The principles of managing acute wounds

The acutely traumatic wound has a broad phenoptype: from superficial abrasions to full-thickness thermal burns. It is crucial that practitioners can identify complex wounds that warrant referral to a plastic surgery unit for specialist assessment. The scar is the final sequela of dermal injury. Under optimal conditions it will mature and become barely perceptible with time; if poorly managed, or in patients at risk from abnormal scarring, it may cause significant functional and psychosocial impairment. The methods by which wound healing should be optimised to achieve a favourable outcome are explored within this paper.

Marc C Swan, George Cherry

KEY WORDS
Emergency department
Sutures
Scarring
Wound healing
Reconstructive ladder

In adult wounds, tissue injury initiates a complex cascade of processes which lead to the restoration of tissue integrity (Mathes and Hentz, 2006). This wound healing process involves three overlapping phases of inflammation, proliferation and remodelling, which finally result in the generation of a mature scar (*Figure 1*) (Gurtner, 2007). As clinicians, it is possible to influence each component of the wound healing process and thus exert considerable control on the final aesthetic and functional result of a scar.

Generally speaking, the majority of wounds presenting to a minor injuries unit or emergency department will be acute wounds capable of primary healing if correctly managed (by direct closure). However, it is important to identify wounds where healing either by secondary intention or tertiary healing (also known as delayed primary closure) will give the most favourable outcome (Gurtner, 2007). Acute wounds are those less than a few weeks of age, while those that present for more than four to six weeks are classified as chronic wounds, and lie beyond the scope of this paper, although many useful articles attempt to address this complex subject (Mustoe et al, 2006).

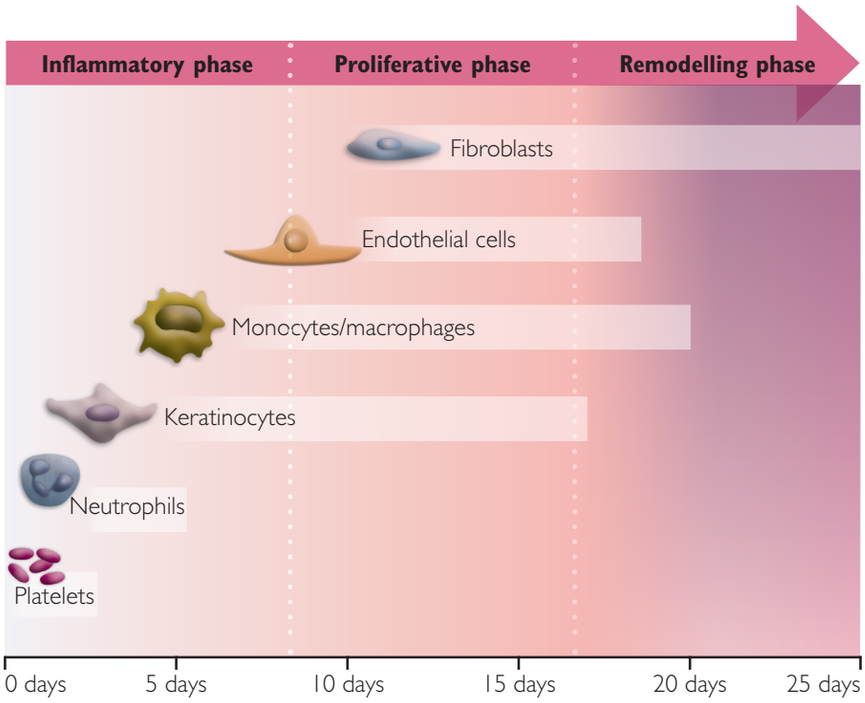

Figure 1. The wound healing process.

Marc C Swan is Specialist Registrar, Department of Plastic and Reconstructive Surgery, West Wing, John Radcliffe Hospital, Headington, Oxford; George Cherry is a Member of the Faculty of the Oxford University Medical School (retired)

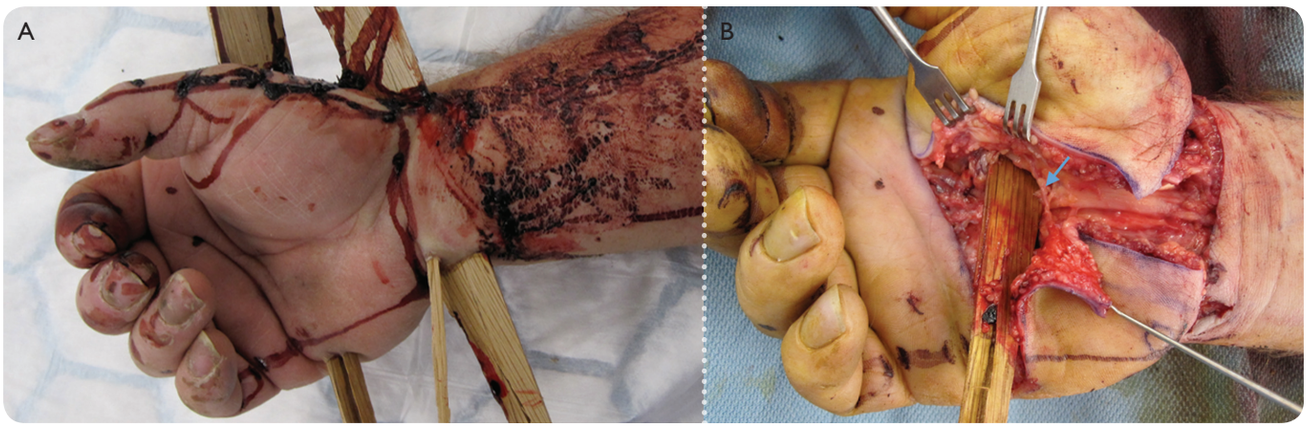

Figure 2. A blunt penetrating laceration with retained foreign bodies ejected from a spindle moulder machine (A). Blunt (as opposed to sharp) objects tend to 'move around' important anatomical structures — the splinter had passed 'between' the branches of the median nerve (blue arrow) in the palm (B). Remarkably, there was no major tendon, nerve of vascular injury and the patient made a full recovery.

Most surgical wounds are incisional wounds that are approximated by sutures, staples or adhesives to facilitate primary healing. Such direct closure generally results in the most optimal scarring, however, local factors appertaining to the wound and general factors related to the patient may influence the wound healing process, the rate of healing, and thus the quality of the final scar (*Table 1*) (Giele and Cassell, 2008). Wounds that cannot be closed directly, such as partial-thickness burns or a superficial graze, or those that are not reapproximated (for whatever reason), must heal by granulation and re-epithelialisation — so-called secondary intention (Gurtner, 2007). Such wounds require regular dressings, have a greater propensity to become chronic and may have a suboptimal final aesthetic result. In the context of burns, if healing takes longer than 21 days, 78% of burn sites will develop hypertrophic scars (Deitch et al, 1983).

Mechanism of acute injury

A thorough clinical history and examination is essential to determine the pattern of injury, which to a significant extent will govern the optimal means of managing the wound in question.

Potential mechanisms include:

- Laceration (either sharp or blunt) (*Figure 2*)
- Abrasion (*Figure 3*)
- Crush
- Degloving (open or closed)
- Burn (flame, scald, contact, electrical, chemical, radiation)
- High energy-blast
- Bite (human or animal) (*Figure 4*).

The zone of injury is an important concept to consider at the time of the initial wound assessment. Clearly, a simple finger laceration sustained while slicing vegetables with a kitchen knife causes localised (although potentially disabling) damage, the extent of

Figure 3. Typical scalp defect resulting from a car 'roll-over' injury. The cranium is exposed and flap reconstruction is required.

Figure 4: Beware of the 'fight bite' injury. This patient presented with septic arthritis affecting the metacarpophalangeal joint of his right ring finger. When explored surgically, the 'divot' in the head of the metacarpal created by the tooth of his opponent is clearly evident.

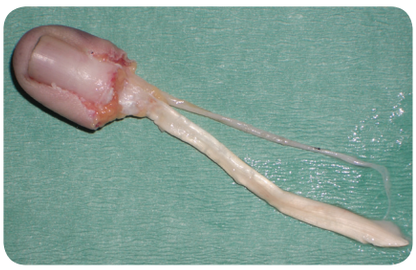

Figure 5. Amputated body parts should always be considered for surgical re-plantation. Even if considered non-salvageable, elements may be utilised for 'spare parts surgery'.

which can be confirmed by clinical examination, whereas a high-tension electrical injury may cause widespread devastating damage to both skin and deep structures at any point between the entry and exit wounds.

Principles of wound management

Following the initial clinical assessment, it may be necessary to undertake specific investigations, the most common of which is a radiograph to exclude an underlying bony injury, or the presence of a radio-opaque foreign body such as a fragment of glass or a tooth. If contaminated, the wound should be thoroughly irrigated with saline solution and a simple dressing (such as jelonet and betadine soaked gauze) employed until arrangements can be made to surgically address the wound. Consideration must be given to the patient's tetanus status, and the affected body part should be elevated to minimise blood loss and oedema. In the case of hand injuries, rings and bracelets must be removed as subsequent swelling could result in vascular compromise and digital gangrene.

Complex wounds (*Table 2* and *Figures 2–6*) should be promptly referred to the appropriate surgical team. However, if the wound is amenable to primary closure and the healthcare professional is competent to undertake the procedure in the emergency department, it will be necessary to employ an appropriate local or regional anaesthetic block (a comprehensive review of their use is available in Mathes and Hentz, 2006). It is important to ensure that sensibility has been accurately documented before infiltration of local anaesthesia, particularly in digits. Adrenaline is frequently used in combination with local anaesthetics (e.g. 1% lignocaine with one in 200,000 adrenaline) to aid haemostasis during surgery and is ideal for suturing facial lacerations. Traditional teaching states that local anaesthetics containing adrenaline should be avoided in the digits (and the penis) due to the risk of distal necrosis. Although evidence supporting this view is limited, most surgeons do not use adrenaline in these anatomical situations (Denkler, 2001). The use of a tourniquet to produce a bloodless operative field is probably best limited to the controlled environment of an operating theatre and thus avoided in the emergency department.

Antibiotics should never be a substitute for an inadequately debrided wound.

As eluded to in *Table 1*, adequate wound debridement is essential and may necessitate a specialist referral in itself, as it is frequently impossible to assess adequately the full extent of an injury to the underlying structures such as nerves, arteries and tendons (*Figure 6*). This is particularly pertinent in children who may be too distressed to cooperate — an examination under general anaesthesia will often be necessary. Abrasions resulting from a 'road rash' injury should be thoroughly scrubbed to remove particulate contamination in order to minimise the risk of permanent scar tattooing (*Figure 7*). Significant damage to deep anatomical structures is commonly associated with extensive injuries or heavily contaminated wounds, and it is important to identify the relevant damaged structures in order that they can be adequately reconstructed. Antibiotics should never be a substitute for an inadequately debrided wound. If wound debridement cannot be undertaken in the emergency department, the local plastic surgery unit should be enlisted to perform the initial exploration.

Penetrating wounds to the fingers

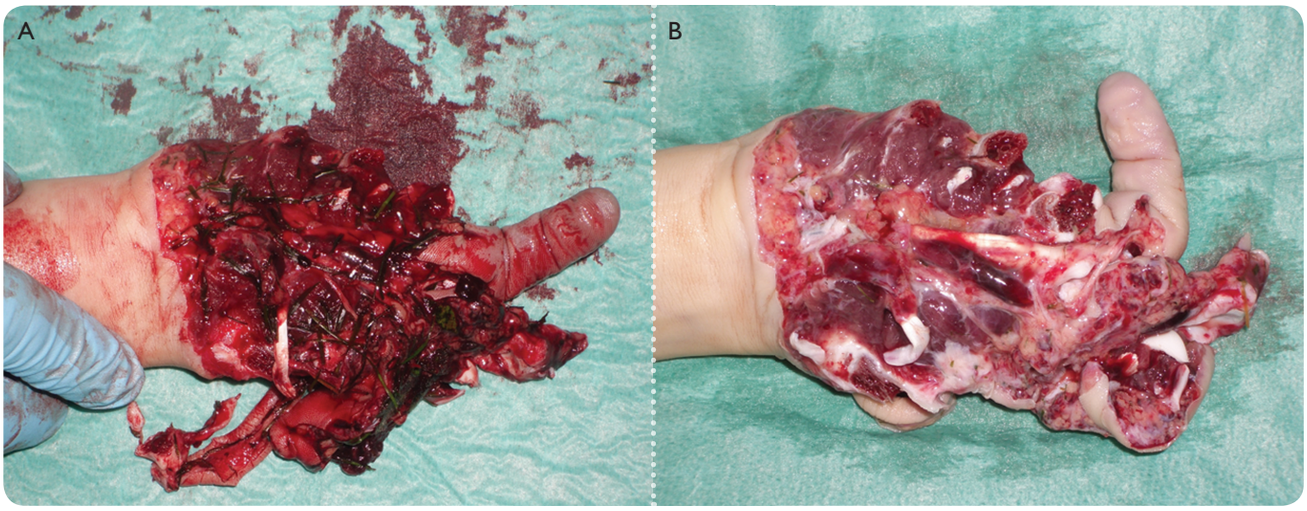

Figure 6. A devastating mutilating hand injury caused by a lawnmower (A). The true extent of the injury is only evident following meticulous surgical debridement (B).

Table I
Local and generalised factors which affect wound healing (Giele and Cassell, 2008)

Local factors	General factors
Tissue handling: poor handling of wound edges, excessive bipolar diathermy use or wound closure under tension are all deleterious to wound healing	**Age:** wound healing is generally delayed in the elderly, whereas the potential for scarless healing exists in the foetus (Siebert et al, 1990)
Infection: this prolongs the inflammatory phase and delays healing. Bacterial infections usually arise from the host (e.g. *Staphylococcus aureus*), but may be exogenous (e.g. *Pasterella multocida* following a cat bite)	**Drugs:** corticosteroids, immunosuppressants, chemotherapy agents, non-steroidal anti-inflammatory drugs (NSAIDS)
Ischaemia: this limits collagen synthesis and may result from local oedema or haematoma formation, or from chronic disease (e.g. peripheral vascular disease)	**Smoking:** causes local vasoconstriction and carboxyhaemoglobin reduces the oxygen-carrying capacity of blood
Non-viable tissue: the presence of devitalised (necrotic) tissue delays wound healing. Thus, adequate wound debridement (by mechanical, chemical or biological means) is critical to optimal wound healing	**Malnutrition:** vitamin A promotes epithelialisation while vitamin C is essential for collagen synthesis by fibroblasts. Zinc is an essential cofactor in numerous crucial enzymes (Arnold and Barbul, 2006)
External beam radiation: causes endarteritis obliterans and lymphatic damage which impair tissue perfusion and cause lymphoedema respectively	**Inherited disorders:** e.g. Ehlers-Danlos syndrome, *pseudoxanthoma elasticum*, Werner syndrome (progeria), osteogenesis imperfecta
Hypoxia: transient hypoxia stimulates angiogenesis, however prolonged hypoxia is detrimental to wound healing	**Acquired disorders:** e.g. diabetes, obesity, chronic renal failure, jaundice, malignancy

such as animal bites or seemingly innocuous injuries arising from splinters or thorns can result in potentially severe infections if the digital flexor sheath apparatus is involved. The cardinal signs of a 'flexor sheath infection' were described by Kanavel in 1925 and include; flexed posture and fusiform swelling of the affected finger, pain on passive extension, and exquisite tenderness overlying the flexor sheath (Ong and Levin, 2009). If clinically suspicious, an urgent specialist referral is necessary as suppurative tenosynovitis, in the same way as a joint infection, may result in significant permanent disability if inappropriately managed.

Generally speaking, plastic surgeons use the systematic 'reconstructive ladder' (perhaps more correctly termed the 'reconstructive toolbox') approach to selecting the optimal technique for achieving wound closure, based on the defect itself and the complexity of the technique in question (*Figure 8*). An uncomplicated lip laceration will invariably be best managed by simple direct closure, whereas exposed cranium (such as that seen in *Figure 3*) will probably require a local scalp flap (with skin grafting of any secondary defect), while the complex hand injury seen in *Figure 6* will almost certainly require free flap coverage. Thus, most wounds capable of being managed in the emergency department will be those that are amenable to direct closure or secondary healing — fortunately, this represents the vast majority of presenting wounds. If an alternative reconstructive technique is indicated, such as split skin grafting in a large pre-tibial laceration or necrotic pre-tibial haematoma, an appropriate referral should be made to the plastic surgery unit.

Figure 7. Permanent tattooing of a peri-orbital laceration that was allowed to heal by secondary intention. The wound was neither irrigated nor debrided, thus the contaminating grit has resulted in this typical bluish appearance.

Suturing in the emergency department

In the first author's experience, plastic surgeons generally favour the use of simple interrupted non-absorbable skin sutures in adults (such as Prolene or Ethilon [both manufactured by Ethicon Inc]) to directly close superficial traumatic wounds in a tension-free manner. Their subsequent removal limits the amount of foreign material in the wound, reduces the incidence of stitch marks and, of course, ensures that the wound is subsequently checked by a healthcare professional to exclude complications such as infection, necrosis or dehiscence. Typically, a 3/0 or 4/0 suture is used on the torso, a 5/0 suture for the hand and a 6/0 suture (or smaller) on the face. Successful suturing is dependent on a co-operative patient, with an appropriately selected wound (for example, it may not be appropriate to suture a full-thickness eyelid laceration under local anaesthetic — if damage to the underlying lacrimal duct is suspected, a formal exploration in theatre is warranted), a sound local anaesthetic technique, and a suitable environment (preferably a dedicated 'minor

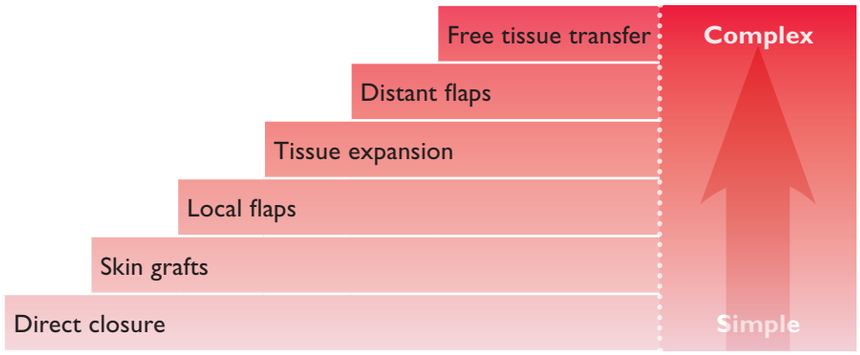

Figure 8. The reconstructive ladder.

operations' theatre with adequate lighting and appropriate instruments and equipment, such as bipolar diathermy if required). Suture removal is typically undertaken at 5–7 days for the face and 10–14 days elsewhere. In situations where the wound extends deeper than skin, closure is achieved in layers in order to minimise dead-space and provide additional mechanical support: interrupted, buried 'dermal' sutures (using Vicryl, Monocryl or PDS suture) may be employed in addition to skin sutures. 'Fat sutures' should be avoided, as they offer little mechanical strength and may cause subcutaneous fat necrosis.

In young or uncooperative children, a general anaesthetic may be required to optimally close the wound in question. This will necessitate admission to hospital, usually as a daycase procedure. Similarly, suture removal may prove to be a traumatic experience for child and parent alike, thus absorbable sutures (such as 7/0 Vicryl rapide for a lip laceration) may be considered. Many emergency departments advocate the use of adhesive strips (e.g. SteriStrips) or glues (e.g. Dermabond®) for paediatric wound closure. Although useful in selected cases, in the first author's experience for cosmetically sensitive areas it is harder to achieve accurate wound approximation when compared to suturing — although they may be used in conjunction with buried dermal sutures. Furthermore, achieving adequate wound edge eversion, which has important implications for the final aesthetic result, is extremely difficult when these techniques are used in isolation. Indeed, deleterious wound inversion and even scar tattooing is possible (Swan et al, 2006).

By applying basic plastic surgical principles it should be possible to triage those patients whose wounds warrant specialist referral, versus those which can be successfully managed locally (usually by direct closure).

Table 2
Potentially complex wounds for which a specialist referral should be considered

- Open fractures
- Vascular compromise of limb or digit (*Figure 5*)
- Suspected deep structural injury (e.g. tendon or nerve, *Figure 2*)
- Bite injuries (animal or human) (*Figure 4*)
- Significant soft tissue infection (e.g. flexor sheath or joint space infection)
- Burns (see Hettiaratchy et al, 2005 for referral guidelines)
- Amputated parts (for replantation) (*Figure 5*)
- Significant co-existing injury (American College of Surgeons, 2004)
- Any wound that the clinician does not feel confident to manage in the emergency department

The first author's unit favour simple dressings for directly closed wounds such as Micropore™ tape (3M Healthcare), as it is relatively inexpensive, does not need to be sterile and is water resistant. Patients are advised that the tape should be in place for a minimum of two weeks following suture removal in order to support the wound. The tensile strength of wounds is only 20% of normal skin at three weeks post-closure, and 70% at six weeks. Thus, immature wounds are prone to inadvertent dehiscence (Mathes and Hentz, 2006). The tensile strength of the final scar is approximately 80% of that of normal skin. Following tape removal, the patient should be advised to massage the wound on a twice-daily basis using a simple moisturiser or emollient for at least three to six months (i.e. during the 'remodelling' phase of wound healing), or until the scar has fully matured. Patients are also advised to avoid exposing their scar to excessive sunlight (i.e. SPF 30+ is recommended if holidaying in warmer climes) until it is fully mature to avoid any abnormal pigmentary changes.

Abnormal scarring

Normal, immature scars are characteristically red, raised and itchy or painful. They may take up to 12–18 months to completely mature, by which time they should be pale and flat (Bond et al, 2008). Abnormal scarring results from an excessive inflammatory response during healing and is classified as being either hypertrophic or keloid in nature. The latter is much commoner in darker skin types and tends to develop within a year of the injury, whereas hypertrophic scars generally occur within four weeks of injury. Keloids are commonest in the auricular, pre-sternal and deltoid areas. Whereas hypertrophic scars are confined to the margins of the original injury, a keloid scar extends beyond the site of the original injury (Broughton et al, 2006) (*Figure 9*).

Hypertrophic scars are characteristically self-limiting

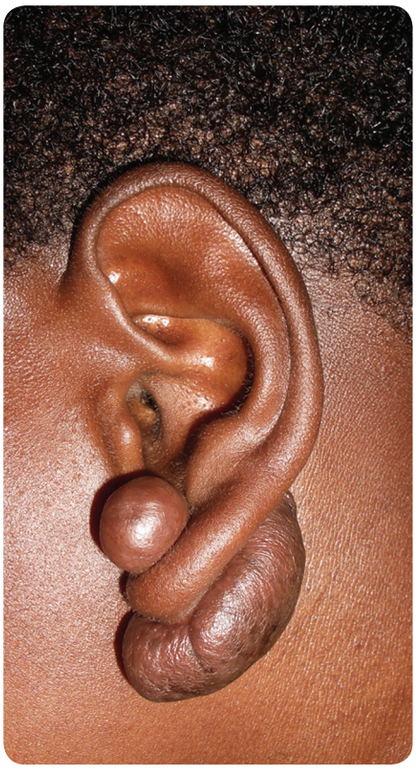

Figure 9. Typical bulky keloid scarring following earlobe piercing.

and involute within two years. If symptomatic or aesthetically unsightly, they may respond to pressure therapy, topical silicone, intra-lesional corticosteroid injections or pulsed dye laser (for decreasing scar erythema) (O'Brien and Pandit, 2006). However, keloid scar formation is permanent and requires specialist intervention. The standard therapies used for hypertrophic scars are of variable effectiveness (Durani et al, 2008), and any form of surgical intervention is prone to a high risk of recurrence (up to 93%) (Broughton et al, 2006). Other treatment modalities for keloids include radiotherapy and intra-lesional interferon.

Conclusions

Although a scar is the inevitable outcome following an acute full-thickness wound, it is the duty of the emergency department practitioner to manage the wound in an appropriate and timely fashion to achieve an optimal aesthetic and functional result. By applying basic plastic surgical principles, it should be possible to triage those patients whose wounds warrant specialist referral, versus those which can be successfully managed locally (usually by simple dressings or direct closure). In the event of an atypical or complex wound, it is prudent to seek the advice of the local plastic surgery unit. WUK

This article was first published in The Second Oxford European Wound Healing Course Handbook, *2010 and is reproduced by kind permission of the Oxford International Wound Healing Foundation, Oxford.*

Key points

- Acute wounds can sometimes distract from more significant systemic injuries — never forget to undertake a primary survey in trauma patients (American College of Surgeons, 2004).
- Understanding the mechanism of injury is crucial to predicting the likely severity and extent of the wound.
- A thorough clinical assessment is mandatory. This can be difficult in young children and a general anaesthetic may be necessary.
- Always check the tetanus status of the patient, remove rings and bracelets in hand injuries, and exclude a foreign body (by radiographic means if necessary) if the history is suspicious.
- If you are unsure or wish to ask for advice, do not hesitate to contact your local plastic surgery unit who will be happy to assist.

References

American College of Surgeons (2004) Committee on Trauma. ATLS, advanced trauma life support program for doctors. 7th edn. American College of Surgeons, Chicago

Arnold M, Barbul A (2006) Nutrition and wound healing. *Plast Reconstr Surg* **117**: 42S–58S Broughton G, Janis JE, Attinger CE (2006) Wound healing: an overview. *Plast Reconstr Surg* **117**: 1e-S–32e-S

Bond JS, Duncan JA, Sattar A, Boanas A, Mason T, O'Kane S, Ferguson MW (2008) Maturation of the human scar: an observational study. *Plast Reconstr Surg* **121(5)**: 1650–8

Broughton G, Janis JE, Attinger CE (2006) Wound healing: an overview. *Plast Reconstr Surg* **117(7)**: 1–32

Deitch EA, Wheelahan TM, Rose MP, Clothier J, Cotter J (1983) Hypertrophic burn scars: analysis of variables. *J Trauma* **23**: 895–8

Denkler K (2001) A comprehensive review of epinephrine in the finger: to do or not to do. *Plast Reconstr Surg* **108**: 114–24

Durani P, Bayat A (2008) Levels of evidence for the treatment of keloid disease. *J Plast Reconstr Aesthet Surg* **61(1)**: 4–17

Giele H, Cassell O (2008) *Plastic and Reconstructive Surgery*. Oxford University Press, Oxford

Gurtner GC (2007) Wound healing: normal and abnormal. In: Thorne CH, Beasley RW, eds. *Grabb and Smith's Plastic Surgery*. 6th edn. Lippincott Williams & Wilkins, London: 15–22

Hettiaratchy S, Papini R, Dziewulski P (2005) *ABC of Burns*. BMJ Books, Oxford

Mathes SJ, Hentz VR (2006) *Plastic Surgery*. 2nd edn. Elsevier Saunders, London

Mustoe TA, O'Shaughnessy K, Kloeters O (2006) Chronic wound pathogenesis and current treatment strategies: a unifying hypothesis. *Plast Reconstr Surg* **117**: 35S–41S

O'Brien L, Pandit A (2006) Silicon gel sheeting for preventing and treating hypertrophic and keloid scars. Cochrane Database Syst Rev 2006:CD003826

Ong YS, Levin LS (2009) Hand infections. *Plast Reconstr Surg* **124**: 225e–33e

Siebert JW, Burd AR, McCarthy JG, Weinzweig J, Ehrlich HP (1990) Fetal wound healing: a biochemical study of scarless healing. *Plast Reconstr Surg* **85**: 495–502; discussi 14on 3–4

Swan MC, Descamps MJ, Broadhurst A (2006) Scar tattooing following the use of tissue adhesive. *Plast Reconstr Surg* **117**: 1054–5