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Clinical and functional outcomes of acute lower extremity compartment syndrome at a Major Trauma Hospital

Loreto Lollo, Andreas Grabinsky

Department of Anesthesiology and Pain Medicine, University of Washington, Seattle, WA, USA

Address for correspondence:
Dr. Loreto Lollo,
Department of Anesthesiology and Pain Medicine, University of Washington, Box 356540, 1959 NE Pacific Street, BB-1469, Seattle, WA 98195-6540, USA.
E-mail: lollomd@uw.edu

ABSTRACT

Background: Acute lower extremity compartment syndrome (CS) is a condition that untreated causes irreversible nerve and muscle ischemia. Treatment by decompression fasciotomy without delay prevents permanent disability. The use of intracompartmental pressure (iCP) measurement in uncertain situations aids in diagnosis of severe leg pain. As an infrequent complication of lower extremity trauma, consequences of CS include chronic pain, nerve injury, and contractures. The purpose of this study was to observe the clinical and functional outcomes for patients with lower extremity CS after fasciotomy.

Methods: Retrospective chart analysis for patients with a discharge diagnosis of CS was performed. Physical demographics, employment status, activity at time of injury, injury severity score, fracture types, pain scores, hours to fasciotomy, iCP, serum creatine kinase levels, wound treatment regimen, length of hospital stay, and discharge facility were collected. Lower extremity neurologic examination, pain scores, orthopedic complications, and employment status at 30 days and 12 months after discharge were noted.

Results: One hundred twenty-four patients were enrolled in this study. One hundred and eight patients were assessed at 12 months. Eighty-one percent were male. Motorized vehicles caused 51% of injuries in males. Forty-one percent of injuries were tibia fractures. Acute kidney injury occurred in 2.4%. Mean peak serum creatine kinase levels were 58,600 units/ml. Gauze dressing was used in 78.9% of nonfracture patients and negative pressure wound vacuum therapy in 78.2% of fracture patients. About 21.6% of patients with CS had prior surgery. Nearly 12.9% of patients required leg amputation. Around 81.8% of amputees were male. Sixty-seven percent of amputees had associated vascular injuries. Foot numbness occurred in 20.5% of patients and drop foot palsy in 18.2%. Osteomyelitis developed in 10.2% of patients and fracture nonunion in 6.8%. About 14.7% of patients underwent further orthopedic surgery. At long-term follow-up, 10.2% of patients reported moderate lower extremity pain and 69.2% had returned to work.

Conclusion: Escalation in leg pain and changes in sensation are the cardinal signs for CS rather than reliance on assessing for firm compartments and pressures. The severity of nerve injury worsens with the delay in performing fasciotomy. Standardized diagnostic protocols and wound treatment strategies will result in improved outcomes from this complication.

Key Words: Amputation, chronic pain, compartment syndrome, injury severity score, negative pressure wound therapy, peroneal nerve paralysis, return to work, skin transplantation, tibial fractures

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INTRODUCTION

Lower extremity compartment syndrome (CS) is characterized by severe pain resulting from increased interstitial pressure within the closed compartments of the calf musculature that impairs local circulation and left untreated results in irreversible peripheral nerve and muscle ischemia.[1] CS can occur in other anatomic regions including the arm, hand, foot, and gluteal area and is an infrequent complication of severe tissue trauma including fracture and crush injury, but it has been associated with minor injuries and uncommon iatrogenic causes have also been identified.[2] Acute CS is a true surgical emergency that must be treated by decompression fasciotomy (DF) without delay to prevent permanent disability, amputation, and death.[3] The diagnosis of acute CS is based on careful clinical examination. Intracompartmental pressure (iCP) measurement, and monitoring if indicated, is a recommended clinical practice in uncertain diagnostic situations.[4] Values of iCP > 30 mmHg above diastolic blood pressure are an absolute indication for emergent DF.[4]

Acute CS following lower extremity trauma is an infrequent complication with many functional consequences that have significant impact on patient quality of life.[5] Persistent lower extremity pain is one of the more common long-term outcomes. In the first few months after clinical presentation, ischemia to the extremity caused by CS leads to fibrotic contracture with deformity and pain from nerve compression.[6] Long-term outcome studies have reported persistent lower extremity pain post-DF, but there is little specific data concerning the degree of pain, clinical and neurologic changes as a result of CS, and functional outcomes following recovery from this condition.[7]

This study is a retrospective chart review of the clinical, neurologic, degree of pain, and functional status with respect to return to work, of patients presenting with acute nontraumatic and traumatic lower extremity CS that required DF. A review of emerging diagnostic, interventional, and prognostic strategies aimed at improving patient care following this complication is included.

METHODS

The Institutional Review Board approval was granted from the University of Washington Human Subjects Division for this retrospective chart review of patients admitted to Harborview Medical Center during the 5-year interval between 2007 and 2011 that either presented with or later developed during their hospital stay, acute lower extremity CS that required DF. Exclusion criteria for this study were age below 18 years.

Patient admission demographic data included age, gender, body mass index, the American Society of Anesthesiology (ASA) physical status score, substance use, toxicology screen results, traumatic and nontraumatic injury, mechanism of injury, injury severity score (ISS), anatomic fracture locations and classification, occupation, and year of admission.

Criteria for the diagnosis of CS were based on serial periodic examination that included increasing changes in lower extremity compartment tension assessed by senior orthopedic residents and escalating pain symptomatology in patients who were able to cooperate with the examination. Diagnosis of CS in nonverbal patients as a result of preexisting aphasic conditions, injury, sedation, or mechanical ventilation was established by the same interval examination of lower extremity compartment tension. iCPs were measured in either verbal and noncommunicating patients when equivocal or conflicting findings presented themselves during the physical examination or history taking.

Patients diagnosed with CS upon admission or during hospital admission had perioperative data recorded that included maximum pain score prior to DF, time interval in hours between maximum pain score and DF incision, i*CP* values prior to DF, peak creatinine kinase (CK) levels in units/ml, associated lower extremity vascular injuries, prophylactic DF at the time of initial surgery for suspected or clinically diagnosed CS, development of CS following prior lower extremity surgical interventions, type and location of DF incisions, initial wound management therapy, and final DF wound closure technique. Patient inability to self-report pain scores due to sedation, mental status changes from intoxication or head injury, and mechanical ventilation was also recorded.

Lower extremity DF was performed with a double incision technique to release and examine all four compartments and debride any necrotic muscle if present. DF of the anterior and posterior thigh compartments was performed with a single lateral incision technique. All wounds were left open and either gauze dressing or negative pressure wound vacuum-assisted closure (VAC) therapy was applied to the incisional areas.

Patient outcome data collected included the final discharge disposition, number of days in hospital length of hospital stay (LOS), delayed postoperative wound infection, subsequent orthopedic interventions on the affected extremity following hospital discharge, neurologic evaluation of the affected lower extremity at the time of discharge from the follow-up clinic, and the maximum pain score at 30 days after DF. Long-term outcome data collected at 1 year after DF were maximum pain score, average 24 h cumulative opioid analgesic medication dosage, and occupational status.

Other information collected from patients included hemodialysis during hospital admission and preadmission use of anticoagulants. Pain scores were self-reported by patients and recorded by nursing staff on the 10-point scale used institution-wide by all departments. Opioid analgesic dosages were converted to mg of intravenous morphine by way of a standard calculator used throughout the hospital system. The data items that were used and collected from the chart review are summarized in Table 1.

Table 1: Data collection points for compartment syndrome patients

Item	Notes recorded from chart
Admission data	
Age	Years
Gender	Male/female
Body mass index	Percent
ASA physical status	1/2/3/4/5 and E if applicable
Nicotine use	Active (packs per day)/former (pack years)
Ethanol use	None/occasional/daily/abuse
Illicit drug use	Type/current/active/former
Diabetic	Yes/no
Urine toxicology screen/ blood alcohol	Quantitative drug detection
Injury	Trauma/nontrauma
Injury severity score	ISS
Injury mechanism	Ballistic/blunt/crush/traffic/other
Fracture type	None/open/closed/location/multiple
Occupation	Employed/retired/unemployed/disabled
Year of hospital admission	2007-2011
Perioperative data	
Peak preoperative pain score	10 maximum/sedated/obtunded/ intubated
Hours from peak pain score to fasciotomy incision	Hours
Vascular injury and repair	Preexisting/none/yes/type of repair
Prophylactic fasciotomy	Absence of diagnosed compartment syndrome
Postoperative compartment syndrome	Previous surgical procedure performed
Intra-compartmental pressures (mmHg)	Lateral/anterior/posterior/deep posterior
Fasciotomy procedure type	Thigh/calf/number and location of compartments
Peak serum creatine kinase level	Units/ml and hours from fasciotomy
Wound closure type	Primary/gauze/vacuum assisted/ secondary
Wound disposition	Primary/delayed closure/skin graft/ amputation
Outcomes data	
Discharge disposition	Home/skilled nursing facility/death
Days in hospital	Days
Delayed postoperative wound infection	Type and culture results
Delayed postoperative orthopedic intervention	None/contracture release/nonunion/ amputation
Follow-up clinic lower extremity evaluation	No deficit/type of deficit if present
Peak pain score at 30 days postfasciotomy	10 maximum
Peak pain score at 12 months postfasciotomy	10 maximum
Opioid analgesic medication use at 12 months	Converted to mg intravenous morphine/24 h
Occupational status at 12 months	Employed/unemployed/disabled/retired
Other pertinent patient details or notes	Hemodialysis, anticoagulant use before admission

ASA: American Society of Anesthesiology, E: Emergency procedure

RESULTS

One hundred twenty-four patients met the criteria for this review, and Table 2 summarizes their admission demographics. There were five deaths during hospital admission and one death after discharge for an overall death rate of 4.8%. Motor vehicle collision was the cause of injury in four of the five hospital deaths. Motorcycle collision was the cause of injury in one patient who died in hospital and pedestrian struck by motor vehicle was the cause of injury in one patient who died during the follow-up observation period.

There were 11 patients (9.2%) lost to short-term follow-up at 30 days after hospital discharge and 13 patients (12%) were lost to long-term follow-up at 12 months. Short- and long-term follow-up data were available for 108 patients.

Nontraumatic lower extremity CS was diagnosed in 19 patients (15.3%). No females were observed in this group. Necrotizing fasciitis as a cause of lower extremity CS occurred in 7 patients (5.6%) and comprised 36.8% of the nontraumatic group. Peripheral vascular disease was the etiology for CS in 7 patients (5.6%) and equated with 36.8% of the nontraumatic group. Rhabdomyolysis from pressure decubiti as a cause of lower extremity CS was observed in 2 patients (1.6%) that comprised 10.5% of the nontraumatic group. Iatrogenic CS from prolonged placement in the lithotomy position was responsible for CS in 2 patients (1.6%) or 10.5% of the nontrauma group. Rupture of a Baker cyst from prolonged overuse was the etiology for CS in one patient in the nontrauma group.

The distribution by gender in the 105 patients with trauma associated lower extremity CS was 81% males and 19% females. Involvement of motorized craft as the mechanism of injury leading to CS was associated with 51% of males and 35% of females. Accidental falls that resulted in patients developing CS were present in 18.8% of males and 50% of females. Ballistic injury causing CS in this group of patients had a frequency of 10.5% in males and 10% in females.

The number of patients who developed acute CS was categorized by the specific fracture or nonfracture injuries sustained and the associated mechanism of harm responsible for hospital admission. The injury patterns and responsible mechanisms of injury are summarized in Table 3. Patients with isolated proximal tibia or tibia shaft fractures comprised 41.3% of the individuals who developed acute CS. All patients with fracture of the proximal tibia were noted to have a bicondylar type injury. Patients with fracture of the shaft of the tibia were noted to have open-type injuries in 45% of this group and closed comminuted injuries in the remaining 55%. In 54% of patients with isolated tibia plateau fracture, it was observed that this injury was sustained as a result of accidental falling. Pedestrian accidents were noted as the mechanism of injury in 50% of tibia shaft fractures. No female patients who developed CS had tibia shaft fracture either as an isolated injury or combined with other fracture types.

Patients with multiple fractures of the lower extremities who sustained CS comprised 18.4% of the group of 104 individuals. Male patients were the only gender observed within the combined pelvic and tibia shaft fracture group, the combined femur and tibia shaft fracture group, the combined proximal tibia and tibia shaft fracture group, and the combined tibia shaft and tibia plafond fracture group. Female patients were the only gender observed within the combined tibia plateau and tibia plafond fracture group.

Table 2: Causative etiology for admission in patients diagnosed with compartment syndrome

	Male	Female
Nontraumatic injury		
Number	19	0
Cellulitis/necrotizing fasciitis	7	
Peripheral vascular disease	7	
Entrapment/rhabdomyolysis	2	
Iatrogenic positioning	2	
Overuse syndrome	1	
Traumatic injury		
Number	85	20
Ballistic injury/gunshot wound	9	2
Minor fall (<10 feet)	16	10
Crush injury	7	1*
Motor vehicle collision	10	4
Motorcycle collision	12	1
Pedestrian	18	1
Bicycle (road/mountain)	4	1
ATV/off-road/watercraft accident	4	
Skiing/paragliding/skateboarding	5	
Total (*n*=124)	104	20

*Entrapment syndrome. ATV: All-terrain vehicles

Acute kidney injury (AKI) requiring hemodialysis occurred in three patients (2.4%). Renal failure in these patients was determined to be prerenal and was associated with prolonged entrapment in two cases and prolonged aortic cross-clamping with hypotension from aortic injury in the third patient.

Serum CK levels were measured in 43 cases (34.7%). Peak serum CK levels were recorded in a range from 192 to 144,000 units/ml. The mean peak serum CK level for the 3 patients who developed AKI was 58,600 units/ml. Serial CK levels were monitored in 21 patients (16.9%). Peak levels of serum CK in 17 of these patients were measured at a time interval from 6 to 48 h after DF. Levels of serum myoglobin (MB) were measured for 10 patients (8.1%) and peak levels ranged between 2 and 306,900 units/ml. There were 4 patients (3.2%) who had repeat CK and MB measurements. In 3 of these 4 patients, it was observed that peak MB levels occurred 6–24 h after the peak CK level was measured.

iCPs using a Stryker iCP monitor (Model 295-000-000, Stryker Surgical, USA) were measured in 17 of the 111 patients (15.3%) admitted with traumatic injury who were also diagnosed with CS during the hospital stay. Readings for iCP in the calf region were measured and recorded in the sequence of anterior, lateral, posterior, and deep posterior compartments. A complete series of measurements of iCP for all 4 compartments was recorded in 6 patients (5.4%). The ranges for iCP were 39–100 mmHg in lateral compartment, 31–140 mmHg in anterior compartment, 33–100 mmHg in posterior compartment, and 16–140 mmHg in deep posterior compartment.

Table 3: Injury classification and mechanism of injury in 104 patients with compartment syndrome

Mechanism of injury	Ballistic	Fall	Crush	MVC	MCC	Pedestrian	Bicycle	ATV	Skiing	Total
Nonfracture injury										
Vascular - no fracture	5			2		1				8
Nonvascular - no fracture	2	1		2						5
Fracture injury										
Pelvis/acetabulum/sacrum	1	1		1				1		4
Pelvis + tibia				1	2					3
Proximal femur	1			1						2
Femur shaft	1	2				2				5
Distal femur	1							1		2
Femur + tibia					3					3
Knee dislocation				1	2					3
Proximal tibia		14		1	3	2	2		1	23
Tibia shaft		2	4		1	10	2	1		20
Proximal tibia + shaft		1		2		3	1		2	9
Proximal tibia + plafond		2								2
Tibia shaft + metatarsals				1						1
Tibia plafond + shaft		1							1	2
Tibia Plafond (pilon)		2		2				1	1	6
Metatarsal/tarsal			2	1	2	1				6
Total	11	26	6	15	13	19	5	4	5	104

ATV includes watercraft and off road vehicle injuries, Skiing includes paragliding and skateboard injuries. MVC: Motor vehicle crashes, MCC: Motorcycle crash, ATV: All-terrain vehicles

The mean ISS, ASA physical status, pain score, and hours from peak self-reported pain score and surgical incision for DF for 111 patients classified by injury type are summarized in Table 4. Of the 111 patients observed in this group, 34 (30.6%) were either mechanically ventilated, sedated, or had altered levels of consciousness and were unable to report pain scores. There were 24 patients (21.6%) who had sustained a previous operative procedure before the onset of CS and required further surgery for DF. Within this group of 24 patients who required reoperation for DF, 18 had undergone orthopedic fracture fixation and 6 had previous vascular repair or bypass as part of the treatment for their injuries.

The methods of surgical wound care following DF and definitive incision closure are summarized in Table 5. Gauze dressing of DF surgical wounds was used in 15 (78.9%) of the nonfracture patients and 18 (16.3%) of the fracture patients. Negative pressure wound VAC therapy was used in 4 (21%) of the nonfracture patients and 72 (78.2%) of the fracture patients. Delayed primary closure (DPC) of DF incisions was performed for 7 (38%) of the nonfracture patients and 48 (52.2%) of fracture patients. Split thickness skin graft (STSG) closure was used to cover DF incisions in 8 (42.1%) of nonfracture patients and 29 (27.2%) of fracture patients. There were 7 patients (8.2%) in the fracture group who underwent lower extremity amputation as definitive treatment for CS. These 7 patients accounted for all of the 3 accident victims in the combined pelvis and tibia fracture group, 2 in the tibia plateau fracture group, and one each in the multi-ligamentous knee dislocation group and the

Table 4: Preoperative admission data classified by injury pattern in 111 patients presenting with compartment syndrome

Injury classification (patients)	ASA	ISS	PS	Hours	Int	OR
Nonfracture injury (19)						
Vascular - no fracture (7)	3E	35 (21)	7	2.85 (2.37)	4	1
Nonvascular - no fracture (5)	2E	26 (6)	10	4.9 (2.81)	2	1
Infectious - necrotizing fasciitis (7)	3E	13 (4)	7 (4)	8.46 (6.68)	2	-
Fracture injury (92)						
Pelvis/acetabulum/sacrum (4)	2E	31	-	5.63	4	2
Pelvis + tibia (3)	3E	27	8	12.17	2	2
Proximal femur (2)	3E	34	9	6.73	1	-
Femur shaft (5)	2E	27 (18)	10 (1)	4.3 (2.18)	1	2
Distal femur (3)	3E	28	10	5.42	-	2
Femur + tibia (3)	3E	37	-	4.05	3	-
Knee dislocation (3)	1E	23	8	7.58	-	1
Proximal tibia (24)	2E	16 (6)	9 (2)	5.98 (3.87)	1	2
Tibia shaft (20)	2E	20 (9)	9 (2)	8.38 (4.75)	8	3
Proximal tibia + shaft (9)	3E	22 (11)	8 (2)	6.94 (6.87)	3	1
Proximal tibia + plafond (2)	3E	9	9	4.88	-	1
Tibia plafond + shaft (2)	1E	13	6	4.63	1	-
Tibia plafond (pilon) (6)	2E	17 (5)	10 (1)	10.63 (7.16)	-	4
Metatarsal/tarsal (6)	2E	21 (10)	10	7.71 (5.09)	2	2

ASA physical status score, Preoperative ISS, PS: Pain score, Hrs: Hours elapsed between maximum pain score and decompression fasciotomy, OR: Patients with prior operative intervention, Int: Patients with altered consciousness, ASA: American Society of Anesthesiology, ISS: Injury severity score

Table 5: Postoperative wound management and discharge wound status following fasciotomy classified by injury pattern in 111 patients

Injury classification (patients)	PC flap	Gauze	VAC	DPC	CSI	STSG	Amp	Death
Nonfracture injury (19)								
Vascular - no fracture (7)	-	6	1	3	-	2	-	2
Nonvascular - no fracture (5)	-	2	3	3	-	2	-	-
Infectious - necrotizing fasciitis (7)	-	7	-	1	2	4	-	-
Fracture injury (92)								
Pelvis/acetabulum/sacrum (4)	-	3	1	2	-	2	-	-
Pelvis + tibia (3)	-	3	-	-	-	-	3	-
Proximal femur (2)	-	1	1	1	-	1	-	-
Femur shaft (5)	-	2	3	3	-	1	-	1
Distal femur (3)	-	-	3	2	-	1	-	-
Femur + Tibia (3)	-	-	3	1	-	-	1	1
Knee dislocation (3)	-	3	-	1	-	1	1	-
Proximal tibia (24)	1	-	22	16	-	3	2	-
Tibia shaft (20)	-	1	19	10	-	10	-	-
Proximal tibia + shaft (9)	-	1	8	2	-	7	-	-
Proximal tibia + plafond 2)	1	-	1	1	-	-	-	-
Tibia plafond + shaft (2)	-	-	2	2	-	-	-	-
Tibia plafond (pilon) (6)	-	-	6	4	-	2	-	-
Metatarsal/tarsal (6)	-	3	3	4	-	2	-	-

PC flap: Primary wound closure or immediate flap closure, Gauze: Kerlix gauze dressing, VAC: Negative pressure wound vacuum therapy, DPC: Delayed primary closure, CSI: Closure by secondary intention, STSG: Split thickness skin grafting, Amp: Amputation combined tibia plateau and plafond fracture group. There were no patients in the nonfracture trauma group who required lower extremity amputation for treatment of CS. In the nontrauma CS group, 6 of the 7 patients (85.7%) with vascular disease required subsequent amputation.

Amputation was performed in 11 of the fracture group patients (12.9%), either during hospital admission (8.2%) or during the 1-year follow-up interval (4.7%). There were 9 male patients in the amputation group (81.8%). Vascular injury necessitating vessel bypass or repair was associated with 4 patients and acute vascular disruption was present in 2 patients. Male patients represented 5 of the 6 patients requiring lower extremity amputation for associated traumatic vascular insufficiency. Lower extremity amputation was carried out in 4 patients (4.5%) with intractable pain from joint contracture in the 12-month period following the original injury. Fracture of the tibia plateau as the original injury was present in two cases and either fracture of the tibia shaft or of the tibia plafond was observed in the remaining two subjects.

The mean LOS classified by injury pattern associated with CS is presented in Table 6 and ranged from a low of 7 days to a maximum of 48.7 days. The number of patients discharged to either home or to special nursing facilities and the employment status at long-term follow-up evaluation are also summarized in Table 6. The employment status rates before hospital admission and at 12 months following hospital discharge are presented in Table 7. All of the members of the group of 7 patients who sustained pelvic fracture either as an isolated injury or in combination with other lower extremity fracture and the group of 3 patients with multi-ligamentous knee dislocation returned to work. Both of the 2 patients with femur fracture in combination with tibia shaft fracture were disabled at the time of long-term follow-up.

The clinical follow-up data at 12 months after hospital discharge for 105 patients categorized by injury pattern with respect to neurologic deficits of the lower extremity, infection, and need for further operative procedures are summarized in Table 8. Numbness of the superficial peroneal nerve (SPN) distribution was noted in 18 fracture patients (20.5%) and drop foot palsy was observed in 16 patients (18.2%) in this group. Direct injury of the sciatic or tibial nerve as a cause of drop foot was diagnosed on admission in 2 of the 16 patients with palsy. The mean time interval to DF for 5 patients with proximal tibia fracture who were discharged with foot numbness was 5.36 h. The mean time interval to DF for 5 patients with proximal tibia fracture discharged with foot drop was 7.25 h. The mean time interval to DF for 3 patients with tibia shaft fracture discharged with foot numbness was 7.73 h. The mean time interval to DF for 3 patients with tibia shaft fracture discharged with foot drop was 10.3 h.

Osteomyelitis developed in 9 patients (10.2%) within the fracture group. There were 16 patients (18.2%) who underwent more surgical procedures on the affected lower extremity. Nonunion of fracture requiring further operative fixation occurred in 6 patients (6.8%). Osteomyelitis was associated with 5 of the 6 patients that developed nonunion of fracture. The original injury in the 6 patients with nonunion of fracture was tibia shaft fracture in 3 cases, tibia pilon fracture in 2 subjects, and one patient with tibia plateau fracture. Cigarette smoking was observed in two patients within the group with osteomyelitis and nonunion of fracture.

Table 6: Mean number of days of hospital admission, discharge and employment disposition following fasciotomy classified by injury pattern in 111 patients

Injury classification (patients)	Days	Home	Rehab	Death	SSI	Unemp	RTW
Nonfracture injury (19)							
Vascular - no fracture (7)	13.5	5	-	2	1	2	2
Nonvascular - no fracture (5)	33.2	3	2	-	3	1	1
Infectious - necrotizing fasciitis (7)	26.3	4	3	-	1	5	1
Fracture injury (92)							
Pelvis/acetabulum/sacrum (4)	33.3	2	2	-	-	-	4
Pelvis + tibia (3)	48.7	1	2	-	1	-	2
Proximal femur (2)	21.5	2	-	-	-	2	-
Femur shaft (5)	10.6	3	1	1	1	2	1
Distal femur (3)	19.3	1	2	-	1	1	1
Femur + tibia (3)	36	--	2	1	2	-	-
Knee dislocation (3)	13	3	-	-	-	-	3
Proximal tibia (24)	17.4	16	7	1	7	6	10
Tibia shaft (20)	17.4	14	6	-	7	5	8
Proximal tibia + shaft (9)	19.2	7	1	1	2	-	6
Proximal tibia + plafond (2)	7	1	1	-	2	-	-
Tibia plafond + shaft (2)	9	2	-	-	-	-	2
Tibia plafond (pilon) (6)	20.3	4	2	-	-	2	4
Metatarsal/tarsal (6)	12	5	1	-	2	2	2

Rehab: Skilled nursing facility, SSI: Patients unable to return to work deemed disabled or voluntarily retired from employment, Unemp: Patients able to work but not employed, RTW: Return to work

Heterotopic ossification (HO) requiring operative resection occurred in 4 patients (4.5%). One of the patients with HO had a below knee amputation from ligamentous knee dislocation and the others had fracture of the acetabulum, subtrochanteric femur, and femur shaft. Cigarette smoking was reported for 2 of the patients in this group.

Gastrocnemius equinus contracture resulting from drop foot palsy that subsequently required tendon release was recorded in three patients (3.4%) at the time of their long-term follow-up visit. The sciatic nerve had been transected as a result of injury in two of these patients who had sustained a femur shaft fracture in one case and fracture of the tibia shaft in the other. The remaining patient had a crush injury to the foot at the time of initial presentation. One patient required knee ligament reconstruction after recovering from the initial fracture of the tibia shaft.

DISCUSSION

This study encountered several limitations including lack of adequate documentation of all the relevant parameters for patients during their hospital stay and at the time of follow-up clinic appointments. Nonverbal patients either as a result of trauma, head injury, and sedation or ventilator dependence presented challenges in assessment for the diagnosis of CS.

Outcomes data were incomplete for some patients as a result of loss to follow-up because of geographic distance from the trauma center and healthcare insurance policy coverages preventing further contact with patients after discharge. The variety of injuries led to the formation of multiple small patient group subsets that did not permit statistical analysis of any observed results other than demographic patterns. The wide variability in the patient care observed in this study supports the notion that a consensus for the diagnosis, treatment, and subsequent wound management of acute CS is lacking.[8]

Injury patterns in the trauma group differed between male and female patients who presented with or later developed CS during hospital admission. All patients admitted with a combination of tibia plateau and shaft fractures were male. The combination of tibia plateau and plafond/pilon fractures was present in female patients only. Ligamentous knee dislocation was an injury noted to occur only in male patients. All males over age 50 with ISS > 40 expired during hospital admission. There were no other observed associations between injury pattern, ISS, maximal preoperative pain score, and hours to DF. The activity and impact velocity causing the injury and fracture pattern could be a significant factor that influenced the gender-specific grouping of injuries observed. Male gender as a predictor of acute CS following tibia shaft fracture has been previously reported.[9]

Table 7: Preadmission and 12 months postdischarge employment status for 105 patients diagnosed and treated for lower extremity compartment syndrome

Employment classification	Preadmission	12 months
Nontrauma (*n* = 18)		
Unemployed	3 (2.9)	6 (5.7)
Disabled/retired	9 (8.6)	9 (8.6)
Employed	6 (5.7)	3 (2.9)
Trauma (*n* = 87)		
Unemployed	7 (6.7)	14 (13.3)
Disabled/retired	15 (14.3)	28 (26.7)
Employed	65 (61.9)	45 (42.9)
Total	105	105

Numbers in parentheses are percentages (%)

Table 8: Neurologic and clinical outcomes of 105 patients classified by injury type at 1 month and the 12 month intervals following fasciotomy for compartment syndrome

Injury classification (patients)	Numb	Palsy	Amp	PS-1	PS-12	Inf	Correct
Nonfracture injury (17)							
Vascular - no fracture (5)	-	1	-	6	1	-	-
Nonvascular - no fracture (5)	-	1	-	7	2	-	-
Infectious - necrotizing fasciitis (7)	1	1	-	5	4	1	-
Fracture injury (88)							
Pelvis/acetabulum/sacrum (4)	2	1	-	6	5	1	-
Pelvis + tibia (3)	-	-	3	5	4	-	2
Proximal femur (2)	-	1	-	7	6	1	1
Femur shaft (4)	-	1	-	7	4	-	1
Distal femur (3)	1	1	-	5	0	-	-
Femur + tibia (2)	-	1	1	5	3	-	-
Knee dislocation (3)	-	1	1	3	0	-	1
Proximal tibia (24)	5	5	4	4	2	4	1
Tibia shaft (20)	3	3	1	5	3	2	6
Proximal tibia + shaft (7)	1	1	-	4	2	-	-
Proximal tibia + plafond (2)	-	-	-	1	1	-	-
Tibia plafond + shaft (2)	1	-	-	2	0	-	1
Tibia plafond (pilon) (6)	3	1	1	4	3	1	1
Metatarsal/tarsal (6)	2	-	-	3	1	-	2

Numb: Peroneal/tibial nerve numbness, Palsy: Peroneal/tibia nerve weakness, Amp: Delayed amputation, Mean pain score (maximum 10) at 1 month (PS-1) and 12 months (PS-12) follow-up clinic appointments, Op: 24 opioid dosage converted to mg intravenous morphine, Inf: Postoperative infection, Correct: Need for further orthopedic and plastic corrective or reconstructive surgery, PS: Pain score

AKI following rhabdomyolysis in the setting of acute traumatic lower extremity CS has been reported to be near 40%.[10] The incidence of AKI following CS in the trauma group was 2.4%. Rhabdomyolysis could have contributed to the onset of this complication but prolonged impaired renal perfusion from hypovolemia and aortic cross-clamping and hypotension played significant roles in the 3 patients reported. Recognition of AKI resulting from CS and carefully planned fluid management aid to reduce the frequency of this complication.[11]

Serum CK and MB levels were neither universally nor serially measured in the patients who developed CS. The results observed in the patients with measured levels of serum CK and MB demonstrated wide variability in absolute peak levels and the times at which the maximum peak levels occurred. A predictive formula for CS using serum CK levels above 4000 units/ml, serum chloride ion level >104 mg/dl, and blood urea nitrogen <10 mg/dl was found to be 100% accurate in a retrospective study.[12] The serum CK level is an adjunct to the clinical diagnosis of CS and minimal time to DF once the condition is diagnosed is the predictor of better functional outcomes.[13] The increase in serum CK levels in the hours observed after DF might indicate improvement in muscle perfusion and subsequent leaching of the enzyme from dead myocytes into the circulation rather than a marker for continuing muscle ischemia. This phenomenon has been observed following reperfusion of acute ischemia of the lower extremity.[14]

Measurement of iCP was also neither universally nor serially obtained in all patients suspected of developing CS. Preoperative measurement of iCP was performed only in cases of equivocal physical findings and lack of cooperation due to patient inability to communicate as a result of sedation, mechanical ventilation, associated head injury, and either trauma-related or preexisting mental status changes. Wide variability in the ranges of pressures measured and the small sample size of recorded observations prevent any conclusions to be drawn from this diagnostic and monitoring technique. Continuous iCP monitoring is recommended in equivocal cases but this procedure is vulnerable to technical error.[15]

Patients capable of self-reporting symptoms voiced increasing lower extremity pain in the presence of soft compartments on clinical examination hours before the clinical alarm for CS was raised. The time interval from maximum pain scores to DF incision for CS ranged from a minimum of under 3 h for patients with vascular injuries without associated fracture to a maximum of 12 h in patients with combined pelvic and tibia shaft fracture. The escalation in pain and changes in sensation that patients report in the injured lower extremity should be considered the cardinal signs for CS and lower the threshold for its diagnosis rather than reliance on assessing for firm compartments and elevations in iCP.[16] A combination of three or more of the cardinal signs for CS (pain, pallor, paresthesia, pulselessness, and paresis) has low sensitivity and high specificity for establishing the diagnosis, but has a poor predictive value and is also found in acute arterial injury and later stages in the clinical course of CS.[17] The absolute iC*P* value of 30 mmHg is considered the threshold for diagnosis of CS and emergent DF is indicated at this point, but absolute values are quite variable and the difference between the diastolic blood pressure and iCP of <30 mmHg in an unanesthetized patient is considered a superior diagnostic indicator.[17] Noninvasive methods are being perfected that allow rapid and accurate evaluation of compartment tissue perfusion that includes near-infrared absorption, ultrasound measurement of tissue elastance, and muscle glucose concentration but these are not surrogates for careful clinical assessment.[18-20]

The incisional wound therapy and closure techniques following DF differed between the nonfracture and fracture injury groups. Wound VAC therapy and DPC were more frequently used for the fracture patients (50.6%). The use of gauze dressings and STSG was more common among the nonfracture patients (21%). This difference in wound care could be associated with the observation that 14 of the 19 nonfracture patients (73.9%) were primarily cared for by general and vascular surgeons and the DF incisions in fracture patients were exclusively managed by orthopedic surgeons. This variability in wound therapy and closure regimens for DF incisions associated with the surgical specialty caring for the patient supports similar reported observations.[21] Wound VAC therapy has become a widely accepted technique for assistance in the closure of large open wounds but data on its efficacy and reports of associated muscle fiber degeneration in animal models warrant further validation of this treatment.[22,23] Presentation of CS following fracture leads to prolonged LOS and early use of SG for wound closure in contrast to serial repeat debridement to achieve DPC can shorten LOS although the functional and aesthetic results are less satisfying for patients.[24,25] The observed 8.2% rate of amputation following CS during hospital admission and the high rates of association with male gender and concomitant vascular injury are similar to the 10% rate reported in a meta-analysis study.[26]

There was no association found between LOS and ISS, fracture or nonfracture injury or wound therapy and closure regimen in patients with CS. Analysis of the gender and age distribution of ISS severity and the associated mechanism of injury has demonstrated that fracture as part of the injury pattern prolongs LOS.[27] It has been reported that LOS is dependent on factors not adequately described by the ISS and a more detailed organ system classification and scoring system such as the ICD-9 ISS is required to demonstrate particular links between specific injury patterns and prognosis and outcomes.[28]

Delay in the recognition and treatment of CS leads to the development of nerve injury.[3] Nerve damage resulting from CS most frequently involves the SPN leading to numbness in the area of the dorsum of the foot, and injury to the deep peroneal nerve (DPN) which leads to drop foot palsy and contractures. The results of this study support the finding that the severity of nerve injury progressively worsens with the delay in performing DF. Foot numbness from SPN damage was more commonly found after earlier DF. Foot drop from DPN injury occurred as a result of increased time to surgical intervention for CS. The establishment of standardized algorithms for the monitoring, diagnosis, and treatment of patients at risk for developing CS to avoid and minimize long-term morbidities has been recommended.[29] Lower extremity CS patients underwent incisional release of all four compartments during the initial DF procedure. Patients with thigh CS underwent release of both the anterior and posterior compartments. Repeat DF or extension of prior incisions did not occur in any patient.

Preexisting microvascular disease as a result of diabetes or cigarette smoking predisposes patients to more severe nerve damage and worse outcomes resulting from ischemic or other forms of injury.[30] Cigarette smoking is associated with higher rates of osteomyelitis and nonunion of fracture.[31] Cigarette smoking rates were elevated in the osteomyelitis and HO groups in this study, but diabetes was not observed to be a risk factor for delayed complications or surgery including amputation.

In this study, there were 10.2% of patients reporting elevated pain scores of 4 or higher at 1 year follow-up evaluation. These patients were all in the groups with pelvic and proximal femur fractures. The rate of patients reporting pain related to DF scars at long-term follow-up has been reported at 10%.[32] Strategies aimed at reducing the incidence of chronic pain resulting from DF include earlier operative intervention to treat CS and limiting delays in wound closure.[33] There were no associations observed between hours to fasciotomy, pain scores, opioid analgesic consumption rates, or return to work status at the 12-month clinic follow-up appointment.

Return to work was observed in 69.2% of those patients previously employed before hospital admission. Data concerning rates for return to work for acute CS are not readily available. In the case of chronic exertional CS, the rates for return to full duty and activity following DF are 41% in the military population and 81% in athletes.[33-35]

CONCLUSION

Acute CS is a surgical emergency. Severe lower extremity pain is the cardinal symptom and an early high index of suspicion for this condition should be maintained when patients report escalation in lower extremity pain or changes in sensation. Vigilant clinical assessment, close monitoring for the evolution of acute CS, and prompt intervention are necessary to avoid disastrous neurologic and functional outcomes. Peroneal nerve injury resulting from CS is progressive over time and delay in preforming DF converts a numb foot into a paralyzed extremity. Future interventions aimed at more rapid and standardized diagnostic algorithms for identifying acute CS and improved specific fasciotomy wound treatment strategies will result in improved outcomes and decreased LOS from this complication.

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Conflicts of interest

There are no conflicts of interest.

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