Acute Compartment Syndrome of the Thigh in Combat Casualties

Brendan D. Masini, MD; Adam W. Racusin, MD; Joseph C. Wenke, PhD; Tad L. Gerlinger, MD; and Joseph R. Hsu, MD

Acute compartment syndrome of the thigh is a rare clinical entity often caused by high-energy trauma and presenting with a spectrum of associated injuries. Service members in combat are at risk for these causative mechanisms. This study presents a large cohort of thigh compartment syndrome combat casualties and investigates the injury mechanisms, associated mortality, and complications related to fasciotomies. Blasts were the most frequent injury mechanism, overall mortality was 23%, burns were associated with a higher mortality, and fasciotomy morbidity was reported by all respondents. The mortality was similar to civilian cohorts with thigh compartment syndrome and was isolated to patients with high Injury Severity Scores. While mortality associated with this injury is high, it is likely related to associated injury patterns rather than the compartment syndrome itself. Thigh compartment fasciotomies carried significant morbidity, consistent with civilian trauma publications. (Journal of Surgical Orthopaedic Advances 22(1):42–49, 2013)

Key words: combat trauma, fasciotomy, thigh compartment syndrome

Acute compartment syndrome of the thigh is a rare clinical entity with an etiology and natural history that is not well defined. Although increasingly reported, studies primarily consist of case reports or small case series. Among these reports, a variety of inciting factors have been implicated for development of the condition including (*a*) high-energy mechanisms such as motor vehicle trauma (1), femur fracture (2, 3), blunt vascular injury (4), and contusion (5, 6); (*b*) compressive mechanisms of injury such as use of antishock trousers (7–9), external compression from narcotic overdose (10), intraoperative positioning (11), and epidural anesthesia (12); (*c*) internal hemorrhage or fluid extravasation such as coagulopathy and intramuscular hematoma (13, 14), false aneurysm (15), hamstring avulsion (16), and knee arthroscopy (17); and (*d*) other causes including hip and knee arthroplasty (18, 19), muscular exertion (20, 21), and a case report of intravenous drug injection (22). This wide range of clinical presentations has equally varied outcomes ranging from significant morbidity and mortality to resolution without functional deficit. There exist two larger reviews addressing the spectrum of disease, one by Schwartz et al. (1) with 17 patients and one by Mithofer et al. (23) with 28 patients. Even among these two larger reviews there is a fundamental difference in conclusion. The patient group in the Schwartz et al. article had a 47% mortality, which was significantly higher than the mortality predicted based on associated injuries, with a conclusion that thigh compartment syndrome contributes to mortality. The Mithofer study, however, had a mortality of 11%, with mortality exclusively in patients with elevated Injury Severity Scores (ISS), indicating that associated injuries rather than the compartment syndrome define the outcomes. Without definitive understanding of the impact of thigh compartment syndromes on mortality, there remains a need for further investigation of this injury to clarify best practices for diagnosis and treatment to optimize outcomes.

Combat trauma produces a variety of injury patterns (24). Blast trauma can cause many of the previously referenced inciting factors, including high-energy injuries, penetrating trauma, compressive injuries, or internal hemorrhage, making soldiers an at-risk population for the development of thigh compartment syndromes. With that in mind, as well as with the knowledge that extremity injuries require the greatest resource utilization to treat and ultimately cause the greatest disability for soldiers (25), it makes sense to critically evaluate acute thigh compartment syndrome as a result of combat trauma.

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No support was received by outside funding or grants. Research was performed at the U.S. Army Institute of Surgical Research, Ft. Sam Houston, Texas.

The opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

Received for publication August 22, 2012; revision received November 6, 2012; accepted for publication November 20, 2012.

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1548-825X/13/2201-0042$22.00/0

DOI: 10.3113/JSOA.2013.0042

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 MAR 2013	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Acute compartment syndrome of the thigh in combat casualties.	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Masini B. D., Racusin A. W., Wenke J. C., Gerlinger T. L., Hsu J. R.,	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **United States Army Institute of Surgical Research, JBSA Fort Sam Houston, TX**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**8**	

This review was performed to further define the relationship between acute compartment syndrome of the thigh and associated injuries on patient mortality as well as to assess this clinical entity in the combat-wounded service member.

Materials and Methods

Patient Population

The U.S. military has been involved in overseas conflicts against insurgent forces since 2001. Over the course of these campaigns, the signature weapon system employed by the enemy has been the improvised explosive device (IED), which has been effective in causing casualties and severe trauma secondary to blast effect. Injured soldiers are moved through a medical evacuation chain that initiates at the site of injury with basic first aid and increases in scope of care, ultimately terminating at military medical treatment facilities in the United States. In the course of the evacuation, U.S. casualties from combat theaters in Afghanistan and Iraq are routed through Landstuhl Regional Medical Center (LRMC) in Germany, where a casualty registry is maintained. Under an institutional review board–approved protocol, a review of the medical charts of service members identified from this registry as having had fasciotomies performed for acute compartment syndromes and treated from January 1, 2005, to August 31, 2006, was performed. Information available for review included inpatient data from LRMC, initial history and physical taken on presentation in the combat theater, operative reports from the combat theater, and an air evacuation request completed before transfer to LRMC (26). From this parent data set, a database was constructed of all soldiers who received fasciotomies for a diagnosis of acute compartment syndrome of the thigh. Extracted data included demographics, mechanism and date of injury, associated injuries, anatomic location of fasciotomy, timing, geographic location of fasciotomy, laboratory findings, and ISS. ISS information in the database was retrieved from the Joint Theater Trauma Registry database. ISS is based on the Abbreviated Injury Scale (AIS) score of 1 to 6 for each of nine body regions. To calculate the ISS, the highest AIS score in each of the three most severely injured ISS body regions is squared and summed. The ISS ranges from 1 to 75 (i.e., AIS scores of 5 for each region assessed). If any of the three AIS scores is a 6, the ISS is automatically set at 75. Because an AIS score of 6 ("unsurvivable") indicates the futility of further medical care in preserving life, this score in any category for any patient in triage may mean a cessation of further care. Mortality data for the cohort were collected from a search of the publicly accessible Department of Defense Personnel and Procurement Statistics (search performed on January 20, 2010).

Diagnosis and Treatment

Diagnostic criteria for compartment syndromes are well described, and diagnosis and surgical indication can be made from clinical signs and symptoms alone (27, 28). These signs include pain out of proportion, weakness and passive pain on stretch of the muscles in the compartment, hypoesthesia in the distribution of nerves running through the compartment, and tenseness of the fascial boundaries of the compartment (26). Often discussed in the diagnosis of compartment syndromes in the civilian population is a difference in patients who are awake and cooperative versus those who are unable to cooperate because of associated injuries, mechanical ventilation, or level of sedation (29). In the combat environment, the diagnosis of the cooperative patient is no different than in the civilian world where the characteristic constellation of symptoms makes reliable clinical diagnosis a routine matter. However, in the sedated or otherwise uncooperative patient, where the civilian surgeon may rely on compartment pressure measurements to confirm a diagnosis or serially monitor the onset of compartment syndrome in a limb at risk, the military surgeon must continue to make a purely clinical diagnosis. In the early levels of the medical evacuation chain, there may not be resources, such as compartment pressure–measuring devices, or sufficient time before evacuation to monitor these extremities as might occur in the civilian setting. Furthermore, during the evacuation, there is no opportunity to perform serial monitoring because there may not be surgical assets available when the disease process demands. Current predeployment training for physicians provides some standardized education for diagnosis and treatment of compartment syndrome. Fasciotomy in all cases studied was done according to described techniques (30, 31). Briefly, a lateral incision is made from the greater trochanter to the lateral condyle of the femur. The iliotibial band is incised and vastus lateralis reflected off the intermuscular septum, bluntly releasing the anterior compartment. The intermuscular septum is then incised the length of the skin incision, releasing the posterior compartment. If required, the medial compartment is released through a separate anteromedial incision. Acute coverage of surgical wound was either by wet-to-dry dressing or negative pressure wound therapy, depending on the level of care in the evacuation chain and availability of supplies.

TABLE 1 Characteristics of mortality associated with thigh compartment syndrome

Mortality Data	ISS	TBSA Burn (%)	Ipsilateral Femur Fracture	Bilateral Compartment Syndromes	ISS $\geq$ 25
Nonsurvivors ($n = 7$)	42.4 ± 8.6	70.1 ± 5.6	0% (0/7)	86% (6/7)	100% (7/7)
Survivors ($n = 23$)	18.8 ± 2.8	11.9 ± 4.6	34% (8/23)	17% (4/23)	34% (8/23)
p value	.012	.0001	.143	.002	.006

Outcomes Analysis

Outcomes data were collected via phone interview in accordance with protocol approved by the institutional review board. Interviews were conducted by the lead author (BDM) and one co-investigator (AWR). Last recorded contact information in the military medical record and registered military e-mail contacts were used to contact patients. Social media and web searches were also performed in an effort to locate missing subjects. For a subject who declined to participate in the survey, a follow-up call was made to confirm that decision. Contacted subjects who could not complete an interview because of medical condition were excluded from analysis. A script was followed for all interviews, which included administration of a fasciotomy-specific questionnaire (see Appendix).

Data Analysis

Statistical analysis was performed to compare survivors and nonsurvivors for characteristics that influenced mortality. A two-sample t test with unequal variances was used to assess the relationship of ISS and total body surface area (TBSA) burns to mortality and the Fisher exact test was used to assess the relationship of ipsilateral femur fracture and bilateral compartment syndrome to mortality. Additional stratification of service members by ISS was performed to look for differences in mortality in multiply injured service members versus those injured in an isolated body region, similar to the analysis performed by Mithofer et al. (23). Fisher exact test was used for this comparison. Because our database is limited in its ability to allow definitive characterization of the severity of injury to each body area, this stratification was done by ISS alone. The threshold for this analysis was set at an ISS $\geq$ 25. Twenty-five is the highest ISS for a survivable injury to a single body region; therefore, a score greater than 25 is by definition either a multisystem injury or unsurvivable. An ISS 25 was included because in this cohort the score of 25 was given to two patients with high TBSA burns (76% and 45%), which can also by definition be described as multisystem. Values are expressed as a mean $\pm$ SEM. A p value $< .05$ was considered significant.

Results

Thirty service members were identified as having undergone fasciotomy for acute compartment syndrome of the thigh. Ten had bilateral fasciotomies performed for a total of 40 fasciotomies. All service members in this group were males with an average age of 25.8 (range, 19–48) years. Twenty-three (77%) were injured by detonation of an IED, three (10%) by high-velocity gunshot, two (7%) by grenades, and one (3%) each by mortar and motor vehicle crash. Overall mortality was 23%. The ISS of nonsurvivors was significantly greater than that of survivors ($p = .01$). Service members with an ISS $\geq$ 25, suggesting injury to multiple body regions, had a greater mortality ($p = .006$). Differences seen in the survivors versus the nonsurvivors are shown in Table 1.

Injury Patterns

Trauma

Sixty-seven percent (20/30) of patients had penetrating injuries to the thigh where compartment syndrome developed. Of the 23 patients whose injuries were sustained in the detonation of an IED, 15 sustained penetrating injuries while eight sustained blunt trauma. The patient injured via motor vehicle crash had a crush component to his injury; however, no patients were identified as having crush syndrome manifested by myoglobinuria, hyperkalemia, and acidosis (10).

Fractures

Forty-seven percent (14/30) of patients had at least one fracture, with 26 total fractures identified. Twenty-seven percent (8/30) of patients and 27.5% (11/40) of thigh compartment syndromes had an ipsilateral femur fracture, with three patients having bilateral femur fractures. Eight femur fractures were open and three were closed. Additional fractures sustained by patients included one pelvis, three tibia, three fibula, one foot, three hand, one forearm, and three humerus fractures. None of the service members who died from wounds had an ipsilateral femur fracture at the site of the thigh compartment syndrome; however, this was not a statistically significant predictor of survival ($p = .143$) in this sample size.

Burns

Burns were an associated injury pattern present in this patient population that has not been commented on before in assessments of thigh compartment syndromes. Although burns are relatively uncommon in civilian mechanisms leading to thigh compartment syndrome, including motor vehicle crashes and compression injuries, burns are a very common component of blast injuries, especially in the presence of unexploded ordinance or vehicle fuel tanks. Of our patients, 13 of 30 (43%) had burn injuries with an average total body surface area of 59% (range, 15%–90%). Ten of 13 burn patients required escharotomies in addition to fasciotomies. There was a greater average TBSA burn percentage among nonsurvivors than survivors ($p = .0001$).

Vascular Injuries

Twenty-three percent (7/30) of patients required vascular surgery interventions to the affected extremity. These procedures included femoral artery to femoral artery bypass grafting, reverse saphenous vein grafting of femoral vessels, primary repair of femoral vessels, and shunting of iliac and femoral veins.

Other Compartment Syndromes

Bilateral thigh compartment syndromes were seen in 10 of the 30 service members. Eighty-two percent (6/7) of nonsurvivors had bilateral compartment syndrome compared to 17% (4/23) of survivors. This difference was statistically significant ($p = .002$). Additional compartment syndromes identified in this cohort and treated with fasciotomy were common. Twenty-one of 30 (70%) patients required lower leg fasciotomy for acute compartment syndrome. Seven service members required forearm fasciotomies with four being bilateral. There were also five service members requiring fasciotomy of the upper arms (two bilateral), five with hand fasciotomies (two bilateral), and two with foot fasciotomies (one bilateral).

Multiple Organ System Dysfunction

Problems with other organ systems were common in this patient population. Seventeen of 30 patients were intubated on arrival to LRMC. Eleven of 30 patients required systemic administration of at least one vasopressor medication. On admission to Landstuhl, 26 surviving patients remained in clinical condition warranting preoperative laboratory evaluation. Of this group, 17 had normal serum creatinine ($<1.5\times$ baseline) indicating no renal dysfunction, two were at risk of renal injury ($>1.5\times$ baseline), four had sustained renal injury ($>2.0\times$ baseline), and one had renal failure (4.0 mg/dL) according to the RIFLE classification (32).

Risk Factors

There was an average transfusion requirement of 3 (range, 0–12) units of packed red blood cells, 4.8 (range, 0–24) packs of platelets, and 3.1 (range, 0–14) units of fresh-frozen plasma. Total volume of intravenous crystalloid fluids was not recorded. Military antishock trousers have been implicated as a causative agent for thigh compartment syndrome by several sources; however, they were not utilized in any of these patients. Six patients in the cohort had documented use of a tourniquet to the extremity in question.

Outcomes

Eleven service members with 15 thigh compartment syndromes treated with fasciotomy were contacted an average of 36 (range, 29–45) months after treatment. There were four lower extremity amputations in three service members. One had a below-knee amputation. Two had through-knee amputations, with one of these service members having a contralateral above-knee amputation.

All fasciotomies had at least one associated symptom (15 fasciotomies in 11 service members) (Fig. 1). Eighty-seven percent (13/15) of fasciotomies were reported to have sensation changes including paresthesias and hyperesthesias, 67% (10/15) have dry skin, and the same number reported symptomatic tethering to the overlying skin. Forty-seven percent (7/15) have chronic limb swelling, with the same number reporting discoloration and motor dysfunction (spasm/cramping/weakness). Thirty-three percent (5/15) have pruritis. Twenty-seven percent (4/15) have symptomatic fascial herniations. Twenty percent (3/15) have ulcerations. One limb required a surgical procedure for symptomatic heterotopic ossification, and two developed surgical site infections. Eight

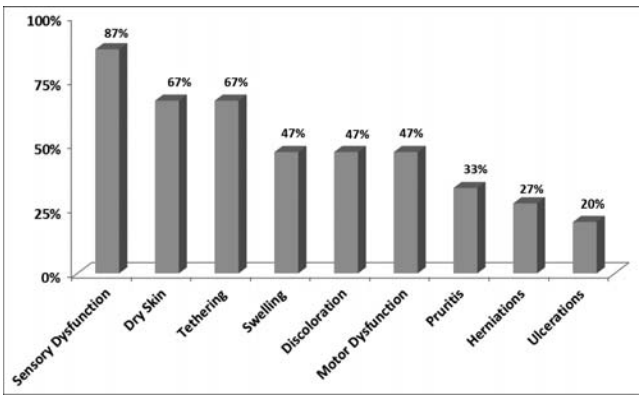

FIGURE 1 Rates of patient-reported morbiditiy from thigh fasciotomy: 15 fasciotomies in 11 patients.

incisions were closed primarily, six with skin graft, and one by secondary intention.

Discussion

Acute compartment syndrome of the thigh has proven to be a clinical entity with limited understanding because of its rarity and varied etiology. The size of this cohort of patients adds to the base of knowledge surrounding this topic, particularly in the multiply injured patient as a result of combat mechanisms of injury.

Mortality is the outcome that is most striking in previous literature on this topic. In the first large series of thigh compartment syndromes, there was a mortality of 47% among 17 patients (1). The precise cause of death of those patients in the aforementioned article was difficult to determine because of the failure of multiple organ systems. Schwartz et al. attempted to quantify the effect of thigh compartment syndrome on mortality by comparing their observed mortality to a predicted mortality of 20% to 25% based on the ISS of their cohort alone. They suggest that compartment syndrome of the thigh increased the mortality that could be anticipated by ISS alone. A second large series by Mithofer et al. (23) of 28 patients further examined the mortality associated with acute thigh compartment syndromes and stratified these patients by ISS, thereby demonstrating that multiply injured patients (ISS $>$ 27) had a greater mortality (75%) than those with more focal injuries (ISS $<$ 27; 0%). This suggested that perhaps the compartment syndrome itself did not have a significant associated mortality. The current study of an even larger group of 30 patients with 40 thigh compartment syndromes supported Mithofer et al.'s findings. Our overall mortality was 23%, which is similar in these small patient numbers to the previously presented values. As described in the methods section, we set a threshold of ISS $\geq$ 25 to define a multiply injured casualty. In our series, mortality was 47% (7/15) in patients with ISS $\geq$ 25, and 0% (0/15) in patients with ISS $<$ 25 ($p = .006$). These are striking data that support a conclusion that mortality in patients with acute compartment syndrome of the thigh is related to the overall burden of trauma as presented previously (Table 2).

Diagnosis of compartment syndromes in an austere environment poses a particular challenge for the deployed surgeon. In the civilian setting, there may be an increased reliance on compartment measurement devices in patients who are obtunded or otherwise incapable of participating in a physical exam. In a deployed setting, these assets may not be readily available. The ability of successful clinical diagnosis of compartment syndrome in the deployed setting was studied by looking for instances of delayed fasciotomies required along the evacuation chain (26). These delayed fasciotomies were associated with greater mortality. The overall rate of delayed fasciotomy in this group of over 600 fasciotomies was 16%. Of note, none of the thigh fasciotomies in this study were found to have delayed or incomplete fasciotomy. This indicates that thigh compartment syndrome in the combat casualty may be more amenable to successful clinical diagnosis in the austere environment than acute compartment syndrome to other body regions.

TABLE 2 Comparison of published mortality rates of thigh compartment syndrome stratified by ISS

	ISS	Mortality Rate	Low ISS (<25, <27)	High ISS (≥25, >27)
Schwartz et al. (1) ($n = 17$)	32.5	47%	-	-
Masini et al. ($n = 30$)	24.3 ± 3.4	23%	0% (0/15)	47% (7/15)
Mithofer et al. (23) ($n = 28$)	11.9 ± 2.4	11%	0% (0/24)	75% (3/4)

One associated injury entity common in our population and not seen in other groups of thigh compartment syndromes previously studied is the severe burn patient. Burns are common in combat casualties with blast mechanisms. As an associated injury, it is possible that burns are more severe than other mechanisms seen commonly in civilian trauma not only because of the tissue damage, which can be widespread and affecting multiple organ systems, but also because the metabolic effects can be as equally difficult to manage as the tissue injuries. In the group of patients who did not survive their injuries, the average TBSA burned was 70%. In the six service members who were burned but survived their wounds, the average TBSA was 45%.

Fractures are common in high-energy trauma, and ipsilateral femur fractures are frequently implicated in the development of thigh compartment syndromes. However, as described in previous studies, femur fracture is not a prerequisite for development of compartment syndrome. Ipsilateral femur fracture was common in our patients, with 23% of the 40 thigh compartment syndromes having an associated fracture; however, it did not appear to be a significant factor in patient mortality because none of the eight service members with ipsilateral femur fracture died of their wounds. It is interesting to note that the average ISS of the patients with femur fracture (20) was lower than the ISS of patients without femur fracture (25).

The ability to analyze our outcome measurements is diminished by the overall low response rate. Of the 23 service members who survived their injuries, we were able to contact 13. One service member declined to participate in the study. One service member had a severe traumatic brain injury and could not participate in the study. Two additional soldiers were located but were

not able to be contacted because of continued military service and deployment. Nine members of the cohort did not have valid forwarding phone numbers, addresses, or other contact information available after their discharge from military service. The small numbers only allow for descriptive statistical analysis.

The main limitation of this study is its retrospective nature, which is further limited by data collection in the combat environment. In all cases, diagnosis of compartment syndrome was based on clinical findings made by different surgeons, introducing a source of variability that could not be controlled. In the analysis of multiply injured patients, additional details of patient care and treatment decisions would have been beneficial. There were also significant limitations in the collection of outcome data. There was significant loss to follow-up in this group and it is possible that the limitation in our ability to contact a large number of subjects who left military service soon after their injuries resulted in the selection of a more disabled population. The greater the injury burden, the greater was the likelihood that the service member sought disability benefits, thereby remaining in the military health care system and having available updated contact information. The injury mechanisms are novel to the deployed military environment and generalization of these findings to a civilian practice may be limited. Strengths of the study include number of subjects representing the largest cohort of thigh compartment syndromes currently in the literature. This allowed additional evaluation of subgroups such as burns, ipsilateral fractures, and bilateral injuries.

In conclusion, this paper supports the concepts that compartment syndrome of the thigh is a common entity in the deployed environment and that associated injuries, particularly burns, are more predictive of patient mortality than presence or absence of thigh compartment syndrome alone.

Acknowledgments

The authors acknowledge the Joint Theater Trauma Registry (JTTR) for providing data for this study as well as MAJ Amber Ritenour for her work in compiling the combat fasciotomy database.

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APPENDIX: Compartment Syndrome and Fasciotomy Patient Questionnaire

Subject name: _____ SSN#_____
Date: _____

Investigator name: _____

A fasciotomy is a long incision made down your arms or legs to release pressure from swelling muscles.

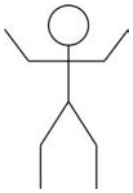
1. Which ones of your limbs had a fasciotomy performed?:

RUE LUE RLE LLE

2. Did you have an infection at the site of your fasciotomy?
RUE- Y / N / NA
LUE- Y / N / NA
RLE- Y / N / NA
LLE- Y / N / NA

3. Did you have any amputations of the affected limb(s)?
RUE- Y / N
LUE- Y / N
RLE- Y / N
LLE- Y / N

Please mark the level of your amputation on the diagram below.



R L

4. How was the fasciotomy site closed?
Primarily (skin edge to skin edge with stitches alone)
Y / N comment _____
With skin graft (skin from another part of your body)
Y / N comment _____
By Secondary intention (daily dressing changes to allow wound to fill in by scar tissue)
Y / N comment _____
Other (e.g. muscle flap, synthetic skin)
Y / N comment _____

5. On the limb with the compartment syndrome and fasciotomy site do you experience
decreased sensation? Y / N comment _____
decreased motor function? Y / N comment _____

6. At the site of the fasciotomy site do you experience
decreased sensation? Y / N comment _____
tethered tendons (scarring of tendons to skin)? Y / N comment _____
recurrent ulceration (recurring wounds)? Y / N comment _____
fascial herniations (muscle bulging out)? Y / N comment _____
dry skin? Y / N comment _____
pruritus (itchy skin)? Y / N comment _____
discolored wounds? Y / N comment _____
swollen limbs? Y / N comment _____