CRUSH INJURY AND CRUSH SYNDROME: A CONSENSUS STATEMENT

KEITH PORTER and IAN GREAVES review the findings of a consensus meeting on crush injury and crush syndrome held in Birmingham on May 31 2001 and co-ordinated by the faculty of pre-hospital care of the Royal College of Surgeons of Edinburgh

ABSTRACT
Crush syndrome remains rare in European practice but is common in areas of civil disorder and where society has given way to civil war or natural disaster. Clinicians in the west are becoming increasingly involved in such situations and there is no reason to believe that the few instances due to conventional causes, such as an elderly person collapsing or road traffic accidents, will cease. Therefore, it is important that clinicians who deal rarely with crush syndrome have access to appropriate guidelines. This consensus report seeks to provide such advice.

INTRODUCTION
Bywaters and Beall (1941) first described the development of crush injury and crush syndrome after several patients who had been trapped under rubble in the London Blitz died of acute renal failure. Since then, they have been described in settings such as earthquakes, war zones, and after buildings have collapsed. Crush syndrome is also seen following industrial incidents such as mining accidents, and road traffic accidents. Crush syndrome is not confined to traumatic aetiologies and has involved people being crushed by their own body weight after stroke or intoxication (Michaelson 1992).

Severity of the condition is related to the magnitude and duration of the compressing force, and the bulk of muscles affected.

Examples of this relationship include a patient whose legs are run over by the wheels of a truck. In this case the force is large, but the duration is very short.

At the other extreme, there is the elderly patient who has suffered a stroke, fall and lies in the same position for hours, sustaining a crush injury to the areas of the body on which they are lying. In this case, the force is relatively small, but crush syndrome may develop as a result of the prolonged period of compression as by a heavy weight.

1. Consensus definitions:
   > Crush injury: A crush injury is a direct injury resulting from crush.
   > Crush syndrome: Crush syndrome is the systemic manifestation of muscle cell damage resulting from pressure or crushing, for example, following the release of a limb or limbs after a prolonged period of compression as by a heavy weight.

PATHOGENESIS AND CLINICAL FEATURES
Typical clinical features of crush syndrome are predominantly due to traumatic rhabdomyolysis and subsequent release of muscle cell contents after pressure or stretching has caused the sarcolemmal membrane to start to leak.

As the sarcolemmal membrane is stretched, sodium, calcium and water leak into the sarcoplasm, trapping extracellular fluid inside the muscle cells. In addition to the cellular
influx of these elements, cells release potassium and other toxic substances such as myoglobin, phosphate and urate into the circulation (Better 1999).

The result of these events is shock, hyperkalaemia and possibly cardiac arrest precipitated by high potassium concentrations, hypocalcaemia, metabolic acidosis, compartment syndrome due to compartment swelling, and acute renal failure. Acute renal failure is due to a combination of hyperkalaemia with subsequent renal vasoconstriction, metabolic acidosis and the insult of nephrotoxic substances such as myoglobin, urate and phosphate.

SHOCK
Haemodynamic instability secondary to crush syndrome is multi-factorial. First, many patients have other injuries such as fractures of the pelvis or lower limbs sufficient in themselves to cause hypovolaemia. The sequestration of fluid into affected muscle compartments has already been described, and results in fluid shift from intravascular to intracellular compartments. This may cause hypovolaemia as the intravascular volume is depleted.

Electrolyte imbalances such as hyperkalaemia, hypocalcaemia and metabolic acidosis have a negatively ionotropic effect, and there is evidence that there is direct myocardial depression caused by other factors released when muscle cells are damaged (Rawlins et al 1999).

APPROACH TO TREATMENT
Treatment of crushed patients can be divided into two phases. The initial pre-hospital phase can, depending on the mechanism of injury, involve a prolonged extrication period. The second phase commences on reaching a clinical care facility. In cases of prolonged on-scene time or transfer delay for geographical reasons, some second phase guidelines can be employed in pre-hospital environments.

In instances of mass casualties, once the scene has been declared safe, a triage system such as the triage sieve (Advanced Life Support Group 2000, Hodgetts and Mackway-Jones 2002) should be used to prioritise patients and assess the need for further treatment. For each individual casualty, an assessment of airway, breathing and circulation is the next priority.

Attention must be given in trauma to the possibility of spinal injury, and full spinal precautions should be maintained. Administration of high flow oxygen by mask should be a treatment priority, as should the arrest of any obvious external haemorrhage and the splinting of limb injuries.

Patients should be exposed enough to allow injury assessment and management, but in hostile environments, where there is a risk of hypothermia for example, exposure should be as limited as possible. Assessment of distal neurovascular status is essential if exposure is to be kept to a minimum. Patients should be released as quickly as possible, irrespective of how long they have been trapped.

FLUID RESUSCITATION
Once an initial survey has been performed, intravenous access should be obtained. If limb crush injury has occurred and there is a likelihood of the patient developing crush syndrome, the following fluid guidelines should be followed. In the presence of life-threatening thoraco-abdominal injury, fluid resuscitation should be performed according to the faculty’s previously published guidelines (Greaves et al 2002).

2. Consensus view on treatment approach:
- Safety is the first priority when approaching accident scenes, and this is particularly relevant in situations where patients have suffered crush injuries, because there could be danger from falling debris or further building collapse.

Organisations represented
- The Voluntary Aid Societies, comprising St John Ambulance, St Andrew’s Ambulance Association and The British Red Cross
- The Ambulance Service Association
- The British Association for Immediate Care
- The British Association for Accident and Emergency Medicine
- The Faculty of Accident and Emergency Medicine
- The Royal College of Anaesthetists
- The Royal College of Physicians
- The Royal College of Surgeons of Edinburgh (RCSE)
- The RCSE faculty of pre-hospital care
- The Intensive Care Society
- The RCN
- The military
ANALGESIA

4. Consensus view on analgesia:
> The use of clinical teams including paramedics, nurses and doctors should be considered at an early stage, and appropriate analgesia should be given. This may involve using Entonox initially but most patients require intravenously administered analgesics, such as opiates, titrated against response. Ketamine use, with or without a benzodiazepine also relieves pain effectively and may help extrication. First responders can give oral analgesia in the absence of senior clinical support.

TRIAGE

5. Consensus view on triage:
> Patients with crush injuries should be taken to hospitals with intensive care facilities and the equipment and expertise necessary to provide renal support therapy such as haemofiltration or dialysis.

TOURNIQUETS

Tourniquet use has a theoretical role in managing these patients. Avoiding the release of crushed muscle cell contents into the circulation, possibly by using a tourniquet, may be of benefit but there is no evidence to support this.

6. Consensus view on tourniquet use
> Tourniquet use should be reserved for otherwise uncontrollable life-threatening haemorrhage. There is no evidence to support the use of tourniquets to prevent reperfusion injury following extrication or the washing of rhabdomyolysis products into the circulation.

AMPUTATION

Is it an advantageous measure to amputate crushed limbs to prevent crush syndrome?

7. Consensus view on amputation:
> There is no evidence to support the use of prophylactic amputation to prevent crush syndrome. The literature suggests that even severely crushed limbs can recover to full function. If limbs are hanging on threads of tissue or patients’ lives are in danger due to limb entrapment, amputation should be considered and appropriate expert advice sought.

IMMEDIATE IN-HOSPITAL CARE

8. Consensus view on immediate in-hospital care:
> Patients should be assessed following normal advanced trauma life support (ATLS) guidelines (American College of Surgeons 1997). Baseline blood tests should be taken to assess full blood count, urea, electrolyte, creatinine kinase and amylase levels, liver function, clotting screen and group. Blood should also be saved in case cross-matching is deemed appropriate. Patients should be catheterised and hourly urine measurements commenced. Central venous pressure and invasive arterial monitoring should be considered.

THE USE OF SOLUTE-ALKALINE DIURESIS

The development of acute renal failure in these patients significantly decreases chances of survival (Ward 1988). Every effort must be made therefore to prevent it occurring. Alkalisation of urine and the use of solute-alkaline diuresis is accepted to be protective against the development of acute renal failure (Better 1990, Better et al 1991).
9. Consensus view on solute-alkaline diuresis: > It is recommended that urine pH is measured and kept above 6.5 by adding bicarbonate in 50mmol aliquots (50ml of 8.4 per cent sodium bicarbonate) to the intravenous fluid regime. Solute diuresis is affected by administering mannitol at a dose of 1-2g/kg over the first four hours as a 20 per cent solution, and then enough to maintain urine output of at least 8l per day (300ml per hour). Fluid requirements are high, usually of the order of 12l per day, due to the sequestration of fluid in muscle tissue. Fluid should be given at approximately 500 ml per hour but regular review of clinical parameters such as central venous pressure and urine output should dictate exact amounts of fluid given. The maximum daily dose of mannitol is 200g and should not be given to patients with established anuria.

CHILDREN

10. Consensus view on children: > There is little evidence in the literature to guide treatment of children with crush injuries. In very young children, the difference in body proportions, namely the reduced percentage contribution to the total made by the limbs, may influence the incidence of crush syndrome. Advanced paediatric life support (APLS) guidelines on fluid resuscitation (Advanced Life Support Group 2001) suggesting an initial bolus of 20ml/kg should be followed.

ELDERLY PATIENTS AND PATIENTS WITH CO-MORBIDITY

11. Consensus view on elderly patients and those with co-morbidity: > In elderly patients and those with pre-existing conditions such as cardiac failure, fluid replacement must be tailored to requirements and given with caution. Close monitoring of clinical state and regular review of fluid requirements are essential.

COMPARTMENT SYNDROME

The development of compartment syndrome in crush injury is due to the uptake of fluid into damaged muscle tissue contained within the restricted compartment. Once compartment pressure exceeds capillary perfusion pressure at about 30-40mmHg, the tissue inside the compartment becomes ischaemic and compartment syndrome develops. The traditional treatment of compartment syndrome is fasciotomy (Shaw et al 1994) but there is now evidence that initial treatment with mannitol can decompress compartment syndrome and avoid the need for surgery (Better 1999, Better et al 1991).

12. Consensus view on compartment syndrome: > In patients with compartment syndrome due to crush injury but no neurovascular compromise, a trial of mannitol therapy should be instigated and specialist opinion sought early.

HYPERBARIC OXYGEN THERAPY

There is theoretical and limited experimental evidence that hyperbaric oxygen therapy can improve wound healing and reduce the need for multiple surgical procedures in crush injury (Bouachour et al 1996). High oxygen concentrations cause systemic vasoconstriction despite delivering adequate oxygen. Similarly, nitric oxide synthase inhibitors can also have a role in preventing excessive vasodilatation in crushed muscle and consequent third space fluid loss (Rubinstein et al 1998).

13. Consensus view on hyperbaric oxygen therapy: > Logistically, hyperbaric oxygen treatment has limited application. Patients with no significant co-morbidity can be treated with hyperbaric oxygen therapy and managed in hyperbaric chambers, where these are available. It is recommended that treatment options are discussed with hyperbaric unit staff. This should not be first line treatment but patients should receive high flow oxygen unless there are specific contraindications.

FURTHER MANAGEMENT

14. Consensus view on further management: > Intensive care support will often be required for crush syndrome complications. If patients become oligo- or anuric, it is likely that they will require haemofiltration or dialysis.

References


Bywaters E, Beal D (1941) Crush injuries with impairment of renal function. British Medical Journal. 1, 427


**MULTIPLE CASUALTIES**

15. Consensus view on multiple casualties: >In UK civilian environments, there will be huge strains on intensive care facilities if there are multiple crushed casualties. Contingency policies at both national and international level should be drawn up to prepare for the dispersal of these casualties. Further information is available in Better’s review of 1999.

**AREAS IDENTIFIED FOR FUTURE RESEARCH**

Use of tourniquets

Is there a role for tourniquets post- or pre-extrication of crush injury casualties? Use of animal models of crush injury was suggested at the Birmingham meeting to assess the suitability of tourniquet administration, as was comparing tourniquet placement versus no tourniquet in delayed intravenous fluid administration. Are there any further deleterious effects of prolonged ischaemia due to tourniquet application? Could cooling limbs slow cellular respiration and consequently decrease oedema and compartment syndrome, and improve limb viability? Tourniquet effectiveness was highlighted as a potential shortfall in their use. A literature search on tourniquet use, particularly regarding their use in Biers blocks, is needed to determine the effectiveness of tourniquet types and drug leakage rates past the tourniquet. This may help establish the likelihood of potassium leaking into systemic circulation.

Fluid administration

Types of fluid currently used for drug administration include normal saline, Hartmann’s solution, dextran and starches. How much Hartmann’s solution should be given? Should we look at urine output, absolute volume intake or urine acidity as a guide to fluid administration? Oedema that is secondary to massive fluid administration may be detrimental. At what stage do we need to worry about this? What effect does it have on compartment syndrome?

Prognostic indicators

Creatinine kinase, myoglobinemia and amy- lase have been suggested as prognostic indicators but it is unclear whether they can predict outcome early enough to allow effective intervention. The use of microalbuminuria as a prognostic indicator of crush syndrome was suggested.

**Hyperbaric oxygen therapy**

Collaboration with the Institute of Naval Medicine (INM) in Gosport, Hampshire, was suggested to evaluate the merits of this treatment but met with little support due to the inconvenience of the INM having only one site.

**Bicarbonate administration**

Early administration of intravenous bicarbonate is thought to decrease metabolic acidosis and promote urine alkalisation, which decreases myoglobin precipitation in renal tubules. Administering bicarbonate immediately post-extrication in cases of anticipated metabolic acidosis was discussed. Has this been shown to be beneficial? Are there detrimental features? What would be appropriate and safe doses to use? Is there a role for the combined use of acetazolamide to prevent metabolic alkalosis following bicarbonate administration?

**Mannitol and compartment syndrome**

There is anecdotal evidence that compartment syndrome in crushed patients is best managed with mannitol alone because fasciotomy complication rates are so high. It is suggested that there is a noticeable difference in lower leg diameter and symptoms within 40 minutes of administering intravenous mannitol (Better 1999). Fasciotomy should be reserved for refractory cases.

Use of animal models was questioned due to anatomical differences from humans. Many animals, such as pigs, sheep and dogs, that are commonly used as models for humans do not have fascial compartments. Primates share similarities but would be more difficult to justify ethically. Further information on existing animal experimentation relating to compartment syndrome is required before planning further projects.