Severe limb injuries

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"L'éspoir vit au coeur de l'homme de chetive pâture"
(Hope lives in the heart of man on simple fodder):
La Fontaine

Until recent times, severe limb injury was commonly fatal. The earliest discovered examples of treated human fractures, found in Egypt and dating from 3000 BC, include an early fatality from an open fracture of the femur.

The creation of open fractures was a method of torture and execution in Europe in the Middle Ages. The only practical treatment was amputation and this carried a high death rate. Amputation remained the mainstay of management of these injuries, with a few exceptions, until the 20th century.

In the First World War, Sir Robert Jones reported an 80% mortality from gun shot wounds of the femur, until the routine use of the Thomas splint applied at the battlefield reduced the shock during transport.

The ability to salvage such limbs has stemmed from a number of advances, including:

- Blood transfusion,
- Competent surgery of the wounding,
- Antibacterial agents,
- Skeletal stabilisation,
- Recognition and understanding of compartment syndromes,
- Better criteria for amputation,
- Greater understanding of the patho-physiology of the injury challenge.

Epidemiology

In most societies, the major causes of severe limb injuries are war, road traffic accidents and industrial trauma.

The incidence of such injuries is greatly variable.

In Great Britain, in any one year about 900,000 fresh fractures present at hospital (1). It is assumed that about 1:10 of these injuries has the potential to result in serious disability unless treated with great skill.

90,000 severe limb injuries a year for a population of 55,000,000 represents an annual incidence of 1:600. This is probably so for most European countries. The incidence is likely to be higher in the USA and other populations where access to firearms is more liberal.

A recent review of all fractures in Edinburgh (24) reported, for a catchment population of 600,000, a total of 15,293 fractures in a 2 year period, approximately 8,000 fractures/year, or 1 fractures/74 persons/year. Of these 34% required admission, equivalent to circa 1 fracture admission/220 persons/year.

Yaremchuk 1986 (26) reported that of 2100 severely injured patients brought to Shock Trauma Centre, Baltimore, Maryland in one year, 100 had open tibial fractures. Of these 86% resulted from road traffic accidents and 64% were Gustilo grade III. The catchment population is not reported.

It is surprising how little is published on the epidemiology of severe limb injury world-wide.

Economics

Most severe limb injuries occur in younger age groups. In a study of 7,180 tibial fractures from the AO Documentation database, 6,300 were between the ages of 15 and 60 years. These are the productive population. Inadequate care of such injuries would constitute a massive loss of investment and a rising cost in terms of loss of productivity and the need to fund handicap.

Francel (9) found that after salvage of Gustilo grade IIIB injuries of the lower leg treated using microvascular soft tissue reconstruction, only 28% secured long term employment and no patient returned to work after 2 years of unemployment. Hansen (15) has described the latter group as "divorced, demoralised and destitute."

By contrast, a study of below-knee amputees after IIIB and IIIC injuries, also reported by Francel, revealed that 68% had returned to work within 2 years.

Butcher et al. (3) reported more optimistic results, with 72% return to work at 12 months after lower extremity trauma and 82% at 30 months. This group however included hip fractures, femoral fractures and some foot fractures, as well as lower leg injuries.

It has been said that the purpose of good trauma care is to return the victim to tax-paying status! This remark is less cynical than may appear initially. To convert a tax-contributing family into a tax-consuming family is a huge loss to a nation's GDP.

Outcomes

Little is known of the outcomes of severe limb injury. The authors of a recent metanalysis of the results of treatment of closed tibial fractures (18), reached the conclusion that the published clinical and outcome data were insufficient to derive any therapeutic recommendations.

Caudle and Stern pointed out that one of the keys to successful limb salvage in Gustilo IIB tibial fractures is early soft tissue reconstruction (4).

Immediate free tissue transfer after generous injury zone excision and skeletal fixation was pioneered by Godina (12) with extremely impressive limb survival rates (Table 1). Great strides have been made in the techniques of soft tissue reconstruction, but the results can be disappointing. Francel (8) stated "Massive lower extremity trauma victims may have a greater than 90% limb salvage by early soft tissue coverage, although functional failures are commonly seen."

The prediction of outcome after severe limb injury is necessary in order to decide clinically between salvage and amputation. Moniz et al (20) found that with combinations of skeletal injury and major vascular trauma, the amputation rates for femoral artery damage were 26%, for popliteal 54% and for arterial damage below the knee 38% (20% for 1 vessel injury, 33% for 2 vessel injury and 100% for 3 vessel injury). The amputation rates were higher for 2 or more fractures in the limb.

The Mangled Extremity Score (MESS) is a prospective scoring system to aid in the decision making and is considered elsewhere (16).

Staniforth (25) reviewed 800 randomly selected personal injury medico-legal reports dealing with multiple or single anatomical site fractures. He had them evaluated additionally by 30 other orthopaedic surgeons. 50% of the patients had no disability, often the result of good care. 30% had residual morbidity which was inevitable regardless of care. 20%, however had residual disability judged to be due to poor management: more than half of these had sufficient morbidity to affect significantly quality of life, independence, work, etc. This extrapolates to over 100,000 patients per year left with disability as a result of sub-optimal are in Great Britain.

Table 1. Results of Godina (12) demonstrating superior outcomes in severe open fractures using radical débridement, skeletal stabilisation and very early free soft-tissue flap reconstruction.

	Time to flap coverage		
	Early < 6 days	Delayed 3wks–3mo	Late > 3mo
Number	134	167	231
Microsurgical failure	1	20	22
Infection	2	29	14
Bone healing average months	6.8	12.3	29
Days in hospital	27	130	259
Anaesthesia episodes	1.3	4.1	7.8

Braithwaite (2) found that after serious injury (ISS>15) 8% were severely disabled as a result of amputation of an arm or a leg. Eighty percent of all long-term disability was due to the original musculoskeletal injury. Continuing problems after 5 years were recorded in 93% of patients with lower limb injury (55% with moderate to severe pain).

Frütiger et al. (11) reviewed a series of patients in Switzerland 5 years or more after multiple injuries. They reported an overall 80% recovery rate. This is better than achieved in other reports: the Swiss have a system of rapid transport, often using helicopters and of aggressive surgical care of fractures. In Switzerland, the training in trauma is a constant thread throughout the 7 years of general surgical training.

Francel wrote of severe lower extremity trauma (9) "Patients need to realise the disruptive nature of this injury on their family, job and future."

A conclusion of the1997 British Orthopaedic Association study of severely injured patients (1) was that "Good recovery is possible after severe and multiple injury with optimal care systems".

Deficiencies of care seem to be due to poor training and to poor organisation of trauma services, with too many small units receiving serious injuries, thereby diluting experience and clinical education.

The expression of outcome after musculo-skeletal compromise has traditionally been in terms of measurable limb function and fracture union parameters. The impact of the illness upon the individual is more relevant in terms of societal reintegration.

Certain health instruments are available for general illness, but few are specifically designed for musculoskeletal injury or disease. Swiontkowski has developed an outcome expression for such pathology and this in the final stages of validation. MacKenzie et al have proposed and validated a Functional Capacity

Index for trauma (19).

The standardisation of such instruments is necessary if comparative studies in the future are to indicate management pathways to maximise treatment potential and to guide decision making.

Clinical considerations

Initial assessment and diagnostic procedures

Primary survey: During the primary survey, life-threatening conditions must be identified and their treatment started simultaneously according to the ATLS protocol (23).

Extremity injuries that pose an immediate threat to life are those with major, uncontrolled hemorrhage, such as complete, or incomplete, traumatic proximal amputations, or multiple open fractures.

Secondary survey and specific evaluation: As soon as perfusion and oxygenation of the vital organs are secured, long-term life-threatening, or potentially fatal, limb injuries must be detected: internal and thus occult haemorrhage, as in bilateral femoral fractures, severe crush injuries with large amounts of necrotic tissue, or contaminated open fractures prone to overwhelming infection (clostridial gangrene).

Limb-threatening trauma includes vascular injuries with distal ischaemia, compartment syndromes with neurovascular ischaemia, severe open fractures and crush injuries, especially neglected ones.

History of the mechanism of injury provides helpful clues, of particular significance being whether an high energy impact ocurred.

Physical examination will reveal wounds, deformities, bruising and swelling. The limb must be assessed for sensation, capillary perfusion, warmth and distal pulses. Careful passive motion by the examiner detects instabilities, whilst manual splinting or traction facilitates the examination for active, voluntary motion.

Vascular assessment: in a hemodynamically stable patient, pulse discrepancies, coolness, pallor, paraesthesia, hypoaesthesia, and abnormal motor function suggest possible impairment of blood flow to the limb. Any abnormality of distal pulses (weakness, or Doppler signal only) strongly suggests a vascular injury. Other hard signs of arterial injuries are pulsating, brisk, external bleeding and a rapidly expanding hematoma. If after checking any immobilisation device and fracture alignment the distal perfusion remains abnormal, immediate surgical intervention, or angiography is mandatory.

Compartment syndrome: whenever tissue pressure in a fascial compartment rises above the capillary perfusion pressure, local ischaemia of muscle and nerve occurs, resulting in permanent paralysis and necrosis (ischaemic contracture) if diagnosis and surgery are delayed.

Muscle compartment pressures greater than 35–45 mm Hg in an haemodynamically stable patient suggest impaired capillary blood flow with the urgent need for fasciotomy. Crush injuries, high energy impact with closed fractures and ischaemia-reperfusion injuries after prolonged shock, or after revascularisation, should carry a high index of suspicion for compartment syndrome. Typical symptoms are: increasing, unrelenting pain, pain on passive stretching of involved muscles, decreased sensation of nerves traversing muscle compartments, swelling and weakness or paralysis of involved muscles, even with intact distal pulses. Intracompartmental pressure measurements are mandatory, especially in unconscious patients.

Soft tissue assessment must include all layers of the soft tissue envelope. The obvious skin wounds do not allow a grading of the deeper soft tissue damage. The assessment and grading of soft tissue wounds are dynamic, progressive processes which assemble increasing evidence during surgical débridement, scheduled ("second look") repeated débridements or complication-enforced revisions. High energy impact, degloving, ischaemia, and neglected wounds with significant contamination determine much more the severity of damage than the size of skin opening.

Assessment of bones and joints: Deformity, instability, and exposure of joints and articular fragments in open wounds constitue obvious evidence of fractures and articular injuries. Occult skeletal injuries are often missed in patients with multiple or severe trauma, the most frequent error is to find only the obvious and dominating of long bone fractures and to overlook additional distal injuries. Radiographs in at least two planes, including adjacent joints, are essential for all suspected limb regions.

Neurological assessment usually requires a cooperative patient. For each significant peripheral nerve, distal voluntary motor and sensory function must be confirmed systematically. It must be borne in mind that impaired sensation and muscle function may be due to arterial occlusion or compartment syndrome.

Imaging: The standard radiographs in two planes are still the workhorse. Additional information can be obtained by stress-films, or radiographs under traction, after closed reduction under anaesthesia. Conventional planar tomography may be helpful, although today mostly superseded by CT scans. Angiography is mandatory in suspected vascular lesions, "mangled extremity" and "proximity" injuries.

MR imaging has its place not so much in the emergency evaluation, but is important for detection of bone bruises, closed cartilage and ligament-injuries and, later, for avascular bone necrosis and muscle fibrosis.

Scoring: Grading and scoring of injuries allows the comparison of treatment protocols and outcome studies. In the acute setting it is important for decision-making, e.g., whether to salvage a limb or to amputate.

The soft tissue damage around fractures can be classified in closed fractures according to Tscherne, in open fractures according to Gustilo, or by the AO-classification of soft tissue injuries (21).

The fracture pattern itself can be graded with the comprehensive fracture classification of long bones by Müller (21). For specific fracture areas there are many published classifications. The overall trauma impact can be scored by the "Injury Severity Score", wherein the extremity lesions are graded according to the "Abbreviated Injury Scale" (5).

The "Mangled Extremity Severity Score" is helpful in decision-making whether an injured limb should be reconstructed or amputated (16).

Treatment methods

The *aims of treatment* are the preservation of life, the reconstruction of the extremities with the minimum objective to allow painfree, independent functions of daily life—and, whenever possible, to regain full form and function. That means at least sufficient perfusion, nerve function and a stable soft tissue envelope without infection. The second priority is joint mobility with a useful range of motion, and the third priority bony healing of fractures without malaligment and with joint-stability.

The *general concept of treatment* is "damage control" as early as possible and then a well planned and coordinated reconstruction of soft tissue and bony structures (14).

"Damage control" involves control of severe haemorrhage, control of contamination by radical débridement, and control of ischaemia by revascularisation, especially fasciotomies to release compartment pressure. These measures must then be followed by open wound management, fracture fixation, tetanus prophylaxis and an adequate antibiotic regimen.

Débridement: open wounds should be covered by a sterile dressing in the prehospital phase. To prevent wound contamination with resistant hospital organisms, the primary wound dressing should only be removed under sterile conditions in the OR by the surgeon.

Under general anaesthesia, the injured limb must be cleansed: the damaged tissue should be copiously irrigated with a physiological medium such as Ringer's lactate solution, preferably using jet lavage.

The surgical débridement has to excise all dead tissue, to remove all dirt and foreign bodies, to release fascial compartments which are under pressure and to expose all wound cavities by redisplacement of the extremity. The most extreme débridement is the amputation of a limb, which must be considered primarily when the reconstruction of the extremity would endanger patient's life (e.g., MESS >7 points).

The débridement should be as extensive an excision of the injury zone as in oncologic surgery.

In most conditions it is difficult to judge whether tissue which seems viable will eventually survive. A "second look" re-débridement must be scheduled after 12–24 hours.

After débridement follows the fracture fixation and open wound management.

Whenever possible neurovascular structures (especially vascular anastomoses), bone, articular cartilage and implants should be covered by vital tissue, or at least protected against desiccation by moist padding, or better by skin-substitutes like Epigard.

Primary local, regional, pedicled or free flaps are mostly not possible and should not normally be undertaken. These plastic procedures should be planned after the first re-débridement, but then performed as early as possible.

Deep tissue defects resulting in cavities are best treated by vacuum sealing.

Fracture fixation is mandatory to protect the soft tissue from further damage, to reduce stress and pain, and to allow adequate posture of the trauma victim and the injured limb, as well as access for soft tissue reconstruction. Splints, casts and traction may cause additional harm to the soft tissues and prohibit early functional treatment. The golden standard today is stable fracture fixation by external fixators, intramedullary nails, or plates and screws.(13) Each of these fixation methods has its "biological price": To gain sufficient stability we should protect bone perfusion and proprioception as much as possible and in the multiple injured patient also avoid additional systemic load, such as pulmonary embolization due to reamed nailing of long bones.(22) The latter means that we should avoid primary intramedullary nailing in patients with an ISS >40.(10)

The most "forgiving" device is the external fixator. However, often it requires a change of fixation method for fear of delayed bone healing, or due to interference with plastic procedures. Therefore, external fixators are often used as preliminary emergency fixation devices, only to be followed by scheduled internal fixation. For shaft fractures of femur, tibia and humerus locked nailing is today the method of choice, preferably with solid nails without reaming, at least in open fractures. Plate fixation employing a minimal access technique can be a good alternative in C-type fractures of shaft and metaphysis, whereas in articular fractures an anatomical reduction and stable fixation with screws and plates is mandatory. Remember that forearm shaft fractures must be considered as articular fractures.

Soft tissue reconstruction comprises from simple split skin grafting to free vascularized flap transfer. The whole repertoire of "the reconstructive ladder" should be available, at least for the definitive reconstruction (17).

The same is true for options in segmental bone loss: bone substitutes, cancellous and cortico-cancellous bone grafts, free vascularized bone transfers, and distraction transport techniques according to the Ilizarov principles.

Rehabilitation: therapeutic interventions initially include positioning, splinting, active and passive exercises, continuous passive motion devices, re-education of activities of daily living, and oedema and scar management.

Psycho-social support and effective pain control may reduce post-traumatic stress disorders. Finally desensitization and vocational rehabilitation must be well coordinated with any necessary salvage or secondary reconstructive procedures.

The future—are there remedies?

Potential solutions lie in five distinct fields: prevention, education and training, data collection, organisation and political attitudes.

Prevention

There is little that the medical profession can do to reduce military conflict!

The reduction of road traffic accidents has elements of driver training, civil engineering, road law enforcement, zero tolerance of drunken driving, altered cultural attitudes to drugs and alcohol, and finally vehicle design.

Industrial injuries can be reduced by safety regulation at work and enforcement of good practices.

The strict control of firearms will also prevent much disability in the longer term.

Education and training

Regulated programmes of post-graduate education are not always satisfactory. In many instances, the involvement of senior and experienced surgeons in the initial care and decision-making is lacking. Much can be done by the professional bodies to emphasise the need for effective training. Training in trauma care should be a continuos pathway from medical school entry to specialist levels of post-graduate education —in many medical schools where fracture care is conducted by orthopaedic surgeons, medical students spend 4 times as long in elective general surgery than they do in trauma! (6)

The promotion and implementation of "Advanced Trauma Life Support" (ATLS) programmes will save lives and limbs (23).

Data collection

There is a crying need for standardisation of acquisition of data for injury management. There is much progress to universal acceptance of structured injury classification systems and this work must continue.

The categorisation of outcome remains heterogeneous. The need for database links to permit the pooling and exchange of data, the establishment of core data sets to express outcomes, not only in terms of traditional clinical measurement but also health impact instruments, are all initiatives in various stages of progression. These must also be encouraged and facilitated.

Organisation

Trauma is inconvenient and makes demands at difficult times. In small units, it is not cost-effective to schedule surgical time for trauma cases that may not arrive, and senior personnel cannot devote sufficient time to this activity. In consequence, a surgeon with a busy day-time schedule will avoid disruption out of hours. The concentration of trauma care on larger units permits realistic surgical timetables and increases senior input and experience.

Structure, organization, and budgeting of health services must include comprehensive trauma care systems as well as an Emergency Medical Systems (EMS) with all 15 basic EMS components (7).

"Task forces" should be constituted for severe limb injuries with expert-consulting-systems (e.g. videoconferences).

Political attitudes

There is no shortage of good professional advice from the surgical constituency to politicians and health planners. There is no doubt that money spent funding good trauma care is an investment for the nation, for the reasons explored above. Regrettably, the short-termism of current political attitudes obscures the vision of those with the power to exert influence and implement change. A political group seeking to control an economy is likely only to see the costs of delivering the care (this is measurable and the sums involved are large), and the long-term benefits are difficult to quantify, poorly understood by the electorate and come to fruition often after the political term of the administration of the day.

The challenge to the profession is to educate the body politic—how many wish to learn?

It is also a matter of regret that managed health programmes rarely are prepared to pay for specialised medical expertise. The profession has to find ways to exert powerful influence upon the managed health industry and increase access to necessary surgical skills, tailored to the patients' needs, not just what the health managers decide within a blatantly commercial framework.

Clinical progress

Pari passu with the initiatives discussed above, there will undoubtedly be continuing clinical advances improving the results of treatment of severe limb injuries.

A detailed examination of these is beyond the scope of this overview. Suffice it to say that innovations are likely to occur in many fields, including:

- Improved criteria for decision-making with regard to amputation versus limb salvage, reducing expensive and fruitless surgical salvage programmes.
- Advances in the biological management of the fracture locus. This will include the development of "Minimal Access Surgery" (MAS) for bone reduction and instrumentation and computer-assisted navigation, especially improving techniques to create "fiducial landmarks" in "moving targets".
- Improved antibacterial agents.
- Prophylaxis and treatment of osteoporosis, radical scavengers, modulation of adhesion molecules.
- Stimulation of fracture healing by physical methods and osseo-active cytokines.
- Research in biomaterials: such as tissue-engineering and surface-engineering of implants, bone-substitutes, augmentation materials for porotic bone, drug-delivery-systems (vital – non vital – hybrid systems).
- Improved techniques of bone reconstruction, including allografting. Concepts for immuno-tolerance of allogenic (and may be xenogenic) tissue components.
- Advances in soft tissue reconstruction.
- Artifical limbs: improvement of technology in myoelectric and hybrid protheses.

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