Aspects of resuscitation in trauma

J. P. Nolan and M. J. A. Parr

In 1988, the Royal College of Surgeons Working Party Report on the management of patients with major injuries highlighted serious deficiencies in the way trauma patients were managed in the UK. At the end of the same year, in an attempt to improve evaluation of UK trauma services, several hospitals started to contribute data to the Major Trauma Outcome Study (MTOS (UK)). This audit system had been established in the USA by Champion and colleagues in 1982. The first report from MTOS (UK), published in 1992, was based on 2 yr of data from 33 hospitals. Unfortunately, its conclusions echoed those of the Royal College of Surgeons’ report 4 yr earlier: “the initial management of major trauma in the United Kingdom remains unsatisfactory”. Specifically, the mortality for 6111 patients sustaining blunt trauma and treated in the 14 busiest hospitals was significantly higher than that predicted from a comparable US data set (actual 408 vs predicted 295.6; \( P < 0.001 \)).

Other key findings from this report were: (a) 21% of patients with an injury severity score (ISS) greater than 15 took longer than 1 h to reach hospital, and (b) a senior house officer was in charge of initial hospital resuscitation in 57% of seriously injured patients.

What initiatives have been taken in an attempt to correct these deficiencies in trauma patient management? Has the outcome for seriously injured patients in the UK been improved? This review addresses these questions while covering the following topics: pre-hospital trauma resuscitation, communication, advanced trauma life support (ATLS), trauma teams, airway management, fluid therapy and resuscitation end-points.

**Pre-hospital trauma resuscitation**

Apart from the severity of injury, probably the single most important factor determining the outcome of a trauma patient is the time interval from the moment the injuries are received to the provision of definitive care. Definitive care for the trauma patient implies achieving a clear airway and effective ventilation, haemorrhage control and restoration of an adequate blood volume.

A recent retrospective study of pre-hospital trauma deaths in North Staffordshire reported that, on the basis of post-mortem evidence, airway obstruction had been present in two-thirds of those patients in whom death was judged not to have been inevitable. Although one can criticize the design of this study, there is a clear message: more bystanders must be trained in simple first-aid and the interval between the time of injury and arrival of the emergency services must be reduced. The authors of this study suggested that first-aid could be tested at the time of the driving test. Current standards for ambulance response times dictate that 50% of all calls are responded to within 8 min and 95% within 14 min (urban areas) and 19 min (rural areas). The ambulance performance standards have been reviewed recently and in the future some form of prioritized dispatch system will be used in an attempt to achieve the new government targets (Table 1).

The main controversies in pre-hospital trauma management concern the type of pre-hospital provider and the interventions they perform. In common with the emergency medical services (EMS) in the USA, most of the UK uses a

<table>
<thead>
<tr>
<th>Category</th>
<th>Response Times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediately life threatening (category A*)</td>
<td>90% &lt; 8 min**</td>
</tr>
<tr>
<td>Serious (category B)</td>
<td>50% &lt; 8 min</td>
</tr>
<tr>
<td>Not life-threatening or serious</td>
<td>Local decision</td>
</tr>
</tbody>
</table>

*Patients in category A are:
A1. Adults with chest pain associated with any of the following: pallor, cyanosis, shortness of breath, sweating, nausea or vomiting; but specifically excluding those for whom the pain is intensified by breathing.
A2. Individuals who are unconscious, fitting or unresponsive for any cause.
A3. Individuals with severe breathing problems who are unable to speak whole sentences.
A4. Injuries to the head or trunk.
A5. Individuals recognized as having anaphylactic shock.
A6. A woman with severe obstetric haemorrhage.
A7. A child under the age of 2 yr.

**An interim target of 75% within 8 min has been accepted for implementation in England from 2000–2001.

Key words

paramedic-based system. In other parts of Europe (in particular, France, Germany and Belgium) ambulance technicians are supported by physicians, usually anaesthetists, in mobile intensive care units (MICU). In the UK, ambulance technicians are trained in basic airway management, cervical spine control and shock advisory defibrillation. Paramedics have the additional skills of tracheal intubation, i.v. cannulation, fluid therapy and use of i.v. analgesia. Supplementary skills provided by physicians include: use of neuromuscular blocking drugs and a broader range of analgesia and fluids, insertion of chest drains, cricoid pressure and the ability to triage the patient to the most appropriate hospital. In theory, the physician’s ability to provide a more sophisticated and individualized continuum of patient care (not necessarily protocol-driven) in the initial hospital phase may expedite definitive care. Unfortunately, there are no randomized, controlled studies proving that the outcome for trauma patients is influenced by the type of pre-hospital provider or even the procedures performed. There are only small, retrospective, observational studies which have produced conflicting results. Some studies have suggested that ALS procedures improve physiological variables but not outcome. One of the problems with pre-hospital trauma studies is the lack of a uniform system or set of definitions for reporting results. A working group has been convened to develop “Guidelines for uniform recording and reporting of performance and outcome after trauma” very much along the lines of the Utstein template for the reporting of pre-hospital cardiac arrest. It is hoped that this will enhance the ability to compare data derived from different EMS systems.

A prominent American emergency physician stated recently that “despite our beliefs and biases, EMS is enormously over-funded in relation to our current ability to scientifically justify its effectiveness.” This dearth of quality data fuels the “scoop and run” vs “treat in the street” debate. To address this problem in the UK, the NHS Executive have commissioned the Medical Care Research Unit at the University of Sheffield to carry out an evaluation of the use of paramedic skills in pre-hospital trauma care. This study involves three ambulance services and compares treatment by ambulance personnel with basic life support (BLS) skills only with first response by BLS crew with an ALS crew attending when requested, with immediate attendance by an ALS ambulance crew. The study is in part a retrospective, observational study, and in part a prospective, randomized study. It will assess the cost-effectiveness of ALS skills and their influence on various outcome measures. The results of this study will be presented later this year (S. Hughes, personal communication). In the meantime, except where patients are trapped, it would seem logical to limit interventions at the scene to establishing an open airway and effective ventilation, controlling external haemorrhage with pressure and expediting transport to a trauma centre. For penetrating cardiac injuries, delays of just 15 min in transportation increase morbidity and mortality, and rapid transport with BLS may give the best chance of survival.

PRE-HOSPITAL ADVANCED AIRWAY MANAGEMENT

Airway management of the trauma patient in the pre-hospital setting is fraught with difficulties. As yet, there is no perfect method. The ideal would be a simple technique that provided effective ventilation, with little risk of gastric insufflation, and which did not have adverse cardiovascular effects in hypovolaemic or head-injured patients. While tracheal intubation remains the gold standard for airway management, it is often an unrealistic expectation in the pre-hospital setting. Pre-hospital personnel must be taught the technique and perform it frequently enough to maintain the skill. They are not able to use neuromuscular blocking drugs, access to the patient may be difficult and being able to see the larynx in strong sunlight can be almost impossible. To compound the problem, the popularity of the laryngeal mask among anaesthetists is limiting the opportunity for paramedics to learn and practice intubation. Are there satisfactory alternatives?

Bag–valve–mask

Bag–valve–mask ventilation with the use of oropharyngeal or nasopharyngeal airways is a difficult skill to master, is best performed by two individuals and has a high potential for gastric insufflation.

Combitube

The Combitube is a double-lumen tube which is designed to ventilate the patient’s lungs whether the tube enters the trachea or the oesophagus. It enters the oesophagus in approximately 90% of insertions. Massive inflation of the stomach occurs if ventilation is applied to the incorrect tube, so confirmation of correct placement is essential. The Combitube has been used successfully during cardiopulmonary arrest and has been evaluated by paramedics in the pre-hospital setting but is contraindicated in severe oropharyngeal trauma.

Laryngeal mask airway

The laryngeal mask airway (LMA) allows rapid, effective ventilation with a single operator, with improved oxygenation, less hand fatigue and probably less risk of gastric insufflation compared with bag–mask–valve ventilation. Although the LMA does not completely protect the airway from aspiration, the risk of this has almost certainly been overstated. Furthermore, the significant risk of unrecognized endobronchial, or worse, oesophageal placement of a tracheal tube is often overlooked. From the perspective of ambulance service personnel, the LMA has several advantages compared with the tracheal tube. Training in use of the LMA is quicker and easier than for tracheal intubation and the retention of skills with the
LMA is better; this would overcome some of the training difficulties faced by ambulance trusts.

The LMA protects the upper airway from soiling from above. This is particularly relevant to the trauma patient with maxillofacial injuries in whom the risk of aspiration of blood is greater than the risk of aspiration of gastric contents. In a recent review of severe trauma patients, 15 patients had aspirated before arrival of an ambulance; of these, 12 had aspirated blood, only two had aspirated blood and vomit, and one had aspirated vomit only.

The LMA may be inserted successfully where access to the patient is limited, for example in entrapments. The LMA can be inserted from the front of the patient while the head and neck are maintained in neutral alignment. Insertion of the LMA causes less cardiovascular response and increase in intracranial pressure (ICP) than laryngoscopy or tracheal intubation. Thus the LMA may offer some advantages for head-injured patients where the increase in ICP in response to laryngoscopy and tracheal intubation, and any coughing and straining, contributes to secondary brain injury. An observational study of pre-hospital use of the LMA has been reported from South Australia. Thirty ambulance officers attempted 233 insertions in the field over a 12-month period and achieved 81% success rate. Sixteen of these were in trauma patients.

In the UK, it would seem logical for both ambulance technicians and paramedics to be trained to insert LMA. The LMA provides the technician with a more effective device than the simple Guedel airway, and gives the paramedic a backup should intubation prove impossible.

PRE-HOSPITAL SURGICAL AIRWAY

If a patient has an obstructed airway, and intubation or LMA insertion are not possible, cricothyroidotomy is a life-saving procedure. In many North American states paramedics are trained to perform cricothyroidotomy and apparently achieve this with considerable success. A recent study of 50 cricothyroidotomy attempts in trauma patients by paramedics in Indiana concluded that the procedure was successful in 47 (94%). This is in close agreement with a study of the procedure performed by air ambulance flight nurses in which a surgical airway was established successfully in 68 of 69 patients (98.5%), with an acute complication rate of 8.7%. As yet, paramedics in the UK are not trained to perform surgical airways. One of the main concerns expressed by ambulance service trainers is that the likelihood of any given paramedic having to perform the procedure would be very low, therefore, even if they could be trained they would have a limited opportunity to maintain the skill. Although this is undoubtedly true, the same argument must apply to most anaesthetists, yet we, quite rightly, are expected to perform a surgical airway in an emergency. Physicians on the London Helicopter Emergency Medical Service (HEMS) perform cricothyroidotomy if a secure, patent airway cannot be established by any other means. HEMS doctors attend to particularly difficult (often trapped) trauma cases and are in a unique position to collect data on the pros and cons of pre-hospital cricothyroidotomy.

PRE-HOSPITAL I.V. FLUID MANAGEMENT

Should a severely injured patient be given i.v. fluids before arrival at hospital? This question is at the hub of the most controversial debate in pre-hospital trauma patient management. Many of the issues also apply to in-hospital fluid resuscitation. The two opposing views on fluid resuscitation are discussed in turn, followed by what we think is a rational solution!

Do not give pre-hospital i.v. fluid

Provided that pre-hospital times are short, some would argue that establishing venous access is not a priority, that the procedure is time consuming and that insignificant volumes of fluid are infused before arrival at hospital. Furthermore, in the presence of uncontrolled bleeding, aggressive fluid therapy may be detrimental. On the basis of several animal studies of uncontrolled haemorrhage it was concluded that i.v. fluids increase arterial pressure but also reverse vasoconstriction, dislodge early thrombus, increase blood loss, cause a dilutional coagulopathy and reduce oxygen delivery causing a metabolic acidosis. In these animal studies, allowing arterial pressure to stay low until control of haemorrhage was achieved, so-called permissive hypotension, improved survival. A close clinical analogy is the patient with a ruptured abdominal aortic aneurysm. In these cases it has been suggested that fluid resuscitation should be minimal in all but the moribund, and a systolic arterial pressure of 50–70 mm Hg should be maintained until the aorta is clamped. The mortality rate of 23% quoted by protagonists of this approach contrasts markedly with a mortality rate of 70% in aneurysm patients who received vigorous fluid resuscitation before surgery. The laboratory research was transplanted to the clinical trauma arena by Bickell and colleagues. In a prospective, controlled study, patients with penetrating torso injury and a pre-hospital systolic arterial pressure of less than 90 mm Hg received either standard i.v. fluid therapy or underwent venous cannulation but received no fluid until arrival in the operating theatre. Of 289 patients receiving delayed fluid resuscitation, 203 (70%) survived to discharge from hospital, compared with 193 of 309 patients (62%) who received immediate fluid resuscitation ($P=0.04$). In a more recent analysis of these data, patients were sub-grouped into major vascular injury, solid organ injury, non-cardiac injury and cardiac injury. While there was a trend towards an improved outcome in all groups, the only patients in whom a statistically significant improvement in in-hospital mortality could be demonstrated were those with penetrating cardiac injury. This study has raised many methodological concerns and several traumatologists disagree with the authors’ conclusions.
Give pre-hospital i.v. fluid

The opposing view is that fluid resuscitation should be started immediately because the longer the period of hypotension, the greater the risk of complications and death, and that hypovolaemia is the cause of one-third of pre-hospital fatalities. Most clinicians would agree that the conclusions of the study of Bickell and colleagues were obtained under very specific circumstances: all patients were injured within the city limits of Houston, only those with penetrating injuries to the torso were included, the mean age of patients was only 31 yr and pre-hospital times were extremely rapid (mean interval between call and arrival at the trauma centre was 30 min). Furthermore, the authors did not discuss the causes of death or details of airway intervention. It would be unwise to extrapolate the findings of this study to older patients with chronic illness, blunt trauma, those with head injuries or to other EMS systems where pre-hospital times may not be as short. There are problems extrapolating from laboratory animal studies to the human trauma victim. Although in porcine models gut barrier function remains intact and survival is good after prolonged hypotension with a mean arterial pressure of 40 mm Hg, the same may not apply to the trauma patient with complicated multiple pathology.

There are at least two circumstances where minimal or no pre-hospital fluid resuscitation is likely to be extremely detrimental: patients with head injury and those where pre-hospital times are prolonged. In both of these situations there is little point in delivering the patient for definitive care when they have already received an overwhelming ischaemic insult. The patient will die regardless of the quality of in-hospital resuscitation. Hypoxia or hypotension increases dramatically the morbidity and mortality after severe head injury, and therefore oxygenation and an adequate cerebral perfusion pressure must be maintained at all times. As cerebral perfusion pressure \( \text{CPP} = \text{MAP} - \text{ICP} \) and assuming an ICP of 20 mm Hg in a patient with a severe head injury, MAP of at least 90 mm Hg needs to be maintained to provide a CPP greater than 70 mm Hg. Hypotension must be treated aggressively to prevent irreversible ischaemia.

Where the pre-hospital phase is prolonged, adequate perfusion of vital organs (especially gut and kidneys) reduces the risk of subsequent multiple organ failure. The gut is a silent organ in the resuscitation setting. Gut perfusion suffers early and may not return despite achieving apparently appropriate resuscitative goals (see resuscitation end-points, below).

A solution to pre-hospital fluid therapy

There is little doubt that the arrival of the trauma patient in the emergency department with venous access secured is an advantage. Attempts at pre-hospital venous cannulation are acceptable provided they do not delay the transfer of the patient to definitive care or distract from maintaining an open airway with effective ventilation and haemorrhage control. Cannulation en route does not add extra time and surprisingly may be as successful as when attempted at the scene.

It is difficult to generalize but in most circumstances fluid resuscitation should be kept to the minimum required to maintain a viable outcome for vital organs until definitive control of haemorrhage has taken place. What is the minimum for any given patient and how can this be assessed in the difficult pre-hospital environment? Should we accept a relatively low arterial pressure. Sustained hypotension of less than 70 mm Hg for more than 30 min correlates with a mortality of 60%, yet allowing a systolic pressure of 50–70 mm Hg in arteriopathies with ruptured abdominal aortic aneurysms produced very good results. In reality, trauma patients represent a spectrum of pathology and what is ideal treatment for one is inadequate for another. Ideally, we should differentiate between uncontrolled and controlled haemorrhagic shock. In uncontrolled haemorrhagic shock control of bleeding has not occurred, haemorrhage is ongoing and aggressive i.v. fluid therapy is likely to increase bleeding. Rapid surgical control of haemorrhage is the priority; sufficient fluid resuscitation to ensure viable survival should be given until haemorrhage is controlled. The great difficulty comes in the translation of these ideals into procedures that can be followed by ambulance personnel. How does the paramedic know which trauma patient has uncontrolled haemorrhage and which does not. Ambulance services are very aware of current thoughts on trauma patient management and are already striving to reduce pre-hospital times. The Staffordshire Ambulance Service NHS Trust strongly encourages its paramedics to insert i.v. cannulae en route, rather than at the scene, unless the patient is trapped. Furthermore, fluid therapy is targeted to maintaining a radial pulse only (C. Carney, personal communication).

When the patient has received definitive care and haemorrhage has been controlled, the goals of resuscitation shift to optimization of oxygen delivery (see below). In clinical practice separation of these two phases may be indistinct because continued haemorrhage may not be definitively controlled by surgery alone and the ischaemic insult before haemorrhage control may determine long-term outcome.

Communication

Communication is vital in providing an efficient link between pre-hospital and in-hospital trauma patient resuscitation. The importance of having advanced warning before arrival of a severely injured patient in the accident department cannot be overstated. Ideally, the ambulance officer at the scene should be able to communicate directly with accident department staff via a talk-through link. This provides concise and essential information on the patient’s condition and the estimated time of arrival at hospital. Accident department staff can
then decide whether to alert individual specialists or, if it exists, the trauma team. Many hospitals have specific criteria for a trauma team call. With advance warning, medical and nursing staff can prepare a resuscitation bay for the patient's arrival.

In-hospital resuscitation

ADVANCED TRAUMA LIFE SUPPORT

A considerable advance in trauma patient resuscitation has been made by the introduction of the advanced trauma life support (ATLS) in the UK in the latter half of 1988. Unfortunately, this is very difficult to prove and only one group has documented a reduction in trauma mortality after the introduction of ATLS. The ATLS course manual and slides are produced by the Committee on Trauma of the American College of Surgeons (ACS). By its very nature, the course is didactic and an identical core content is taught to all doctors on ATLS courses across the world. Not unexpectedly, this has led to a certain amount of criticism, particularly from British anaesthetists. For example, earlier editions of the ATLS manual strongly promoted blind nasal intubation, a concept that was never accepted by UK anaesthetists. The UK ATLS Committee has had some influence on later versions of the manual and the approach to these controversial areas has been rationalized. ATLS provides a useful framework on which we can base our resuscitation efforts. Although the course is aimed at the single-handed physician working in a rural hospital, the ATLS procedures can be adapted easily for a team approach. It is testament to the perceived use of ATLS that since its introduction to the UK more than 9000 individuals have attended a provider course and there are now 621 ATLS instructors (O. Egerton, personal communication). More information on ATLS can be received from the ATLS office, Raven Education Department, RCS (tel. 0171 973 2102, fax 0171 973 2117, E-mail atlscrcseng.ac.uk).

The ATLS course focuses on the initial management of patients with major injuries during the so-called "golden hour". Donald Trunkey has described previously the trimodal distribution of trauma patient deaths. The first peak of death is within seconds to minutes of injury (e.g. severe head and chest trauma) and only measures to prevent trauma will reduce it. The second peak of death, the early deaths, are those dying, for example, from intracranial haemorrhage and multiple injuries with hypovolaemia; timely and appropriate resuscitation of these patients should reduce mortality. The third peak of death represents those patients dying, a few weeks later, from sepsis and multiple organ failure. Appropriate management of the patient in the resuscitation phase, with rapid restoration of cellular oxygenation, should also reduce this third peak of deaths. The classic "trimodal" distribution of trauma patient deaths has been challenged recently, but this should not detract from the philosophy of rapid, systematic and appropriate management.

THE TRAUMA TEAM

Trauma patient resuscitation is most efficient if undertaken by a team of appropriately trained doctors and nurses. In this way a variety of tasks can be undertaken simultaneously, a process known as "horizontal organization". The precise composition of the team inevitably varies from one hospital to another. The composition of a typical team and the team members' roles are listed in table 2. The role of the team leader is particularly important and has been defined comprehensively by a British

Table 2 Composition of a typical trauma team

- Team leader—primary and secondary surveys, co-ordination of team, overall responsibility for the patient while in the A&E department.
- Anaesthetist—airway, ventilation, central venous access, difficult peripheral access, fluid balance, analgesia
- Other doctor—all other procedures, chest drain, fracture splintage, urethral catheter
- Nurses x 2—measure vital signs, record data, remove clothes, assist doctors.
- Radiographer—cervical spine, chest and pelvic x-rays, other x-rays as requested by team leader.
- Porter—to take samples to pathology labs, to retrieve urgent blood from blood bank.

Table 3 The role of the trauma team leader (reprinted with permission)

- To offer advice to any hospital wishing to discuss or refer a patient, and to accept appropriate referrals
- To obtain a history from the ambulance staff (for direct admissions) or from the referring doctor and medical escort (for transferred patients)
- To examine the patient (performing primary and secondary surveys)
- To establish the priorities for investigation and intervention
- To co-ordinate the trauma team
- To maintain an overview, avoiding undue involvement in practical procedures, but intervening appropriately in critical situations.
- To supervise the administration of fluids, blood and blood products.
- To provide analgesia
- To request and interpret investigations in conjunction with other team members
- To consult with or refer to other specialists where appropriate, indicating any perceived needs for urgent intervention
- To supervise spinal precautions
- To supervise the patient during transfer within the hospital and during imaging procedures
- To co-ordinate the assignment of the consultant responsible for continuing care
- To arrange transfer to the operating theatre, intensive care unit or other ward area (or to another hospital when indicated), and to provide a detailed hand-over to their staff
- To review the patient subsequently to help maintain continuity
- To inform the family
- To excuse the trauma team members at the end of the resuscitation, and to debrief the team after difficult cases
- To make a detailed note in the patient's records and to record agreed information for audit.
Aspects of resuscitation in trauma

Trauma Society Standards Working Party (table 3).99 These standards represent the ideal and are probably achievable only by hospitals with relatively large trauma units. Nevertheless, many hospitals have worked hard to create a system that brings senior, experienced clinicians into the trauma resuscitation room before, or soon after, admission of a seriously injured patient.

PRIMARY SURVEY AND RESUSCITATION

The initial resuscitation of the trauma patient entails the primary survey, simultaneous resuscitation and identification of those injuries that require immediate surgery. The aim of the primary survey is to look systematically for immediately life-threatening injuries, in the order that they are most likely to kill the patient (table 4). If life-threatening problems are detected they are treated immediately, before proceeding to the next step of the primary survey. A head-to-toe examination of the patient is not undertaken until the patient’s vital signs have been stabilized.

Airway and cervical spine

Every patient sustaining significant blunt trauma, particularly above the clavicles, should be assumed to have a cervical spine injury until proved otherwise. These patients should have the cervical spine immobilized with a semi-rigid cervical collar and bilateral sandbags or blocks joined with tape or straps across the forehead (fig. 1)106 or by manual in-line stabilization (MILS). If the patient has an unstable cervical spine injury, further movement may cause or worsen injury to the cord. Thus all airway manoeuvres must be performed carefully, and without moving the neck.6 15 30 55 86 141 The cervical spine cannot be deemed undamaged until the patient has been examined by an experienced clinician and appropriate radiological procedures have been completed.154 A reliable clinical examination cannot be obtained if the patient has sustained a significant closed head injury, is intoxicated or has a reduced conscious level from any other cause.

In the unconscious patient, or in the presence of hemorrhage from maxillofacial injuries, the airway is best secured by placing auffed tube in the trachea. Other reasons for intubating the trachea of a trauma patient during the resuscitation phase are to improve oxygenation and control ventilation, and to allow appropriate procedures to be performed on uncooperative patients. For example, in the case of the combative, intoxicated trauma patient with head and other potentially severe injuries, induction of anaesthesia and intubation facilitate definitive investigation (e.g. CT scan) and prevent secondary injury (self-inflicted trauma and secondary brain injury from hypoxia, hypercapnia, hypotension and hypertension). There is increasing evidence that, if performed with care, tracheal intubation of a patient with a cervical spine injury carries relatively little risk.30 However, uncontrolled intubation in a patient with an unstable cervical spine injury can result in serious damage to the spinal cord.53 Thus a sensible approach to airway management of patients with known mechanisms of injury is to initially treat all of them as if they had an unstable cervical spine injury, even if the initial plain films are normal.131

The technique of choice for emergency tracheal intubation in a patient with a potential cervical spine injury is direct laryngoscopy and oral intubation with MILS, after a period of preoxygenation, i.v. induction of anaesthesia, paralysis with suxamethonium and application of cricoid pressure (fig. 2).29 152 Placing the patient’s head and neck in neutral alignment tends to make the view at laryngoscopy
worse but intubation is aided greatly by the use of a gum-elastic bougie. If intubation of the patient’s trachea proves impossible, a laryngeal mask may provide temporary oxygenation and ventilation while surgical cricothyroidotomy is performed.

Smooth induction of anaesthesia and neuromuscular block provide optimal conditions for intubation in high-risk patients. All anaesthetic induction agents are vasodepressors and respiratory depressants, and have the potential to produce or worsen hypotension. There is no evidence that the choice of induction agent alters survival in major trauma patients. Their appropriate use during resuscitation involves careful assessment of the clinical situation and thorough knowledge of their clinical pharmacology. The safest strategy is for the anaesthetist to use agents with which he or she is familiar; the trauma resuscitation room is not the place for experimentation. Major trauma patients are at significant risk of awareness. Anaesthetic requirements need to be judged, as always, on an individual basis and the risk of awareness kept to a minimum.

Severely injured patients requiring intubation generally fall into three groups: (a) patients who are stable and adequately resuscitated; they should receive a standard or slightly reduced dose of induction agent, (b) patients who are unstable or inadequately resuscitated but require immediate intubation; they should receive a reduced, titrated dose of induction agent (in this situation factors such as best guess, skill and experience come into play), and (c) patients who are in extremis, and are severely obtunded and hypotensive; here induction agents would be inappropriate but neuromuscular blocking agents may be used to facilitate intubation. As soon as adequate cerebral perfusion is achieved, anaesthetic and analgesic drugs should be administered.

Suxamethonium retains its status as the neuromuscular blocker with the fastest onset of action, and remains the first choice blocker for intubation of the acute trauma patient. The concerns that suxamethonium may cause an increase in ICP in severe head-injured patients appears to be overstated provided adequate anaesthesia is provided. Rocuronium is almost as fast in onset and is favoured by many trauma anaesthetists. In the US, before the availability of rocuronium, vecuronium was a popular choice for use in acute trauma patients.

Circulation
After arrival in hospital, failure to maintain an effective circulation remains the leading cause of death in severely injured patients. I.v. access. Severely injured patients require at least two large-bore i.v. cannulae. If peripheral placement of these cannulae is impossible percutaneously, other options include: cut-down on a peripheral vein, percutaneous femoral cannulation, central venous cannulation or the intraosseous route. Cut-downs have few complications and can be performed quickly with minimal training. Possible cut-down sites include: the antecubital fossa, saphenous vein at the ankle and proximal saphenous vein. Most anaesthetists are more familiar with the Seldinger technique for placement of large bore cannulae and this choice is supported by a multicentre, prospective, randomized study comparing i.v. access by saphenous cutdown with percutaneous femoral cannulation. In a total of 78 trauma patients, the mean time for cut-down (5.6 ± 2.6 min) was significantly longer than that required for percutaneous femoral cannulation (3.2 ± 1.2 min). The main disadvantage of the percutaneous femoral approach is that it requires a palpable femoral arterial pulse. Internal jugular or subclavian access is preferred by many anaesthetists but central venous access may not be easy in the hypovolaemic patient and there is a risk of creating a pneumothorax. If the
central route is used, a 8.5-French gauge pulmonary artery introducer sheath is ideal for rapid fluid resuscitation.

The intrasosseous route\textsuperscript{118} (usually via the proximal tibia) is useful in children but, using conventional fluids, does not allow high enough flow rates for effective fluid resuscitation in adults. However, there is a possibility of infusing hypertonic intrasosseous fluids in adults.\textsuperscript{79}

**Fluid warming.** All i.v. fluids should be warmed properly. A high capacity fluid warmer, such as the Level 1,\textsuperscript{21,95} is required to cope with the rapid infusion rates used during trauma patient resuscitation. Hypothermia (core temperature less than 35 °C) is a serious complication of severe trauma and haemorrhage.\textsuperscript{82} The aetiology of hypothermia in the patient requiring massive transfusion is multifactorial and includes exposure, tissue hypoperfusion and infusion of inadequately warmed fluids. In trauma patients hypothermia correlates with survival; those with a core temperature decreasing to less than 34 °C have a 40% mortality compared with a 7% mortality for those whose lowest recorded core temperature is 34 °C or above.\textsuperscript{71} Hypothermia has several adverse effects:

- the oxyhaemoglobin dissociation curve is shifted to the left, thus impairing peripheral oxygen delivery in the hypovolaemic patient at a time when it is most needed
- shivering may compound lactic acidosis which typically accompanies hypovolaemia and this may be aggravated further by decreased metabolic clearance of lactic acid by the liver
- it contributes to the coagulopathy accompanying massive transfusion.\textsuperscript{102} The likely mechanisms involved include: retarding the function of enzymes in the clotting cascade\textsuperscript{111} enhanced plasma fibrinolytic activity;\textsuperscript{103}, and reduced platelet aggregation.\textsuperscript{142} Recent studies have shown that bleeding time and prothrombin time, in particular, are prolonged by hypothermia.\textsuperscript{101,129,143}

Care must be taken with some of the more powerful warming and rapid infusion systems. There is a potential for rapid circulatory overload unless patients are monitored appropriately and continually.\textsuperscript{52}

Principles of fluid management emphasize that restoration of intravascular volume should be fast and efficient. Recognizing that anaemia is tolerated better than hypovolaemia allows the initial fluid resuscitation to be non-blood. While the choice of fluid may be less important than the speed and adequacy of volume replacement, the increasing variety of fluids available tends to confuse the issue. Resuscitation fluids currently available include: isotonic crystalloids (sodium chloride, Hartmann’s solution, Ringer’s lactate solution), hypertonic saline with or without a colloid component, gelatin solutions (polygeline, succinylated gelatin), etherified starch solutions (hetastarch, hexastarch, pentastarch), dextrans and blood. Haemoglobin solutions are undergoing clinical studies and will be available in the near future.

**Colloids vs crystalloids.** The crystalloid vs colloid debate continues and for reasons discussed below, is unlikely to be resolved. As an increasing number of colloids become available, the controversy may evolve into which colloid vs crystalloid.\textsuperscript{138} There are some areas of agreement between the opposing views. Most agree that colloids are more efficient in that equivalent intravascular volume expansion is achieved with less colloid. Colloids are more expensive than crystalloids. There is no risk of anaphylaxis with crystalloids. Colloid oncotic pressure is better maintained with colloid. Fluid overload is bad for the patient regardless of the type of fluid used. The amount of interstitial oedema is dependent on the volume of fluid given and there is a negative correlation between a positive fluid balance and survival in critically ill patients.\textsuperscript{90} As it takes 2–6 times the volume of crystalloid compared with colloid to maintain the same haemodynamic state in critically ill patients,\textsuperscript{64} it is not surprising that crystalloid fluid resuscitation causes greater interstitial oedema. In theory, interstitial oedema has several adverse effects:

- cerebral: obtunded conscious level
- pulmonary: impaired gas exchange
- myocardial: reduced compliance
- tissue: impaired wound healing
- gut: reduced absorption and enhanced bacterial translocation

Despite these reservations, no prospective, randomized studies have demonstrated clearly the superiority of colloids over crystalloids for trauma resuscitation. Double-blind studies with the power to define any advantages are unlikely given the complexity of trauma cases and the difficulty in establishing matched controls. There is also great difficulty in deciding the most appropriate endpoints for such studies. Should it be survival or duration of hospital or ICU stay, or the incidence of organ failure? Other variables, such as age, ISS and pre-injury pathology, are inevitably greater discriminators of outcome than the choice of resuscitation fluid.

**Crystalloids.** The American College of Surgeons’ ATLS committee recommends the use of lactated Ringer’s solution for the initial resuscitation of severely injured patients.\textsuperscript{135} The use of normal saline may cause a hyperchloeraemic acidosis and may compound any underlying pathological acidosis.\textsuperscript{83} Part of the rationale for using crystalloids is that trauma patients have sustained considerable interstitial fluid losses and intravascular loss. An alternative explanation is that gelatin solutions are not available in the USA, and alternative colloid solutions such as starch and albumin would be expensive or limited by the volume that can be infused.

**Gelatin solutions.** Gelatins are the only cheap colloid available that can be infused in unlimited volumes, they have no effects on the cross matching of blood and act as an osmotic diuretic. While it has been suggested that in comparison with saline, fluid resuscitation with gelatin solution prolongs bleeding time,\textsuperscript{40,87} the case is far from proved and further study is required.

**Hydroxyethyl starch solutions.** Hydroxyethyl starch solutions are synthetic polymers derived from amylopectin. Different degrees of substitution of
Hydroxyethyl starch groups for glucose result in solutions of varying properties. HES 450/0.7 has an average molecular weight of 450 000 Da and a high molar substitution ratio (0.7). This solution has a long half-life (more than 24 h) and results in prolonged haemodilution. The fact that it accumulates in the reticuloendothelial system has not yet been shown to cause problems. It also causes a coagulopathy via an effect on factor VIII and von Willebrand factor. For these reasons the maximum dose of high molecular weight HES is restricted to 20 mg kg\(^{-1}\) day\(^{-1}\) and it cannot be recommended for trauma patient resuscitation. Pentastarch (HES 200/0.5) is diathermied to produce a more homogenous solution (10–1000 kDa) which has a lower weight average and a half-life of approximately 6 h. Animal studies suggest that these medium weight HES solutions may be capable of plugging leaky capillaries in inflammatory states.\(^{16,149,158}\) Penta fraction (100–500 kDa) is even more homogenous than pentastarch and is the most effective at reducing transvascular leak.\(^{92,109}\) Hydroxyethyl starch encourages restoration of macrophage function after haemorrhagic shock.\(^{120}\) A recent study of trauma and sepsis patients showed that 10% HES (200/0.5) resulted in significantly better systemic haemodynamics and splanchic perfusion than volume replacement with 20% human albumin.\(^{17}\) Although the medium weight starch solutions appear very attractive for resuscitation from haemorrhagic shock, the fact that they are expensive and can cause anaphylaxis may temper our enthusiasm.\(^{78,93}\)

**Hypertonic saline solutions.** Hypertonic crystalloid solutions are attractive as they provide small volume resuscitation and rapid restoration of haemodynamics with laboratory evidence of improved microcirculatory haemodynamics.\(^{79}\) They exert their effect by recruitment of interstitial volume thus increasing circulating volume and increasing arterial pressure. However, as discussed above, increasing arterial pressure may not always be an ideal goal, and their role in trauma resuscitation has yet to be defined. Many clinical studies are now using small volumes of highly hypertonic solutions (7.5% saline) for pre-hospital resuscitation.\(^{36,89,145}\) These studies have yet to show a clear improvement in survival as the primary end-point.\(^{77}\) However, in a subset of head-injured patients with a Glasgow coma scale score of 8 or less, survival to hospital discharge was higher in patients receiving hypertonic saline (with or without dextran 70) compared with those receiving Ringer's lactate.\(^{145}\) The potential for benefit in head-injured patients is not surprising in that small changes in serum sodium exert much greater effects on serum osmolality, and therefore on brain water and intracranial pressure, than do changes in colloid oncotic pressure.\(^{139}\) However, hypernatraemia may induce its own problems; administration of large volumes of hypertonic saline to patients with burns resulted in a four-fold increase in acute renal failure and a two-fold increase in mortality.\(^{61}\)

**Blood and haemoglobin solutions.** Blood, while being the ideal replacement for haemorrhage, is expensive, in short supply, antigenic, requires cross matching, has a limited shelf life, requires a storage facility and carries a risk of disease transmission. It is well known that blood transfusion has an immunosuppressive effect and one study showed that the volume of blood infused and injury severity score were the only two significant predictors of infection.\(^{2}\) However, this phenomenon is more likely to be a reflection of the duration and severity of shock.\(^{119}\)

Having overcome several problems related to toxic stroma, short intravascular half-life and high colloid osmotic pressure, a number of haemoglobin solutions are now at advanced stages of development.\(^{27a,33,70,110}\) In a rat model of haemorrhagic shock, diasprin cross-linked haemoglobin (DCLHb) was more effective in restoring tissue perfusion and improving survival than lactated Ringer’s solution or 7.5% hypertonic saline.\(^{80}\) DCLHb has been given to patients undergoing elective abdominal aortic repair\(^{45}\) and to patients with sepsis syndrome.\(^{113}\) It has a significant vasopressor effect which is thought to result from binding nitric oxide and from an effect on adrenergic receptors.\(^{122}\) In 76 human volunteers, genetically engineered haemoglobin (rHb1.1) also produced a transient increase in arterial pressure and studies are underway in anaesthetized patients.\(^{70}\) The potential for using haemoglobin solutions to resuscitate trauma patients, particularly in the pre-hospital phase, is very exciting. An increase in mean arterial pressure, in conjunction with decreased viscosity of haemoglobin solutions, may result in significantly better oxygen delivery to vital organs. In a rat model of controlled haemorrhage, DCLHb was superior to crystalloid, albumin and blood in gut resuscitation.\(^{42}\) The potential disadvantages in increasing arterial pressure in uncontrolled haemorrhage (as discussed above) have still to be considered. Furthermore, the long-term safety of massive transfusion with haemoglobin solutions in humans has yet to be demonstrated.

What is the optimal packed cell volume (PCV) in the acute trauma patient? Hypovolaemia is tolerated considerably less well than anaemia. Traditional teaching is that all patients require a PCV of 30% or a haemoglobin concentration of 10 g dl\(^{-1}\) for optimal oxygen delivery. However, normovolaemic patients with good cardiodiastolic function tolerate haemoglobin concentrations as low as 7 g dl\(^{-1}\).\(^{94}\) In a small, randomized pilot study, the mortality of a group of critically ill patients with haemoglobin concentrations maintained at 7–9 g dl\(^{-1}\) was no different to a group with concentrations of 10–12 g dl\(^{-1}\).\(^{158}\) Provided normovolaemia is achieved the reduction in viscosity results in a significant increase in cardiac output\(^{127}\) and tends to improve tissue oxygenation.\(^{144}\) The problem is that during resuscitation of the acute trauma patient, a history of ischaemic heart disease or significant respiratory disease may not be available. Furthermore, the haemoglobin concentration of a haemorrhaging patient undergoing resuscitation is changing rapidly. Under these conditions the margin of safety is very small if the haemoglobin concentration is reduced to as low as 7 g dl\(^{-1}\) even if the patient is previously healthy. As part of the systemic inflammatory response syndrome, the
severely injured patient has an increased oxygen requirement and therefore it would be unwise to chose a “transfusion trigger” on the basis of data that have been obtained from stable anaesthetized patients. Until more data are available from studies on critically ill patients, the haemoglobin concentration of severely injured patient should be targeted at around 10 g dl\(^{-1}\). However, in the confirmed cardiovascularly healthy trauma patient with only moderate injuries, a haemoglobin value as low as 7 g dl\(^{-1}\) may be acceptable.

**Monitoring**

By any definition, major trauma patients are critically ill and it is entirely appropriate to provide monitoring in the emergency department which is to the same standard as that in the intensive care unit. Arterial cannulae and central venous catheters should be inserted as soon as possible. Small, portable monitors that display ECG, invasive arterial pressure, oxygen saturation, central venous pressure, end-tidal carbon dioxide and temperature are available widely and should be used in all major trauma patients.

**Resuscitative thoracotomy**

Resuscitative thoracotomy may be a life-saving procedure. However, it is a high-risk procedure for those individuals involved in resuscitation and should not be undertaken in futile cases. The surgical skill and facility required should be available in the resuscitation area of all hospitals that receive major trauma patients on a regular basis. The indications for emergency resuscitative thoracotomy include:

- control of intrathoracic haemorrhage
- relief of cardiac tamponade
- electromechanical dissociation after penetrating trauma
- uncontrollable haemorrhage below the diaphragm where cross-clamping the thoracic aorta allows haemorrhage control
- control of a massive air leak.

Of 423 patients undergoing emergency thoracotomy, the overall survival rate was 13%.

**Resuscitation end-points**

When haemorrhage control has been achieved, the goals of resuscitation are to optimize oxygen delivery and improve microcirculatory perfusion to facilitate the repair process. Patients with severe injuries have high oxygen requirements immediately, and rapidly accumulate a significant oxygen debt, as indicated by high blood lactate concentrations and an increasing base deficit. Shoemaker and colleagues have demonstrated a reduction in mortality in a variety of high-risk surgical patients using therapy targeted to achieve supranormal values for cardiac index (CI) (>4.5 litre min\(^{-1}\) m\(^{-2}\)), oxygen delivery index (Do\(_{2}\)I) (>600 ml min\(^{-1}\) m\(^{-2}\)) and oxygen consumption index (Vo\(_{2}\)I) (>170 ml min\(^{-1}\) m\(^{-2}\)). More recently, investigators have examined the potential benefit of goal-directed therapy, specifically in trauma patients. There is little doubt that failure to achieve supranormal values of Do\(_{2}\)I and Vo\(_{2}\)I is a strong predictor of multiple organ failure and death, while the standard haemodynamic measurements of MAP and CVP fail to differentiate between survivors and non-survivors. What we really need to know, however, is whether we can improve outcome by striving to achieve these goals. A recent study in patients with predominantly penetrating injuries showed that mortality can be reduced by targeting the following resuscitation goals: CI > 4.5 litre min\(^{-1}\) m\(^{-2}\), Do\(_{2}\)I > 670 ml min\(^{-1}\) m\(^{-2}\) and Vo\(_{2}\)I > 166 ml min\(^{-1}\) m\(^{-2}\). This approach to the trauma patient requires insertion of a pulmonary artery flotation catheter and some authors have suggested that this should be placed early in the resuscitation process.

Recent evidence has suggested that aggressive efforts to increase Do\(_{2}\)I in critically ill patients may be detrimental. Another study of goal-directed therapy in a group of predominantly trauma patients failed to show any difference in the incidence of organ failure or death. The current popular approach to fluid resuscitation of severe trauma patients is to increase Do\(_{2}\)I with appropriate fluid resuscitation and moderate doses of dobutamine (up to 20 µg kg\(^{-1}\) min\(^{-1}\)), while monitoring mixed venous oxygen saturation (S\(_{\text{vO}_2}\)), base deficit and/or blood lactate concentration.

Several investigators have criticized the use of global oxygenation indices to detect the presence of tissue dysoxia and a recent consensus conference has addressed these issues. It is possible to have regional ischaemia that would not necessarily be reflected by a change in Vo\(_{2}\)I or plasma base deficit. The splanchic bed is the first region to be rendered ischaemic during shock, and after resuscitation is the last to have perfusion restored to normal. Gastric mucosal pH (pH\(_{\text{m}}\)) is monitored using a gastric tonometer and correlates well with intestinal oxygen consumption and hepatic venous P\(_{\text{O}_2}\), lactate and outcome. pH may be a better resuscitation goal in trauma patients than Do\(_{2}\)I and Vo\(_{2}\)I. The standard technique of gastric tonometry using a saline-filled balloon is rather laborious and allows only intermittent measurement of pH\(_{\text{m}}\) partly for this reason it is infrequently used in clinical practice. New developments in gastric tonometry allow continuous measurement of pH\(_{\text{m}}\) either from an air-filled balloon connected to a modified capnometer (“capnometric recirculating gas tonometry”) or by directly measuring luminal P\(_{\text{CO}_2}\) with a fiberoptic P\(_{\text{CO}_2}\) probe.
The UK Trauma Audit and Research Network

The Major Trauma Outcome Study (MTOS) (UK) has been collecting data on seriously injured patients for 8 yr. There are 86 000 patients on the database and 117 hospitals in the UK have enrolled with MTOS.136 Last year MTOS (UK) changed its name to the UK Trauma Audit and Research Network and formed links with the Cochrane Centre and the NHS Centre for Reviews and Dissemination. It is hoped that this will facilitate the development of evidence-based guidelines for the management of major trauma. On the basis of the data collected so far, MTOS participating hospitals have good cause for optimism. Between 1988 and 1996 the overall mortality ratio (the observed number of deaths divided by the expected number of deaths × 100) has improved from 124 to 97 (fig. 3). Over the 7-yr period 1989–1995, after severity of injury is controlled for, the odds of death in children and young adults (less than 24 yr) after severe injury declined by 16% a year.114 It is not possible to identify with certainty which of the many facets of trauma patient management have contributed to this apparent improvement in outcome. However, it is likely that developments in assessment and resuscitation techniques, many of which have been discussed above, are major factors. One certain fact is that the proportion of seriously injured patients seen first by consultants or senior registrars has increased from 17% in 1988 to 30% in 1995136 (fig. 4). In the context of the debate on pre-hospital trauma management, it is of some concern that pre-hospital times have increased from a mean of 37 min in 1988 to 58 min in 1995. Bearing in mind that during this period there was no change in the number of trapped patients or in the distribution of injury severity, we must establish the specific effect of this trend on outcome. Perhaps the Medical Care Research Unit pre-hospital study62 will provide some answers.

The International Trauma Anaesthesia and Critical Care Society (ITACCS)

In 1988 a group of enthusiasts in Baltimore established ITACCS. The society holds an annual symposium, numerous seminars, offers research grants and has been responsible for several publications on trauma anaesthesia and critical care. More than 1000 members from 44 countries exchange and develop ideas on all aspects of trauma anaesthesia, resuscitation and critical care. Information on the society can be obtained from ITACCS World Headquarters, PO Box 4826, Baltimore MD 21211 USA (Fax +1 410 235 8084).
Conclusion

Several deficiencies highlighted by the 1988 Royal College of Surgeons Working Party Report on the management of patients with major injuries have been addressed and there is some evidence that developments in trauma patient management have improved outcome. The principles outlined above provide the basis for making rational decisions in trauma resuscitation. There is no substitute for training, experience, good communication and team work if resuscitation of the trauma patient is to be completed rapidly and effectively. Trauma continues to be the most common cause of death in the first four decades of life and as part of a multidisciplinary team, the trauma anaesthetist must strive to reduce this mortality.

References


Aspects of resuscitation in trauma

237


Aspects of resuscitation in trauma


118. Staab DB, Sorensen VJ, Fath JJ, Raman S, B, Horst HM, 239
240


