented a compartment syndrome, justifying the potential for additional fasciotomy morbidity. However, over 200 limbs underwent fasciotomy without documentation of findings suspicious for a developing compartment syndrome. The relative benefit of fasciotomy in these limbs is less clear. Because this analysis relies on data collected from in-theater medical records, we must consider the possibility that some fasciotomy limbs exhibited these findings but that they were not recorded. Due to of the liberal application of fasciotomy in this military lower extremity vascular injury cohort, we cannot know the true incidence of compartment syndrome with such injuries.
- As of yet, there is no effective way to measure intracompartmental pressure during military evacuation following limb revascularization and prophylactic fasciotomy seems to remain indicated in limbs deemed at high risk for compartment syndrome.

Study Limitations

Due to the difficulties inherent in compiling and transmitting these battlefield theater data records, there exists the possibility for missed cases or incorrect or incomplete documentation of injuries or early care. To lessen any potential bias, a detailed abstraction guide and data dictionary were implemented throughout the course of data collection. Timing data are particularly troublesome and despite covariate adjustment, residual confounding may exist. For example, a valid survival analysis was precluded as 40.6% of the study population did not have data on procedural timing. To minimize the potential for confounding, a sensitivity analysis survival analysis was conducted on the subset of the study population with timing data available.

Recommendations

- Fasciotomy is associated with significant limb morbidity however and the procedure should be performed after careful consideration of the balance between the potential for compartment syndrome and the increased wound burden it produces
- Further research into measurable risk factors for the development of compartment syndrome and fieldable compartment monitoring strategies should be undertaken to decrease the use of fasciotomy and the incidence of wound complications in the future.

What opportunities for training and professional development has the project provided?
This project provided the opportunity for surgical residents to participate in data analysis, manuscript writing and presentation at national medical conferences as part of their career development.

Surgical Residents that participated on the project (see PRODUCTS):

- Capt Lydia Piper (USAF BAMC Gen Surg)
- Capt David Schechtman (USAF BAMC Gen Surg)
- Capt Sarah Thomas (USAF BAMC Gen Surg)

How were the results disseminated to communities of interest?
The results of this data were disseminated through presentation at relevant medical society meetings (Western Trauma Association; American College of Surgeons; Vascular and Endovascular Surgery Society); Military Medical Meetings (Military Health Services Research Symposium) and to the Joint Trauma Theater Registry.

What do you plan to do during the next reporting period to accomplish the goals?
This is a final report, however, additional papers using the FaVIO database are planned, e.g.
"Utility of the Mangled Extremity Severity Score in Predicting Amputation in Military Lower Extremity Arterial Injury"
As the most comprehensive existing database for wartime extremity vascular injuries, it is likely to be the source of a number of publications and presentations in the future.

4. IMPACT:

What was the impact on the development of the principal discipline(s) of the project?
This study showed fasciotomy is associated with significant limb morbidity and the procedure should be performed after careful consideration of the balance between the potential for compartment syndrome and the increased wound burden it produces. Additionally, we reported that the fasciotomy rate among this cohort of casualties with LEVI averaged 65%. This fasciotomy rate was possible because of short prehospital times and the availability of trained surgeons at Forward Surgical Team (Role of Care 2) and Combat Support Hospital (Role of Care 3) medical facilities. However, the medical delivery systems established during OIF and OEF are unlikely to exist in future military operations. Instead, future scenarios are expected to involve prolonged care by less skilled medical providers, delayed and long-distance medical evacuation, and large numbers of casualties; making it critically important to develop technologies that could aid these medical providers in determining which high risk casualties require fasciotomy.

What was the impact on other disciplines?
These results strongly support the need for the development of medical device(s) that can aid in diagnosing ACS or in the prediction of casualties that require fasciotomy. This will require biomedical engineers and related disciplines.

What was the impact on technology transfer?
Nothing to Report

What was the impact on society beyond science and technology?
Nothing to Report

5. CHANGES/PROBLEMS:

Changes in approach and reasons for change
Nothing to Report

Actual or anticipated problems or delays and actions or plans to resolve them
Nothing to Report

Changes that had a significant impact on expenditures
Nothing to Report

Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents

Significant changes in use or care of human subjects
N/A

Significant changes in use or care of vertebrate animals
N/A

Significant changes in use of biohazards and/or select agents
N/A

6. PRODUCTS:

- **Publications, conference papers, and presentations**

Journal publications.

1. Kauvar DS, Staudt AM, Arthurs ZM, Propper BW, Piper LC, Ryan KL, Walters TJ. Effect of Early Fasciotomy on Limb Salvage and Complications in Military Lower Extremity Vascular Injury. J Trauma Acute Care Surg. [Submitted]
2. Kauvar DS, Propper BW, Arthurs ZM, Wayne Causey M, Walters TJ. Impact of Staged Vascular Management on Limb Outcomes in Wartime Femoropopliteal Arterial Injury. Ann Vasc Surg. 2019 Aug 30. pii: S0890-5096(19)30707-1. doi: 10.1016/j.avsg.2019.08.072. [Epub ahead of print] PMID: 31476424
3. Kauvar DS, Thomas SB, Schechtman DW, Walters TJ. Predictors and timing of amputations in military lower extremity trauma with arterial injury. J Trauma Acute Care Surg. 2019 Jul;87(1S Suppl 1):S172-S177. doi: 10.1097/TA.0000000000002185. PubMed PMID: 31246923.
4. Kauvar DS, Miller D, Walters TJ. Tourniquet use is not associated with limb loss following military lower extremity arterial trauma. J Trauma Acute Care Surg. 2018 Sep;85(3):495-499. doi: 10.1097/TA.0000000000002016

Federal support acknowledged in all publications

Books or other non-periodical, one-time publications.
Nothing to report

Other publications, conference papers and presentations.

Posters

1. Walters, T. J., D. L. Miller, T. Le and J. C. Rivera. Fasciotomy and Vascular Injury Outcomes Study (FaVIO): Complications Associated with Prophylactic Fasciotomy following Lower Extremity Vascular Injury. Military Health Services Research Symposium (MHSRS) Orlando, FL. (2017)
2. Rivera, J. C., D. L. Miller, L. N. Le and T. J. Walters. Fasciotomy and Vascular Injury Outcomes Study (FaVIO): The Impact of Prophylactic Fasciotomy on Hospitalization following Lower Extremity Vascular Injury. Military Health Services Research Symposium (MHSRS) Orlando, FL. (2017)

Podium Presentations

3. Piper, L. C., D. S. Kauvar, J. C. Rivera, D. L. Miller, B. Propper and T. J. Walters. "Outcomes of Lower Extremity Fasciotomy in Wartime Vascular Injury." American College of Surgeons Annual-Excelsior Surgical Society Meeting. San Diego, CA. (2018)

4. D. S. Kauvar and T. J. Walters. Tourniquet Use is Not Associated with Limb Loss Following Military Lower Extremity Arterial Trauma. Military Health Services Research Symposium (MHSRS) Orlando, FL. (2018)
5. Kauvar, D.S. Utility of the Mangled Extremity Severity Score in Predicting Amputation in Military Lower Extremity Arterial Injury - Vascular and Endovascular Surgery Society. Snowbird, Utah (2019)
6. Kauvar, D.S. Impact of Staged Vascular Management on Limb Outcomes in Wartime Femoropopliteal Arterial Injury - Military Health Services Research Symposium (MHSRS) Orlando, FL. (2019)
7. Kauvar, D.S. Effect of Early Fasciotomy on Limb Salvage and Complications in Military Lower Extremity Vascular Injury. Western Trauma Association, Sun Valley, Idaho (2020)

Federal support acknowledged in all posters and presentations

- **Website(s) or other Internet site(s)**
  Nothing to Report

- **Technologies or techniques**
  Nothing to report

- **Inventions, patent applications, and/or licenses**
  Nothing to report

7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on the project?

Name:	Thomas J. Walters, PhD
Project Role:	PI
Researcher Identifier (e.g. ORCID ID):	
Nearest person month worked:	3
Contribution to Project:	Dr. Walters is the PI on this project, responsible for grant authorship, protocol writing, regulatory responsibilities, initial data base design, oversight of the research nurse staff, data analysis, manuscript writing, and presentation of data at medical conferences.
Funding Support:	Government employee-no support from grant

Name:	MAJ Zachary Arthurs, MD
Project Role:	Co-PI
Researcher Identifier (e.g. ORCID ID):	
Nearest person month worked:	1.2
Contribution to Project:	MAJ Arthurs Rivera is a vascular surgeon assigned to the Vascular Service at Brooke Army Medical Center. He was responsible for guidance on database construction and manuscript writing
Funding Support:	Active Duty Military (Army) -no financial support from grant

Name: Diane L. Miller, MPH, RN
Project Role: Project Manager
Nearest person month worked: 9
Contribution to Project: Protocol writing, obtaining approval for all database and patient record access, database development, extraction of patient data, supervision of data extractors, drafting quarterly reports
Funding Support: Geneva Foundation

Name: Leslie M DuBois, RN
Project Role: Data Abstractor
Nearest person month worked: 9
Contribution to Project: extraction of patient data
Funding Support: Geneva Foundation

Name: Julie Cutright, RN
Project Role: Data Abstractor
Nearest person month worked: 9
Contribution to Project: extraction of patient data
Funding Support: Geneva Foundation

Name: Amanda Staudt, PhD, MPH
Project Role: Epidemiologist/Statistician
Nearest person month worked: 2.4
Contribution to Project: Statistical Analysis, subgroup analysis
Funding Support: Geneva Foundation

Name: LTC David S. Kauvar, MD
Project Role: Co-PI (2018-2019)
Researcher Identifier (e.g. ORCID ID):
Nearest person month worked: 3

Contribution to Project: LTC Kauvar is a vascular surgeon assigned to the Vascular Service at Brooke Army Medical Center. He was responsible for database revisions, data analysis, statistical analysis, manuscript writing, data presentation at medical meetings, overseeing and mentoring surgical residents with projects involving the FaVIO database (see below).

Name: MAJ Jessica Rivera, MD
Project Role: Co-PI (2015-2018)
Researcher Identifier (e.g. ORCID ID):
Nearest person month worked: 1.2

Contribution to Project: MAJ Rivera is an orthopedic surgeon and the former director of orthopaedic research in the orthopedics department at Brooke Army Medical Center and former member of the Extremity Trauma Department at the USAISR. She contributed to initial

	database construction; particularly that relating to fractures, as well as data analysis, and presentation of data at medical conferences
Funding Support:	Active Duty Military (Army) -no financial support from grant

Name:	CPT Lydia Piper, MD
Project Role:	AI
Researcher Identifier (e.g. ORCID ID):	
Nearest person month worked:	3
Contribution to Project:	CPT Piper is a general surgery resident at Brooke Army Medical Center. She contributed to manuscript writing and presentation of data at medical conferences
Funding Support:	Active Duty Military (Air Force) -no financial support from grant

Name:	CPT David Schechtman, MD
Project Role:	AI
Researcher Identifier (e.g. ORCID ID):	
Nearest person month worked:	1.2
Contribution to Project:	CPT David Schechtman is a general surgery resident at Brooke Army Medical Center. He contributed to manuscript writing and presentation of data at medical conferences
Funding Support:	Active Duty Military (Air Force) -no financial support from grant

Name:	CPT Sarah Thomas, MD
Project Role:	AI
Researcher Identifier (e.g. ORCID ID):	
Nearest person month worked:	1.2
Contribution to Project:	CPT Sarah Thomas is a general surgery resident at Brooke Army Medical Center. She contributed to manuscript writing and presentation of data at medical conferences
Funding Support:	Active Duty Military (Air Force) -no financial support from grant

Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?
Nothing to Report

What other organizations were involved as partners?
Organization Name: Brooke Army Medical Center
Location of Organization: 3551 Roger Brooke Dr, Fort Sam Houston, TX 78234
Partner's contribution to the project:

- Facilities (e.g., project staff use the partner's facilities for project activities);
- Collaboration (e.g., partner's staff work with project staff on the project);

1. Gennarelli TA, Wodzin E. AIS 2005: a contemporary injury scale. *Injury.* 2006;37(12):1083-1091.
2. Johansen K, Daines M, Howey T, Helfet D, Hansen ST, Jr. Objective criteria accurately predict amputation following lower extremity trauma. *J Trauma.* 1990;30(5):568-572; discussion 572-563.
3. Rush RM, Jr., Kjorstad R, Starnes BW, Arrington E, Devine JD, Andersen CA. Application of the Mangled Extremity Severity Score in a combat setting. *Mil Med.* 2007;172(7):777-781.
4. Wade G, Talbot M, Shero J, et al. Acute Extremity Compartment Syndrome (CS) and the Role of Fasciotomy in Extremity War Wounds (CPG ID: 17). In. JOINT TRAUMA SYSTEM CLINICAL PRACTICE GUIDELINE2016.
5. Rasmussen T, Stockinger Z, Antevil J, et al. Vasuclar Injury (CPG ID: 46). In. *Joint Trauma System Clinical Practice Guideline*2106.
6. Ritenour AE, Dorlac WC, Fang R, et al. Complications after fasciotomy revision and delayed compartment release in combat patients. *J Trauma.* 2008;64(2 Suppl):S153-161; discussion S161-152.
7. Kragh JF, Jr., San Antonio J, Simmons JW, et al. Compartment syndrome performance improvement project is associated with increased combat casualty survival. *The journal of trauma and acute care surgery.* 2013;74(1):259-263.
8. Kragh JF, Jr., Dubick MA, Aden JK, 3rd, et al. U.S. Military Experience From 2001 to 2010 With Extremity Fasciotomy in War Surgery. *Mil Med.* 2016;181(5):463-468.
9. Fox N, Rajani RR, Bokhari F, et al. Evaluation and management of penetrating lower extremity arterial trauma: an Eastern Association for the Surgery of Trauma practice management guideline. *The journal of trauma and acute care surgery.* 2012;73(5 Suppl 4):S315-320.
10. Branco BC, Inaba K, Barmparas G, et al. Incidence and predictors for the need for fasciotomy after extremity trauma: a 10-year review in a mature level I trauma centre. *Injury.* 2011;42(10):1157-1163.
11. Farber A, Tan TW, Hamburg NM, et al. Early fasciotomy in patients with extremity vascular injury is associated with decreased risk of adverse limb outcomes: a review of the National Trauma Data Bank. *Injury.* 2012;43(9):1486-1491.
12. Rush DS, Frame SB, Bell RM, Berg EE, Kerstein MD, Haynes JL. Does open fasciotomy contribute to morbidity and mortality after acute lower extremity ischemia and revascularization? *J Vasc Surg.* 1989;10(3):343-350.
13. Walters TJ, Kottke MA, Hargens AR, Ryan KL. Noninvasive diagnostics for extremity compartment syndrome following traumatic injury: A state-of-the-art review. *The journal of trauma and acute care surgery.* 2019;87(1S Suppl 1):S59-S66.