UPPER AND LOWER LIMB FRACTURES WITH CONCOMITANT ARTERIAL INJURY

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We describe a management strategy for upper- and lower-limb fractures with associated arterial injury and report the results in 113 cases treated over a period of 18 years. Primary amputation was performed in 23 patients and of those who underwent primary vascular repair, 27 needed secondary amputation, two-thirds of them within a week of the injury. Of those requiring secondary amputation, 51.8% had ischaemia exceeding six hours, 81.4% had severe soft-tissue injury and 85.2% had type III open fractures. The patients whose limbs had been salvaged were followed up for an average of 5.6 years. The eventual outcome depended on the severity of the fracture, the degree of soft-tissue damage, the length of the ischaemic period, the severity of neurological involvement, and the presence of associated major injuries. There was a 30% incidence of long-term disability in the salvaged limbs, largely due to poor recovery of neurological function.

Prompt recognition of such combined injuries is vital and requires a high index of suspicion in patients with multiple injuries and with certain fracture patterns. We recommend a multidisciplinary approach, liberal use of pre-operative angiography in upper-limb injuries and selective use of intra-operative angiography in lower-limb injuries. Stable external or internal fixation of the fractures and re-establishment of limb perfusion are urgent surgical priorities to reduce the period of ischaemia which is critical for successful limb salvage.

The alarming rise in the incidence of severe trauma in civilian life has been matched by an increase in vascular injuries associated with limb fractures. While great improvements have been made in methods of patient transportation and diagnosis and treatment, vascular injuries are still a danger to limb and sometimes life. There is a race against time in the diagnosis and treatment of these combined injuries. Despite prompt and correct management, the outcome is sometimes unfavourable due to the overwhelming nature of the trauma. It is even more tragic if delay in diagnosis or inadequacy of treatment contribute to such a result.

There have been many reports of the vascular complications of limb trauma (Fabian et al 1982; Heberer et al 1983; Meek and Robbs 1984; Menzoian et al 1985; Downs and MacDonald 1986) and of methods of fracture fixation for these injuries (Rich et al 1971; Allen et al 1984; Meek and Robbs 1984; Howard and Makin 1990).

Most refer to the lower limb and the results are described in terms of amputation rates rather than eventual limb function. Our study, based on 113 cases treated during the last 18 years, describes our management strategy for upper- and lower-limb trauma, evaluates the factors affecting outcome, and presents the long-term results in the salvaged limbs.

PATIENTS AND METHODS

Between 1973 and 1990, we treated 113 patients with combined limb fracture and vascular injury in the Department of Traumatology, University of Freiburg. These injuries constituted 0.4% of all fractures seen during that period. The group included 39 patients referred from other hospitals.

The average age of the patients was 26 years (six to 75). There were only 15 women. The injury resulted from high-velocity trauma in 76.3% of the lower limbs and 54% of the upper limbs (Fig. 1). The sites of skeletal and arterial injury are shown in Figure 2. The tibia and the popliteal artery were most commonly involved and in 45% of cases there was an associated lesion of a named vein. The fractures were open (4.4% type I, 8.8% type II, 59.3% type III) in 72.5% and comminuted in 44.3% (Allgöwer 1971). Soft-tissue injury to the limb was classified according to Tscherne and Oestern (1982); 16.8% were type I, 18.6% type 2 and 64.6% type 3 lesions.
Neural involvement, assessed in all cases by a neurologist, was found in 75.2% of cases. There were associated major injuries to the head, chest or abdomen in 50.5% of the patients.

Management. The algorithm shown in Figure 3 was used as a guide. We used a Doppler probe if there was a suspicion of vascular injury based on absent pulses, ischaemic signs, evidence of neurological involvement, or a fracture pattern known to have a high incidence of associated arterial damage. In upper-limb fractures, if the result was equivocal, prompt conventional pre-operative angiography was performed in most cases (Fig. 4). For injuries of the lower limb angiography was only used exceptionally (Fig. 5). We performed intra-operative angiography by femoral puncture when required.

The patients were examined under anaesthesia on the operating table to assess damage to the skin, soft tissues and major nerves as well as the extent of comminution and contamination of the fracture. Taking into account the anaesthetist’s verdict on the patient’s general condition, and considering any associated major injuries, a joint decision was made by the multidisciplinary team to proceed either with limb salvage or amputation.

When the first option was chosen, the fracture was stabilised either temporarily or definitively. The artery was then explored and an intraluminal catheter was passed to effect thrombectomy and allow regional heparinisation. The arterial repair was carried out by the vascular surgeon. If there was a neurological deficit, the nerve was exposed to differentiate lesions in continuity.
from transections. For a transection, we preferred delayed repair at two to three weeks, only tagging the nerve ends in the acute stage.

We performed fasciotomy through a single lateral incision over the fibula if the period of ischaemia exceeded six hours, if there was severe soft-tissue damage with a closed fracture, or if the artery and vein were both damaged. No fasciotomies were required for the upper limbs. Treatment of the soft tissues was by irrigation, debridement, antibiotic administration and delayed wound closure. In some recent cases, synthetic skin grafts were used. Early wound coverage by flaps was not employed except in selected cases in which we rotated local muscle flaps.

Close surveillance of limb perfusion by clinical, Doppler and digital subtraction angiographic methods was maintained. Temporary fracture fixation was revised to the definitive form when the soft-tissue status permitted.

RESULTS
Fracture stabilisation. During the 18-year period of this study there was an evolution of the methods used (Fig. 6) with an increasing trend towards external fixation although internal fixation was most common. Kirschner wires were generally used for supracondylar fractures of the humerus in children.

Vascular repair. We performed pre-operative angiography in 33 cases. Figure 7 shows the types of arterial lesion and the methods of repair. In 80% of cases an autologous vein graft was used, in 14.4% an end-to-end anastomosis; in 3.3% a prosthetic graft, and in 2.2% simple suturing. Repeated operation was successful in the 5% of cases that developed postoperative thrombosis of the repaired vessel. One repair with a synthetic graft failed, necessitating amputation.

Duration of ischaemia. The time interval between injury to the vessel and restoration of the circulation was less than three hours in 21.1% of cases, three to six hours in 43.2%, and more than six hours in 35.7%. The ischaemic period was more than six hours in 27.6% of the lower-limb and in 46% of the upper-limb lesions.

Fasciotomy. Before 1982, we had performed fasciotomy in only four cases, but since then we have used it more routinely in a further 12. In eight it was done during the primary operation and in eight as secondary procedures.

Secondary bone grafting. In 16.8% of the fractures, bone grafting was needed, usually for delayed union after satisfactory soft-tissue healing. Four fractures in the upper and two in the lower limb failed to unite, and required further treatment. Eventually, union was obtained in all cases.

Primary amputations. In 23 cases (20.4%) primary amputation was performed; most were of the lower limb (16). Table I shows the factors that were considered in making this decision. All the amputated cases had type 3 soft-tissue lesions, 95.6% had type III open fractures and 69.6% had severely comminuted fractures.

Hospital stay. The average stay in hospital was 67 days with a maximum of nearly one year in two cases.

Complications
Infection. Infection occurred in 13.5% of the upper-limb and 40.8% of the lower-limb injuries. Of these, 72.2%
Figure 5a – An open type III femoral fracture in a 24-year-old motorcyclist. There was also complete division of the femoral artery and vein and contusion of the sciatic nerve. No pre-operative angiogram was necessary. Figure 5b – External fixation was used to stabilise the fracture and the femoral artery was repaired. Figure 5c – Digital subtraction angiography done three weeks after the injury shows patency of the femoral arterial repair. Figure 5d – Radiographs three years after injury.
had type 3 soft-tissue lesions, 61.7% had type III fractures, and 50% comminuted fractures. There was an 8.8% incidence of osteomyelitis; one case needed amputation but the others healed after removal of implants, sequestrectomy, and bone grafting.

Secondary amputation. In 27 cases (23.9%) secondary amputation was required owing to a combination of overwhelming sepsis and gangrene. In one there was failure of a synthetic vascular graft and in another a severely paralysed leg was amputated. Two-thirds of the amputations were carried out within a week of injury; 70.4% were on the lower limb. In 51.8% of secondary amputations the ischaemic period was longer than six hours, in 81.4% there was a type 3 soft-tissue lesion and in 85.2% an open type III fracture (Fig. 8).

Mortality. There were 11 early deaths all in patients with multiple injuries. One patient died several years later from an unrelated cause.

Long-term results. Excluding the patients who had undergone amputation, the remainder (51) were followed up for an average of 5.6 years (Fig. 9). They were examined clinically for limb girth and length, range of joint motion, neurological function and circulatory status. A Doppler probe or an oscillogram was used in doubtful cases. One upper limb had an abnormal Doppler flow, but the oscillogram was normal. Five lower limbs had an abnormal Doppler flow which was confirmed by the oscillogram in two. The patients were asymptomatic and refused angiography. Radiographic examination showed that all the fractures had united. There was one case of post-traumatic arthritis of the knee following a fracture of the proximal tibia and one patient had malunion of the radius and ulna. We used the system of Mollowitz (1986) for assessing disability and classified the patients into four groups according to their ability to use the involved limb (Table II).

Prognostic factors. We found that the following factors contributed to a poor result (groups 3 and 4 in Table II):

1) an open fracture of type III (66.6% of group 3 cases and 40% of group 4);
2) a soft-tissue lesion of type 3 (55% of group 3 cases and 60% of group 4);
3) an ischaemic period of more than six hours (33% of upper-limb and 66.6% of lower-limb injuries in groups 3 and 4);
4) the presence of significant neural deficit (33% of group 3 and 4 cases had median or radial nerve lesions and 45.4% had peroneal or tibial nerve lesions);
5) associated major organ-system injuries.

Socio-economic evaluation. The average hospital stay was 67 days and the average time off work was 14 months after these injuries. In 39% of the upper-limb and 26% of the lower-limb cases, the patients were unable to return to their previous jobs. Of these, 18.7% were unemployed and 12.5% had retired prematurely. Incomplete neurological recovery, particularly in the upper limb, was the major obstacle to the recovery of useful function. Using the criteria of Mollowitz (1986), we found an overall incidence of 30% of long-term disability.

DISCUSSION

Re-establishing the circulation in an injured limb is a priority surgical procedure and time is of the essence if limb salvage is to be effective. Of the various factors responsible for a poor result, the period of ischaemia is perhaps the only one which can be altered by prompt diagnosis and immediate action. A high index of suspicion of vascular damage must be maintained by all involved in the care of trauma victims. This is especially true when dealing with those with multiple injuries and with certain fracture patterns such as supracondylar humeral fractures in children, fractures and dislocations around the knee, and segmental or severely comminuted tibial fractures. Good treatment requires close cooperation between radiologist, anaesthetist, traumat-
logist, and the vascular and plastic surgeons. Immediate transfer to a centre with such expertise, if necessary by helicopter, is clearly desirable.

The presence of a peripheral pulse does not exclude the possibility of proximal arterial damage (Meek and Robbs 1984). An absent pulse, coupled with ischaemic signs, signifies the need for urgent intervention. Although a Doppler probe may be used to monitor patients with equivocal signs, it is not accurate enough to exclude vascular injury and it may lead to a false sense of security in inexperienced hands (Mansfield et al 1989). The measurement of Doppler pressures in the presence of severe proximal damage may not be feasible, and haemorrhage around vessels can prevent the accurate transmission of signals.

Angiography is the single most valuable diagnostic procedure. For upper-limb injuries we recommend the use of pre-operative conventional angiography on the least suspicion, since the excellent collateral circulation around the shoulder and the elbow can often maintain palpable pulses and a good Doppler flow. Proximal humeral fractures were associated with lesions of the subclavian artery in three cases, the axillary artery in four and of the brachial artery in two. Radio-ulnar fractures were associated with injury of the brachial artery in four cases, of the radial artery in three and of the ulnar artery in three.

For the lower limb, pre-operative angiography is not essential and may add significantly to the delay in treatment (Lange et al 1985). Intra-operative angiography by femoral puncture can easily be done, and provides all the necessary information. Angiography serves not only to exclude injury but, if there is a lesion, also to define its location and extent and the state of the collateral circulation and distal vessels. Digital subtraction techniques should be used to assess the postanastomotic patency of vessels (Fig. 5c). This helps to identify and rectify thrombotic problems early.

Debate continues about the order of precedence of fracture stabilisation and vascular repair. We stabilise the fracture while the vascular surgeon harvests the vein graft. Internal fixation is preferred for upper-limb and femoral fractures and external fixation for tibial fractures. Early conversion to definitive fixation is practised when possible. Our low incidence of nonunion may be due to this policy and to the early use of bone grafting. We cannot comment on the relative merits of external versus internal fixation as we use them frequently in complementary fashion.

Fasciotomy is being used increasingly to prevent the postanastomotic compartment syndrome and its routine application has been advocated (Bone and Bucholz 1986).

An interposed autologous vein graft is the repair of choice. Although synthetic grafts have been used occasionally, we have reservations about them in massive soft-tissue lesions with the ever-present risk of sepsis. The indications for repair of isolated forearm or leg

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**Fig. 8**

Frequency of secondary amputation in relation to ischaemic period, soft-tissue lesion, and type of fracture.

**Fig. 9**

Overall outcome.

**Table I. Criteria for primary amputation**

<table>
<thead>
<tr>
<th>Criteria</th>
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<tbody>
<tr>
<td>Open fracture type III with soft-tissue lesion type 3</td>
</tr>
<tr>
<td>Duration of ischaemia &gt; six hours</td>
</tr>
<tr>
<td>Concomitant major nerve injury (e.g., brachial plexus injury)</td>
</tr>
<tr>
<td>Prolonged shock</td>
</tr>
<tr>
<td>Older patients</td>
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<tr>
<td>Pre-existing medical illness (e.g., diabetes, nephropathy)</td>
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<tr>
<td>Associated major organ-system injury</td>
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</tbody>
</table>

**Table II. Long-term results in salvaged limbs**

<table>
<thead>
<tr>
<th>Group</th>
<th>Use of limb* (per cent)</th>
<th>Percentage in each group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Upper limb</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>53</td>
</tr>
<tr>
<td>2</td>
<td>75</td>
<td>17.6</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>11.8</td>
</tr>
<tr>
<td>4</td>
<td>&lt;50</td>
<td>17.6</td>
</tr>
</tbody>
</table>

* Mollowitz (1986)
arteries, when there are normal uninjured parallel vessels, remain uncertain. In our series, isolated lesions of radial, ulnar and anterior and posterior tibial arteries were repaired when this could be done expeditiously and without further trauma to soft tissues or without resort to complex grafting. We have not routinely repaired veins or performed venography. In this context the possible risk of thrombosis needs to be weighed against the possible benefit of reduced oedema (Timberlake, O'Connell and Kerstein 1986). We do not have any experience of the use of temporary vascular shunts.

The reported rates of primary amputation in other published series cannot be compared with ours since they have not been clearly stated. Those of secondary amputation have varied widely (Table III). The vascular injury is not, itself, the deciding factor. The state of the soft tissues, the type of fracture, the nerve lesions, the general status of the patient, and the associated major organ-system damage must all be considered. The multidisciplinary team must make a joint decision early in the course of treatment. We agree with Lange et al (1985) that amputation should not be regarded as a failure of treatment.

Several studies (Lange et al 1985; Hansen 1987; Pozo et al 1990) have focused on the dilemma of salvage versus amputation and scoring systems have been designed to assist with the decision (Luba and Costello 1984; Pozo et al 1990; Robinson 1990). While there is merit in trying to identify a limb that may be doomed from the beginning, thereby minimising the need for repeated operations, prolonged suffering and financial hardship, we feel that the predictive value of such scores is limited. The decision has medical, social, financial and medicolegal consequences and there are many pitfalls in the management of these complex injuries. It is therefore unlikely that any system of guidelines could take account of all the possibilities; the decision must be made by combined clinical judgement. Our practice has, perhaps, been slightly more in favour of primary amputation than others. This is reflected in the short average hospital stay of nine weeks in our series; in comparison Pozo et al (1990) reported 21 weeks for patients who had had amputation between one month and one year after injury and 34 weeks for those having it more than one year after injury.

As the success rates of revascularisation have improved, ultimate function depends mainly on the degree of recovery from nerve injury. Thus, it is not the amputation rate but the rate of return to work that is the more accurate and valid measure of outcome. Neurological defects were the main reason for the permanent disability rate of 30% in our series. Perhaps the focus of attention needs to be shifted from the problem of vascular repair to the management of the injured nerves. Besides early and meticulous repair of transected nerves, there may be merit in early exploration of lesions in continuity two to three months postoperatively when any neuro-praxia would have resolved. The use of intra-operative monitoring of the nerve action potential and excision of segments lacking axonal regeneration need to be studied in the quest to reduce disability.

Table III. Reported rates of secondary amputations

<table>
<thead>
<tr>
<th>Authors</th>
<th>Total</th>
<th>Combined arterial and skeletal injury</th>
<th>Secondary amputations (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabian et al 1982</td>
<td>164</td>
<td>25</td>
<td>68</td>
</tr>
<tr>
<td>Allen et al 1984</td>
<td>14</td>
<td>14</td>
<td>42</td>
</tr>
<tr>
<td>Meek and Robbs 1984</td>
<td>100</td>
<td>100</td>
<td>16</td>
</tr>
<tr>
<td>Lange et al 1985</td>
<td>23</td>
<td>21</td>
<td>39</td>
</tr>
<tr>
<td>Downs and MacDonald 1986</td>
<td>63</td>
<td>49</td>
<td>22</td>
</tr>
<tr>
<td>Caudle and Stern 1987</td>
<td>9</td>
<td>9</td>
<td>77</td>
</tr>
<tr>
<td>Letsch et al 1987</td>
<td>165</td>
<td>25</td>
<td>33</td>
</tr>
<tr>
<td>Howard and Makin 1990</td>
<td>35</td>
<td>35</td>
<td>20</td>
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Conclusions
1) Time is of the essence; the goal is to reduce the ischaemic period.
2) A high index of suspicion is required when treating patients with multiple injuries and with certain fracture patterns.
3) A multidisciplinary approach and swift transfer to an appropriate hospital are essential.
4) Prompt pre-operative angiography is required for most upper limbs at risk, and selective intra-operative angiography for lower limbs.
5) An early decision regarding amputation must be made.
6) Stable fracture fixation and vascular repair are surgical priorities to re-establish limb perfusion.
7) Careful postoperative surveillance of the soft tissues, the arterial anastomosis, fracture healing, and nerve recovery is important.
8) The outcome depends on the severity of the initial injury and the duration of ischaemia.
9) Neurological function largely determines the usefulness of the salvaged limb and close attention must therefore be paid to the treatment of nerve injuries.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

REFERENCES


