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Case Report

Successful Salvage of the Upper Limb After Crush Injury Requiring Nine Operations: A Case Report

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Emergency treatment of amputation is one of the most frequently used therapeutic methods for patients with severe upper limb crush injury with a mangled extremity severity score (MESS) of more than 7. With the development of advanced surgical repair techniques and reconstructive technology, cases that once required amputation can now be salvaged with appropriate management, and some limb functions may also be reserved. A patient with a severe upper limb crush injury with a MESS score of 10 was treated in our hospital. The limb was salvaged after 9 surgeries over 10 months. The follow-up visits over the next 18 months post-injury showed that the shoulder joint functions were rated as "excellent" (90) according to the Neer score, the Harris hip evaluation (HHS) for elbow joint functions was "good" (80), and the patient was very satisfied with the overall therapeutic outcome. We conclude from the successful outcome of this extreme injury that salvage attempts should be the first management choice for upper limbs with complex injuries to save as much function as possible. Amputation should only be adopted when the injury is life-threatening or no more function can be saved. The level of evidence was V.

Key words: Trauma – Upper limb – Crush injury

With the rapid development of transportation and modern industries, there is an increasing incidence of limb injuries caused by high energy trauma, such as road traffic and machine injuries. As a consequence of the development of surgical repair and reconstruction technology, limbs damaged by high energy trauma that might have needed to be amputated in the past can now be salvaged by surgical reconstruction.[1] The choice between amputation or salvage of lower extremities with mangled injuries was made according to the Gustilo scale, the scale of the Orthopaedic Trauma Association, and

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the mangled extremity severity score (MESS).[2,3] Satisfactory outcomes can be achieved with the use of artificial limbs after amputation. However, severe upper limb crush injuries differ as upper limbs have fewer muscles, longer ischemic tolerance times, and complex functions that cannot be substituted by artificial limbs. Togawa *et al*[4] adopted the MESS system to judge the necessity of amputation in complex upper limb injuries. Two cases with MESS ratings of 11 and 7 were both salvaged by microsurgical repair, while another case with a score of 11 required amputation due to primary shock.[4] Prichayudh *et al*[5] applied the MESS system in a group of cases with upper limb injuries; all cases with MESS ratings less than 7, and some cases with scores >7, were successfully salvaged. Currently, no appropriate criteria have been developed used to decide whether amputation or salvage is the most appropriate therapy in cases of complex upper limb injury, and this remains a dilemma for both surgeons and patients.[6]

This study describes the case of a 49-year-old female patient with left upper limb crush injury after an accident. This was an example of successful limb salvage with functional preservation after 9 surgeries over a 10-month period.

Materials and Methods

A 49-year-old female had her left upper limb crushed by the front wheel of an unloaded truck while riding her bicycle and was admitted to the emergency department of Jinshan Hospital, Fudan University (Shanghai, China) 3 hours later. Physical examination showed reduced consciousness (GSC score of 13), with a blood pressure of 80/40 mm Hg and heart rate of 130 beats per minute (bpm). There was a longitudinal laceration of the skin in the left axillary fossa of approximately 10 cm in length. There was wide laceration of the left forearm skin associated with a circumferential degloving injury of the skin in addition to a further degloving injury of the left posterior upper arm to the axillary fossa. The wounds were obviously contaminated. The left forearm was deformed with crushed flexor muscles and exposed fracture ends and musculature. The finger peripheral blood supply was poor, and the filling time of the nail capillary bed was delayed. Imaging on x-ray showed comminuted fractures of the proximal left ulna, distal left radius and left scapula. The computed tomography results showed a scalp hematoma over the left occipital frontal region, a left pleural effusion, and a fracture of the second left rib. The diagnoses were: hemorrhagic shock; open multiple fracture (IIIc; fracture of the proximal left ulna, distal left radius and left scapula); soft tissue mangled injury of the left forearm; fracture of the second left rib with pleural effusion; and scalp hematoma over the left occipital frontal region.

Antishock therapy and debridement were conducted in the emergency setting. In the process, we found that the ulnar artery was contused over a length of 4 cm, and that 5 cm of the radial artery was damaged. However, the ulnar, cephalic, and basilic veins were intact. The median and ulnar nerves were only mildly contused and appeared to have good continuity. Therefore, limb salvage surgery was planned.

During the initial surgery, the hemorrhagic muscle tissues (including brachioradialis, flexor carpi radialis, pronator teres, flexor pollicis longus, abductor pollicis longus, partial flexor digitorum superficialis and profundus, and the interossei) were removed, and the forearm fractures were fixed with external fixation. The radial artery was repaired via autologous venous transplantation from the basilic vein of the contralateral forearm. Only the outer membrane of the ulnar artery was injured and, after local hot-wet soaking, its pulse recovered. The degloved skin of the left forearm and upper arm was debrided and sutured in situ, and the wound was covered and drained using a vacuum-assisted dressing (VAC; Figs. 1A–1C). An antibiotic (cefuroxime sodium, 1.5 g every 8 hours) was used postoperatively to prevent infection. Urine alkalization and diuretic therapy were administered to prevent crush syndrome. Due to the use of VSD, protection of the renal function was taken into account. For this reason, mannitol was not used.

Results

We carefully observed the blood supply of the fingers after the operation (e.g., finger abdominal fullness, finger color, capillary filling time, etc.). Vascular crisis was not observed. One week after surgery, the degloved skin of left forearm and upper arm became necrotic and was removed under general anesthesia. Closed drainage with VAC was used to prevent infection and promote the growth of granulation tissue. At the same time, the scapular fracture was treated by open reduction and internal fixation using steel plates (Figs. 2A–2C). However, as a result of infection and the poor growth of granulation tissue, a second debridement and VAC

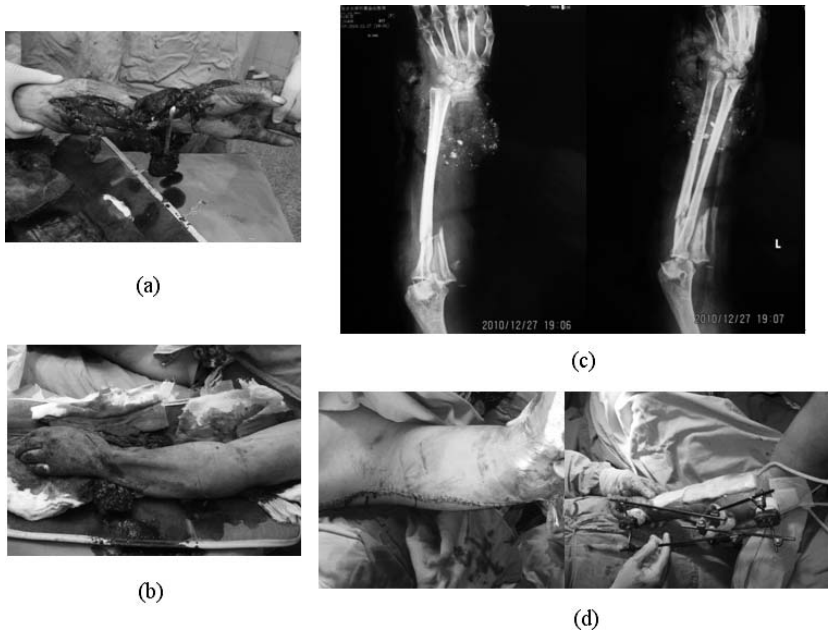


Fig. 1 (a) Left forearm crush injury; flexor digitorum and flexor carpi muscle groups were crushed with significant defects; ulnar and radial arteries were contused and embolized. (b) Left forearm crush injury; circumferential degloving injury of the left forearm skin and avulsion injury to the left upper arm skin. (c) Comminuted fracture of the left proximal ulna and distal radius, with foreign bodies within the wound. (d) Surgery to debride and repair the ulnar and radial arteries by transplantation. The ulna and radius were fixed by external fixation, and the avulsed skin was sutured in situ.

drainage was conducted (Fig. 3). After 4 weeks, the infection was controlled and the granulation tissue was growing well.

The fifth surgery included autologous stamp-like skin grafting to cover the wounds on the left forearm and left upper arm (Fig. 4). The grafted skin survived and the sixth surgery was conducted 9 weeks after injury to manage the proximal ulnar fracture by open reduction and internal fixation with a steel plate. Additionally, the distal radial

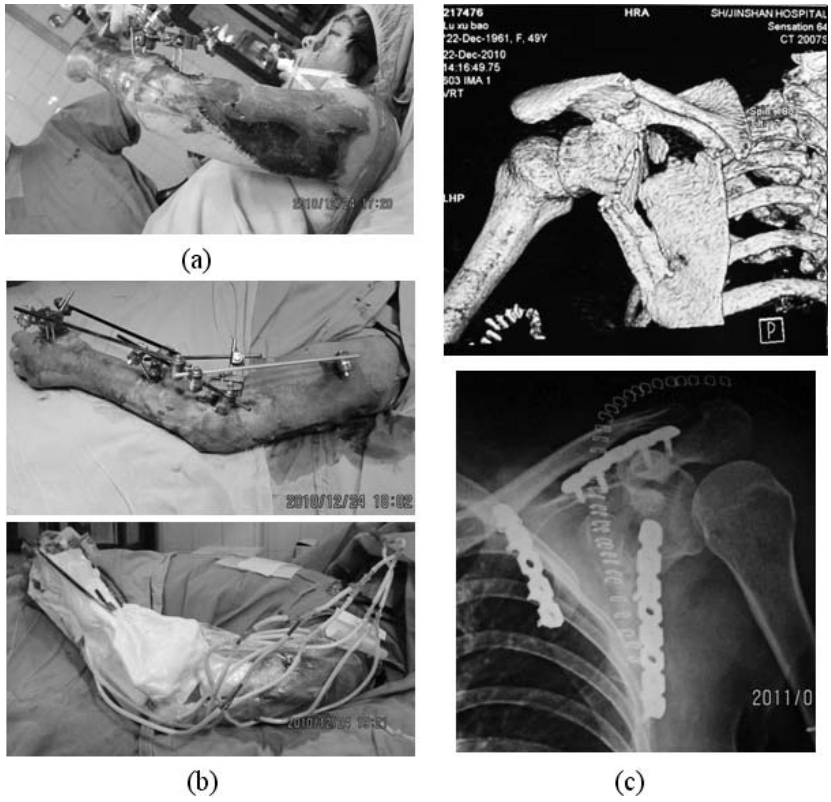


Fig. 2 (a) One week after emergency surgery, avulsed skin of left forearm and upper arm was necrotic and blackened. (b) Vacuum-assisted closure after debridement and resection of necrotic skin. (c) Open reduction and internal fixation with steel plate of scapular fracture.

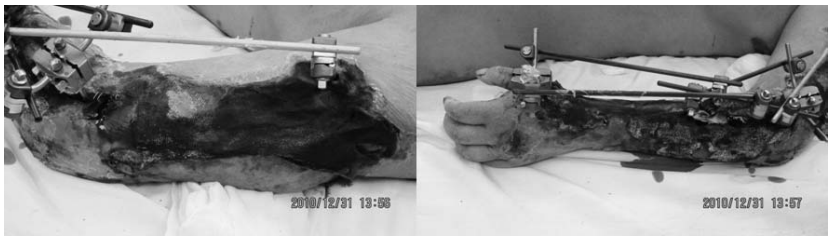


Fig. 3 The avulsed skin was further necrotic and resected.

fracture was fixed internally using Kirschner wire fixation (Figs. 5A, 5B).

Ten weeks after the internal fixation of the proximal left ulna fracture, the patient developed obvious symptom of ulnar nerve compression and elbow joint adhesion with a small range of motion (flexion 15°, extension 30°). Thus the patient was hospitalized for the second time and underwent a seventh surgery, which comprised the subcutaneous anterior transposition of the ulnar nerve and lysis of the elbow joint.

Nine months after the injury, abduction of the shoulder joint was restricted by scarring of the left axilla. The eighth surgery was conducted to release the scar tissue with a Z-plasty, and to remove the steel plate that fixed the proximal ulna and the K-wire in the radius (Figs. 6A, 6B). The shoulder and elbow joint functions recovered well, but those of the fingers did not. Therefore, the ninth surgery reconstructed the flexion function of the thumb by a transposition of the palmaris longus tendon; furthermore, the flexion function of the index finger was reconstructed by the transposition of flexor digitorum superficialis from the ring finger (Fig. 7).

Follow-up visits were conducted over 18 months after injury. At the final visit, the Neer score[7] for shoulder joint function was rated as "excellent" (90), and the HHS score[8] for elbow joint functions indicated a "good" outcome (80). According to the scoring criteria developed by Chen *et al*,[9] the functional grade of the injured limb was Grade 2 (Figs. 8A, 8B).

Discussion

Choice of amputation or salvation

Severe limb injuries are emergency events that require clinicians to decide within a short time period whether to amputate or salvage the limb. The MESS system for lower limbs reported by Helfet[2] scores the condition of the patient according to age, traumatic energy, shock, and severity of the limb ischemia. For lower limb injuries, if the MESS rating is >8, amputation is considered necessary; if the score is 6–7, the injured limb can be salvaged but with a poor functional recovery; if the score is ≤ 5, limb salvage therapy should be adopted. However, for injuries to the upper limbs, there remains a lack of an acknowledged standard to assess whether to amputate or attempt limb salvage. Togawa *et al*[4] used the MESS system for severe injuries of upper limbs, with variable outcomes and some successes for salvage operations with a score of 11 and 7. Prichayudh[5] also reported the use of MESS in 19 patients with scores >7, of which 12 limbs were successfully salvaged. The patient in this case was scored as 10 according to the MESS system (scores: age $= 1$, traumatic energy $= 4$, shock $= 2$, and limb ischemia $= 2 \times 2$). The injured limb was successfully salvaged after fracture fixation, blood vessel repair, skin-grafting and tendon transposition, and the patient was satisfied with the overall outcome.

Crush syndrome, shock as a result of massive hemorrhage, and serious infection are considered to be indications for amputation. As the forearm has less muscle mass compared with lower limbs, crush syndrome can be prevented by thorough debride-

Fig. 4 After three attempts at debridement, the granulation tissue grew well, and the autografting of thick skin was conducted.

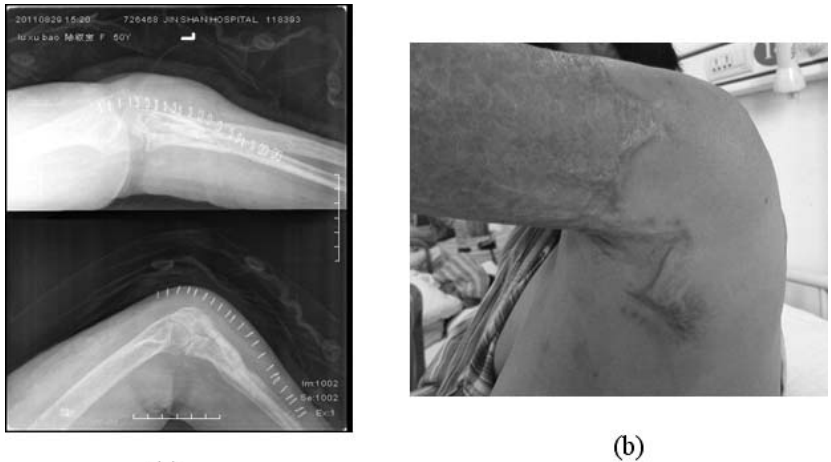
(a) (b)

Fig. 5 (a) Wound healing 5 weeks after skin grafting. (b) Internal fixation with the steel plate of a proximal ulnar fracture; Kirschner wire fixation was applied to the distal radial fracture.

ment, urine alkalization, and diuretic therapy. Fleischmann[10] first reported the use of a vacuum-assisted closure system, which controls wound edema, reduces bacterial wound colonization, enhances hemoperfusion and promotes vascularization, and reduces wound fibrosis, as well as improves the survival rate of second phase skin grafting.[11,12] In this present case, the hemorrhagic and necrotic muscular tissues were completely debrided, and thus crush syndrome was avoided effectively. Debridement and VAC drainage were used to control the cutaneous necrosis and infection and the granulation tissue grew well. Overall, the combined use of external fixation and VAC drainage are considered to be critical throughout the therapeutic process.

Management of skin avulsion injury

Skin avulsion means the detachment of the skin from the superficial layer of the deep fascia or an undermining dissection, in which the vascular supply to the skin is severely damaged by the massive contusion of the vascular network. Arnez *et al*[13] classified skin avulsion into 4 patterns: abrasion/avulsion, noncircumferential degloving, circumferential single plane, and circumferential multi-plane degloving. Yan *et al*[14] defined three patterns of avulsion injury: a purely degloving injury (pattern 1), a degloving injury with the involvement of deep soft tissues (pattern 2), and a degloving injury with long-bone fractures (pattern 3). In patterns 1 and 2 there are two subtypes: noncircumferential degloving and circumferential degloving. The skin avulsion in this case was a circumferential degloving injury with fractures of the ulna and radius, as well as injury to the deep soft tissues. Complicated limb injury accompanied by massive skin degloving is a very difficult clinical scenario to manage. It is commonly accepted that circumferential degloving cannot be treated simply



(a) (b)

Fig. 6 (a) Removal of the internal fixation after 6 months. (b) Z-plasty of the axillary scar after removal of the internal fixation.

Fig. 7 Reconstruction of the flexion function of the thumb and ring finger.

by suturing the skin in situ, but rather by three steps of therapy: complete debridement, fat resection and thinning of the avulsed skin, and replantation in situ with compression bandaging [15, 16]. The patient had circumferential degloving of her left forearm with severe contamination of the muscles and deep soft tissues and was in a state of hemorrhagic shock. After debridement, fracture fixation and arterial repair by vasotransplantation, the blood pressure of the patient was unstable due to the long operation time, thus the surgeons decided to suture the avulsed skin in situ. However, the avulsed skin was completely necrotic, and became infected within 1 week. This was treated by three separate debridements and the insertion of VAC drainage to promote the growth of granulation tissue, followed by auto-grafting. The following clinical lessons can be summarized: (1) necrosis is inevitable for circumferential avulsed skin that is sutured in situ, which increases the numbers of debridements, risk of infection, and difficulty of limb salvage; (2) the surgical procedure should be in strict accordance with complete debridement, fat resection and thinning of the avulsed skin, and replantation in situ with compression bandaging; (3) if there is difficulty in one phase of the reimplantation due to poor condition of the soft tissue bed or other reasons, the avulsed skin can be debrided and thinned as full-thickness skin and stored in refrigerator before the second phase skin grafting.[17,18]

Scar adhesion on the skin around joints may cause disorders of joint movement. In this case, scar adhesion occurred along the longitudinal laceration of the left axilla after direct suturing following the first debridement. The abduction of the shoulder joint was obviously restricted, and this was relieved by scar adhesion lysis Z-plasty. If a Z-plasty had been performed during the initial emergency treatment immediately after debridement, this subsequent surgery might have been avoided. The operative plan for emergency treatment should be more detailed and comprehensive. Especially in the cases of transarticular longitudinal wounds, Z-plasty during the first phase of wound suturing is recommended.

Ulnar nerve anterior transposition

The ulnar nerve is fixed in the cubital tunnel and is easy to be distracted and compressed by trauma and fractures around the elbow joint. Even if there are no symptoms of ulnar nerve injury, delayed ulnar nerve compression is possible because of scar hyperplasia, cubital tunnel stenosis or cubitus valgus. It remains controversial whether to apply ulnar nerve anterior transposition as a routine therapy when conducting internal fixation of the fractures around the elbow joint.[19,20] In this case, the comminuted fracture of the proximal ulna was accompanied by soft tissue crush and avulsion injuries, as well as obvious scar hyperplasia and contractures after the necrosis of the local skin. Therefore, there was a high risk of delayed ulnar

(a) (b)

Fig. 8 (a) Functional restoration of the shoulder joint. (b) Adequate functions of the elbow joint and digits.

nerve compression. As a result, ulnar nerve anterior transposition should be considered together with internal fixation of proximal ulna comminuted fractures to prevent subsequent unnecessary surgeries.

Conclusion

For complex injuries of upper limbs, the choice of amputation or limb salvage remains controversial. As artificial limbs cannot yet restore the complex functions of the upper limbs, limb salvage and functional reservation therapy is preferential during emergency treatment. Although the case reported here is a successful example of salvaging a severely injured upper limb with satisfactory functional recovery, many aspects of the case are worthy of further consideration. A large area of skin avulsion should not be debrided and sutured *in situ*, as this will inevitably cause necrosis and infection, increasing the numbers of debridements required and the risk of future amputation. Thus, the wound should be thoroughly debrided and the avulsed skin should be reimplanted to the original position after fat resection and thinning, or made into a full-thickness skin graft and refrigerated for second-phase grafting. Plastic surgery should be performed simultaneously when suturing longitudinal transarticular wounds to prevent scar adhesion, which will influence joint functionality. In cases of fractures around the elbow joint accompanied by soft tissue injury, delayed ulnar nerve compression is likely to happen. Therefore, it is suggested that when internal fixation to fractures around the elbow joint is performed, anterior transposition of the ulnar nerve should be routinely adopted.

References

1. Chen ZW. Progress in limb and digital replantation: Part A–Introduction. *World J Surg* 1990;**14**(6):804–806
2. Helfet DL, Howey T, Sanders R, Johansen K. Limb salvage versus amputation. preliminary results of the mangled extremity severity score. *Clin Orthop Relat Res* 1990;**256**(7):80–86
3. Battiston B, Tos P, Pontini I, Ferrero S. Lower limb replantations: indications and a new scoring system. *Microsurg* 2002;**22** (5): 187–192.
4. Togawa S, Yamami N, Nakayama H, Mano Y, Ikegami K, Ozeki S. The validity of the mangled extremity severity score in the assessment of upper limb injuries. *J Bone Joint Surg Br* 2005;**87**(11):1516–1519
5. Prichayudh S, Verananvattna A, Sriussadaporn S, Sriussadaporn S, Kritayakirana K, Pak-art R. Management of upper extremity vascular injury: outcome related to the Mangled Extremity Severity Score. *World J Surg* 2009;**33**(4):857–863
6. Prasarn ML, Helfet DL, Kloen P. Management of the mangled extremity. *Strategies Trauma Limb Reconstr* 2012;**7**(2):57–66
7. Neer CN. Displaced proximal humeral fractures. II. Treatment of three-part and four-part displacement. *J Bone Joint Surg Am* 1970;**52**(6):1090–1103
8. de Boer YA, van den Ende CH, Eygendaal D, Jolie IM, Hazes JM, Rozing PM. Clinical reliability and validity of elbow functional assessment in rheumatoid arthritis. *J Rheumatol* 1999;**26**(9):1909–1917
9. Zhong-Wei C, Meyer VE, Kleinert HE, Beasley RW. Present indications and contraindications for replantation as reflected by long-term functional results. *Orthop Clin North Am* 1981; **12**(4):849–870
10. Fleischmann W, Strecker W, Bombelli M, Kinzl L. Vacuum sealing as treatment of soft tissue damage in open fractures. *Unfallchirurg* 1993;**96**(9):488–492
11. Wong LK, Nesbit RD, Turner LA, Sargent LA. Management of a circumferential lower extremity degloving injury with the use of vacuum-assisted closure. *South Med J* 2006;**99**(6):628–630
12. Hou Z, Irgit K, Strohecker KA, Matzko ME, Wingert NC, DeSantis JG. et at. Delayed flap reconstruction with vacuum-assisted closure management of the open IIIB tibial fracture. *J Trauma* 2011;**71**(6):1705–1708
13. Arnez ZM, Khan U, Tyler MP. Classification of soft-tissue degloving in limb trauma. *J Plast Reconstr Aesthet Surg* 2010; **63**(11):1865–1869
14. Yan H, Gao W, Li Z, Wang C, Liu S, Zhang F *et al*. The management of degloving injury of lower extremities: Technical refinement and classification. *J Trauma Acute Care Surg* 2013;**74**(2):604–610
15. Khan AT, Tahmeedullah, Obaidullah. Degloving injuries of the lower limb. *J Coll Physicians Surg Pak* 2014;**14**(7):416–418
16. Rijal L, Nepal P, Ansari T, Joshi KN, Joshi A. Use of ring fixator in the management of degloving injuries of lower limb. *Eur J Orthop Surg Traumatol* 2013;**23**(4):493–496
17. Nogueira A, Martinez MJ, Arriaga MJ, Perez A, Tevar A. Delayed full-thickness autografting of cryopreserved avulsed skin in degloving injuries of the extremities. *Plast Reconstr Surg* 2001;**107**(4):1009–1013
18. Dini M, Quercioli F, Mori A, Romano GF, Lee AQ, Agostini T. Vacuum-assisted closure, dermal regeneration template and degloved cryopreserved skin as useful tools in subtotal degloving of the lower limb. *Injury* 2012;**43**(6):957–959
19. Chen RC, Harris DJ, Leduc S, Borrelli JJ, Tornetta PR, Ricci WM. Is ulnar nerve transposition beneficial during open reduction internal fixation of distal humerus fractures? *J Orthop Trauma* 2010;**24**(7):391–394
20. Worden A, Ilyas AM. Ulnar neuropathy following distal humerus fracture fixation. *Orthop Clin North Am* 2012;**43**(4): 509–514