

Surgical management of closed crush injury-induced compartment syndrome after earthquakes in resource-scarce settings

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Crush injuries are reportedly the second most common cause of death after earthquakes.¹ Crush injuries of extremities can lead to compartment syndrome, in which raised pressure within the fascial compartment compromise circulation and function of tissues.² Untreated compartment syndromes may lead to amputations and can be lethal. In earthquake-ravaged resource scarce countries, treating compartment syndrome is often complicated by limited resources and late arrival of foreign surgical relief. Consequently, surgery must be adapted to this context requiring specific knowledge and experience. Recent experience from the 2010 Haiti earthquake illustrates well the immense surgical problems faced when arriving several days into an earthquake in a resource scarce setting. After the earthquake in Haiti, many foreign surgeons were ill prepared to care for earthquake victims and lacked knowledge of providing care given limited resources.³ Because of late arrival, foreign surgical teams did not manage to provide care until after 72 hours after the major earthquake, a time lack that is reflected in other earthquakes as well.⁴ In addition, several of the foreign surgical teams in Haiti stayed for only a few days and left patients without assurance of continued treatment.⁵ A common condition after the earthquake in Haiti was compartment syndromes (Fig. 1). However, this acute condition was not examined and treated until several days or weeks after the injury. The controversies regarding the surgical management of crush-induced compartment syndrome, which also came to light in Haiti, have existed in the field for more than 20 years.⁶ When confronted with limited resources, massive number of injured that arrive very late, and the postoperative consequences of an operation that create large open wounds that need dressings and often skin graft, more context adapted evidence is needed to guide the surgical strategy. This article explores to what extent findings of previous reviews on crush injury-induced compartment syndromes can help develop treatment guidelines for care of the syndrome after earthquakes in resource scarce settings.

MATERIALS AND METHODS

We searched the online databases PubMed, Web of Science, and The Cochrane Library during May 14-15, 2011. The string “crush AND earthquake” was used to search PubMed, “crush AND earthquake*” for Web of Science, and “earthquake” for The Cochrane Library. To be eligible, each article had to:

1. Discuss surgical treatment (defined as conservative treatment, fasciotomy, or amputation) of compartment syndrome in earthquake victims AND,
2. Be indexed as a review OR,
3. Include a statement that a review had been performed OR,
4. Compromise an overview of the literature extensive enough to be judged a review by the author performing the screening AND,
5. Have been published in a peer-reviewed journal in English since 2000, on the presumption that reviews published since then would cover relevant literature published before 2000 and include new studies.

One author checked records retrieved by the searches, and potentially eligible articles were obtained in full. As all included reviews were narrative in nature, we were limited to performing a narrative overview to collate findings. Recommendations about the use of conservative treatment, fasciotomy, or amputation were extracted from the reviews. The key concepts crush injury, compartment syndrome, crush syndrome, and acute renal failure (ARF) are defined in Table 1.

RESULTS

Our database searches identified 374 potentially relevant articles (Fig. 2). After we removed duplicates and articles published before the year 2000, the remaining articles were screened for relevance based on titles and abstracts. Our final analysis included 14 full reviews (Table 2).

Conservative Treatment

Our evaluation shows that conservative treatment of crush injury is favored over surgery in three reviews,⁷⁻⁹ whereas one review considers conservative treatment and surgery equally beneficial.¹⁰ Managing a crush-induced compartment syndrome conservatively means providing general treatment of the crush injury without any early surgical interventions. The aim of the general treatment is to prevent crush syndrome and ARF, as well

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Figure 1. Compartment syndrome of upper extremity treated at a field hospital after the 2010 Haiti earthquake.

TABLE 1. Definitions of Key Concepts

Concept	Definition
Crush injury, ^a injury type	“Swollen limb with history of limb compression.”
Crush syndrome, ^b ICD 10: T79.5	“Severe systemic manifestation of trauma and ischemia involving soft tissues, principally skeletal muscle, due to prolonged severe crushing. It leads to increased permeability of the cell membrane and to the release of potassium, enzymes, and myoglobin from within cells. Ischemic renal dysfunction secondary to hypotension and diminished renal perfusion results in acute tubular necrosis and uremia.”
Compartment syndrome, ^b ICD 10: T79.6	“Conditions in which increased pressure within a limited space compromises the blood circulation and function of tissue within that space. Some of the causes of increased pressure are trauma, tight dressings, hemorrhage, and exercise. Sequelae include nerve compression; paralysis; and ischemic contracture.”
Acute renal failure, ^b ICD 10: N17	“Abrupt reduction in kidney function defined as an absolute increase in serum creatinine of ≥ 0.3 mg/dL, a percentage increase in serum creatinine of [mtequ]50% or a reduction in urine output. Acute kidney injury encompasses the entire spectrum of the syndrome including acute kidney failure, acute kidney tubular necrosis, and other less severe conditions.”

^a Definition adapted from *Crit Care Med and Surg Clin North Am.*^{12,14}
^b MESH definition, available at: <http://www.nlm.nih.gov/mesh/MBrowser.html>.

as save the limb.^{11–13} To prevent crush syndrome, early vigorous fluid administration is crucial.^{7,8,10,11,13–18} The fluid should ideally be administered before the victim is extracted from the rubble.^{10,11,17,18} To lower the raised compartment pressure, mannitol should be added to the fluid regimen.^{10,15,16} However, mannitol is contraindicated in patients with oliguria, anuria,¹¹ or

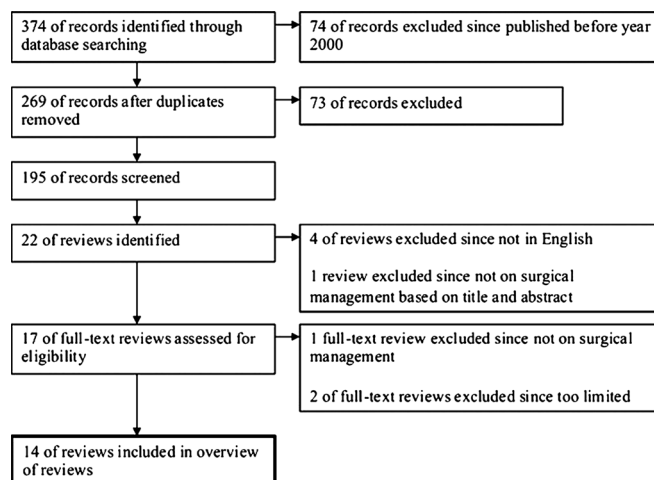


Figure 2. Flow chart of study selection.

ARF.⁷ Limbs may be splinted in a functional position and then later corrected by reconstructive surgery.^{7,16} Hyperbaric oxygen treatment has also been suggested.^{7,8}

Fasciotomy

Fasciotomy is the conventional surgical intervention for compartment syndrome and decompresses the compartment by incisions through the skin and fascia.^{11,12} We found that the use of fasciotomy in closed crush-induced compartment syndrome after earthquakes is controversial,⁸ mainly because of the increased risk for infection when a closed injury is turned into an open wound.^{10,13} Sepsis and death have been reported as complications of fasciotomy.^{7,16,17} In nine reviews, fasciotomy is recommended after closed crush injury-induced compartment syndrome.^{11–13,15–20} In five of these nine reviews, a distinction is made between early and late fasciotomy.^{8,11,13,15,17,20} The definition of “late” ranges between 6 to 12 hours after extraction. In these five reviews, early fasciotomy is recommended, whereas late fasciotomy is advised against as muscle and nerve damage would be too extensive to be reversed.

In one review,⁷ a difference in pathophysiology between crush-induced and ischemia-induced compartment syndrome is described (Text box 1). The difference would be that in ischemia-induced compartment syndrome, the raised compartment pressure is the cause of muscle death. In contrast, in crush-induced compartment syndrome, the muscle necrosis causes the raised compartment pressure. On the basis of this difference that review concludes that there is no place for fasciotomy in crush-induced compartment syndrome because the muscle is already dead.

Amputation

Amputation is mentioned as a management strategy in three reviews.^{12,14,16} It might be a lifesaving operation and facilitate extrication,^{14,16} but it should only be used as a last resort.¹²

DISCUSSION

In this study, we show that current reviews on treatment of compartment syndrome after earthquakes are limited in their

TABLE 2. Summary of Included Reviews (n = 14)

Review	Surgical Treatment Options			Comment
	Conservative	Fasciotomy	Amputation	
Atef-Zafarmand and Fadem ¹⁹	Mannitol may protect injured muscle and reduce leakage of nephrotoxins.	Compartment pressure within 10-30 mm Hg of patient's diastolic BP. Perform fasciotomy if 4-6 h after extraction. Discourage fasciotomy if 6-8 h (or more) since the release of the crushed part.	—	—
Briggs ¹⁴	—	—	Field amputation is an operation that can be lifesaving.	—
Efstratiadis et al. ¹¹	Mannitol decompresses the interstitial and muscular compartments. However, the administration of mannitol should be done under close monitoring and must stop, if the patient develops oliguria or anuria	Compartment pressure above 40 mm Hg.	—	—
Gonzalez ¹²	Crush syndrome and muscle necrosis in a closed injury without compartment syndrome may be followed clinically, until healing or demarcation of a gangrenous part occurs, providing the patient's general medical condition (including renal function) can be maintained.	Compartment pressure within 30 mm Hg of patient's diastolic BP.	The role of amputation is limited in the management of crush syndrome. The field amputation of an entrapped limb should be a procedure of last resort only.	—
Holt and Moore ¹⁵	Mannitol should only be used when it is aimed specifically at reducing compartment pressure.	Fasciotomy should be undertaken only as a last resort when compartment pressures exceed 40 mm Hg.	—	—
Malinoski et al. ¹⁶	Interval fasciotomy performed 6-12 months after injury combined with reconstructive procedures may correct most ischemic contractures and offer the best physical outcome, if early fasciotomy cannot be performed.	Fasciotomy may be performed within 10-12 h after injury. Compartment pressure within 20 mm Hg of patient's diastolic BP.	Amputation may be required when massive extremity necrosis progresses to an extent that limb salvage is not possible.	—
Reis and Better ⁷	Mannitol or hyperbaric oxygen may be used to reduce compartment pressure. Mannitol is contraindicated in patients with ARF. Joints should be splinted in a functional position, whereas active and passive movements are encouraged as soon as pain allows. Ischemic muscle contractures and paralysis are corrected by late reconstructive surgery.	Fasciotomy is contraindicated in patients with closed acute muscle crush compartment syndrome. The only indication for fasciotomy is when the distal pulse is absent and when both direct, major arterial injury and systemic hypotension have been excluded.	—	Differ between compartment syndrome caused by crush injury and compartment syndrome with other causes.
Sever ²⁰	Mannitol may be used to reduce compartment pressure. Mannitol should not be used in anuric patients.	Fasciotomy may restore circulation and reduce necrotic muscle mass. Should be based on objective criteria such as raised compartment pressure.	—	—
Sever et al. ¹⁷	Mannitol decreases compartment pressure	Compartment pressure above 35 mm Hg.	—	—

TABLE 2. (Continued)

Review	Surgical Treatment Options			Comment
	Conservative	Fasciotomy	Amputation	
Singh et al. ¹⁸	Mannitol decreases compartment pressure. Mannitol should not be used in oligoanuric patients.	Compartment pressure above 35 mm Hg with no tendency to decrease after a maximum of 6 h.	—	—
Smith and Greaves ⁸	Give a trial of mannitol therapy before undertaking surgical decompression.	If the compartment pressure is so high that it obliterates the arterial supply to the distal part of the limb.	—	Advises reader to seek specialist surgical opinion early in the course of management.
Stein et al. ⁹	Early and aggressive treatment of these patients with intravenous hypertonic mannitol effectively induces reduction in the intramuscular and compartment pressure of the affected limb muscles. Muscle damage resistant to mannitol treatment should be corrected with late surgical reconstruction.	Fasciotomy should be reserved for patients with clear interruption of arterial circulation. Skin over a crush injury site should never be debrided.	—	—
Vanholder et al. ¹⁰	—	—	—	Compartment pressure above 30 mm Hg produces clinically significant muscle ischemia requiring either fasciotomy or mannitol.
Vanholder et al. ¹³	Mannitol decreases compartment pressure and reduces muscular swelling and nerve compression.	Compartment pressure above 50 mm Hg or if pressure values between 30 and 50 mm Hg show no tendency to decrease after a maximum of 6 h.	—	—

BP, blood pressure.

consideration of timeliness of response, resource-limited settings, and best practices and treatment strategies. Taken together, the reviews analyzed in this study do not provide sufficient evidence on which to base clinical practice guidelines. Improved reporting of treatment approaches and quality assessments of approaches are needed to create an evidence base for future guidelines.

To date, no review on the treatment of compartment syndrome discusses management strategies for teams that arrive several days after an earthquake. Treatment recommendations for crush injury-induced compartment syndrome after earthquakes should take into consideration the late arrival of surgical teams as foreign medical teams usually do not arrive within the first 3 days after sudden onset disasters.⁴ Best practices and treatment options are likely to differ from treatments provided immediately.

Our analysis also showed that a number of proposed management components in the present reviews are not applicable to resource-scarce earthquake settings. For example, considering conservative treatment, it is well known that most victims trapped under rubble after an earthquake in resource scarce settings are not extricated by experienced search and rescue teams with the capacity to administer intravenous fluids.

Instead, most victims are removed by untrained relatives and neighbors.²¹ Furthermore, the availability of devices for measuring compartment pressure and the facilities for administering hyperbaric oxygen are likely to be extremely limited in the resource scarce earthquake setting. This reality has to be taken into account in preparing new guidelines that might otherwise be based on experience and research from well-resourced, conventional settings.

The use of fasciotomy in closed crush-induced compartment syndrome after earthquakes is controversial,⁸ because of the increased risk for infection. Although two thirds of the reviews seem to recommend fasciotomy, more than half of these discourage the use of late fasciotomy. However, both late and early fasciotomy seems common praxis. Many patients with old compartment syndrome after earthquakes in resource-scarce settings have fasciotomy, as reported in several recent articles.^{22–24}

Reports from earthquakes in Japan,²⁵ Iran,²⁶ and Turkey^{27,28} discourage the use of fasciotomy in crush injury-induced compartment syndrome. An exception is one report from the Tangshan earthquake²⁹ and another report from the Bam earthquake²⁴ that both favor fasciotomy. Given our lack of knowledge and data from evaluations of fasciotomies on compartment

TEXT BOX 1. Proposed Differences in Pathophysiology between Crush- and Ischemia-Induced Compartment Syndrome

Historically, the pathophysiology of compartment syndrome has been described as the same regardless of underlying cause.² However, more recently, a difference in pathophysiology depending on whether the compartment syndrome is caused by ischemia or crush injury has been suggested.³⁵

Common pathway

Under normal conditions, the cytosol of myocytes is negatively charged and hyperoncotic in relationship to the extracellular fluid. The intracellular content of sodium and calcium is low. Energy-requiring extrusion pumps protect the myocyte from swelling by balancing slow leakage of sodium and calcium into the myocyte by actively removing sodium and calcium. Extrusion pump dysfunction results in loss of myocyte ability to regulate cell volume.^{36,40} Hence, swelling of the myocyte occurs. Swelling of muscle inside the noncompliant fascia will result in muscle tamponade, compartment syndrome.³⁵

Ischemia-induced compartment syndrome

Muscle ischemia compromises supply of oxygen to tissue resulting in depletion of intracellular energy stores. Depletion of intracellular energy leads to intracellular calcium overload, by extrusion pump dysfunction (decreased efflux) and compromised sequestration of calcium in intracellular pools. Eventually, high calcium leads to activation of autolytic enzymes and myofibril and membrane phospholipid injury.³⁷ After 4 to 6 h of ischemia, the muscle damage is irreversible.^{6,7} However, the final lysis of myocytes and, hence, most of the injury in ischemia-induced compartment syndrome occurs when blood flow is reestablished, commonly referred to as reperfusion injury. When blood flow is reestablished, polymorphonuclear neutrophils and inflammatory mediators accumulate. Because of the high levels of intracellular calcium, neutrophils release oxygen-derived free radicals, which eventually mediate cell death.³⁸

Crush-induced compartment syndrome

The myocyte sarcolemma is mechanically stretched in crush injury. Stretching of the sarcolemma increases cation leakage into the cell to an extent that overwhelms the capacity of extrusion pumps, resulting in pump dysfunction. Intracellular calcium concentration increases, eventually leading to the activation of autolytic enzymes and depletion of energy stores.³⁵ In crush injuries, the muscle directly beneath the crushing object dies immediately,⁶ but even when the shear force of crushing is not enough to mangle the muscle, the combination of pressure and pressure-induced hypoxia will lead to muscle death within 1 h.^{7,39} In a later stage, this baromyopathy causes ischemic myopathy

syndromes older than 48–72 hours, studies are needed to assess the relevance of this procedure on such late crush-induced compartment syndromes.

Amputation was one of the most common surgical interventions in the Project Medishare field hospital in Haiti.³⁰ Although amputations may be lifesaving in selected critically ill patients with crush injuries, if and how these treatment options should be applied in earthquake settings warrants further investigation. Scoring systems³¹ designed to assess the likelihood of a limb to be salvageable or not should be taken into consideration for these purposes. When performing an amputation in a foreign country, it is also paramount to have sufficient understanding of the social consequences and stigma of the amputation because this may differ significantly from those encountered by the surgeon “at home.” In addition, bearing in mind the irrevocable socioeconomic consequences of a limb amputation, especially in

a resource-scarce setting, it is good medical practice to base the recommendation for amputation on the advice by two different physicians in the team. This practice is already institutionalized by a few organizations providing foreign medical teams to resource-scarce settings after earthquakes. Generally, physiologic and psychosocial consequences and advantages of amputation have to be balanced with those of a malfunctioning but remaining limb. It must be recognized that this balance might be different in the setting of the earthquake in a low-income country than in the surgeon’s home country.

Limitations

This overview of reviews has been restricted to published, peer-reviewed articles in English. Articles in other languages may contain additional, relevant data and information as may treatment protocols from various organizations working in earthquake-affected areas. Such protocols may add to a more complete review of best practices and recommended guidelines. In addition, review articles were selected, and data were extracted by a single author, which might have led to some eligible articles and information being missed.³²

Implications for Clinical Practice and Research

The lack of adequate reporting of the approaches used to select studies in the included reviews and the lack of any quality assessment of the evidence severely limits the use of the selected review articles in creating an evidence base for future guidelines. Accordingly, it was not possible to perform an overview of reviews to the standards recommended by The Cochrane Collaboration.³³ However, some treatment suggestions of value to surgeons sent to earthquakes in resource-scarce settings can be derived (Table 3). Since three reviews favor conservative treatment over fasciotomy and an additional five recommend against late fasciotomy, we mean that conservative treatment, mannitol, and late reconstructive surgery should be considered for patients who have survived the initial days with a compartment syndrome. Compared with the evidence base for fasciotomy, the evidence base for amputation as the treatment of crush-induced compartment syndrome is even weaker. We suggest that amputation should only be used as a last resort, in cases of crush injury and compartment syndrome.

TABLE 3. Treatment Suggestions for Closed Crush-Induced Compartment Syndrome After Earthquakes in Resource-Scarce Settings

Treatment Option	Time After Extraction (h)		
	0–6	6–12	[mt]12
Mannitol ^a	++	++	++
Fasciotomy ^b	++	+	[minus]
Amputation ^c	[minus]	[minus]	[minus]

++, may be applied; +, apply carefully; and [minus], do not apply.

^a Contraindicated in oligouric and anuric patients and patients with ARF. Give at a dose of 1–2 g/kg body weight over 4 h as 20% infusion. Maximum daily dose is 200 g.

^b Take into consideration the growing literature stating that there is no place at all for fasciotomy in closed crush-induced compartment syndrome.

^c Apply only as a last resort.

Furthermore, a systematic approach is needed to determine whether crush-induced compartment syndrome should be treated surgically after earthquakes in resource-scarce settings. Randomized trials may not be possible in this context but prospective studies that clearly monitor the outcome of different treatment strategies may be. It should also be possible to design animal studies that further explore the difference in pathophysiology between ischemia-induced compartment syndrome and crush-induced compartment syndrome. However, as far as we know, such studies are lacking.

Given the present lack of randomized controlled trials and prospective studies, other methods are needed at this point to develop guidelines on optimal treatments after earthquakes. These guidelines should be based on evidence from systematic reviews of the current literature. Such an approach would also fit well with recent initiatives to register and improve the skills of foreign medical teams providing treatments after disasters such as earthquakes.³⁴ Evidence-based standards used to determine surgical interventions in high-income countries can also be applied to decisions about such interventions performed by foreign medical teams after earthquakes in resource-scarce settings.

CONCLUSIONS

Current reviews of surgical treatment of crush-induced compartment syndrome after earthquakes provide evidence that is of too low quality to base new treatment guidelines on. The use of fasciotomy is controversial as it increases the risk for infection. Conservative treatment should be considered for patients with compartment syndrome presenting late, 48 to 72 hours after onset of symptoms. Amputation should be used only as a last resort. More methodologically, sound research is needed to create guidelines for treatment of crush-induced compartment syndrome after earthquakes in resource scarce settings.

AUTHORSHIP

M.G. and J.v.S. designed this study. M.G. performed the search and data extraction and wrote the first draft, which A.W. and J.v.S. critically revised. M.G., A.W., and J.v.S. contributed significantly to the consequent re-writing of the manuscript.

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DISCLOSURE

The authors declare no conflicts of interest.

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