Acute Compartment Syndrome Cliff

Branch Baseline

Acute compartment syndrome is a potentially devastating condition in which the pressure within an osteofascial compartment rises to a level that decreases the perfusion gradient across tissue capillary beds, leading to cellular anoxia, muscle ischemia, and death. A variety of injuries and medical conditions may initiate acute compartment syndrome, including fractures, contusions, bleeding disorders, burns, trauma, postischemic swelling, and gunshot wounds (Olson, 2005)

The Skin may also act as a restricting membrane in certain circumstances (Parks, 2011). Common areas where acute compartment syndrome occurs are the lower leg, forearm, foot, hand, the gluteal region, and the thigh (Parks, 2011).

Incidence Data Included in the Model

The model imports the following incidence information from the IMM database: incidence data category, space adaption status, incidence data, incidence and occurrence distribution data and incidence data characteristics. Data category defines the type of data available for incidence calculations (i.e. raw data vs. fixed data). Space adaptation identifies medical events that onset occurs in the first 5 days of flight and does not reoccur. Incidence values vary by data category and define the number of medical events per person-year or medical events per person-at-risk for each medical condition. Incidence values can be modified by crew characteristics such as gender. Modifying characteristics are noted below and incidence values are listed individually for each characteristic. Distributions are assigned to medical events incidence values and occurrences in the model. For each crew member in a given trial, the incidence and number of occurrences of each medical condition are randomly selected from these probability distributions. Detailed descriptions of the distributions are included in the IMM Technical Description Document.

Incidence	
Data Category:	Fixed
Space Adaptation:	No
Incidence Type:	Rate

Distribution Data	
Incidence:	Fixed
Occurrence:	Poisson

Female Data Characteristics	
Fixed Rate:	7E-06

Male Data Characteristics	
Fixed Rate:	7.3E-05

Incidence Comments

Compartment syndrome has never been reported on space flight. Lacking phenomenological data, IMM is using terrestrial data for the model incidence. Data was collected in an Orthopedic Trauma Unit in Scotland between 1988 and 1995. This unit serves a population of 650,000. Acute compartment syndrome was diagnosed clinically or by monitoring of compartment pressure. The threshold for fasciotomy was nominated as a differential pressure of less than 30 mmHg between the tissue pressure and diastolic blood pressure (McQueen, 2000).

There were 164 patients with acute compartment syndrome, 149 men and 15 women, with a mean age of 32 years (14 to 88). The mean age for men was 30 years and for women, 44 years. The average incidence was **0.000073** (7.3 per 100,000) for men and **0.000007** (0.7 per 100,000) for women, in events per person year. The primary condition causing acute compartment syndrome was a fracture, which occurred in 113 patients (69%). The two most common were of the diaphysis of the tibia in 59 patients (36%) and of the distal radius in 16 (9.8%). Injury to the soft tissues without a fracture occurred in 38 patients (23.2%). Of note the incidence in those over 35 years of age decreased threefold for fractures of the tibial diaphysis and 30-fold for fractures of the distal radius (McQueen, 2000).

Information Regarding Prevention

Selection criteria

Disqualifying criteria in the musculoskeletal area include: Traumatic, inflammatory, degenerative, congenital (or hereditary) and metabolic disorders, or disease of any bone, joint, muscle or supporting structure that interferes with the performance of duties; chronic arthritis with functional disability that interferes with the performance of duties; active infections of bone, joint, muscle or tendon (e.g. osteomyelitis, soft tissue infections and septic arthritis); presence or history of musculoskeletal malignancy; benign tumors or cysts, single or multiple, sufficiently large to interfere with performance of duties, or to create a fracture potential; osteochondromatosis or multiple cartilaginous exostoses that interfere with performance of duties; joint instability (recurrent subluxations or dislocations of an articulation); intra-articular loose bodies in any joint (osteocartilaginous or metallic foreign objects) that interfere with performance of duties; Non-union of fractures; Mal-union of fractures that interferes with performance of duties. [International Space Station Program, 2009]

Special Consideration by the MSMB is required for history of osteomyelitis with no recurrence; History of osteochondromatosis or multiple cartilaginous exostoses that have been successfully surgically excised; History of joint instability that has been medically or surgically corrected; History of intra-articular loose bodies in any joint surgically removed with no residual dysfunction. Any fracture, in which hardware (e.g., rod, plate, pin or screw) was used for fixation, if the fixation devices remain in place, will require orthopedic consultation and Special Consideration by the MSMB. [International Space Station Program, 2009]

Other

NASA requirements and documents support safety first. However, injuries result from an accident and there are no real medical preventive measures available.

Incidence Level of Evidence (LOE)

The IMM level of evidence appropriate assessment of the quality of the IMM input data. Since IMM incorporates input data from a wide variety of sources including astronaut population, terrestrial or analog populations, and external models, an innovative approach to assess the quality of input data was required. Information obtained from the astronaut population and/or space flight is the more relevant so it is assigned the highest level of evidence and less relevant data sources are assigned a lower level of evidence.

Citation	LOE Value	LOE Category
McQueen, 2000	2	Incidence

Incidence data not included in the model

The model pulls the incidence information from the IMM database ... the information shown below does not go into the model.

Incidence	
Data Category:	Fixed
Space Adaptation:	No
Incidence Type:	Rate

Distribution Data	
Incidence:	Fixed
Occurrence:	Poisson

Male Data Characteristics	
Fixed Rate:	7.3E-05

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Citation	LOE Value	LOE Category
McQueen, 2000	4	Incidence

Alternative Incidence Data

A systematic review of the English literature from 1990 until 2010 was undertaken, comprising 32 eligible articles reporting on 3060 open tibial fractures study to analyze comparatively certain outcome measures of open tibial fractures. Outcome measures included rates of union progress and certain complication rates including compartment syndrome. The fractures were stratified using the Gustilo-Anderson classification. A pooled estimate of effect size, along with the 95% confidence interval (CI) was calculated. Prevalence rates of ACS were: Grade I was not estimable due to significant statistical heterogeneity, Grade II 10% (5-15%), Grade IIIA 5% (0-10.7%), Grade IIIB 7% (2.8-11.3%), and Grade IIIC 85.7% (57.1-98.2%). (Papakostidis, 2011)

A retrospective review was performed of combat casualties who underwent fasciotomies in Iraq, Afghanistan, or at Landstuhl Regional Medical Center (LRMC) between January 1, 2005 and August 31, 2006. A total of 336 subjects were included. In theater, 494 fasciotomies were performed on 294 patients; 65% of patients had at least one sign or symptom of compartment syndrome. Most patients (243 of 294, 83%) who underwent fasciotomies in theater did not undergo revision at LRMC. Only 17% of patients underwent fasciotomy revision. During our study time period, 73 patients underwent 177 fasciotomies at LRMC. Most (85%) patients had a diagnosis of compartment syndrome at the time of fasciotomy. The author determined that patients who underwent early versus delayed fasciotomies had higher rates of muscle excision (25% vs. 11%, *p* _ 0.01), amputation (31 vs. 15%, *p* _ 0.01), and mortality (19% vs. 5%, *p* _ 0.01) than patients who received their fasciotomies in theater (early). Anatomical distribution was similar to previous civilian studies. Time from injury to fasciotomy, in hours, was 5.6 +/- 5.6 (early) and 26.2 +/- 22.0 (delayed). (Ritenour, 2008)

More recently, a study estimated time to necrosis in patients with ACS. Between 1989 and 1997 there were 76 cases of ACS in 4 teaching hospitals in Montreal, Canada. Most cases occurred in young men (median age 32) as a result of a traumatic incident (82%). Forty-nine percent (37/76) of all patients suffered some level of muscle necrosis, and 30% (11/37) of those with necrosis lost more than 25% of the muscle belly. Necrosis occurred in 2 of 4 cases in which the patient had been operated on within 3 hours of the injury, and our exploratory survival analysis estimates that 37% (95% confidence interval, 13%-51%) of all cases of ACS may develop muscle necrosis within 3 hours of the injury (Vaillancourt, 2004).

Treatment and Outcomes

Based on the best evidence available best and worst case percentage ranges are assigned. The medical condition is divided into three clinical phases in all three clinical phases a functional impairment is assigned. The clinical phase I and II's functional impairments remain for the duration for that respective clinical phase. The function impairment in clinical phase III represents final impairment for this medical condition and remains for the rest of the mission. Other mission end states include evacuation and loss of crew life.

The IMM checks medical resource availability once the number of medical events and scenarios has been established. If there is not sufficient essential resources called out in the CliFF, then the medical condition will go down an untreated best or worst case scenario pathway.

The table below summarizes the treated and untreated best and worst case scenarios.

	Clinical Phase I Diagnosis & Initial Treatment[1]		**Clinical Phase II On-going Treatment / Convalescence[2]**		**Clinical Phase III Recovered / Mission End State[3]**		
	FI* (%)	**Duration (hrs)**	**FI* (%)**	**Duration (hrs) (Min - ML - Max)**	**FI* (%)**	**EVAC** (%)**	**LOCL** (%)**
ISS-based Treatment (best case scenario %: 8 - 68)	100	2	2 - 19	0 - 6 - 12	2 - 19	100	0
ISS-based Treatment (worst case scenario %: 32 - 92)	100	2	12 - 34	1 - 6.5 - 12	12 - 34	100	0
Untreated Best Case	N/A	N/A	12 - 34	0 - 6 - 12	12 - 34	100	0
Untreated Worst Case	N/A	N/A	21 - 64	1 - 6.5 - 12	21 - 64	100	0

[1]Clinical Phase I: Clinical phase I covers only the initial assessment of the affected crew member to define his or her medical condition, and completion of appropriate initial treatment to stabilize the crew member. While the affected crew member is being assessed, he or she is not able to perform any assigned tasks, thus Functional Impairment during this phase is considered 100%. In the untreated case, there is no diagnosis performed or treatment given, therefore Functional Impairment and Duration will always be "not applicable".

[2]Clinical Phase II: On-going Treatment and Convalescence- During clinical phase II, the affected crew member is receiving any appropriate follow-on treatment for his or her medical condition to allow the crew member to recover as much as he or she is able to recover in the ISS environment. Clinical phase II also encompasses relapses or reoccurrences of the same original medical condition in clinical phase I necessitating additional treatment or recovery time due to unsuccessful primary treatment response. The duration in Clinical Phase II is expressed in minimum, most likely (ML) and maximum hours. This was updated for future capabilities in IMM but is currently not being used by the model.

[3]Clinical Phase III: Recovered/Mission End State- Clinical phase III is reached once the affected crew member has recovered from the medical condition as much as he or she is able to recover in the ISS environment. This may or may not be recovery from the given medical condition to the full extent possible. If this "recovered" state results in an evacuation or loss of the crew member, this will be noted in the mission end state results.

*Functional Impairment (FI) is a measure of the affected crew member's health and performance ability.

**Two mission end state results are addressed in the CliFF: 1) Evacuation (EVAC) - crew and patient are evacuated from the spacecraft due to the medical condition, and 2) Loss of crew (LOCL) - death of affected crew member due to medical condition. EVAC is considered as an end state result if any of the following criteria are met: 1) potential LOCL, 2) potential significant permanent impairment, or 3) potential intractable pain. Probability distributions are assigned for each range of values within the Table of Treatments and Outcomes.

Refer to the Integrated Medical Model Technical Document for more information on how risk is reported by the IMM, Crew Health Index (CHI) and Quality Adjusted Mission Time calculations.

Definition and Probability of Best and Worst Case Scenario: (includes definitions of best and worst case scenarios and identifies the probability of those scenarios.)

Scenario Comments

The **best case scenario** is defined as compartment syndrome diagnosed less than 1 hour after onset. This scenario is more likely to result in normal limb function after fasciotomy

The **worst case scenario** is defined as compartment syndrome diagnosed more than 1 hour after onset. This scenario is more likely to result in abnormalities in limb function after fasciotomy.

Percentages of best case vs. worst case scenario were obtained from terrestrial data. In 1976, Sheridan and Matsen (Sheridan, 1976) reported that in two groups of 22 patients each, one group had fasciotomy before 12 hours and the second had fasciotomy after 12 hours. In the first group 68% had normal lower extremity function at the time of final follow up, while only 8% did in the delayed treatment group. Finkelstein (Finkelstein, 1996) reported on five patients who underwent fasciotomy 35 hours after the compartment symptom diagnosis, one patient died of multisystem organ failure secondary to fasciotomy complications and the remaining 4 required amputation .

Based on Sheridan's study, the estimate for worst cases is 32-92% (100-32 & 100-8%). Thus the best case scenario results in 8-68%.

ACS may progress to sepsis which is addressed in the Sepsis CliFF. Terrestrially, death has occurred in delayed fasciotomies among civilians (20%) (Finkelstein, 1996) and among the military (19%) (Ritenour, 2008). However, on board LOCL is not expected with urgent evacuation.

Best Case Comments

Acute Compartment Syndrome functional impairments (FI) calculation follows the IMM severe non-space adaptation template for Clinical Phase II. Because no improvement is expected without surgical intervention, FI for Clinical Phase III remains the same as Clinical Phase II. Lower Extremity Impairment (LEI) ratings are based on Table 16-1 p 495. Complex Regional Pain (LEI) syndrome gradings are based on Table 16-15, p 541 (American Medical Association, 2008). Both the LEI and the CRPS (LEI) ratings are converted to percentage of Whole Person Impairment (WPI), which are based on Table 16-1, p 495 (American Medical Association, 2008). Total FI ratings are calculated combining the mentioned WPI values using the Combined Values Chart as indicated in Appendix A, pp 604-606 (American Medical Association, 2008). For further information refer to this CliFF Appendix A.

By definition in Clinical Phase I, FI is 100%. Duration to follow procedures specified in ISS checklist, i.e. physical exam, vital signs, oral or intramuscular medications, plus time to deploy the ultrasound unit, up-stow and activate procedure/checklist, and perform the exam, is estimated in 2 hours.

During Clinical Phase II, FI is estimated in 2 to 19%. Duration is estimated at 0 to 12 hours based on best case definition for the lower limit, and time to evacuation on the higher limit. 12 hours has been the ideal time defined to get the best outcomes after fasciotomy (Sheridan, 1976)

In Clinical Phase III, by definition recovery is not expected without surgery and FI remain 2-19%. ACS has not occurred among the astronaut corps (Johnston, 2008). By definition, EVAC will be required for 100% of acute compartment syndrome due to the potential for significant permanent impairment and required surgery. Urgent evacuation is indicated for all compartment syndromes in the military (US Special Operations Command, 2011). LOCL is not expected for the best case scenario.

Worst Case Comments

Acute Compartment Syndrome functional impairments (FI) calculation follows the IMM severe non-space adaptation template for Clinical Phase II. Because no improvement is expected without surgical intervention, FI for Clinical Phase III remain the same as during Clinical Phase II. Lower Extremity Impairment (LEI) ratings are based on Table 16-1 p 495. Complex Regional Pain (LEI) syndrome gradings are based on Table 16-15, p 541 (American Medical Association, 2008). Both the LEI and the CRPS (LEI) ratings are converted to percentage of Whole Person Impairment (WPI), which are based on Table 16-1, p 495 (American Medical Association, 2008). Total FI ratings are calculated combining the mentioned WPI values using the Combined Values Chart as indicated in Appendix A, pp 604-606 (American Medical Association, 2008). For further information refer to this CliFF Appendix A.

By definition in Clinical Phase I, FI is 100%. Duration is estimated in 2 hours similar to the best case scenario. During Clinical Phase II, FI is estimated at 12 to 34%. Time has been estimated at 1 hour based on the scenario definition for the lower limit, and 12 hours based on the time to evacuation for the higher limit. 12 hours has been the ideal time defined to get the best outcomes after fasciotomy (Sheridan, 1976)

In Clinical Phase III, by definition recovery is not expected without surgery and FI remains 12-34%. ACS has not occurred among the astronaut corps (Johnston, 2008). By definition, EVAC will be required for 100% of acute compartment syndrome due to the potential for significant permanent impairment. Urgent evacuation is indicated for all compartment syndromes in the military (US Special Operations Command, 2011). LOCL is not expected.

Untreated Best Case Comments

Acute Compartment Syndrome functional impairments (FI) calculation follows the IMM severe non-space adaptation template for Clinical Phase II. Because no improvement is expected without surgical intervention, FI for Clinical Phase III remain the same as during Clinical Phase II. Lower Extremity Impairment (LEI) ratings are based on Table 16-1 p 495. Complex Regional Pain (LEI) syndrome gradings are based on Table 16-15, p 541 (American Medical Association, 2008). Both the LEI and the CRPS (LEI) ratings are converted to percentage of Whole Person Impairment (WPI), which are based on Table 16-1, p 495 (American Medical Association, 2008). Total FI ratings are calculated combining the mentioned WPI values using the Combined Values Chart as indicated in Appendix A, pp 604-606 (American Medical Association, 2008). For further information refer to this CliFF Appendix A.

During Clinical Phase II, FI is estimated in 12-34%. Duration is estimated at 0 12 hours, similar to the treated best case scenario. In Clinical Phase III, by definition recovery is not expected without surgery and FI remains 12-34%. By definition, EVAC will be required for 100% of acute compartment syndrome due to the potential for significant permanent impairment and required surgery. LOCL is not expected.

Untreated Worst Case Comments

Acute Compartment Syndrome functional impairments (FI) calculation follows the IMM severe non-space adaptation template for Clinical Phase II. Because no improvement is expected without surgical intervention, FI for Clinical Phase III remain the same as during Clinical Phase II. Lower Extremity Impairment (LEI) ratings are based on Table 16-1 p 495. Complex Regional Pain (LEI) syndrome gradings are based on Table 16-15, p 541 (American Medical Association, 2008). Both the LEI and the CRPS (LEI) ratings are converted to percentage of Whole Person Impairment (WPI), which are based on Table 16-1, p 495 (American Medical Association, 2008). Total FI ratings are calculated combining the mentioned WPI values using the Combined Values Chart as indicated in Appendix A, pp 604-606 (American Medical Association, 2008). For further information refer to this CliFF Appendix A.

During Clinical Phase II, FI is estimated in 21-64%. Duration is estimated at 1-12 hours, similar to the treated worst case scenario. In Clinical Phase III, by definition, recovery is not expected without surgery and FI remains 21-64%. By definition, EVAC will be required for 100% of acute compartment syndrome due to the potential for significant permanent impairment and required surgery. LOCL is not expected similar to the worst case scenario.

Treatment and Options Level of Evidence (LOE)

The IMM level of evidence appropriate assessment of the quality of the IMM input data. Since IMM incorporates input data from a wide variety of sources including astronaut population, terrestrial or analog populations, and external models, an innovative approach to assess the quality of input data was required. Information obtained from the astronaut population and/or space flight is the more relevant so it is assigned the highest level of evidence and less relevant data sources are assigned a lower level of evidence.

Citation	LOE Value	LOE Category
American Medical Association, 2008	3	FI
American Medical Association, 2008	3	FI
Sheridan, 1976	4	BCWC
Johnston, 2008	2	EVAC
US Special Operations Command, 2011	2	EVAC

The Resource Table (RT)

Resource	Units Required Best Case	Units Required Worst Case	Units Available At Start Of Mission	Consumable	Essential	Rationale
Ace bandage 2 inches	1	1	1	No	Yes	To wrap wound after fasciotomy.
Ace bandage 3 inches	1	1	1	No	Yes	To wrap wound after fasciotomy.
Ace bandage 4 inches	1	1	1	No	Yes	To wrap wound after fasciotomy.
Blood Oximeter	1	1	1	No	Yes	To monitor pulse, oxygen level, and circulation.
Blood Pressure Cuff (regular, large)	1	1	2	No	Yes	Measure blood pressure
Blood Pressure Monitor	1	1	1	No	Yes	Measure blood pressure
BZK wipes	6	6	60	Yes	No	To cleanse skin
CMRS	1	1	1	No	No	Restrain crew member to ensure safety
Dilaudid (Hydromorphone) 2mg/mL, 1mL syringe	6	6	18	Yes	Yes	Pain relief
Gauze pads (4x4)	50	50	50	Yes	No	To contain bleeding from fasciotomy.
Iodine Swab Stick	14	14	14	Yes	No	To clean area for fasciotomy
IV administration set	1	1	3	Yes	Yes	To administer IV fluids
IV Cap	1	1	5	Yes	No	To maintain IV when not in use.
IV Catheter (18G, 20G, or 22G)	1	1	14	Yes	Yes	IV fluid administration
IV Fluid 1L (1000mL)	4	4	5	Yes	Yes	To provide intravenous hydration.
IV Fluid Air Filter	1	1	3	Yes	No	**To filter air from IV set**
IV pressure infuser	1	1	1	No	No	To provide intravenous hydration
Medical tape	0.5	0.5	5	Yes	No	To secure dressing to skin
Nonstick Bandage (Telfa pads)	4	4	20	Yes	No	Non pressure dressing
SAM splint - Leg/Arm Splint	1	1	1	No	Yes	to secure affected extremity
Tourniquet	1	1	1	No	No	To assist with obtaining IV access.
Tylenol (Acetaminophen) 325 mg	18	18	150	Yes	Yes	Pain Relief
Urine Catheter Foley	1	1	2	Yes	No	To accurately monitor urine output.
Vicodin HP (Hydrocodone/ Acetaminophen HP) 10 mg/660 mg	12	12	30	Yes	Yes	Pain relief

Resource Comments

Acute Compartment Syndrome is not addressed in the ISS medical checklist. To create the resource table IMM used the US Special Operations Command Medic Training and Advanced Life Training support protocols (US Special Operations Command, 2011), (Parks, 2011).

All resources are available in the ISS medical checklist (Mission Operations Directorate (MOD), 2011).

Required Resources Level of Evidence (LOE)

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Citation	LOE Value	LOE Category
US Special Operations Command, 2011	2	Resources
Parks, 2011	3	Resources

Level Of Evidence

Input Data	LOE Average
Incidence	2
Functional Impairment	3
Best Case / Worst Case	4
EVAC / LOCL	2
Resources	2.5
QUALITY OF EVIDENCE	**2.7**

Description	Range
Excellent	1-2
Good	2.1-3
Fair	3.1-4
Poor	4.1-5

Reference List

Reference
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