Management of IED Injury:

A Case Reflective of Contemporary Treatment and Understanding of Resources Required to Save Life

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Of times past:

When you're wounded and left on the Afghanistan plain

And the women come out to cut out what remains.

Just roll on your rifle an' blow out your brains

An' go to your God like a soldier.

– Rudyard Kipling

Of times present:

The improvised explosive device (IED) produces the most devastating complex tissue injury that contemporary military surgical teams have to deal with[1-2]. It is the signature form of wounding of present day Australian and Coalition service personnel[3]. A system of care that can deal with these injuries will, by definition, be capable of dealing with a wide range of other injuries. This system must also be able to deal with civilian injury and illness- both adult and paediatric- that will be unavoidable in conflict. There is a readily accepted moral and humanitarian responsibility to be prepared to treat such casualties.

The whole tenet of asymmetric warfare is to damage morale and mission by sudden brutal demoralizing strike in a political environment in which the loss of life of the military personnel carries sensitive consequence. Protection by warfare means have been developed (fighting doctrine, personal protection, offensive and defensive technology). The principle lesson of the present time is that health protection by means of appropriately equipped hospitals, with appropriately trained staff can be developed to meet this threat, but they require a depth of resource and skills available to manage such wounding[4].

Care of the combat wounded involves many in the battle space, and with varying degrees of sophistication. Modern treatment dictates actions by all involved from the point of wounding through to sophisticated transfer out of the Area of Operations. This paradigm is illustrated in Figure 1 (next page).

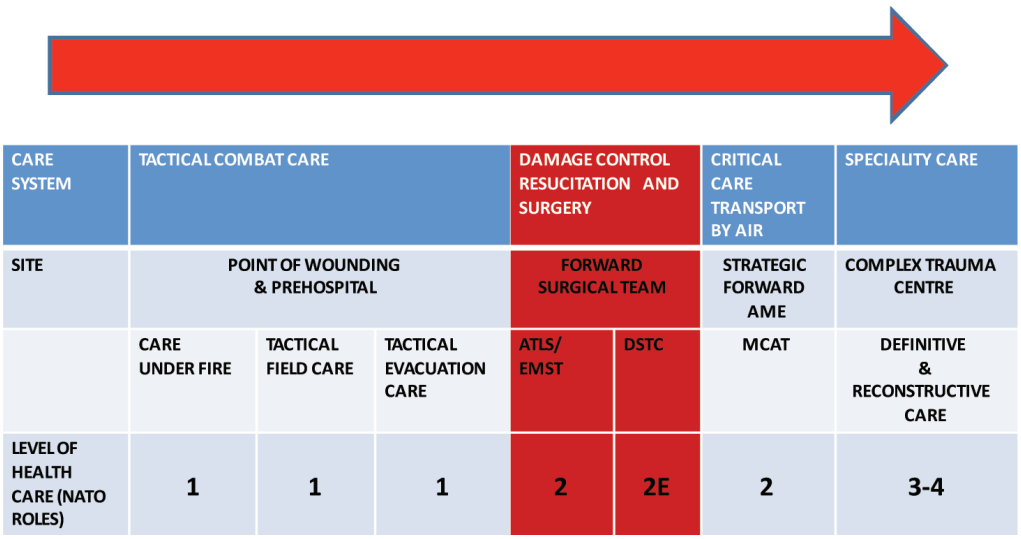

Figure 1: *Levels of Care across the Battlefield.*

All stages of the system need to be in place to ensure the optimal care of the combat wounded. It must be acknowledged, right from the start, that the provision of the system of combat casualty care is expensive, people and resource intensive and requires robust, flexible and responsive logistic support. Resuscitation, Surgery and Intensive Care must be proximate, and varying types of aero- medical evacuation must be available in a timely manner to transport casualties between various levels of care, including intercontinental[4] .The very size and complexity may well mean it is likely beyond the capability of one national military element to provide it or sustain it totally, and that it will most often be achieved by collective effort of a coalition of partner nations.

Using such systems of care has yielded results[4-6]. The risk of death from military wounding has never been lower and more severely injured are surviving, with wounds that were likely fatal in previous conflicts [4,6].

The authors present a case of severe wounding which is illustrative both of the comprehensive system of care and the cooperation of various coalition health assets to achieve survival in an otherwise extremely severe combination of injuries. This patient, with traumatic below limb partial amputations and pelvic fracture, nearly died from hypovolaemaeic shock. Cold and acidotic he experienced a severe coagulopathy which complicated these injuries. Using contemporary techniques life was saved and the patient returned to his home country (Holland) and made a documented good physical recovery.

Wounding

Towards the end of its mission in Afghanistan in April 2008 the 10 person Australian Surgical Team (AUS MTF1) had been relieved in place in the Dutch-Australian Role 2E Hospital Camp Holland, Oruzgan Province.

At this time notification was received that 3 urgent surgical cases were expected from an IED strike against a coalition vehicle convoy. It eventuated that two of the patients had minor injuries. The driver was more severely injured, and is the centre of this discussion.

Commentary:

Pre-hospital care has improved, especially with the routine use of pressure bandages, haemostatic agents and combat tourniquets[6] . The doctrine of Tactical Combat Casualty Care (TCCC)[6, 7], known in Australia as Care of the Battle Casualty, is well rehearsed amongst soldiers and widely practiced.

In this scenario the receiving medical teams really have a very wide expectation of numbers of casualties and type of injury. There is a realisation that information provided in a NATO Nine Liner CASEVAC is provided in the heat of battle and can vary in accuracy...all the treating team is sure of is to stand by to receive potential seriously injured coalition members.

In the setting of a medium size forward surgical team this will be a challenge. The multiple casualty plan is activated, and three resuscitation teams are stood up- the duty team, the off duty team and a composite team made of the primary health care team staff assemble. Surgical space is cleared, and throughout the hospital teams wait in readiness to receive. All stretcher teams are made ready, the Operating Room (OR) is prepared, and Pathology, Radiology and Intensive Care Unit (ICU) clear all tasks. The Senior Nursing Officer assesses all inpatients for possible ambulatory discharge if necessary.

Resuscitation

On arrival the patient was alive and responding. Pre-hospital care had focussed on physical security of the patient, the application of bilateral tourniquets and rapid evacuation. It was clear that he had suffered very complex lower limb injuries with blood loss, and at this stage extremity bleeding was controlled. Airway and breathing assessment showed he had a clear airway by virtue of his conversation and his trachea was midline, oxygen saturation was 99%. The presence of tympanic membrane rupture was noted. Two above knee tourniquets had been placed and these remained in situ.

The resuscitation team worked around him with a main effort directed at assessing and treating his hypovolamic shock. The initial haemodynamic parameters showed the patient to be in probable Grade 3 shock: blood pressure 90/40 mmHg, PR 120

Figure 2: *Complex Lower limb IED Injury*

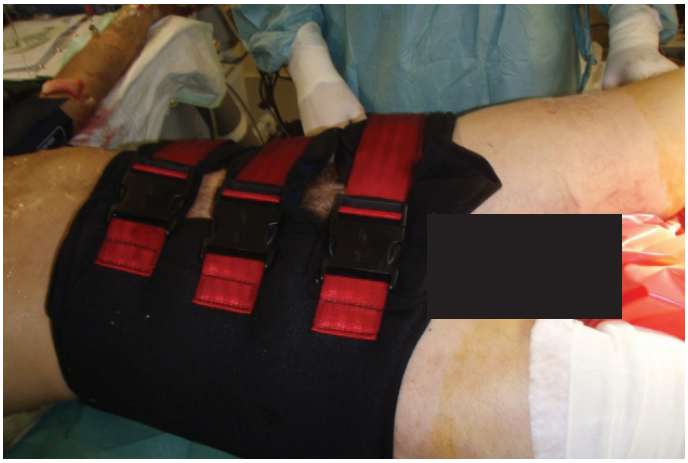

Figure 3: *Pelvic Sling in situ*

bpm, pale with capillary return > 2 secs. Warming was begun. The trauma x-ray series was performed, and the pelvis x-ray showed a significant vertical shear fracture of the pelvis. A FAST showed free pelvic fluid. A pelvic binder was applied. Bloods were drawn as baseline studies. At this time the resuscitation was not guided by them, but rather by the obvious injuries suffered and the haemodynamic parameters. Time was not wasted in dressing wounds as he would shortly move to the next room for surgery. It was clear that the tourniquets were effective.

Direct liaison with the pathology technicians alerted them to the need for rapid availability of blood product-including packed cells, fresh frozen plasma and platelets. In this case all blood products where supplied frozen. While there was always a certain amount defrosted, ready for immediate use, it was obvious this supply would soon be exhausted and so staff began the process of defrosting, washing and cross matching more blood. Additional staff was called upon to aid this process.

Commentary:

Control of blood loss remains the highest priority for resuscitation teams, and this is combined with obtaining intravenous access. Large bore peripheral lines will most

often suffice; intra-osseous access is reliable and quick, with an estimation of 95 % success within ninety seconds. Central venous cannulation has a role in experienced hands only and should not delay transfer to the OR.

The understanding of the coagulopathy of severe trauma has been informed by experience in Operations Iraq and Enduring Freedom8, and resuscitation with whole blood, platelets and coagulation factors has led to improvements in the care of coagulopathic wounded[4, 7-9]. Aggressive warming, restriction of crystalloid, and the doctrine of damage control resuscitation are understood, and part of routine forward care [4,9].

The need for large volumes of blood product is recognised now by the development of massive transfusion protocols, and the ability to switch to these directly in cases of severe wounding has promoted survival in cases of complex, severe military wounding. It has been estimated that up to 7% of battle casualties may require massive transfusion[9].

Blast injury contains at least three elements of possible injury: blast overpressure, fragmentation and burn. Other more complex elements in this scenario can include consequent vehicle crash, trapping by compression and secondary attack whilst alighting from the vehicle. The injuries can be complex, with many elements. Traumatic brain injury and mid face injuries are common enough, and can add to the injury severity score[10-12].

The suspicion of primary blast injury (with pulmonary and cerebral effect) is highlighted by recognising the mechanism of injury and by the presence of perforated tympanic membranes, though not excluded by absence of the latter[10,11]. The Resuscitation Team (and later the anaesthetist) should be alert to the potential need for intercostal catheterisation[12]. CXR is an important adjunct in this assessment.

Figure 4: *AP Pelvis x-ray showing vertical shear fracture.*

Surgery

From the time of wounding it was clear that this patient would require surgery and as resuscitation continued the Anaesthetist began the process of assessment and consideration for rapid transition to the OR for damage control surgery, and it was becoming clear that the signs of blood loss were ongoing and could not be accounted for by his leg injuries alone.

The anaesthetic pre-operative assessment issues included consideration of timing for intubation. By this time the patient was increasingly shocked with HR of 172 bpm and systolic BP 60mmHg, after an initial bolus of 2 litres of crystalloid. With the patient still talking and without airway issues, intubation is probably best performed at the time of anaesthetic induction, when the surgeons are ready to start operating. All effort is focussed around preventing delay in commencing surgery. In this man, by virtue of his age and service, the absence of co-morbidities was assumed. He was cold, and despite attempts at warming the exposure required to identify injuries, perform x-rays and ultrasound and commence resuscitation had allowed heat loss by evaporation and refraction. Rapid assessment showed this would be an issue. At this time the anaesthetist was also the intensivist and the ICU needed to be made ready, including clearing and preparing a bed.

The Australian surgical team were asked by their Dutch colleagues to help.

Rapidly the three surgeons moved to complete the amputations. Surgical pneumatic tourniquets replaced the combat application ones, and rapid (in this case guillotine) amputations completed.

As the patient remained very unstable, ongoing bleeding into the pelvis was assumed the cause. Angiographic embolisation was not possible in the forward surgical facility and in consultation the surgeons decided stabilisation followed by damage control laparotomy with packing was next. A pelvic fixator was applied rapidly with anterior compression to close the pelvic volume and stabilise the pelvis, but all recognised the limitations of this in a vertical shear fracture. With continuing instability a laparotomy was performed which showed extensive pelvic haematoma. Despite initial packing the pelvic bleeding continued, after discussion the situation was universally concluded to be desperate. As a final surgical intervention the left common iliac artery was ligated, the pelvis repacked and the abdomen left open with drains and negative wound pressure dressing in situ.

Intraoperative Lab Results
pH 7.115
paCO2 43.0 mm Hg
paO2 142 mm Hg
HCO3 14 mmol/L
Base Excess -16 mEq/L

Table 1: *Intra-operative Pathology results*

The challenges of Anaesthesia for this man were keeping up with blood loss (both observed and unknown), his hypothermia (inadequate temperature monitoring was a challenge), his evolving acidosis and the coagulopathy. Vasoconstrictor (noradrenaline infusion) was commenced at this time. Perioperatively he was transfused 22 units of packed cells, 15 units of fresh Frozen Plasma and 6 units of platelets with a dose of 60 micrograms/kg of Factor VIIa, which in the presence of severe hypothermia and acidosis may not have been effective.

The intraoperative physiological features showed increasing acidosis (Table 1). His coagulopathy is

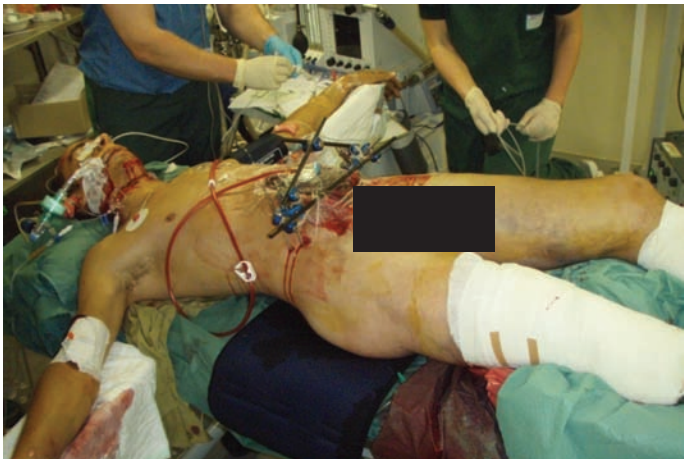

Figure 5: *Coagulopathy apparent at the end of surgery.*

illustrated in the Figure 5. In this clinical photograph the observer can note general ooze from every line site, the external fixation pins and even his multiple small facial lacerations.

Commentary:

The understanding of the role of damage control surgery has been informed by wounding in the recent era of operations in Iraq and Afghanistan. The principles of this approach, developed by Rotando[13], Schwab[14] and Holcomb [15]and others are highlighted in figure 6. The key features are very short duration haemostasis surgery, performing only life and

DAMAGE CONTROL KEY PRINCIPLES

- HAEMOSTASIS (CABC)
- TIMELY METICULOUS WOUND DEBRIDEMENT
- DECONTAMINATION
- ADEQUATE DRAINAGE
- IMMOBILIZATION INCLUDING FRACTURE STABILISATION
- DELAYED WOUND COVERAGE OR CLOSURE
- APPROPRIATE ANTIBIOTICS

Figure 6: *Key principles of damage control surgery CABC is the philosophy of identifying and treating life threatening circulation (C) problems ahead of airway and breathing issues (ABC).*


KELLY

limb saving surgery with rapid transition to ICU where the physiological derangements associated with such major injury are reversed, and then for more complex surgery to be performed later. These later surgeries may be done by the forward surgical team, so as to allow transfer ("stabilisation") or later in a more advanced hospital, usually out of the Area of Operations[4, 15].

Intensive Care and Preparation for Evacuation.

As day turned to night, following packing of the pelvis and abdomen, the patient arrived in ICU with his abdomen open and obviously coagulopathic. The challenge of blood product transfusion seemed huge and all were aware that surgical options had been exhausted. He continued to bleed. He still seemed volume depleted. He remained on high dose noradrenaline, his temperature was 33.4 oC. His blood pressure was 110/50 mm Hg, and he was tachycardia (110 bpm). Measured urine output was minimal. He remained intubated and sedated on IPPV, 40% FiO2. The Factor VIIa dose was repeated (60microgms/kg) and once again in the presence of hypothermia and acidosis was likely to be ineffective.

The situation looked grim. The surgical team talked despondently of repacking the abdomen if necessary .Physiologically the patient was more acidotic, and despite transfusion and surgery his haemoglobin had fallen to 65 g/L and now measured for the first time, his coagulopathy was significant.

Lab Results on arrival in ICU
pH 7.108
paCO2 55.4 mm Hg
pO2 103 mmHg on 40% FiO2
HCO3 18 mmol/L
Base Excess -12 mEq/L
PT 21 sec
APTT 55 sec Hb 65 g/L

Table 2: *Laboratory results on return from OR.*

Arrangements were put in place for aeromedical evacuation, his condition from the outset realised to require definitive treatment elsewhere. At this stage the patient was far from stable enough to transfer, and it was uncertain if he would become so. Clearly the focus of the entire medical treatment facility was around his care, with little spare capability if other needs arose.

Over the next 18 hours he was rewarmed but still remained acidotic. (Ph. 7.29, Base Excess –10 mEq/L) and coagulopathic (APTT 63 sec, PT 20 sec, Platelet count 13x10 6 /L). Transfusion of blood and factors continued and Noradrenaline was administered at high dose. The mean arterial pressure stayed at a 75 mmHg and his urine output established and continued at around 70mls/hour. However his measured blood loss was 300 ml/hr and he remained unfit for flight.

Evacuation to Europe, an expensive resource intensive arrangement and highly necessary for this patient, was potentially being delayed and possibly turned around. The next course of action was far from clear. Our Australian anaesthetist, a highly experienced intensivist, worked with her Dutch colleague to treat the coagulopathy. More blood components, especially platelets were transfused. Ventilation was adjusted to help mitigate the acidosis. With these measures plus the fact that the patient was no longer hypothermic allowed a more appropriate dose of Factor VIIa (120MCG/kg) to be administered along with Vitamin K. Tranexamic acid was not available. With modern communication the intensivist was able to discuss the actions taken with colleagues in Australia ("phone a friend").

Figure 7: *UK Critical Care Evacuation Team*

Within 3 hours he was weaned off Noradrenaline and all bleeding had ceased. Repeat arterial blood gases showed that his coagulopathy and acidosis had been corrected.

A British intensive care retrieval team, launched several hours before, arrived at this time and were able to transport the patient without difficulty on a ten hour flight, during which he was stable without the need for transfusion or further inotropes. Eighteen months later an Australian team preparing for deployment in Holland became aware of his further good function when casually reading an article in a Dutch Army magazine.

Commentary:

The coagulopathy of trauma[9] exacerbated by hypothermia and acidosis (i.e. "lethal triad") nearly killed this soldier, and this case illustrates the comprehensive system of care that is required for supportive medical treatment of such cases. Blood products in sufficient amount are required. Crystalloid to replace volume should be restricted as much as possible. Red Cells with platelets and fresh frozen plasma are recommended to be given in a 1:1:1 ratio from the outset[9, 16]. Although a walking blood bank can provide warmed coagulation factor and platelet rich blood, it was not available in this situation. A frozen blood bank was, and through this means the massive transfusion required was achieved[16]. Greater than 100 units of blood products were transfused including 65 units of packed cells and 25 units of platelets (note larger volume than Australian equivalent). Without a frozen blood back with its capacious supply it is possible that his transfusion requirements

would not have been met by a walking blood bank. Even then it required hard work by technicians as the frozen blood must be washed and prepared. Two persons can produce 6 units of blood in two hours from a frozen supply. Defrosting of platelets and fresh frozen plasma is quicker.

Acidosis alone promotes coagulopathy by impairing thrombin generation, is critical to optimal coagulation function and thus needs to be aggressively managed. This was achieved by volume loading with blood components once haemostasis was obtained. The desired end-state required is the restoration of a normal blood lactate, base deficit or pH as the ultimate goal[9]. This was achieved in the ICU, after some time and collaborative hard work.

Despite knowledge of the adverse effects of hypothermia as an independent variable for mortality in trauma[9,18,19]the treating team were challenged to keep this patient warm. The exposure required for resuscitation and surgery and the volume of fluid transfused, despite active warming of the patient and blood product, mitigated against maintenance of core temperature. His temperature was a dangerously low at 33.4 C on arrival in ICU. Events simply moved to fast on this occasion. Wishaw has outlined the physiology of hypothermia and mechanisms for rewarming[20].

The patient received Factor VIIa on three occasions, and it was not till the patient's acidosis and hypothermia were corrected, that a larger dose in combination with Vitamin K reversed his coagulopathy. At the time of this case the early use of Factor VIIa was thought to be associated with a fall in early mortality in severely wounded combat casualties[21], but later evidence has shown this not to be the case though it is associated with a lower need for blood product[22]. Tranexamic acid is becoming increasingly used in major trauma and likely will have an increasing role with similar cases in the future[23]. It was not available in this case.

His story was one of a profoundly quick physiological deterioration after injury and a long fight in ICU to reverse this.

Oxygen supply can be problematic. One ventilated patient on FiO2 50% with tidal volume 700mls at 12 breaths/minute needs 7,000 litres in 24 hours. In other words 10 Australian E Cylinders. Probably a portable oxygen generator is the best way to produce the very large amounts needed in all areas of a forward hospital.

Even in the forward surgical team the addition of an Intensivist is considered by many to be essential. This case illustrates the complex care required in the ICU, and it may be too much to expect a single anaesthetist to manage such a patient and keep working in an operating room on other cases. Fortunately this episode occurred at a time of relief in place, and support could be given by the departing team.

Holcolmb[9] makes the point that damage control resuscitation continues from arrival in the resuscitation bay through the OR and into ICU much more often in the severely injured battle casualty than in civilian practice. This supports the argument for an ICU physician separate to the Anaesthetist. This certainly was the case here, and for this reason is so illustrative of resources and personnel required for effective treatment.

Australian Medical Taskforce team (AUS MTF 1) at Tarin Kowt, Afghanistan.

Finally the care provided in this challenging case occurred on the platform of a physically robust hospital with excellent pharmaceutical and logistic support and adequate personnel. It represented the best that four nations could provide in cooperative health care and is the minimum standard expected.

Acknowledgement: the authors would like to thank their Dutch Colleagues who allowed us to share the care of this patient and learn from the events.

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