

Power tool injuries to the hand and wrist

Power tool injuries to the hand and wrist are complex injuries which can have a profound impact on the function of the patient. This article gives an overview of the principles, and provides a systematic approach, to the management and rehabilitation of the injured limb and patient required to minimize future disability.

The recent injury of golfer Greg Norman has highlighted the potential dangers posed by chainsaws and other power cutting tools (Almasy and Hassan, 2014). Each year approximately 36 000 people in the USA sustain chainsaw injuries (Centers for Disease Control and Prevention, 2014). In the UK, while the Health and Safety Executive do not report data on exact numbers of injuries, there have been at least five chainsaw-related deaths, most resulting from neck lacerations (www.hse.gov.uk/treework/areyou/chainsaw-operator.htm). Despite the common use of power tools and caseload of associated injuries, there is little in the literature to guide optimal management. This article provides an overview for the management of these potentially devastating injuries.

Background

The original 'chainsaw' was a manually-powered bone-cutting device designed by Bernhard Heine, a German orthopaedic surgeon (Seufert, 1980). The modern chainsaw comprises a powered, toothed chain that runs along the sawblade at speed. They are commonly stocked in hardware and DIY stores throughout the UK.

There are two principal mechanisms for chainsaw injuries. The first, most frequently encountered of these is a phenomenon known as 'kickback' (Koehler et al, 2004; Dabrowski, 2012). This occurs when the teeth of the chainsaw become transiently embedded in a material without successfully cutting it. The chain stops moving, but its forceful attempts to continue rotating cause the blade to violently jump backwards, often into the path of the operator. The second primary mechanism occurs when a downward cutting motion inflicts a slicing injury, producing a laceration, fracture or amputation to limb tissue.

Chainsaw injuries classically affect the non-dominant side (Haynes et al, 1980; Macfarlane, 1980). The hand is

most commonly affected, accounting for over 50% of chainsaw injuries (Macfarlane and Harry, 1977). The face, neck and feet are also frequently affected (Haynes et al, 1980). Greg Norman's injury affected his left arm, a not uncommon presentation. Common radiological features of chainsaw injury to the hand include chipping of phalanges and metacarpal bones, breaching of joint cavities and partial severing of tubular bones (Verow, 1982).

Circular saws are a related power tool, also functioning via a rotating blade. An investigation into circular saw injuries reported a similar predominance of injuries to the hand, with the non-dominant side affected more frequently than the dominant. One finger was injured more commonly than two fingers, two more than three and three more than four. However, cumulatively, two or more fingers were affected more frequently than one finger. The most commonly affected digit was the thumb, followed by the index, middle, ring and little fingers in descending order. Injuries included lacerations, amputations, fractures, avulsions, crush injuries and contusions or abrasions. As well as extensive soft tissue damage, structures such as nerves, tendons and vessels were also affected (Frank et al, 2010).

Other power tools particularly inclined to cause operator hand injuries are nail guns (Hussey et al, 2008) and high pressure injection devices, such as paint or grease guns (Bekler et al, 2007). As with saws, the radial aspect of the non-dominant hand is most often affected (Frank et al, 2010). Most high pressure injection injuries affect the non-dominant index finger (Amsdell and Hammert, 2013).

The hand is a complex structure and its sizeable representation on both motor and sensory homunculi are indicative of its importance (Penfield and Boldrey, 1937). Normal function of the hand depends on the presence of all structures, intact sensation and active movement without pain. The loss of any of these attributes causes disability (Belcher, 2010). Unsurprisingly, therefore, the treatment of power tool hand injuries presents a considerable challenge to all health-care professionals concerned. This review outlines the management of these complex injuries (Figure 1).

Principles of management

Initial assessment of these injuries follows advanced trauma life support principles with focus on the diagnosis and emergent treatment of life-threatening injuries (American College of Surgeons Committee on Trauma, 1997).

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Particular attention should be given to the 'circulation and haemorrhage' control portion of the primary survey. The patient should be resuscitated appropriately and haemostasis achieved with a combination of pressure dressings, elevation and splinting. No effort should be made to explore the wounds or directly clamp bleeding vessels.

Once the patient has been stabilized, a further detailed history of the hand injury can be taken. A thorough physical examination follows before radiological studies are performed. Tetanus prophylaxis and broad spectrum antibiotics should be given as routine (Amsdell and Hammert, 2013). Where bony injuries are present, the injured part should be splinted to help pain control and prevent further soft tissue injury.

An injury causing significant vascular compromise or amputation should be considered for a revascularization or replant procedure. The decision to attempt replantation or revascularization must be made in conjunction with the relevant surgical team. The amputated part should be kept cool and the patient urgently referred to a team or centre with appropriate microsurgical expertise. The amputated part should be wrapped in moist gauze, placed in a sealed bag and transferred on ice, but not in direct contact with ice to prevent frostbite. The classical indications for replantation are listed in *Table 1* (Soucacos, 2001).

It is important to note that any thumb amputation should be considered for replantation as opposition is vital to hand function. Warm ischaemia time should be minimized, ideally to less than 6 hours, or 8 hours for a digit. However, successful replantations in cases that would be contraindicated under these criteria have prompted suggestions that they should be treated only as a general guide (Casal et al, 2013). Importantly, even if the amputated part cannot be replanted at the original site, it should be wrapped in moist gauze; this facilitates harvesting of tissue or ectopic replantation (Weinzweig and Weinzweig, 2005). There are a number of comprehensive reviews of current techniques; these lie beyond the scope of this article but it is important to remember that any replant proximal to the metacarpals will contain significant muscle and fasciotomy is indicated in these circumstances. This is discussed further below in the section on vascular injury and fasciotomy.

If replantation is not appropriate, further surgical options include stump revision, ray amputation or toe transfer. The purpose of these procedures is to achieve maximal function within the confines of digit loss, while considering and optimizing cosmetic appearance. Many are performed as secondary elective procedures at a later date, with considerable planning and consultation with the patient. Reconstructive options must consider the patient's ability to tolerate multiple operations, his/her vocational and recreational needs, and whether the dominant hand is affected.

Principles of surgical management

Anaesthesia

Where possible a regional anaesthetic technique should be considered for the management of all hand injuries (British Society for Surgery of the Hand, 2007). It provides good postoperative analgesia, prevents patients waking up from a general anaesthetic agitated and potentially disrupting their repairs, and has the additional benefit of vasodilation in the context of vascular injury.

Where an appropriate set up exists the use of a regional block can be expanded to a 'block on arrival' (Sabapathy et al, 2007) whereby a regional anaesthetic is used for analgesia in the emergency department.

Figure 1. Example of a power tool injury to the finger demonstrating injuries to multiple structures including, skin, nerve, tendon and bone in a dysvascular finger.



Table 1. Classical indications for replant surgery

| |
|--|
| Any thumb amputation |
| Multiple digit amputation |
| Mid-palm amputation |
| Amputation at the distal wrist |
| Amputation of any hand part in a child |
| Amputation of a single digit distal to flexor digitorum superficialis tendon insertion |

Debridement

Thorough and meticulous debridement of all tissues is the most important step in the management of all open injuries. Foreign material and all non-viable tissue is excised (Diefenbeck et al, 2013) to maximize the healing potential of remaining intact tissue and minimize the risk of infection. A single thorough and radical debridement may be preferable to serial, more conservative debridements (Neumeister et al, 2010; Guthrie and Clasper, 2011). However, re-exploration of the wound may be necessary at 24–72 hours, when the demarcation of viable and non-viable tissue becomes clearer in the days following the initial traumatic insult.

The severity of initial injury determines whether a primary repair of existing structures is possible, or a more complex reconstruction is required to maintain and restore function. Following injuries where the hand sustains significant tissue damage alongside traumatic amputation(s), reconstructive options can be aided by use of the ‘spare parts’ and harvesting of valuable autologous bone and soft tissue. Once a satisfactory debridement has been performed each of the injured structures should be addressed in a systematic fashion.

Bony injury

The exact sequence in which injured structures are addressed is flexible but it is generally preferable to prioritize skeletal fixation in order to establish a scaffold around which soft tissue reconstruction can be achieved (Neumeister et al, 2010). Skeletal fixation is required to stabilize bony structures; generally rigid internal fixation is required to allow early mobilization and attempt to restore gliding surfaces. Temporary external fixation can be considered where large defects cannot be immediately filled. Small bony defects can be replaced by cancellous bone blocks or chips. Larger defects require the use of an autologous bone graft, the type of which is determined by the vascular status (Neumeister et al, 2010). If conditions dictate, bone grafting can be delayed.

Tendon injury

Where possible, tendons should be primarily repaired directly with a sufficiently strong repair to allow early motion (Battiston et al, 2013; Starr et al, 2013). For flexor tendons, this requires at least a four-core strand technique with an epitendinous suture (Osada et al, 2006; Savage, 2014). The authors’ preference is the ‘Adelaide’ type repair

(Figure 2) (Sandow and McMahon, 2011). Traditionally, non-absorbable sutures have been preferred for tenorrhaphy, although there is some evidence that absorbable sutures can be safely used in flexor tendon repair (Kang et al, 2012). If necessary, autologous tendon tissue can be grafted, or tendon transfer can be performed (Weinzweig and Weinzweig, 2005; Neumeister et al, 2010).

Vascular injury and fasciotomy

Microsurgical direct tension-free anastomosis with fine non-absorbable monofilament of damaged arteries is preferred. Damaged sections can be replaced by harvested ‘spare parts’, or autologous superficial veins. Venous reconstruction in the non-replant situation is rarely necessary (Weinzweig and Weinzweig, 2005; Neumeister et al, 2010). In situations of extreme vascular compromise with prolonged warm ischaemic time, arterial shunting (Orthopaedic Associates of Michigan, 2014) should immediately follow debridement, taking precedence over skeletal fixation.

Routine fasciotomy to decompress all involved compartments should be considered part of the revascularization procedure of any body part which contains muscle, in order to prevent a compartment syndrome developing and worsening the ischaemic insult. This can be precipitated by the hyperaemia, vasodilation and subsequent oedema formed as part of the reperfusion process (Walker, 1991).

Nerve injury

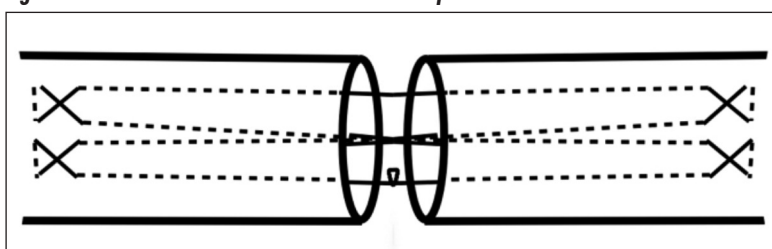
If there is sufficient intact nerve remaining, primary microsurgical neuroorrhaphy with a tension-free anastomosis is the favoured solution. If a tension-free anastomosis is not possible, alternatives include nerve grafts, conduits or nerve transfer (Ray and Mackinnon, 2010).

Soft tissue

The ‘reconstructive ladder’ options range from direct wound closure to the use of grafts, local flaps and distant flaps (Spyropoulou and Jeng, 2010). This is perhaps better thought of as a reconstructive elevator and the most appropriate mode of wound coverage should be sought rather than opting for the simplest – particularly when considering wounds involving the highly specialized glabrous skin of the palm and the potential for wound contracture.

Other options include the use of skin substitutes, such as a dermal regeneration template (Integra, Integra LifeSciences Corporation, Plainsboro, NJ). These can also be used to cover sites from which pedicle flaps have been raised for hand reconstruction, as well as for the hand itself (Adani et al, 2014).

Figure 2. Schematic of a four-strand ‘Adelaide’ repair.



Infection prevention

Tetanus prophylaxis and broad-spectrum antibiotics are crucial in preventing wound infection following major hand trauma. Antibiotic-impregnated bone grafts offer

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a novel option for combating bone infections, but there is currently a lack of conclusive evidence (Anagnostakos and Schroder, 2012). There is no need for later surgery to remove the antibiotic carrier, unlike antibiotic-loaded bone cement.

Timing of interventions

Irrigation, debridement and antibiotic administration are the initial management priorities. Animal studies of a contaminated open fracture model suggest that early debridement and antibiotic administration significantly reduce the risk of wound infection (Brown et al, 2010; Penn-Barwell et al, 2012). However, delayed debridement (>8 hours) may not increase the risk of infection for upper extremity fractures, as long as antibiotic administration is prompt (Malhotra et al, 2014).

The British Orthopaedic Association and British Association of Plastic, Reconstructive and Aesthetic Surgeons (2009) have set standards for the management of severe open lower limb fractures. These dictate that vascular impairment requires immediate surgery, debridement of the wound by an appropriate team should occur within 24 hours and definitive cover of the wound should occur within 72 hours. While these are standards of care for lower limb trauma, they provide a frame of reference for the management of any injured limb, including the mutilated upper limb, providing evidence for timing of intervention.

Postoperative rehabilitation

Close multidisciplinary working is essential to achieve the best possible outcome for these injuries. The hand therapy team will facilitate and supervise the patient's recovery, which may take many months and be labour intensive for both patient and therapist.

Splinting of the injured hand is common and may be used to reduce inflammation, control pain, support healing tissues, increase joint motion and glide, and influence scar formation (Colditz, 1996). Splints are usually custom made for each patient by the hand therapist, and excellent communication is needed between surgeon and therapist to allow an appropriate rehabilitation regimen to be created.

Psychological impact of traumatic hand injury

Many chainsaw injuries are occupational and return to work is an important consideration. Residual pain, symptoms of post-traumatic stress disorder and the location in which accident occurred are all predictors of return to work (Opsteegh et al, 2009).

Following an accident, depression, hand function and the overall impact of the event on the patient's life improve with time. Late functional outcome is influenced by the degree of impact of an event and functional status of the hand in the acute phase (Dogu et al, 2014).

Psychological impact after severe hand injury can persist for over 18 months (Grunert et al, 1992). While symptoms such as nightmares, flashbacks and affective lability are extremely common following severe hand injury, these improve over the first 2 months. However, there are corresponding increases in preoccupation with phantom limb sensations in amputees, and cosmetic concerns over this time period (Grunert et al, 1988). This evidence supports a clear role for psychological interventions following major hand trauma. This should be an important consideration in the overall management of patients with chainsaw or other power tool injuries.

Injury prevention

Given the potential severity, complex management and prolonged recovery of chainsaw-related injuries, it is clear that prevention strategies are vital. These fall into three categories: machine design, personal protective equipment and operator training.

Machine design

Chainsaws have an in-built depth gauge which is crucial for safe use. This regulates the depth to which the teeth can cut, providing a degree of control. It also affects a chainsaw's 'kickback angle', which underpins the kickback phenomenon. Other influential factors in chain design are chain type (chisel or semi-chisel) and changes in the slope angles of cutting edges. The kickback angle is further affected by engine capacity, guide bar length, and the nature of the guide bar nose and sprocket teeth (Dabrowski, 2012).

Operator handling also affects the kickback angle (Dabrowski, 2012). The interaction of human and mechanical factors in precipitating kickback demonstrates the importance of a multifaceted approach to chainsaw injury prevention. Both newer and older chainsaw designs have been associated with fatalities when the machines have been operated in an unsafe manner (Koehler et al, 2004).

Personal protective equipment

Compulsory use of personal protective equipment in industrial situations has been associated with relatively low chainsaw injury incidence (Verow, 1982). Personal protective equipment includes safety helmets, goggles, kneepads and safety boots. It has been suggested that the minority who ignore safety regulations are those who more commonly suffer preventable injury, and that the domestic use of chainsaws by unskilled operators without personal protective equipment may lead to more injuries.

A study of farmers in the USA investigated personal protective equipment use in various activities including chainsaw operation (Carpenter et al, 2002). Despite a perception of satisfactory personal protective equipment availability, usage was low and this was found to be a personal decision influenced little by third parties. Stressing the risk of personal injury to the individual

farmer was highlighted as a potential strategy for increasing personal protective equipment usage rates.

Loggers have testified to the benefits of personal protective equipment in preventing chainsaw accidents (Klen and Vayrynen, 1983). In Denmark, the introduction of legislation regarding safety equipment has been associated with a plateau in the number of reported chainsaw accidents despite increased chainsaw sales (Mortensen and Jorgensen, 1991). On the basis of this, researchers recommended the provision of written information about personal protective equipment for every chainsaw purchaser, and a campaign about correct chainsaw use and personal protective equipment. They also suggested that personal protective equipment issue should be compulsory with hired chainsaws, and that gloves should be included in safety requirements. Within European legislation the EN 381-7 describes the requirements for chainsaw protective gloves but there is no equivalent standard for wrist protection and there appears to be little in the way of wrist personal protective equipment. Chain teeth are inherently sharp, so lacerations can occur even when the machine is not running.

Operator training

Recommendations of operator training were echoed in a later study which investigated compliance with safety warnings contained in chainsaw operating instructions (Zeitlin, 1994). Classroom lectures delivered safety orientation. It was reported that compliance was far lower in those experienced with chainsaws than in the inexperienced. Compliance was influenced subjectively by tool experience and safety orientation, showing the importance of operator training in promoting safe chainsaw use.

Conclusions

Power tool injuries to the hand can be complex and severe. They require a systematic and multidisciplinary

approach to the management of the patient from the moment he/she initially presents to the emergency department until the end of rehabilitation to optimize the patient's functional recovery. **BJHM**

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KEY POINTS

- Power tool injuries to the hand are often severe, requiring complex surgical management with a lengthy recovery process. A well-functioning multidisciplinary team is beneficial.
- A systematic approach to managing the patient according to advanced trauma life support principles is the first priority in all potentially serious injuries.
- Timely antibiotic administration, tetanus prophylaxis, splinting and a thorough and meticulous debridement are priorities.
- An injury causing significant vascular compromise or amputation should be considered for a revascularization or replant procedure and fasciotomies considered.
- Each injured structure needs to be addressed in a logical fashion with a plan for primary repair or reconstruction.
- Anatomical, functional and psychological deficits can all result from traumatic hand injury and should all be considered in patient management.
- There is growing evidence that preventative strategies minimize traumatic hand injury associated with power tools.

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