CARE OF THE POLYTRAUMATISED PATIENT

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The treatment of patients with multiple injuries is challenging, but early optimal management is essential after trauma, since many life-threatening situations can occur. Any delay in diagnosis and treatment will contribute to long-term complications such as sepsis and organ failure and will increase late mortality (Regel et al 1996).

The principles of the management of multiple trauma are early and simultaneous assessment and resuscitation, followed by a complete physical examination and diagnostic studies to establish the priorities for life-saving surgery (Trunkey 1991).

We discuss trauma management in each of four different periods:
1) Acute or resuscitation (1 to 3 hours).
2) Primary or stabilisation (1 to 72 hours).
3) Secondary or regeneration (3 to 8 days).
4) Tertiary or rehabilitation (after the 8th day).

ACUTE PERIOD (1 to 3 hours)

Assessment and resuscitation

The primary goals in the resuscitation phase are to establish adequate ventilation, to maintain the circulation (intravascular volume and cardiac function) and to assess the global neurological status.

Optimal oxygenation of the patient must be guaranteed (Sturm et al 1979; Moylan et al 1988; Sturm, Regel and Tscherne 1991). This requires immediate intubation and ventilation of all patients not already intubated at the scene of injury. The standard principles of ventilation therapy include positive end-expiratory pressure (PEEP) and high tidal volumes of 8 to 10 ml/kg body-weight (BW) (Tscherne, Oestern and Sturm 1983; Regel et al 1993).

Arterial blood-gas determination should be used to assess the adequacy of oxygenation; if the results remain abnormal other mechanical causes for hypoxia must be ruled out. These include tension pneumothorax, haemothorax, and flail chest. Tension pneumothorax should be suspected if there are decreased breath sounds on the affected side and increasing maximal airway pressures on ventilation. On the chest radiograph, a shift of the normally midline trachea to the contralateral side should create suspicion. Immediate decompression by chest-tube drainage should be performed; if a large haemothorax is also likely the tube should be inserted in the midaxillary line at the fifth thoracic interspace.

Surgical shock is not always adequately represented by haemodynamic parameters such as blood pressure (BP) and heart rate (HR) (Sturm et al 1979, 1991); maximal resuscitation is therefore recommended, starting before admission to hospital. We use crystalloid solutions according to the algorithm shown in Table I. During this primary resuscitation, blood loss should be assessed with a view to starting substitution. In addition to existing intravenous lines, the most reliable way to gain access to the circulation is by cutdown on the saphenous or cubital vein to allow the insertion of large-diameter tubes.

The immediate use of universal donor blood (group O, Rhesus negative) is required only for exsanguinated patients, since type-specific, cross-matched blood should be available within 20 minutes of the admission of a patient to a trauma centre. In most cases we use packed red cells, and the administration of specific blood components depends on the results of the first blood samples. Thrombocytopenia is treated only at levels of below 50 000/μl; hypofibrinogenemia and factor V or factor VIII deficiencies are covered in the initial phase by the use of fresh frozen plasma.

Resuscitation should be controlled by monitoring the urinary output, aiming at 0.5 ml/kg BW/hour in adults and 1.0 ml/kg BW/hour in children. Atrial filling pressures are monitored by measuring the central venous pressure (CVP); elderly patients and those with severe thoracic trauma require a pulmonary artery catheter (Fig. 1). Measurement of the pulmonary artery pressure (PAP) and the pulmonary capillary wedge pressure (PCWP) gives important information on pulmonary haemodynamics. The cardiac index (CI) represents the circulating blood volume per minute. Other important parameters such as systemic vascular resistance (SVR) and the arterial-alveolar oxygen difference (AaDO₂) can then be calculated. Measurement of the temperature difference (ΔT) between the body core and the peripheral regions is also important and shows the extent of prolonged shock (Sturm et al 1991) (Fig. 1).

The neurological status at the scene of the accident and on admission must be documented according to the Glasgow Coma Scale (GCS) (Tscherne et al 1983; Bone and...
Table I. Algorithm for volume replacement in the first 24 hours after multiple trauma

3000 ml Ringer lactate (RL)
150 ml NaHCO₃

Circulation?
Urinary output?

Circulation stable
Urinary output +
RL: 15 ml/kg BW/h
Blood if haemoglobin < 9 g%

Circulation unstable
No urinary output
Postrenal reason?
RL: 15 ml/kgBW/h
Blood transfusion
RL: 2000 ml/10 min

No urinary output?
Hypovolaemia?
Cardiac reason?
Central venous pressure (CVP)

CVP low
Hypovolaemia
Rapid blood transfusion
RL: 2000 ml/10 min

CVP high
Mechanical reasons?
(thoracic trauma)

Yes
Surgical therapy
Fluid resuscitation
Stop fluid resuscitation
Pharmacological treatment
Specialised monitoring

No

Buchholz 1986; Zink and Samii 1991), since this is the best predictor of the later outcome of cerebral injuries (Zink and Samii 1991). The four primary reflexes (triceps, biceps, patella and ankle) should be checked. Any neurological deterioration or a GCS < 10 is strong evidence of either a space-occupying lesion or of significant cerebral oedema. CT will be needed and should be performed as soon as any massive internal haemorrhage can be ruled out.

Live-saving surgery
Massive haemorrhage. In haemodynamically unstable patients early diagnostic procedures should be limited to plain chest and skull radiographs, a lateral film of the head and cervical spine under traction to show the lower cervical vertebrae, and a posteroanterior film of the pelvis. Parallel with this, ultrasound examination of the abdomen should be performed. In our hospital, this has replaced peritoneal lavage for the diagnosis of intra-abdominal free fluid (Hoffmann et al 1992); it has nearly 100% sensitivity and specificity when it is repeated at frequent intervals during primary resuscitation. Plain chest radiographs and ultrasound of the abdomen allow the diagnosis of 95% of all massive haemorrhages.
When a haemothorax has been diagnosed, a chest drain should be inserted as soon as possible, and any indication for thoracotomy will depend on the amount of blood lost through it. Any widening of the mediastinum requires further evaluation (Fig. 2), but there is rarely an indication for acute operation for aortic rupture.

Massive bleeding within the peritoneal cavity in a haemodynamically unstable patient usually requires an immediate laparotomy (Tscherne et al 1983). Such bleeding is most frequently from the liver or the spleen. For liver bleeding, the need for operation depends on the severity of the injury which is usually classified according to Moore, Eiseman and Dunn (1979). Ruptures of the spleen are relatively common; splenectomy is usually indicated since attempts at reconstruction will aggravate haemorrhagic shock and can therefore be life-threatening. In children, however, salvage of a bleeding spleen is recommended if possible. In all such cases the origin of the blood loss must be evaluated before laparotomy: bleeding from the pelvic region must be ruled out (Bone and Buchholz 1986; Tscherne et al 1987; Trunkey 1991; Pohlemann et al 1994). Failure to recognise this may often have fatal consequences for the patient (Fig. 3). When a negative ultrasound scan has ruled out intra-abdominal blood and there is an unstable pelvis, the source of bleeding is obvious.

We treat massive bleeding from the pelvis by the protocol which is outlined in Table II (Pohlemann et al 1994). The first decision, made within three to five minutes after admission, is whether emergency surgical haemostasis is required for patients with external massive bleeding or...
crush trauma. Injuries to large pelvic vessels usually cause such rapid massive haemorrhage that shock cannot be corrected until bleeding is surgically controlled and this, including early simple fixation of an unstable pelvic ring, must be part of primary resuscitation.

The second decision depends on the response to initial resuscitation. After about ten minutes, continued haemodynamic instability requires immediate and massive blood replacement. Significant posterior pelvic instability requires acute reduction and compression of the posterior ring using a pelvic clamp; this may be life-saving in terms of the control of haemorrhage (Ganz et al 1991).

The third decision should be made in the next 20 to 30 minutes after admission. Surgical control of the bleeding becomes mandatory in patients who remain unstable. Most pelvic haemorrhages, especially diffuse bleeding from the

Table II. Algorithm for management of massive bleeding in the acute period after pelvic injury

<table>
<thead>
<tr>
<th>Decision 1</th>
<th>Massive haemorrhage?</th>
<th>if +ve Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 to 5 min</td>
<td>Overall trauma?</td>
<td>if -ve Maximum resuscitation Radiograph thorax, pelvis; ultrasonography</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision 2</th>
<th>Haemodynamic stability?</th>
<th>if +ve Polytrauma algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 min</td>
<td>if -ve</td>
<td>Massive blood replacement C-clamp</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Decision 3</th>
<th>Haemodynamic stability</th>
<th>if +ve Polytrauma algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 to 30 min</td>
<td>if -ve</td>
<td>Operation</td>
</tr>
</tbody>
</table>

A 22-year-old woman with an unstable pelvic fracture (‘open-book’ type) after a motor-cycle accident (a). The hospital that carried out the initial treatment found no significant bleeding in the abdomen at emergency laparotomy on this haemodynamically unstable patient. An external fixator was installed without closing the anterior pelvic ring (b). Angiography detected no major arterial lesions (c). Persisting haemodynamic instability led to transfer to our department. We removed nearly two litres of haematoma and packed ruptured venous plexuses to stop continuous, diffuse bleeding, then stabilised the anterior pelvic ring (d). This soon secured haemodynamic stability and the patient was extubated on the third day.
venous plexuses, are best controlled by local packing which can be changed or removed during a second-look operation, usually 48 hours later (Pohlemann et al 1994). After packing, reduction and internal fixation of the pelvic ring are essential. Therapeutic angiography, including embolisation, is very rarely required; it is indicated only when all other methods have failed to control the haemodynamic state.

Patients with haematuria should have retrograde cystography to reveal possible rupture of the bladder or urethra; intravenous pyelography (basic and at 30 minutes) can rule out a more proximal lesion of the urinary tract. In our practice, these diagnostic studies are all performed simultaneously with initial resuscitation and should be complete by the time that the patient leaves for the operating room.

Intracranial bleeding. The second priority after massive haemorrhage is the treatment of intracerebral space-occupying lesions. CT is needed for evaluation and even minor intracranial lesions should be kept under careful review, since secondary epidural bleeding may occur. The immediate and early evacuation of any significant epidural or subdural blood is mandatory, because delay before decompression correlates inversely with the grade of recovery (Zink and Samii 1991).

PRIMARY PERIOD (First 72 hours)

The primary period of treatment starts when all vital functions have been stabilised. Adequate ventilation, haemodynamic stability and control of intracranial or internal haemorrhage should have been achieved.

More diagnostic procedures may be indicated for specific injuries including:

1) Further laboratory tests (Faist et al 1983; Tscherne et al 1987; Sturm et al 1991).
2) Advanced cardiovascular measurements, such as pulmonary artery pressure and cardiac index. These are important in patients with a prolonged shock phase and those with thoracic trauma.
3) The exclusion of specific vascular injuries by Doppler sonography or angiography.
4) The exclusion of injuries of the urogenital system by retrograde cystography.
5) Skeletal radiography for fractures and joint injuries.

After this assessment, and given continued haemodynamic stability, second-priority injuries can then be treated (Table III) by what has been called ‘delayed primary or day-one surgery’. Sometimes several injuries can be dealt with simultaneously, for instance maxillofacial lesions and fractures of the limbs.

Cerebral injuries. In the acute period, intracranial bleeding, especially epidural and subdural haematoma, has the second priority after massive haemorrhage. All other cranial injuries should be treated during the delayed primary phase.

The localisation, extent and severity of the cerebral injury are best evaluated by CT, the indications for which include primary unconsciousness (Glasgow Coma Scale < 8), focal neurological lesions, open brain injuries, deterioration of clinical and neurological status, and skull fractures. The reason for unconsciousness requires analysis and possible relation to other life-threatening injuries should be ruled out. Focal neurology in conscious patients may be related to a previous injury, but in other cases a lesion of the carotid artery must be excluded. An increasing neurological deficit is always a sign of intracranial bleeding or oedema and is an absolute indication for CT.

After the primary treatment of any intracranial lesion, the continuous measurement of intracranial pressure is necessary in all patients with space-occupying lesions, midline shift, or collapse of basal cisterns and in those with deterioration of neurological status during the post-traumatic period.

Eye and maxillofacial injuries. Perforating injuries of the eyes and major lesions of the facial soft tissues need immediate operation at the beginning of the primary period. In most cases a simultaneous approach to these injuries and to fractures of the extremities is possible; this is recommended to shorten the duration of the operative procedure.

Maxillofacial fractures are normally treated in two stages. Initially, unstable fractures are stabilised by maxillomandibular fixation. Definitive reconstruction and stabilisation are delayed until the facial swelling has decreased; the delay will reduce infection and allow better wound healing.

Compression of the spinal cord. Progressive compression of the spinal cord is an absolute indication for operation in the primary phase. When the neurological status cannot be verified (as in primarily unconscious patients) a complete radiological assessment is necessary with anteroposterior and lateral views followed by CT when this is indicated.

Recovery from spinal-cord trauma depends on the amount of initial damage or contusion of the cord as well as on mechanical factors, such as compression of the neurological structures by fragments of bone and disc. The surgeon cannot directly alter tissue disruption, but preven-

Table III. Priorities for surgical treatment after resuscitation during the primary or stabilisation period

| 1) | Cerebral injuries |
| 2) | Eye and facial injuries |
| 3) | Progressive compression of the spinal cord |
| 4) | Visceral injuries |
| 5) | Musculoskeletal injuries |
| Fractures with concomitant injuries to major vessels | |
| with severe compartment syndrome | |
| with open soft-tissue injuries | |
| with open joint injuries | |
| Closed-shaft fractures | |
| Pelvic-ring injuries | |
| Unstable spine fractures | |
tion of movement of the injured cord and relief of persistent compression of the neural structures by fragments of bone or disc may help to preserve the remaining neural function. The immediate stabilisation of spinal fractures protects the cord and allows earlier mobilisation of the patient (Aebi et al 1986; Blauth, Tschernes and Haas 1987).

**Visceral injuries.** Visceral injuries are not always associated with heavy intra-abdominal bleeding but may still lead to a life-threatening situation if they are not diagnosed early in the primary period. The history of the accident is useful, since its mechanism often gives important clues to specific injuries. Thoracic and vertebral injuries are often associated with abdominal trauma (Aebi et al 1986; Blauth et al 1987), but routine diagnostic tests such as laboratory investigations and ultrasound may be non-specific. The diagnostic value of CT is not yet clear (Helfet et al 1990).

One example of this is rupture of the diaphragm, which is a rare injury in patients with multiple trauma (1% to 7%). This is often missed or concealed during the primary phase by an ipsilateral thoracic injury such as lung contusion or haemothorax. Radiological evaluation by chest radiography, using contrast medium given by nasogastric tube, may be needed in case of doubt. Laparotomy is indicated in 80% of these cases (Regel et al 1995).

Injury to the small intestine and its mesentery is the most frequent bowel lesion in blunt abdominal trauma (3% to 18%). A typical mechanism is the so-called ‘seat-belt syndrome’ in which ‘submarining’ under a strap leads to bursting of the intestine (Garrett and Braunstein 1962). Perforation may occur after a delay of several days and at this stage the most reliable diagnostic procedure is peritoneal lavage. This diagnosis requires immediate laparotomy (Garrett and Braunstein 1962).

Lesions of the pancreas and duodenum are difficult to diagnose after blunt abdominal trauma. The clinical symptoms are often non-specific and CT is recommended, especially for suspected pancreatic trauma (Jeffrey, Federle and Crass 1983). The results of laboratory investigations do not correlate with the severity of the injury, and there may be changes in those with delay after trauma.

Injury to the genito-urinary system is normally diagnosed during the initial phase, because of the presence of haematuria. Ultrasound of the abdomen and specific radiological investigations, as mentioned above, will help to make an accurate diagnosis; CT with contrast medium can be valuable.

**Musculoskeletal injuries.** The principle of fracture treatment in polytrauma is to achieve stable osteosynthesis which will allow early mobilisation. Fractures with a concomitant vascular injury or compartment syndrome have the first priority for treatment followed by open fractures and joint injuries (Table III).

**Concomitant vascular injuries.** The most important prognostic factors for fractures with vascular lesions are the ischaemic interval and the degree of any reperfusion disturbance. Muscles lose their function after two to four hours of ischaemia; irreversible destruction may develop after four to six hours. Nerve tissue loses some function after 30 minutes, and irreversible injuries can develop after 12 to 14 hours of complete ischaemia. In the blood vessels, severe changes in capillaries and the endothelium are seen after three hours of ischaemia. These result in changes in the permeability of the capillary bed, leading to post-ischaemic swelling of the soft tissues in 30% to 60% of cases. This damage is aggravated in multiply traumatised patients with generalised hypoxaemia.

Vascular injury therefore requires prompt diagnosis and direct treatment. Reconstruction of the arterial lesion has first priority, and in cases in which an immediate repair is
difficult, the use of a temporary shunt should be considered.

Some regions are particularly susceptible to vascular injuries. These include the subclavian artery near the clavicle and the brachial artery near the shaft of the humerus. The femoral artery in the region of the femoral shaft and the popliteal artery at the knee are also in danger because of their fixation to bone. Dislocation of the knee involves rupture of vessels in about 50% of cases (Tscherne et al 1987; Regel et al 1995).

The development of a compartment syndrome leads to an increase in intrafascial pressures and eventually to irreversible muscle, nerve and vascular injuries (Fig. 4). In an isolated injury a compartment pressure of 30 to 40 mmHg is pathological and immediate fasciotomy is needed. For patients with polytrauma, this guideline level is less valid since generalised hypoxia can lead to irreversible changes at much lower compartment pressures. In our own series of patients with compartment syndrome nearly half had multiple injuries. The highest risk is in patients with comminuted closed fractures of the proximal and distal tibia, and those with complex foot injuries (Hansen 1987; Regel et al 1995). If a compartment syndrome is treated conservatively, continuous monitoring of compartment pressure is advisable and cryotherapy should be initiated immediately (Tscherne et al 1987).

Open fractures. All open fractures should be treated during the primary period (Seibel et al 1985; Bone and Buchholz 1986; Tscherne et al 1987; Trunkey 1991). Extensive debridement is needed with possible exploration of the vessels, and then stable fixation of the fracture in a standardised manner (Table IV). The type of osteosynthesis depends on the degree of soft-tissue injury. In the past, many fractures with associated severe soft-tissue damage have been treated by external fixation, but more recently, unreamed intramedullary nailing has been used with low risk, even for shaft fractures with Gustilo type-IIIb and -IIIc open injuries (Fig. 5).

The most important factor is the treatment of the soft-tissue injury. Primary closure is not recommended, especially in multiply traumatised patients. Relative hypoxia has the potential to delay soft-tissue healing and gives an increased susceptibility to infection. We therefore recommend secondary closure of the soft tissues in these patients.
Despite this, it is necessary to cover osteosynthetic material; we use a synthetic skin during the primary period, with definitive closure five to ten days after sequential partial closure of the wounds.

Open intra-articular fractures are also treated initially by debridement, with usually a reconstruction of the articular surface using a minimum of implant material and an external transarticular fixation of the joint. Definitive internal fixation of the articular component to the shaft may be delayed until the secondary or regeneration period of treatment (Fig. 6).

Closed fractures. The most important principle is to provide a definite or at least temporarily stable fixation of closed fractures in the primary period. All skeletal traction and casts should be removed by the end of this period to allow early mobilisation during the intensive-care period. Stable fixation of a fracture minimises pain, secondary soft-tissue injury, and the risk of fat and bone marrow embolisation (Seibel et al 1985; Goris 1987; Bone et al 1989; Pape et al 1993; van Os et al 1994). The stabilisation of limb fractures also reduces stress, traumatic shock and consequent post-traumatic complications such as adult respiratory distress syndrome (ARDS) and multiple organ failure (MOF) thus avoiding higher morbidity and mortality rates (Seibel et al 1985; Bone et al 1989; Pape et al 1993).

Fractures of the shafts of the femur and tibia are important, since the local soft tissues are susceptible to continuing damage. Our order of priority for the treatment of closed fractures is tibia-femur-pelvis-spine-upper limb. To follow this sequence, alternative methods have to be available for dealing with, for example, ipsilateral and contralateral fractures of the lower limbs (Table V). In one case, for example, we temporarily fixed a fracture of the femur with a large AO distractor, then stabilised an ipsilateral tibial fracture with an unreamed nail and finally performed the definitive fixation of the femur by an unreamed nail (Krettek et al 1994). An example is shown in Figure 7.

For this type of management, both haemodynamic and respiratory stability is required. In our experience, closed long-bone fractures associated with a severe head injury or

| Table V. Sample protocols for the management of double ipsilateral and contralateral fractures of the lower limb (Krettek et al 1994) |
|---|---|
| **Floating knee** | |
| 1 Standard table, whole extremity draped | |
| 2 Femur: distractor, reduction | |
| 3 Tibia: unreamed tibial nail, manual reduction | |
| 4 Decision | Condition of patient |
| +ve | -ve |
| 5 Unreamed femoral nailing | Intensive care |
| Pinless fixation | Femoral nailing delayed |
| **Bilateral tibial fractures (limb salvage)** | |
| 1 Standard table, both legs draped | |
| 2 Unreamed nailing of first tibia: manual reduction or distractor for the other | |
| 3 Decision | Condition of patient |
| +ve | -ve |
| 4 Unreamed nailing of second tibia | Pinless fixation |
| Intensive care | Unreamed nailing of second tibia delayed |
thoracic trauma such as a lung contusion need an alternative approach (Pape et al 1993, 1994). We recommend continuous intraoperative control of respiratory function, ventilatory parameters (capnography) and pulmonary haemodynamics. Continuous monitoring of the intracranial pressure is advisable in patients with severe head injuries (Hofman and Goris 1991; Zink and Samii 1991; van Os et al 1994).

Fractures of the femoral shaft are a special problem in the treatment of multiply traumatised patients (Seibel et al 1985; Bone et al 1989; Pape et al 1993; van Os et al 1994). In our series, up to 1993, of 3711 shaft fractures in such patients, 1778 involved the femur (48%) and 1142 the tibia (31%). Femoral fractures are also associated with the highest morbidity because of blood loss, amount of soft-tissue injury and other factors. Since the early 1980s we have favoured primary stabilisation of femoral fractures by intramedullary nailing (Seibel et al 1985; Bone et al 1989; Pape et al 1993).

This policy has been questioned recently, because an unusually high number of patients have developed respiratory complications (ARDS) in association with primary reamed intramedullary nailing (IMN) (Pape et al 1993, 1994). Reaming was considered to be the major factor,
causing more fat and bone marrow to be carried into the lungs, but in our experience pulmonary failure is especially associated with pre-existing pulmonary injury such as lung contusion. Patients with thoracic trauma developed ARDS more often if submitted to IMN within 24 hours than those operated secondarily. In contrast, patients with no thoracic trauma had a low incidence of ARDS regardless of the time of operation. If no lung injury was present, IMN was associated with a shorter ventilation time and a lower risk of infection.

In view of these principles we suggest the following therapeutic strategies to prevent pulmonary failure after IMN: primary stabilisation of the femur must remain a major goal in the care of the multiply traumatised patient. If there is pulmonary damage, reaming of the medullary canal should be avoided. Unreamed nailing procedures have been favoured in recent years and seem to be a good alternative in this special situation (Pape et al 1993, 1994). In a critically ill patient the use of an external fixator for temporary stabilisation should be considered. Secondary intramedullary nailing can then be performed more safely after an interval of at least two to three days.

**Limb salvage versus amputation.** Modern microsurgical procedures and more sophisticated methods for bony reconstruction such as those of Ilizarov have made it possible to salvage revascularised limbs which would formerly have been amputated. Increasing experience with these techniques has led to a more careful evaluation of the clinical outcome in such patients and recent work on the outcome of limb salvage indicates that this may sometimes result in a less desirable outcome for the patient than immediate amputation (Hansen 1987; Helfet et al 1990).

There is also a significant increase in patient morbidity and mortality associated with failed attempts of limb salvage. The judgement between these alternatives is extremely difficult, highly individualised and impossible to quantify. Operative techniques in relation to individual variables are extremely important in multiply traumatised patients. Decision-making protocols have looked at absolute and relative indications and also considered concomitant injuries or associated polytrauma (Lange 1989; Helfet et al 1990). The Mangled Extremity Severity Score (MESS) devised by Helfet and his co-workers is an attempt to classify these severe injuries and assist in decision-making. The MESS system is shown in Table VI, and in a retrospective study it was shown that a score of seven points or more correlated well with the decision to amputate. The Hannover Fracture Scale (HFS) similarly selects and ranks important variables to provide guidelines for decisions between reconstruction and amputation (Regel et al 1993).

Most authors agree that in a severely injured limb a warm ischaemia time of over six hours, especially with crush injury, has a very poor prognosis, as does division of the tibial nerve which will render the plantar surface of the foot insensitive (Hansen 1987; Helfet et al 1990). Although such limbs may be technically salvageable, the patients do not do well (Hansen 1987). Once a limb-salvage attempt has been chosen, the treatment of a severely injured limb

<table>
<thead>
<tr>
<th>Group</th>
<th>Type</th>
<th>Characteristics</th>
<th>Injuries</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skeletal/soft</td>
<td>Low energy</td>
<td>Stab wounds, simple closed fractures, small calibre gunshot wounds</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>tissues</td>
<td>Medium</td>
<td>Open or multiple-level fractures, dislocation, moderate crush injuries</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Shotgun blast (close range), high-velocity gunshot wounds</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Massive</td>
<td>Logging, railroad, oil-rig accidents</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Shock</td>
<td>Normotensive</td>
<td>BP stable in field and in operating room</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Transient hypotension</td>
<td>BP unstable in field but response to intravenous fluids</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Prolonged hypotension</td>
<td>Systolic BP less than 90 mmHg in field but response to intravenous fluid only in operating room</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Ischaemia</td>
<td>None</td>
<td>Pulsatile limb without signs of ischaemia</td>
<td></td>
<td>0*</td>
</tr>
<tr>
<td></td>
<td>Mild</td>
<td>Diminished pulses without signs of ischaemia</td>
<td></td>
<td>1*</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>No pulse by Doppler, sluggish capillary refill, paraesthesia, diminished motor activity</td>
<td>2*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Advanced</td>
<td>Pulseless, cool, paralysed and numb without capillary refill</td>
<td></td>
<td>3*</td>
</tr>
<tr>
<td>Age</td>
<td>&lt; 30 years</td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>30 &lt; 50 years</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>&gt; 50 years</td>
<td></td>
<td></td>
<td>2</td>
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</table>

*2 if the ischaemic time exceeds 6 hours
can be standardised (see Table IV).

Unstable pelvic injuries. Pelvic instability, especially in multiply traumatised patients, requires an aggressive and well-planned therapeutic regimen (Bone and Buchholz 1986; Ganz et al 1991; Pohlemann et al 1994). The use of a standard management protocol for all such patients facilitates management after the initial stabilisation of their general condition. Early physical and radiological assessment is necessary for evaluation and planning. The mechanism of injury, the clinical instability and the injury are classified. The pelvic ring is recorded as stable, partially unstable or completely unstable using one of the alternative classification systems (Pohlemann et al 1994). If there are injuries to the posterior pelvic ring (sacroiliac displacement, sacroiliac fracture-dislocation, sacral fractures), CT should be performed as soon as possible. After the classification of the pelvic injury, unstable fractures should be treated during the primary operative period.

A standardised protocol for the treatment of unstable pelvic fractures should include both internal and external fixation methods. An external fixator is a simple anterior stabilisation device and adequate for transpubic instabilities. It is also appropriate after the posterior internal fixation of type-C injuries. An exact assessment of the type and nature of every fracture of the different parts of the pelvic ring is therefore essential before fixation (Pohlemann et al 1994).

For stabilisation of the posterior pelvic ring we prefer the supine position whenever possible. An anterolateral approach gives good visualisation of the iliac bone and sacroiliac joint, and especially in polytrauma this position allows access to the patient for simultaneous procedures.

Displaced sacral fractures must be considered as part of an unstable pelvic-ring fracture (type-C injury); internal stabilisation is therefore required, but it is imperative to avoid further damage to the posterior pelvic soft tissue. Different stabilisation methods are discussed by Pohlemann et al (1994).

Complex pelvic fractures show additional severe intra-pelvic or extrapelvic soft-tissue trauma (Pohlemann et al 1994). This may compromise skin, muscle or major structures including the iliac vessels, nerves, urogenital tract, rectum, and sphincter mechanisms. The fracture may be open or closed and in most of such cases the circulation is unstable. These concomitant injuries will require treatment after the control of massive bleeding and the internal stabilisation of the pelvis.

Unstable injuries of the spine. In recent years, acute spinal trauma with neurological involvement and/or relevant bony deformity with segmental instability has been treated more often by operation. The non-operative management of unstable osteoligamentous injuries does not always result in stability; subsequent increase in bony deformity can often lead to persistent pain and/or later neurological deterioration (Aebi et al 1986; Blauth et al 1987). Early operative treatment lessens both the amount and intensity of patient care required and shortens the duration of hospitalisation and immobilisation (Aebi et al 1986; Blauth et al 1987; Bone et al 1989; Trunkey 1991).

Most fractures and dislocations should be reduced in a closed manner as soon as possible, and then CT helps to determine the type of spinal injury. Since a fracture of the cervical spine can otherwise be immobilised only with a Halo fixator or continuous traction, an operative approach is recommended. In the upper cervical spine we prefer a dorsal approach for the occipito-cervical junction, a ventral approach with screw fixation for odontoid fractures and a ventral fusion of C2-C3 for Hangman’s fractures.

Unstable fractures of the lower cervical spine are usually treated via an anterior approach which allows decompression of the spinal cord in patients with a neurological deficit. Stable fixation is accomplished after decompression and removal of the disc by an inter-body fusion, stabilised by an anterior H-plate fixation.

The initial management of thoracolumbar spinal injuries is by closed reduction and correction of alignment. Subsequent posterolateral decompression with transpedicular stabilisation is performed as early as possible. For burst fractures an additional ventral fusion is needed. In multiply traumatised patients we advise a two-stage approach (Aebi et al 1986; Blauth et al 1987).

It is rare for unstable fractures of the thoracic spine to need immediate treatment in the primary period; nearly all cases are associated with severe thoracic trauma, which may destabilise the thorax. Intensive-care treatment is nearly impossible, unless the unstable spine is fixed. Most fracture-dislocations in this region lead to a haemothorax, caused by rupture of the pleura and bleeding from a segmental artery. The main goals of treatment are first the decompression of the spinal cord and then adequate stabilisation. Operative technique and suitable fixation devices must guarantee a short operative period, and for long-term prognosis, preferably a short fusion of the spine (Aebi et al 1986; Blauth et al 1987). The possible disadvantages of prone positioning and thoracotomy in these patients during the primary period are still a matter of controversy.

SECONDARY PERIOD (3 to 8 days)

The secondary period is a phase of regeneration. Haemodynamic and respiratory stability is essential before any further operations. Secondary deterioration of organ function must be prevented by the evacuation of haematomas, the extensive debridement of soft-tissue necrosis and the elimination of septic foci (Tscherne et al 1983; Regel et al 1993). During this phase reconstructive treatments include: secondary wound closure and soft-tissue reconstruction; definitive treatment of frontobasal and facial fractures; osteosynthesis of the upper extremity and especially the forearm; and complex joint reconstructions.

Extensive soft-tissue defects. These defects should be covered at a maximum of 72 to 94 hours. The type of soft-tissue reconstruction needed is decided at the time of wound revision, the so-called ‘second-look’ operation...
Large soft-tissue defects place high demands on the skills of the surgeon and a well-defined therapeutic plan is necessary. The strategy will be influenced by the degree of exposure of bone, tendons and nerves. Bone that is devoid of periosteum requires coverage with soft tissues with a good blood supply.

Local flaps such as advancement or rotational flaps are the classic techniques used to resurface soft-tissue defects of limited size. Muscle, myocutaneous and fasciocutaneous flaps are simple and safe when used to cover defects of moderate size. For these techniques, it is necessary to consider not only the blood supply of the muscle in question, but also the permissible range of the transfer. For the frequent defects at the front of the tibia, we recommend gastrocnemius and soleus flaps. For large defects, microvascular free flaps are now considered: the latissimus dorsi flap is the most widely used at present.

**Osteosynthesis of the upper extremity.** If the general condition is unstable in the primary period, the operative treatment of forearm fractures should take place in the secondary period (Tscherne et al 1983, 1987), which is the best time to obtain stable osteosynthesis. In the past, we have used plate osteosynthesis for these fractures, but we now prefer an intramedullary rod system to reduce the known risks associated with the invasive approach required for plating.

Monteggia fractures are of special interest because the dislocation of the radiohumeral joint is often not diagnosed and therefore not reduced adequately, leaving residual shortening of the ulna. These injuries should be stabilised during the primary period.

**Complex joint reconstruction.** Anatomical reconstruction of the joint surface and realignment of the articular component to the shaft are the essential principles of osteosynthesis. In isolated injuries this is normally performed immediately after admission, but in multiply traumatised patients, these time-consuming operations should be postponed until the general condition of the patient has stabilised and soft-tissue swelling and disruption have settled. Exact preoperative planning, sometimes requiring special radiological investigations such as tomography, or CT with 3-D reconstruction, is obligatory. Before operation, external transarticular fixation devices are removed to allow an open reduction and reconstruction of the joint. A minimally invasive approach or closed reduction and stabilisation with percutaneously applied implants is possible and may be recommended, provided that stable osteosynthesis is achieved and early mobilisation will be possible.

**TERTIARY PERIOD (after 8 days)**

By eight days, in the tertiary period, the prognosis of the multiply traumatised patient is normally apparent, but in some cases organ dysfunction may increase and isolated ARDS may develop. In these patients further operative procedures cannot be considered.

In all other cases, recovery continues, and final reconstructive operations are required. These include: bone grafting at the site of massive bony defects; special soft-tissue reconstructions; definitive closure of amputation sites; and all remaining procedures postponed from the secondary period.

In this period, the patient is normally being weaned from respiratory support and has definite haemodynamic stability. He or she should cease to require sedation and need only a low level of analgesic medication. An intensive programme of physical rehabilitation is required; it should start during hospital care and be continued until complete rehabilitation and social reintegration have taken place.

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