The Belfast Approach to Managing Complex Lower Limb Vascular Injuries

A.A.B. Barros D’Sa,* D.W. Harkin, P.H.B. Blair, J.M. Hood and E. McIlrath

Regional Vascular Surgery Unit, The Royal Victoria Hospital, Belfast, UK

Introduction. Complex lower limb vascular injuries (CLVIs) in high-energy penetrating or blunt trauma are associated with an unacceptably high incidence of complications including amputation. Traumatic ischaemia and ischaemia-reperfusion injury (IRI) of skeletal muscle often lead to limb loss, the systemic inflammatory response syndrome (SIRS) which affects remote organs and even the potentially fatal multiple organ dysfunction syndrome (MODS). Surgical care of CLVIs everywhere, including Northern Ireland until 1978, was governed by an anxiety to restore arterial flow quickly often using expedient and flawed repair techniques while a damaged major vein was frequently ligated.

Materials and methods. A new policy centred on early intraluminal shunting of both artery and vein, restoring arterial inflow and venous outflow, respectively, was introduced at the Regional Vascular Surgery Unit of The Royal Victoria Hospital, Belfast in 1979. It imposed a disciplined one-stage comprehensive approach to treatment involving a sequence of operative manoeuvres in which all damaged anatomical elements receive meticulous and optimal attention unshackled by time constraints.

Results. Comparisons drawn between the pre-shunt period of unplanned treatment (1969–1978) and the post-shunt period centred on the use of shunts (1979–2000) showed that early shunting of both artery and vein in both penetrating (P) and blunt (B) injuries significantly reduced the necessity for fasciotomy (P: p = 0.016, B: p = 0.02) and caused a significant fall in the incidence of contracture (P: p = 0.018, B: p = 0.02) and of amputation (P: p = 0.009, B: p = 0.012).

Conclusions. The policy of early shunting of artery and vein in CLVIs has proved to be of great benefit in terms of significantly improved outcomes, better operative discipline and harmonious collaboration among the specialists involved.

Keywords: Complex lower limb vascular injuries; Pathophysiology of traumatic ischaemia; Belfast approach to management; Intraluminal shunting of artery and vein; Shunting and operative discipline.

Introduction

Complex limb vascular injuries, almost exclusively observed on the battlefield until the mid-20th century,1 became increasingly prevalent in civilian life as a consequence of the worldwide proliferation of motor vehicles, advancing industrialisation and a mounting culture of urban violence and endemic terrorism.2–4 Victims of terrorism, being indiscriminate targets, are necessarily of all ages and of both sexes, while the majority of other casualties tend to be young males and generally productive members of society.

The nature and severity of injury to the limb is determined by the wounding energy dissipated on impact. The transient ‘cavitation’ perpendicular to the trajectory of a high velocity bullet disrupts all structures well away from its path, fragmenting bone to form secondary missiles, while sucking in clothing and other contaminants, the small entrance wound and a larger exit wound belying the damage within.5 The magnitude of energy imparted by the concentrated ‘spread’ of shot from a shotgun discharged at close range causes severe injury. The immense shearing forces generated by the sudden deceleration of a fast moving vehicle produce significant disruption of soft tissues and fracture and angulation of long bones which pierce vessels or indirectly cause vascular tears at points of relative fixity. Posterior (fracture) dislocations of the knee are accompanied by avulsive forces which literally tear apart popliteal vessels and adjacent soft tissue structures.

High-energy trauma, whether penetrating or blunt, meriting the term complex, is characterised by considerable damage to all structures. The main artery and vein are often transected or avulsed and long vessel segments may be crushed, punctured, and possibly denuded of adjacent viable muscle and soft tissue;
the severity of the injury may be further compounded by factors such as atherosclerosis or extensive contamination. Fractures are characterised by comminution, periosteal stripping and joint dislocation which may be open. Typical features are damage and loss of muscle and soft tissue, disruption of collateral vessels, high-pressure haematomas, nerve injury and varying degrees of wound contamination. Coexisting head trauma and exsanguinating injury to vital organs within the chest and abdomen may result in fatality at the scene or in transit. Those who survive hypovolaemic shock, exposure and delay must rely on optimal resuscitation and timely operative intervention, ideally in a dedicated trauma centre.

If such a scenario is attended by delay either in recognising vascular injury or in providing treatment, an unfavourable outcome is almost inevitable. Arterial injury and arrest of distal infl ow results in hypoperfusion of tissues further aggravated by hypovolaemic shock and generalised vasoconstriction. Striated muscle tolerates ‘warm ischaemia’ for 6–8 h depending on the level of injury and the availability of collateral flow, and for longer periods at ambient temperatures approaching 0 °C. The pathophysiological mechanisms which bring about ischaemia-reperfusion injury (IRI) of muscle compounded by damage to organs remote from it have been acknowledged (Fig. 1). The literature shows that vascular injuries are present in 10–48% of cases of complex limb trauma and amputation rates in this group as high as 85% have been reported.

For almost 30 years since 1969 the indiscriminate assault on the civil population of Northern Ireland by terrorists using sophisticated high velocity weaponry and massive bombs resulted in tens of thousands of casualties and a human tragedy of unprecedented proportions. During that time the Royal Victoria Hospital, the main teaching hospital of The Queen’s

Fig. 1. Schematic of the pathophysiological consequences of combined arterial and venous injury in complex lower limb trauma.

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University of Belfast and trauma centre for the province, received the vast majority of injuries. The Regional Vascular Surgery Unit of this hospital, one of the first three dedicated specialist vascular centres in the British Isles, acquired a substantial, albeit unsolicited, experience in dealing with all forms of vascular trauma including complex penetrating lower limb vascular injuries, supplementing the regular toll of blunt trauma from road and other accidents. These injuries often necessitated the cooperative endeavours of vascular and orthopaedic, and sometimes plastic, surgeons, not to mention a range of specialist nurses, radiologists, accident and emergency physicians, anaesthetists and intensivists. In a proportion of cases treatment had to be postponed until life-threatening head and torso injuries were treated.

Clearly, the most efficient use of the limited amount of operative time available is central to survival of the limb. Between 1969 and 1978 these complex limb vascular injuries were treated conscientiously but, in keeping with practice everywhere else, in an unplanned and unstructured manner. In 1979, a policy was introduced at the Regional Vascular Surgery Unit of the Royal Victoria Hospital, Belfast (Fig. 2) of early placement of intraluminal shunts to bridge both injured artery and vein at the earliest opportunity, revitalising the distal limb and re-establishing drainage from it, respectively.

**Materials and Methods**

The years of unplanned treatment (1969–1978) are referred to as the ‘pre-shunt’ period and those during which operative treatment was centred on the use of shunts (1979–2000) as the ‘post-shunt’ period. In the light of the literature and recognising the initial evident advantages conferred by shunting from 1979 onwards in terms of outcome as well as operative discipline, it was considered unethical to submit patients to randomised treatment based on the use or non-use of shunts.

**Clinical presentation**

Patients with straightforward limb vascular injuries were usually admitted well within 4 h but delays often occurred in those with complex limb vascular injuries. This might have been because they had been admitted to a peripheral hospital for resuscitation and damage control before secondary transfer or if difficulties were encountered in retrieval of casualties, for example, from the rubble following a bomb explosion or from a vehicle in which they had been trapped at a road accident. In certain cases the vascular surgeon from the Royal Victoria Hospital, equipped with a ‘vascular pack’ went to a peripheral hospital to perform definitive surgery. The casualties suffering complex lower limb vascular injuries fell into two groups: penetrating (pre-shunt 34, post-shunt 57), mean age 39 years, 5 male : 2 female; blunt (pre-shunt 38, post-shunt 49), mean age 25 years, 9 male : 2 female. Several permutations of anatomical injuries to the limb accounted for variations in clinical presentation, but common to all patients were different degrees of vessel (artery and vein 77%, artery alone 23%), bone and soft tissue damage.

**Early management**

In tandem with the essential resuscitative principles of securing an airway and correcting hypovolaemic shock, external bleeding was controlled, not by tourniquet or the hazardous practice of blind application of artery forceps, but by pad and bandage. Patients with life-threatening head and torso injuries were taken rapidly to theatre for damage control followed by definitive surgery. Anti-tetanus immune globulin and broad-spectrum antibiotics against aerobic and anaerobic organisms were administered adhering to local protocols. ‘Hard’ signs of ischaemia such as absent distal pulses, pallor, mottling, coolness and numbness were of value only when circulatory stability had been restored. In most open injuries duplex scans were of no value. In cases where pre-operative angiography was likely to lead to delay, on-table angiography proved to be eminently informative. In the case of the ‘mangled extremity’, particularly from...
bomb or crush injury, the surgeon either went on to ‘complete’ an amputation or, in the borderline case, after careful assessment and consultation, decided whether reconstruction was an acceptable option or not.

Operative management

A sequence of operative steps, centred round the use of shunts, was then set in motion (Fig. 3). Bleeding vessels were exposed and controlled. The damaged vessel ends were then trimmed back to a point where the vessel wall was of pristine quality. After thrombectomy the damaged segments of both artery and vein were bridged by shunts thereby arresting the relentless advance of ischaemia. The influence of shunting in restoring arterial inflow and venous outflow and thereby averting the pathophysiological sequelae of IRI and remote organ injury (Fig. 4) are discussed below.

These shunts had to be of a length which provided slack sufficient to cope with the range of movement necessary for reduction and fixation of the fracture (Fig. 2). Commercially available shunts offer adequate choices but silicone elastomer or similar tubing of suitable consistency, length and calibre, with its ends carefully tailored to avert intimal damage, represented an acceptable alternative.21,24,27 Venous outflow was restored only after blood, rich in potassium and the products of ischaemia and IRI, had been flushed out to protect the lungs and myocardium. A shunt incorporating a sidearm offered a convenient portal for injection of heparinised saline or contrast medium, or for estimation of blood gases. Early restoration of flow by shunts sharpened the distinction between viable and dead tissue and facilitated more accurate debridement at the outset. It also bought time for careful wound toilet. Injured nerves were identified and tagged with an epineurial stitch. Debris, foreign bodies and bone fragments were removed and the field copiously irrigated to dilute the bacterial inoculum and so minimise the chances of sepsis. Sloppy wound excision or cleansing allows Gram-positive and Gram-negative cocci as well as bacilli, acting synergistically, to initiate cellulitis and even necrotising fasciitis. The anaerobic environment of poorly debrided ischaemic tissue favours the growth of Clostridium spores some of which can cause gas gangrene.

Attention was then turned to restoring skeletal integrity in order to ensure the safety of subsequent vascular repairs. The fractures were reduced and stabilised either by internal or external fixation7 before repairs of artery and vein were commenced (Fig. 5). In principle, had shunts not been used when artery and vein were simultaneously severed, arterial repair would have taken priority, the shortening of ischaemia time and IRI being the key objective. If, however, anxieties over time had been dispelled by the insertion of shunts, then neither artery nor vein would have warranted preferential attention as the order of
repair would have been immaterial; in a sense, shunting had eliminated that debate. Furthermore, as time was no longer at a premium, greater use was made of the long saphenous vein in reconstructing vessels. Donor vein was usually harvested from the contralateral limb and drawn over the shunt which, acting as a stent, encouraged precise suture technique and prevented ‘purse-stringing’ at the anastomoses. If the calibre of donor vein was less than desirable then a compound vein graft of suitable diameter was fashioned affording better prospects for long-term patency.2–4,6,7,21–27,30 A proven method at this centre, however, was to take two, and if necessary three, segments of vein graft of equal length, open them longitudinally to form panels, excise any valves and then sew them together side by side either ‘on the bench’ or over a shunted vessel to create a panelled compound vein graft; alternatively a longitudinally slit length of vein, bereft of valves was wound spirally over a bridging shunt and the adjoining vein margins sutured to produce a spiralled compound vein graft.

In the older patient the presence of atheromatous disease in the vicinity of the injured segment sometimes called for the use of an outlying shunt and in such cases a bypass rather than an interposed graft seemed a more prudent option. When skin and soft tissues were damaged or lost extensively along the axis of the vessels, an extra-anatomic vein bypass, tunnelling the graft through clean tissue, represented a more prudent option.

Indications of success elsewhere using polytetrafluoroethylene (PTFE) grafts in injured arteries31 did not induce complacency in dealing with the kind of open contaminated wounds seen in Northern Ireland, in particular those caused by bomb explosions. It should be acknowledged, however, that although a PTFE graft riddled with sepsis remains immune to breakdown, the host vessel at the anastomoses begins to disintegrate heralding perilous secondary haemorrhage.32 By contrast, an infected vein graft is attacked directly by bacterial collagenases and undergoes necrosis leading to the same outcome.

A disrupted major vein segment was usually reconstructed by fashioning the kind of compound vein graft used for a large artery (Fig. 6). The importance attached to restoring venous outflow is discussed below.

On completion of arterial and vein repairs, the indications for fasciotomy were considered: they included delayed admission, the presence of significant oedema or raised compartment pressure possibly accentuated by a pressure haematoma, and a discernible drift towards plantar flexion of the foot. The standard double-incision approach decompressing all four compartments was the mainstay in fasciotomy technique employed at this centre and it proved both simple and effective.33

At closure, and in the knowledge that debridement and cleansing had been thoroughly executed, careful attention was paid to eliminating dead space and ensuring satisfactory vessel cover by virtue of adjacent muscle and soft tissue because a vein graft left exposed to desiccation is unlikely to survive. In instances of soft tissue loss, superficial muscles were freed and swung over to ensheathe vessel repairs but when these defects were larger and deeper (Fig. 5), cover was achieved by rotating muscle flaps or preferably by employing free vascularised musculocutaneous flaps. While it was fairly safe in closed injuries to proceed to primary closure of incisions, in open wounds delayed primary suture following inspection 5–7 days later was felt to be the wiser course.
Post-operative management

Post-operatively, the injured limb was nursed horizontally. Antibiotics, anticoagulants and fluids were administered as necessary. Provided the patient was haemodynamically stable, a mannitol infusion was sometimes administered perioperatively with the aim of accelerating the inactivation of oxygen reactive species. Peripheral pulses and skin perfusion were closely monitored aided by Doppler ultrasound. Any suspicion of post-operative arterial graft failure was confirmed by immediate angiography and if indicated followed swiftly by revision of the repair. A small calibre thrombosed vein graft bridging an artery was usually replaced by a compound vein graft of suitable diameter, a precept applied similarly to cases of mismatch between vein and interposed vein graft, regardless of the possibility that it might occlude in the longer term. Regular swab cultures of wounds were taken. When deemed necessary, re-explorations for additional debridement, irrigation and drainage were undertaken under general anaesthesia. Only when satisfied with the cleanliness of the wound was delayed primary suture undertaken. Early commitment to rehabilitation was crucially important.

Results

The duration of review was between 2 and 5 years depending on need except in cases where a patient was lost to follow-up. Arterial graft patency was of the order of 90% at 5 years in those who had not lost the affected limb. In a consecutive series of 13 patients in whom compound vein grafts were used to replace segments of a major leg vein a patency rate of 41% at 3 years was recorded. Hospital deaths in complex limb vascular injuries at initial admission were as follows: penetrating nine (pre-shunt five, post-shunt four), blunt 12 (pre-shunt three, post-shunt six); all were primarily due to concurrently sustained injuries of the head, chest and abdomen and not a direct consequence of the limb injuries, subsequent sepsis or secondary haemorrhage. The pre-shunt and post-shunt groups were comparable in terms of the degree of complexity of trauma and the quality of vascular, anaesthetic and intensive care given, the standards of which were uniformly high throughout the period in question.

Using three parameters, namely, fasciotomy, contracture and amputation, comparisons were drawn between the pre-shunt period of unplanned treatment (1969–1978) and the post-shunt period centred on the use of shunts (1979–2000) and the findings are shown in Table 1. In penetrating complex injuries shunting significantly reduced the necessity for fasciotomy (OR 3.5, CI 1.3–9.2, \( p = 0.016 \)), the incidence of contracture (OR 3.7, CI 1.3–10.6, \( p = 0.018 \)) and of amputation (OR 5.0, CI 1.6–16.0, \( p = 0.009 \)). In blunt complex injuries shunting also significantly reduced the need for fasciotomy (OR 3.0, CI 1.2–7.4, \( p = 0.02 \)), the incidence of contracture (OR 3.1, CI 1.2–7.9, \( p = 0.02 \)) and of amputation (OR 3.9, CI 1.4–11.0, \( p = 0.012 \)).

The incidence of re-exploration and secondary repair fell as the policy of shunting became routine. The incidence of sepsis, both immediate and late, was scrutinised in relation to the use of shunts but, unfortunately, records were not always complete and the exact sources of infection were not clear-cut. Assessment was further complicated by the fact that some primary wounds and incisions, but mainly

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<td>Fasciotomy</td>
<td>17/30 56.7</td>
<td>13/48 27.1</td>
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Data were analysed using the statistical package SPSS version 10.0 for windows (SPSS Inc., Chicago, IL). Clinical characteristics of the two study groups were compared and analysed by \( \chi^2 \)-test (Yate's corrected), and Fisher's exact test (when appropriate). Corresponding odds ratio (OR) and 95% confidence interval (95% CI) values were calculated. Variable were considered statistically significant at \( p < 0.05 \).
fasciotomies, had a tendency to become superinfected with *Pseudomonas aeruginosa*, staphylococci, and during the latter years methicillin-resistant *Staphylococcus aureus* (MRSA) and a variety of other resistant bacteria often acquired while in intensive care. The sepsis rate fell with increasing implementation of the policy of shunting, although it has to be accepted that this trend was not statistically significant: in penetrating injuries it fell from 18 to 12% and in blunt injuries from 9 to 5%.

**Discussion**

Certain aspects of the management of complex lower limb vascular injuries must be understood. These include not only the pathophysiology of ischaemia and IRI and the significance of impaired venous outflow but also the clinical rationale for, and the benefits of, shunting both artery and vein. In addition, specific practical questions such as management of the mangled extremity, the place of angiography, reconstruction of a major venous channel and aspects of fasciotomy require discussion.

**Pathophysiological considerations**

The importance of the pathophysiology of interrupted arterial inflow and venous outflow should be understood. Reduced tissue oxygenation depletes high-energy phosphates essential to cell metabolism and increased levels of purine metabolites and cellular acidosis create an intracellular environment which, on reperfusion, richly favours the production of oxygen reactive species. These species, namely, superoxide anions, hydrogen peroxide, and hydroxyl radicals bring about IRI. Failure of local anti-oxidant scavenging systems in the face of overwhelming production of oxidants is central to injury associated with oxidative stress. These oxidants promote lipid peroxidation and lysis of cell membranes metabolising arachidonic acid to generate a cascade of potent vasoactive eicosanoids such as thromboxane A2 and leukotriene B4 which have both local and systemic pro-inflammatory effects. Local recruitment, activation and sequestration of neutrophils also release oxygen reactive species and proteases, further compounding IRI. A systemic inflammatory response syndrome (SIRS) affects the bowel and generates cytokine release which has implications for the liver, lungs, heart, brain, and kidneys. This scenario represents the multiple organ dysfunction syndrome (MODS) and usually results in fatality.

Modern advances in molecular medicine have given us new insights into the intracellular effects of skeletal muscle ischaemia-reperfusion. Recent reports using gene-microarray techniques have shown that skeletal muscle hypoxia induces specific transcriptional responses within the cell leading to differential expression, both upregulation and downregulation, of a variety of genes, such as: proinflammatory genes, adhesion molecule-related genes, angiogenesis-related genes, cell-cycle control genes, DNA damage repair genes, pro-apoptotic and anti-apoptotic genes, and signal transduction and transcription genes. It appears that both the extent and duration of ischaemia is crucial to this process, and, therefore, any measure initiated which curtails the ischaemic period should offer some clinical benefit. Reports also suggest that gene therapy can be helpful in managing the chronic ischaemic limb and it would not be unreasonable to expect such therapies of the future to tackle the harmful effects of acute limb ischaemia.

In the lower limb, endothelial cell injury promotes increased microvascular permeability, transcapillary filtration and tissue oedema thereby gravely reducing tissue perfusion, and contributing to the compartment syndrome; endothelial activation and swelling is associated with microvascular stasis, thrombosis, aseptic muscle necrosis, Volkmann’s contracture, ischaemic nerve palsy and amputation. Of the lower leg compartments the anterior, bounded by rigid osseous and inelastic fascial confines, is the most vulnerable. In limb trauma involving combined major artery and vein injury, delay or failure to restore flow through the injured vein accentuates membrane lipid peroxidation, and as has been shown at this centre, not only aggravates IRI, compounding the oedema, raising peripheral resistance, lowering arterial inflow and compromising arterial repair, but also enhances neutrophil mediated lung injury manifesting itself as non-cardiogenic pulmonary oedema.

**Rationale for the Belfast approach to management**

The rationale for a new approach to treating complex limb vascular injuries at Belfast’s Royal Victoria Hospital in 1979 arose from a number of considerations. Even when the injury is confined to a leg, the complex characteristics of the condition demand a finite, and sometimes unacceptably prolonged, period of time to complete the definitive operative tasks of exposure, wound care, control of bleeding, bone fixation and repair of artery and vein, however, swiftly they may be executed. In fact the awareness of advancing ischaemia and an understandable desire to restore flow

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quickly not infrequently leads to lapses of surgical principle and technique. For example, in order to restore flow urgently, a fracture is left unreduced and unstable while the artery is being repaired. In that hurry to restore flow there is often a tendency to use expedient and less than ideal techniques, for example, lateral suture which often results in ‘hour-glass’ constriction, direct end-to-end anastomosis under tension which causes stenosis, interposition vein grafts which are either too short and break down or too slack and kink; in all these instances thrombotic occlusion of the artery follows inevitably. Further, if in attempting to abbreviate operating time a major vein is injudiciously left unreconstructed, ligation results in compartment hypertension in turn impairing tissue perfusion and compromising arterial repair (Fig. 1). In addition to these drawbacks, the necessarily robust manipulations of bone fragments to achieve reduction and fixation by the orthopaedic surgeon are liable to wreck a delicately executed vascular repair. The alternative approach is to stabilise the fracture prior to executing vascular repair, but again the constraints on time imposed by continuing ischaemia may, conceivably, lead to hurried and defective fixation, which in turn may have negative consequences for bony union.

The mangled extremity

Despite the recognised advantages of intravascular shunting caution must prevail in treating the ‘mangled extremity’. Unreasonable zeal in attempting to salvage an irreparably damaged leg, especially when the sciatic or posterior tibial nerve is severed, will simply condemn the patient to a protracted series of amputations, prolonged hospitalisation, and eventually the disappointment of an insensate and possibly septic limb requiring amputation, even if it later occludes, enhances early limb survival and prevents the development of the chronic post-phlebitic limb manifested by oedema, induration and ulceration. Vein ligation has been shown to be responsible for a significantly higher incidence of limb oedema than that after vein repair. The sequelae of vein ligation, whether in

Importance of vein repair

Any examination of the case for reconstruction of a major venous channel must begin with the acknowledgement that as survival is the priority, the control of bleeding and repair of an artery takes precedence, and in dire circumstances, ligation of the vein is entirely forgivable. The suggestion, however, that ligation of a major vein is acceptable in general, cannot but be regarded as an assumption and possibly an excuse to do the minimum. In the average case, and certainly if arterial and venous shunts are in place, any objection to vein repair on the grounds that it is time-consuming is invalidated. It is also often stated, rather glibly, that in view of the richness of collateral venous flow it is fine to ligate a major vein. The fact remains that in complex injuries significant elements of the venous network, and of potential collateral pathways and lymphatics, within soft tissue have already been destroyed and cannot be relied upon.

We know from the evidence in the literature, both experimental as well as our own experience over the last three decades that ligation causes venous hypertension, raises compartment pressure and compromises the patency of a concomitant arterial repair; further that a vein repair, even if it later occludes, enhances early limb survival and prevents the development of the chronic post-phlebitic limb manifested by oedema, induration and ulceration. Vein ligation has been shown to be responsible for a significantly higher incidence of limb oedema than that after vein repair.
the military or civilian setting cause moderate to significant morbidity. Moreover, it has been proved convincingly at this centre that failure to repair a major vein or to ligate it accentuates IRI and also leads to remote lung injury. It is sometimes asserted, rather sweepingly, that a major vein graft repair inevitably undergoes thrombosis with subsequent loss of valve function. In a sizeable proportion of cases, however, the valves proximal and distal to that segment might, quite reasonably, be expected to function effectively. In fact, it has been demonstrated that valve function, whether within interposed vein grafts or in inferior vena cava xenografts, is retained.

The fact that vein grafts used to bridge arteries fail because of technique, but most frequently because donor vein calibre is small, applies more convincingly to an injured femoral vein which is not only of greater diameter than its companion artery but also tolerates lateral suture much better. There is no point in wasting time interposing a vein graft of poor calibre in the knowledge that it is likely to undergo thrombosis. It is infinitely preferable to proceed to other options. The internal jugular vein represents a useful alternative donor site when replacing a vein of the calibre of the deep femoral. The kind of compound vein graft used in Belfast to reconstruct arteries was also employed in repairing veins (Fig. 6). Such grafts have been used to repair injured veins with patency rates of 41% at 3 years and of 38% in comparison to 15% for simple vein grafts at 5 years. There is no more than anecdotal experience in complex limb vascular injuries at this centre of constructing a temporary arteriovenous fistula to maintain patency of a vein graft in the early post-operative period. This technique may well have theoretical advantages but one would have to be certain that perfusion to a leg already threatened by traumatic acute ischaemia is not impaired further by ‘steal’ at the fistula halfway down the leg.

Fasciotomy

It has been suggested that a compartment pressure of between 30 and 45 mmHg, a range at which nutrient blood flow ceases, is an indication for fasciotomy. It should be understood, however, that pressure monitoring is notoriously unreliable, and indeed that was confirmed in the early stages of our experience. At this centre the confidence placed on a judgement made on clinical grounds as to the necessity for fasciotomy in the individual case has been borne out over the years and that has particular relevance for complex limb vascular injuries. The one-incision transcutaneous fibulectomy method was tried briefly and quickly abandoned, reliance having been placed thereafter on the standard double-incision approach decompressing all four compartments. Fortunately, the incidence of this complication declined in proportion to the falling fasciotomy rate accompanying the increasing practice of intravascular shunting. Nevertheless, in some complex limb vascular injuries, fasciotomy was required regardless of the use of shunts.

Benefits of shunting

Evidence now exists reaffirming our clinical conviction that restoration not only of arterial inflow but also of venous outflow was crucial to minimising local IRI and curtailing remote organ injury (Fig. 4). The Belfast approach to management has been influential in averting the complications of the compartment syndrome, myonecrosis, ischaemic nerve palsy, contracture and amputation. Furthermore, the practice of shunting imposes a disciplined and logical sequence of operative steps which consequently promotes harmonious collaboration among the specialists involved. Ample time is available for proper fixation of fractures, meticulous wound care and in making the correct choices in repairing both artery and vein. It is, therefore, a policy of proven efficacy in offering solutions to a number of dilemmas surrounding the management of complex lower limb vascular injuries. Having observed the benefits of shunting of both artery and vein, a shunt specifically designed for limb vascular trauma was proposed and although experimental studies undertaken subsequently at another centre in the United Kingdom gave encouraging results, a modified version of that shunt still awaits manufacture.

Conclusions

Vascular surgeons have to be prepared to deal with patients presenting with complex limb vascular injuries from road and other accidents and those arising from urban violence, flash points of civil strife and increasingly in theatres of sustained terrorism or war. Early placement of shunts in both artery and vein is the key to disciplined management of complex limb vascular trauma aimed at reconstruction of all injured anatomical structures at the first encounter. Restoration of arterial inflow and venous outflow by means
of shunts, particularly in cases of delayed admission, abbreviates limb ischaemia and IRI and buys time for meticulous care, significantly reducing the need for fasciotomy and bringing about a significant fall in the incidence of both contracture and amputation. There are no reports in the literature of the prolonged application and monitoring of such a comprehensive approach to managing complex limb vascular trauma as documented here. By definition, this Belfast approach is also intolerant of attitudes of indifference towards major vein injury and champions the case for optimal vein reconstruction. The implementation and efficacy of this policy in treating the uniquely challenging injuries faced in Northern Ireland has relied on a keen awareness of the deleterious consequences of progressive ischaemia and ischaemia-reperfusion injury, a sense of conviction of the logic of arresting that process as quickly as possible by means of shunts, the encouragement generated by accumulating evidence of improved outcomes and the close practical cooperation among vascular and other key medical and nursing staff.

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