MASSIVE HAND CRUSH: THE ROLE OF A FREE MUSCLE FLAP TO OBLITERATE THE DEAD SPACE AND TO CLEAR DEEP INFECTION

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Death of tissue and/or deep infection leading to amputation is not an uncommon course of events after massive crush injuries of the central part of the hand. Management of this injury faces the dual problem of having to carry out debridement in the central part of the hand which is radical enough to remove all dead tissue but which, in itself, creates a huge dead space in the depths of the wound. Inadequate debridement and/or leaving a dead space which fills with fluid and detritus behind the flexor tendons leads on to infection, devascularisation of the fingers and amputation. This paper presents the results of very radical debridement of the hand dorsal to the flexor tendons, including the intermetacarpal spaces, and filling the dead space with a well-vascularised free muscle flap in two hands which were referred in a pre-amputation stage, with one already being infected. Both hands were salvaged.

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Crush injuries of the hand are a common injury. In the typical case, one can expect metacarpal fractures, ragged skin flaps and an unusually high incidence of compartment syndromes (Piñal et al., 2002). ''Crush to the carpus'' is a much rarer, high-energy injury associated with axial wrist dislocations (Garcia-Elias et al., 1985). Sometimes, the fourth and fifth metacarpals dislocate ulnarly with their corresponding carpal bones (the hamate and triquetrum) while, in other cases, the first metacarpal and the radial column subluxes radially. Garcia-Elias et al. (1989), from a review of the literature, recognised a sub-group of these injuries with a concomitant vascular injury in which hand amputation was the end-point of treatment if urgent vascular reconstruction was not carried out. These injuries can usually be salvaged, provided vascularity is maintained or restored.

Less well recognised in the literature is what we call the ''massively crushed hand'', in which extremely high energy, such as that resulting from presses for bending metals or plastics, is delivered to the hand and wrist. These injuries include multilevel fractures of the carpal

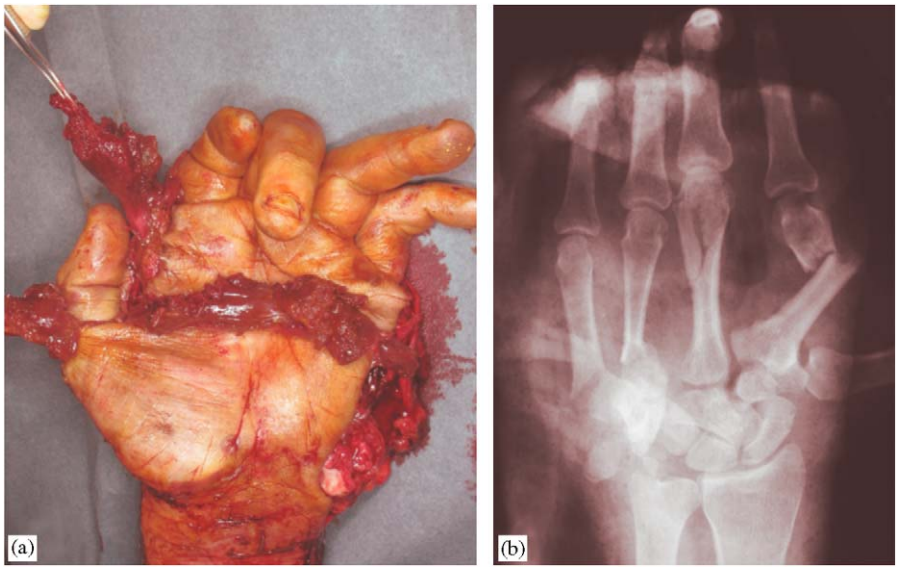

Fig 1 Case 2 (Admission picture and X-ray). The severity of the injury can be inferred by the amount of bone comminution and the hydraulic extrusion of the short muscles of the hand. Apart from the obvious fractures and the derangement of the carpal arch, the scaphoid was free and the first metacarpal was disconnected from the trapezium. The trapezoid was rotated through 180°.

and metacarpal bones, extrusion of loose carpal bones and intrinsic muscle and devascularisation of the fingers (Fig 1). There is little in the literature about the acute management of these injuries. Fortunately, these are rare injuries, as the outcome is often unrewarding, despite the tremendous surgical effort required. The result is often trans-carpal, or metacarpal, amputation of the hand.

This paper presents two patients who suffered such massive crush injuries to the hand and wrist which were treated with a free muscle flap to obliterate the dead space deep in the palm with successful retention of the hand and fingers.

CASE REPORTS

Case 1

A 22 year-old male construction worker was referred for amputation of his right hand with uncontrolled deep infection 3 weeks after suffering a severe crush injury when a dumper truck tilted and trapped his hand. He was treated initially by bone stabilisation of several carpal and metacarpal fractures and hand fasciotomies. Disruptions of both the radial and ulnar arteries at the wrist were vein grafted. The postoperative course was complicated by a sudden loss of digital pulses and pain at 24 hours. Deep infection followed 2 weeks after the accident.

On admission to our unit, the hand was red and swollen. Doppler signals were absent in all of the digits, with pulp pad necrosis present, particularly on the small finger. Purulent material was discharging through the hypothenar, thenar and dorsal fasciotomies wounds. Enterobacter was isolated in the cultured material.

At a first operation, we radically debrided all of the intrinsic muscles and any other devitalised tissue with a rongeur, skeletonising the metacarpals and carpal bones (Figs 2a and b). Two days later, a free vascularised extensor digitorum brevis muscle was used to fill the dead space in the centre of the palm behind the flexor tendons and to revascularise the hand and digits by interposing the anterior tibial-dorsalis pedis artery axis between the ulnar artery proximal to the wrist and the superficial palmar arch in the palm (Fig 3). Post-operatively, the pain abated and the Doppler signals were positive in all five digits. Paraesthesiae in the digits disappeared over the following 3 weeks.

The result 6 months after surgery is shown in Fig 3. At this time, the thenar muscles were reconstructed with a free functioning muscle transplant. He was lost to clinical follow-up after 18 months. When contacted by telephone, 12 years after the operation, he claims no recurrence of problems with the hand.

Case 2

A 39 year-old male suffered a severe crush injury to his left hand and wrist, with devascularisation of all of the digits (Fig 1). Initial treatment consisted of pinning of the carpal and metacarpal fractures and reconnecting the defect from the ulnar artery proximal to the wrist to the second and third commissural arteries with a "Y" shaped vein graft. The radial artery had been severed at two levels in the anatomical snuff-box, so was not

Fig 2 (a and b) Case 1. The extent of the debridement is shown by the rongeur passing freely through the hand deep to the flexor tendons. All of the intrinsic muscles had been removed. The ischaemia of the hand can be inferred from the visible necrosis of the digital terminal pulp pads of the index and little fingers.

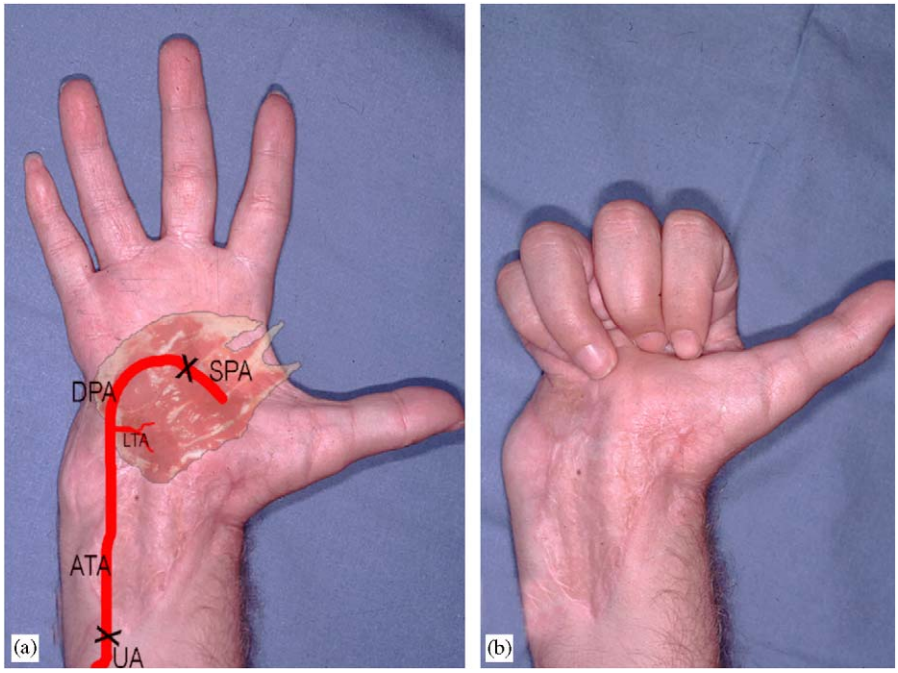

Fig 3 Case 1. The result at 6 months. An extensor digitorum brevis free flap was used to obliterate the dead space deep to the flexor tendons and to revascularise the hand (UA, Ulnar artery; ATA, anterior tibial artery; DPA, dorsalis pedis artery; SPA, superficial palmar arch; LTA, lateral tarsal artery).

repaired. All of the fingers were successfully revascularised. The thumb could not be revascularised as the digital vessels had been avulsed distally from the thumb pulp but was retained as a pedicled flap for possible use later for skin cover elsewhere on the hand. Over the next few days, the hand swelled, despite having left very little muscle at the first debridement, and the skin of the first web and thumb necrosed. On the ulnar side of the hand, skin necrosis threatened to expose the vascular repair. The patient was then placed under the care of the first author (F.D.P.).

The likelihood of amputation being necessary was discussed with the patient. Because hand survival was doubtful and even less likely if treatment was delayed, reconstruction was carried out immediately. After removing the necrotic tissue in the first web, a huge dead space filled with blood and debris dorsal to the flexor tendons became evident (Fig 4). As in the first case, all devitalised tissue dorsal to the flexor tendons, including the intermetacarpal spaces and the thenar area, was debrided with the help of rongeurs. The trapezoid bone was floating freely, so was excised. Although the reduction of the carpus was far from anatomical, it was accepted for fear of putting the hand itself at risk by further reduction manoeuvres.

A free gracilis muscle was then interposed between the vital palmar structures, viz. the flexor tendons, vascular grafts and nerves, and the skeleton, to obliterate the dead space. The muscle was passed from the radial skin opening to the ulnar opening (Figs 5a and b), and back again over the palm to sandwich the vascular repairs in muscle, allowing us to resect the necrotic palmar skin which had been covering the vascular grafts. Revascularisation of the muscle was carried out from the radial artery in the anatomical snuff-box. Most of the palmar skin which was

Fig 4 Case 2. Intraoperative view 7 days after the initial injury. The flexor tendons are retracted in a palmar direction to show the huge dead space dorsal to them, which was filled with clots and devitalised tissue.

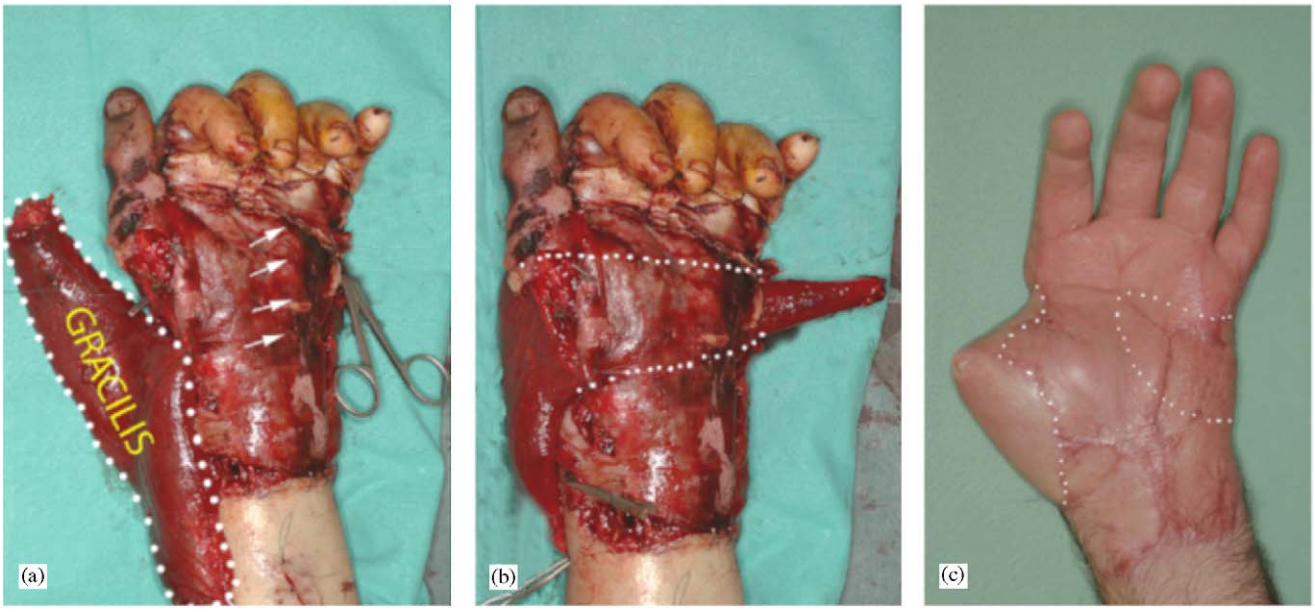

Fig 5 (a) Case 2. The gracilis muscle is ready to be pulled across the palm by a tendon passer under the flexor tendons and palmar to the carpal bones and fractured metacarpals. Arrows point to the clearly demarcated necrotic palmar skin which was debrided. The necrotic thumb, still attached to the hand, was amputated at the same operation. (b) The most distal part of the muscle, lying beyond the ulnar side of the palm, was then swung around as cover of the tendons and neurovascular structures on the ulnar side of the palm after excising obviously necrotic superficial fat and skin. Although all of the palmar skin had dubious vascularity, most of the skin of the central palm survived, probably as a result of relief of tension and improvement in circulation by the muscle placed below it. (c) Result at 5 months. The dotted line highlights the margins of the gracilis muscle (thumb reconstruction was pending at this stage).

not clearly necrotic was preserved as it was thought that the relief of tension and the placement of well vascularised tissue adjacent to it might improve the local conditions sufficiently for it to survive. This skin did survive.

The patient had an uneventful postoperative course and the exposed parts of the free muscle transfer was skin-grafted 5 days after the free muscle reconstruction. On the tenth day, the swelling in the hand was controlled by wrapping the central part of the hand with Coban® type bandage. This was changed every 2 to 3 days. Five months after the operation (Fig 5c), surgery on the ulnar side of the carpus was necessary to treat a combined hamate-carpometacarpal and hamato-triquetrum dislocation. Because of the very poor local conditions, a vascularised cortico-periosteal flap (Sakai et al., 1991) was used to aid fusion. During the operation, no infection or granulating tissue was found. Wound cultures from the deep tissues were taken and reported as negative. More importantly, the healthy gracilis was seen to be sticking to the palmar surface of the carpal and metacarpal bones (Fig 6). Thumb reconstruction is planned in the near future.

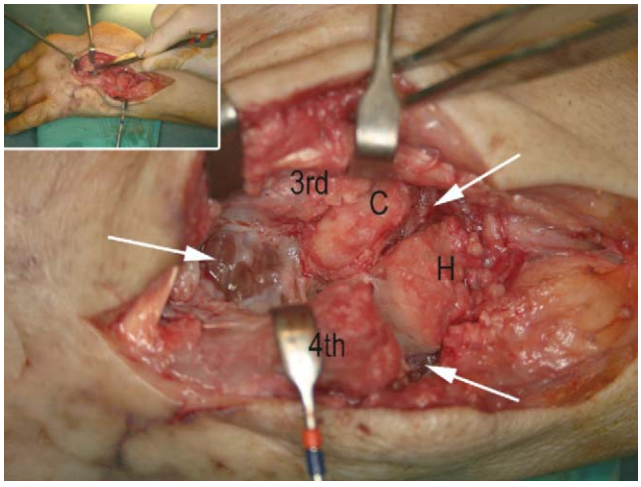

Fig 6 Intraoperative view of case 2 during a secondary operation carried out through a dorsal approach to reduce and fuse a complex carpometacarpal dislocation. The healthy gracilis muscle (white arrows) can be seen palmar to the bony framework, to which it was attached (H, hamate; C, capitate; 3rd, middle metacarpal; 4th, ring metacarpal).

DISCUSSION

In trauma surgery, it is crucial for avoidance of infection to debride doubtful tissues radically, to obliterate dead space and to provide immediate vascularised skin cover (Godina, 1986; Gupta et al., 1999; Lister and Scheker, 1988). In major replantation, deep infection is the most dreaded complication once the period of vascular compromise has passed. Infection is associated with insufficient debridement, and, since the very early days

of replantation, radical shortening has been recommended to allow for excision of marginal tissue (Idler and Steichen, 1992; Meyer, 1991). When immediate complete debridement is impossible or contamination is massive, Godina et al. (1986) proposed placing the amputated part ectopically until the infection had cleared. Chen et al (1994) and Shibata (2003), under unusual circumstances, have suggested giving some function to the extremity by replanting the fingers in the proximal wrist, or even in the forearm. Unfortunately, none of these techniques is applicable after massive crush injuries of the body of the hand.

Massive crush to the hand and wrist is a devastating injury. Axial carpal fracture-dislocations, fractured metacarpals, finger devascularisations with avulsed vessels, devascularised muscle and lack of skin cover, all coexist in this injury. Each of the component injuries is, in itself, a challenge to the most skilled hand surgeon. Tremendous surgical effort is required: the bones are replaced and re-aligned with extreme difficulty, the fingers only revascularised by the use of interposition vein grafts and cover of the vital structures may require an emergency free flap. Unfortunately, over the early postoperative days, everything may slowly go to pieces, with infection developing in the deep tissues of the body of the hand, the skin suffering patchy necrosis, the revascularised fingers dying and, finally, the hand coming to distal amputation.

This is not surprising if we consider how we have taken care of this injury in the past (Graham, 2006). Management has included bone fixation, bypassing the area of damage in the central part of the hand with vein grafts in order to revascularise the fingers and even providing cover of the vital structures with the help of free flaps, but the basic principle of total debridement of the deep tissues then obliteration of the dead space has not been carried out adequately. Often the first operation has resulted in a combination of inadequate debridement and/or a huge dead space deep to the flexor tendons (Fig 4), in which devascularised carpal bones and multifractured metacarpals float in haematoma: a most unprotected state for resisting infection.

Taking as an inspiration the treatment of tibial osteomyelitis where, after debridement, a free muscle is used to fit into the tridimensional bony defect created (Anthony and Mathes, 1991), in these two cases, we obliterated the dead space in the hand with a free vascularised muscle transfer after total debridement of dead and dubious tissue. The muscle both introduces new blood supply, adapts effectively to the irregular defect of the dead space and can be used to revascularise the digits (Piñal and Herrero, 2000). In our first case, the muscle helped deal with infection already present and, in the second, helped prevent progression to infection and death of the digits distally.

The massive crushed hand poses a phenomenal reconstructive challenge. By using a free muscle transfer to obliterate the dead space left on the deep palm after total debridement of all but the vital longitudinal structures, we have been able to clear, or avoid, infection in two cases while preserving the fingers.

This approach is recommended in the desperate situation of the massive crush injury to the body of the hand.

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