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Wound Management in Disaster Settings

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Abstract
Background Few guidelines exist for the initial management of wounds in disaster settings. As wounds sustained are often contaminated, there is a high risk of further complications from infection, both local and systemic. Healthcare workers with little to no surgical training often provide early wound care, and where resources and facilities are also often limited, and clear appropriate guidance is needed for early wound management.
Methods We undertook a systematic review focusing on the nature of wounds in disaster situations, and the outcomes of wound management in recent disasters. We then presented the findings to an international consensus panel with a view to formulating a guideline for the initial management of wounds by first responders and subsequent healthcare personnel as they deploy.
Results We included 62 studies in the review that described wound care challenges in a diverse range of disasters, and reported high rates of wound infection with multiple causative organisms. The panel defined a guideline in which the emphasis is on not closing wounds primarily but rather directing efforts toward cleaning, debridement, and dressing wounds in preparation for delayed primary closure, or further exploration and management by skilled surgeons.
Conclusion Good wound care in disaster settings, as outlined in this article, can be achieved with relatively simple measures, and have important mortality and morbidity benefits.

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Introduction

In naturally occurring and man-made disaster situations, wounds are a major source of morbidity and mortality. They place substantial demands on strained, disrupted, and often rudimentary and makeshift health services. Wounds tend to be contaminated by a variety of environmental organisms and foreign matter, with crushed and devitalized tissue providing a medium for bacterial growth and invasion. First responders are often not medically trained and, though well intentioned, the treatment they provide is often compromised by a misconception that wounds should be closed to enable them to heal [1]. Experienced surgeons know that poor early wound management is often complicated by more extensive infection and tissue necrosis requiring wide excision or amputation, and preventable systemic sepsis, gangrene, and mortality [2]. Safe and effective early management of wounds by first responders in a disaster setting can prevent

Table 1 Wound Management Consensus Panel Participants 2.00 p.m.–5.30 p.m., 26 September 2012–RACS Council Room

Russell Gruen (Chair)	Australian National Delegate to the International Society of Surgery, and Director, National Trauma Research Institute
Prasit Wuthisuthimethawee	Trauma Surgeon, Sonkra, Thailand & Weary Dunlop Boon Pong Fellow
David Watters	Convenor RACS/ASAP Global Burden of Surgical Disease Forum, former Chair, RACS Pacific Islands Project (2001–2011) and RACS International Committee (2007–2012)
Kiki Maoate	RACS, Pacific Islands Project (PIP) Director, New Zealand
Haydn Perndt	Australian and New Zealand College of Anaesthetists, Australia
Ian Norton	Director of Disaster Preparedness and Response, National Critical Care and Trauma Centre, Darwin, Australia
James Kong	RACS Myanmar Program Director
Zaw Wai Soe	Professor of Orthopaedic and Traumatology, Myanmar. General Secretary, Myanmar Orthopaedic Society and Academic Secretary for Orthopaedics at the Myanmar Medical Association.
Douglas Pikacha	Consultant Surgeon, National Referral Hospital, Solomon Islands
Dr Clay Siosi-Lewi	Surgical Registrar, Solomon Islands
Lord Tangi o Vaonukonuka	Chief Surgeon, Tonga
Eddy Rahardjo	Department of Anaesthesiology & Chairman, Centre for Disaster Study and Management and Head of Disaster Management Training Program at Airlangga University, Surabaya Indonesia.
Manjul Joshipura	Scientist, Department of Violence and Injury Prevention, WHO, Geneva
Kelly McQueen	Associate Professor, Department of Anesthesiology, Director of Vanderbilt Anesthesia Global Health & Development, Affiliate Faculty, Vanderbilt Institute for Global Health
	Co-Director, Alliance for Surgery and Anaesthesia Presence
Eileen Natuzzi	Solomon Islands Living Memorial Project
Stephen Bickler	Professor of Surgery and Paediatrics at the University of California
James Forrest Calland	Assistant Professor of Surgery, University of Virginia Health System
	Chair of the WHO GIEESC Burden of Surgical Disease Committee
Ifereimi Waqa	General Surgeon, New Zealand. Former Medical Superintendent at the Colonial War Memorial Hospital and former Honorary Senior Lecturer in Surgery for post graduate surgical trainees at the Fiji School of Medicine (FSM) in Suva, Fiji. Former RACS Rowan Nicks Scholar
Osborne Liko	Chief of Surgery, University of Papua New Guinea
David Bradt	Faculty, Center for Refugee and Disaster Response
	Johns Hopkins Medical Institutions
Ornella Clavisi	Program Manager, Neurotrauma Evidence Translation Program, NTRI
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complications and save limbs and lives, and both first responders and subsequent healthcare personnel should be clear about what this entails.

Disasters such as the 2004 Tsunami, Hurricane Katrina in 2005, and the 2010 Haiti earthquake, were all characterized, to greater or lesser degree, by remote location, overwhelming numbers of casualties, inadequate resources, over-burdened healthcare services, and inexperienced caregivers. Much has been written about the health consequences of these disasters in general. We aimed to systematically review the nature of wounds and outcomes of wound management in recent disasters, and we then convened an international consensus panel to consider these results and formulate a concise guideline for the initial wound management for first responders and non-expert healthcare providers. It was anticipated that a generic guideline could be widely distributed, discussed among members of relevant organisations, modified according to local needs where required, and put into practice in many types of clinical settings.

Methods

We searched Cochrane Library (Wiley), Cinahl (Ebscohost), Medline (Ovid), Embase (Elsevier), and WHO Guidelines with the key words "wounds," "crush injuries," "open fractures," with related complications such as "infections," "necrosis," "tetanus." These terms were combined with disaster-related key words such as "tsunami," "cyclone," "earthquake," and "flood." The search included articles published up to 1 September 2012. The searches were limited to English language publications and human studies. The present review excluded burns, military blast injury, high-velocity injury, and penetrating injury. The reference lists of included articles were searched for other potentially relevant publications. Each article was assessed independently by two reviewers.

We then collated results and presented them to a consensus meeting of experts in surgery and disaster medicine

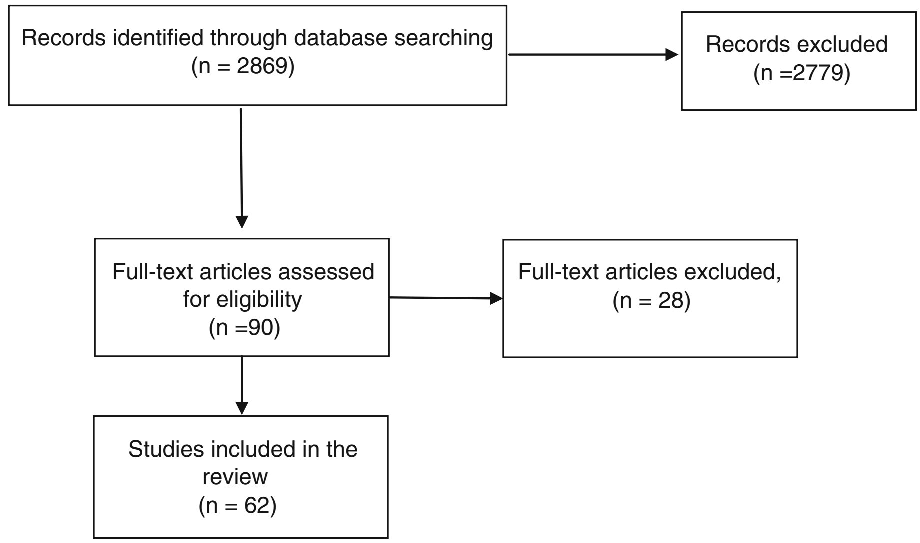

Fig. 1 Flow diagram of methodology/search strategy

that was held at the Royal Australasian College of Surgeons in September 2012. The invited experts came from Australasia and the Pacific, North America, South East Asia, and the Indian subcontinent (Table 1). This group considered the review findings and discussed and sought agreement on a set of principles that were then presented for comment and critique to an International Symposium on the Global Burden of Surgical Disease involving 151 delegates. The present report presents the results of these deliberations and a proposed simple guideline.

Results

Our literature search yielded 2,894 articles for screening, from which 62 proved to be relevant, as shown in Fig. 1. Those articles described details of the nature of wounds, wound care, and outcomes from various major incidents, including earthquakes in Marmara, Turkey (1999), Pakistan (2005), Wenchuan, China (2008), Haiti (2010), and Christchurch, New Zealand (2011); terrorist bombings in Bali, Indonesia (2002); and the 2004 tsunami centred near Banda Aceh, Indonesia.

The nature of wounds

Depending on the nature of the catastrophe, extreme forces led to a spectrum of wounds variously characterized by multiple breaches of skin, deep puncture injuries [3], crushing and destruction of soft tissues, fractures of bone, and contamination with dirt, mud, seawater, sand, and debris, as well as feces and saliva [1, 4–8].

Of course many victims also had life-threatening respiratory or circulatory impairment or significant head and internal injuries. In earthquake-related disasters, 30 % of patients had head and neck injuries, and a quarter had significant chest, thoracolumbar spine, or spinal cord injuries, a third of whom required surgical interventions [9]. Musculoskeletal injuries are common, in earthquakes in particular, with the proportion of patients with closed fractures, sprains, open fractures, and neurovascular injury observed to be approximately 22, 6, 11–54, and 6 %, respectively [9].

Infection

High rates of infection occurred from contamination, tissue loss, inadequate or delayed wound cleaning and debridement, and premature wound closure [1, 6, 8]. For example, delayed initial wound care more than 24 h after injury and primary wound closure were independent predictors of secondary wound infection among tsunami victims [6]. Environmental pathogens and contaminated water used for cleaning wounds were the usual causes. Infections were often polymicrobial and included atypical bacteria and fungi [1, 7, 9], as detailed in Table 2.

The most common infective organisms following crush injuries were Gram-negative bacilli (67 %), *Acinetobacter* (36 %), *Pseudomonas aeruginosa* (21 %), Gram-positive cocci (17 %), and *Enterobacter* species (12 %) [10–12]. For example, following the 2008 earthquake in Wenchuan, China, 50 of 98 injured children studied developed wound infections [13], and *Acinetobacter baumanii*, *Enterobacter cloacae*, and *P. aeruginosa* were the pathogens most commonly isolated [13]. Prior to the earthquake, at the same institution, pediatric infections were more commonly caused by *Escherichia coli* and *Staphylococcus aureus* [13].

Among wounded tsunami survivors, it was estimated that half to two-thirds of wounds became infected, mostly within the first 72 h following the event [6], although many wounds were infected within the first 24 h [10]. *Aeromonas*

Table 2 Organisms and rates of infection

Reference/ author/year	Event/geographic location/hospitals	SSTI rates (n/d) %	Organisms	Comments
Prasartritha et al. [1]	Indian Ocean tsunami, Thailand, 2004; Phang-Nga Hospital; Takuapa Hospital; Surat Thani Hospital	116/644 patients (18 %) had early infected wounds (Phang-Nga database)	10 patients died of Gram-negative septicemia in Takaupa Hospital [7].	>70 % of patients had polymicrobial infection Spreading of infection due to underestimation, delay in wound care, extensive contamination, and skin loss
Kang et al. [3]	Earthquake, Wenchuan County, Sichuan, China, 2008	725 clinical isolates from 2,002 culture samples (36.2 % culture positive)	Organisms, $n = 725$ (%) *Acinetobacter baumannii* 130 (17.9 %); *E. coli* 119 (16.4 %); *S. aureus* 90 (12.4 %); *P. aeruginosa* 67 (9.2 %); *E. cloacae* 64 (8.8 %); *K. pneumoniae* 47 (6.5 %); *Candida albicans* 43 (5.9 %); *Stenotrophomonas* (Xanthomonas) *maltophilia* 22 (3 %); *Aeromonas hydrophila* 14 (1.9 %)	Gram-negative bacilli 71.3 % Gram-positive bacteria 18.9 %
Edsander-Nord [4]	Indian Ocean tsunami, Thailand, 2004; Karolinska University Hospital		Organism examples (no data on numbers) Acinetobacter *Aeromonas hydrophila* Allescheriasis (*Scedosporium apiospermum*) *Bergeyella zoohelcum;* Candida (*Candida tropicalis*) *Chryseobacterium meningosepticum* *E. coli, Enterobacter faecium/E. cloacae* Coagulase-negative staphylococci *Microsporum gypseum* (dermatophytes) *Pseudomonas* Zygomycosis (*Saksenaea vasiformis*)	
Doung-Ngern et al. [6]	Indian Ocean tsunami, Thailand; Takuapa Hospital (177 beds); Vachira Phuket Hospital (500 beds), Talang Hospital (60 beds); Patong Hospital (30 beds), 2004	523 patients with 1,013 wounds; 674/1,013 wounds (66.5 %) became infected; 2 people progressed to septic shock and acute renal failure; 56 of 84 people (66.7 %) followed up had wound infection	Organisms, $n = 155$ (%) *E. coli* 26 (16.8 %) *K. pneumoniae* 19 (12.3 %) *S. aureus* 18 (11.6 %) *P. vulgaris* 14 (9 %) *P. aeruginosa* 14 (9 %) *Proteus mirabilis* 9 (5.8 %) *Enterobacter* spp. 7 (4.5 %) *Klebsiella ozaenae* 6 (3.9 %) *Enterobactor aerogenes* 6 (3.9 %) E. cloacae 6 (3.9 %)	Polymicrobial wound infections 45 %; 75/92 (81.5 %) cases were culture positive; mixed organisms 43.5 %; single organism 38 % Most isolates were Gram-negative bacteria
Kiani et al. [7]	Earthquake, Pakistan; Shifa International Hospital, 2005	56/171 patients had wound infections (32.7 %); 103/129 cultures positive	Organisms, $n = 108$ (%) *P. aeruginosa* (30.5 %) *Enterobacter* spp. (22.3 %) *Acinetobacter* spp. (15.8 %)	Gram-negative infections (89 %), RR 2.31 (95 % CI: 1.91–2.79; $p < 0.0001$) Polymicrobial infections (59.6 %), RR 3.45 (95 % CI: 2.45–4.85; $p < 0.0001$); multi-drug resistant organisms (61.5 %), RR 1.53 (95 % CI: 1.23–1.92) ($p < 0.0002$) Hospital stay was 3× longer in infected group vs non-infected group
Hiransuthikul et al. [8]	Indian Ocean tsunami, Southern Thailand; Samitivej Hospital; Bangkok Nursing Home Hospital; Bumrungrad Hospital; Bangkok General Hospital, 2004	515/777 patients (66.3 %) had skin and soft tissue infections; organism growth in 305/396 cases (77.0 %)	5 most commonly isolated organisms: *Aeromonas* species 145 (22.6 %) *E. coli* 116 (18.1 %) *K. pneumoniae* 93 (14.5 %) *P. aeruginosa* 77 (12.0 %) *Proteus* species 47 (7.3 %)	219/305 (71.8 %) poly-microbial infections; Gram-negative bacilli 612/641 isolates (95.5 %); Gram-positive bacteria 4.5 % of isolates

Table 2 continued

Reference/ author/year	Event/geographic location/hospitals	SSTI rates (n/d) %	Organisms	Comments
Bartels and VanRooyen [9]	Earthquakes, worldwide, multiple years		Post-earthquake pathogens included: *Acinetobacter baumannii, E. cloacae, E. coli, P. aeruginosa*	Gram-negative bacteria were more prevalent than Gram-positive bacteria
Kespechara et al. [10]	Indian Ocean tsunami, Bangkok, Thailand; Bangkok Hospital Phuket; Bangkok General Hospital; Samitivej Hospital; BNH Hospital, 2004	70/391 patients (18 %) had wound infections; 70 % of infected patients needed surgical revision; 10 % septicemia; 1 patient developed MSOF and died	Organisms, $n = 70$ K. pneumoniae 24 %; *E. coli* 19 %; *Proteus* spp. 16 %; *Aeromonas* spp. 14 %; *Enterobacter* spp. 7 %; *P. aeruginosa* 5 %; *Klebsiella* spp. 3 %; *Acinetobacter* spp. 2 %; *Pseudomonas* spp. 2 %; *Staphylococcus* spp. 2 %; *P. vulgaris* 3 %; *Alpha viridans* streptococcus 1 %; *Vibrio parahaemolyticus* 1 %;	
Keven et al. [11]	Earthquake, Marmara, Turkey, 1999	223/639 renal patients (34.9 %) developed infections; 121 (18.9 %) sepsis; of 121 with sepsis, 55 had positive blood cultures (45.4 %) Microbiological examination yielded 134 positive wound cultures in 55 (8.3 %) patients	Organisms, $n = 134$ (%) *Acinetobacter* spp 45 (33.5 %); *Pseudomonas* spp. 45 (33.5 %); *Klebsiella* spp. 11 (8.2 %); *S. aureus*, 4 of which were methicillin resistant; *Staphylococcus epidermidis* 4 (3 %); *E. coli* 7 (5.2 %); *Proteus* spp. 4 (3 %); *Enterobacter* spp. 4 (3 %); *Citrobacter* spp. 1 (0.7 %); *Bacteroides* spp. 1 (0.7 %); *Enterococcus* spp. 2 (1.5 %)	Gram-negative aerobic bacteria and *Staphylococcus* spp were most common organisms
Kazancioglu et al. [12]	Earthquake, Marmara, Turkey, 1999	Microbial growth in 67/112 (60 %) of samples from 38 of 41 patients (95 %); all 51 wound cultures grew organisms	Organisms, $n = 51$ (%) *Acinetobacter* spp. 23 (45.1 %); *P. aeruginosa* 11 (21.6 %); methicillin-resistant *S. aureus* 9 (17.6 %); *Serratia marcescens* 2 (3.9 %); *K. pneumoniae* 2 (3.9 %); *Enterobacter* spp. 2 (3.9 %); *Candida albicans* 2 (3.9 %)	Non-fermenting Gram-negative bacilli (67 %) Gram-positive cocci (17 %) Enterobacteriaceae (12 %); yeast-like fungi (4 %)
Ran et al. [13]	Earthquake, Wenchuan Province, China, 2008. Children's Hospital; Chongqing Medical University; Chongqing, China	50/98 admitted children had wound infections; microbial growth was found in 31/50 (62 %)	Organisms, $n = 99$ (%) *Acinetobacter baumannii* 27 (27 %); *E. cloacae* 18 (18 %); *P. aeruginosa* 13 (13 %); *S. aureus* 5 (5 %); *E. coli* 4 (4 %); *K. pneumoniae* 4 (4 %); Coagulase-negative staphylococci 4 (4 %)	Gram-negative bacteria most common isolate; *S. aureus* primary; Gram-positive bacterium identified; 99 pathogens isolated → 16 (16 %) Gram-positive bacteria, 81 (82 %) Gram-negative bacteria. Co-infection with ≥ 2 pathogenic bacteria in 21/31(68 %)
Janda and Abbott [14]	Indian Ocean tsunami, Thailand, 2004	305 patients with wound infections;	*Aeromonas* > 20 % of the 641 isolates	
Okumura et al. [22]	Indian Ocean tsunami, Banda Aceh, Indonesia, 2004	Of 367 wounds, 211 (57 %) were infected	Gram-negative bacteria, $n = 49$ (%) *Aeromonas* sp. 24 (49 %); *Vibrio* sp. 16 (33 %); *K. pneumoniae* 15 (31 %); *E. coli* 7 (14 %); *Proteus* sp. 6 (12 %); *Enterobacter* sp. 3 (6 %); *Acinetobacter* sp. 1 (2 %); *Pseudomonas* sp. 1 (2 %)	
Johnson and Travis [53]	Indian Ocean tsunami, Krabi Province, Southern Thailand, 2004; Krabi Hospital (340 beds)	513/777 patients (66 %) had skin and soft tissue infections	Most common isolate was *Aeromonas* sp.	

Table 2 continued

Reference/ author/year	Event/geographic location/hospitals	SSTI rates (n/d) %	Organisms	Comments
Liu et al. [55]	Earthquake, Wenchuan Province, China, 2008	43/82 (52.4 %) wound infections	Organisms, $n = 59$ (%) *S. aureus* 26 (44.1 %) MSSA 23 MRSA 3; *Staphylococcus epidermidis* 12 (20.3 %); Gram-negative bacteria 21 (35.6 %); *E. cloacae* 13 (22 %); *Serratia rubidaea* 5 (8.5 %); *K. pneumoniae* 3 (5.1 %)	59 strains pathogenic bacteria; 21 Gram-negative bacterial infection (35.6 %); 38 Gram-positive bacterial infections (64.4 %); 16/82 (19.5 %) mixed infections

SSTI skin and soft tissue infections, *MSOF* multi-system organ failure, *MSSA* methicillin-sensitive *Staphylococcus aureus*, *MRSA* methicillin-resistant *Staphylococcus aureus*

Table 3 Wound management in disaster settings (poster outline)

A. ABC
1. Scene assessment
2. Primary survey
airway
breathing
circulation
disability environment/exposure
3. *Stop bleeding* preferably by direct local pressure
Consider use of a tourniquet if direct pressure fails. Record time of tourniquet and remove within 1–1.5 h* (*upper limb: within 1 h, *lower limb: within 1.5 h)
B. Baseline wound assessment
1. Distal function
2. Associated fractures
3. Underlying structures
4. Need for exploration or extension
C. Control contamination
1. *Anaesthesia* Use anaesthesia if available and indicated
2. *Clean* Wash the wound. Use potable (drinkable) water, saline or antiseptic solution. DO NOT use river water or seawater
3. *Remove foreign matter* Pick out removable foreign material
4. *Scrub* the wound to remove embedded foreign material
5. Explore to assess wound and underlying structures. This may require extension of wound margins
6. *Excise* Debride to remove remaining foreign material and necrotic and devitalised tissue. This may require trimming or excision of wound edges
D. Don't close—dress and document
1. Leave wound open
2. *Pack wound loosely* with moist gauze. Saline soaked gauze is best
3. *Dress* with clean, dry dressing
4. *Document* on dressing, label or case notes:
Place, date and time
Procedure
Proceduralist
Plan
E. Explain, elevate and essential medicines
1. *Elevate the limb* and minimise wound movement
2. Consider tetanus status
administer tetanus toxoid prophylaxis if unimmunised or uncertain
3. Broad spectrum antibiotics
Single dose if no established infection
IV route if practical
Continue if hands, feet or underlying fracture
Continue if established infection
F. 48 h follow-up
1. Re-inspect the wound
2. Plan for definitive wound closure if no signs of infection
3. Re-debride and further excise if signs of infection, necrosis or contamination persist
G. Get specialist
1. Wounds that can't be closed
2. Complex orthoplastic reconstruction
3. Complex wounds in children
4. Decisions about amputation and withdrawal of care

was the single most common pathogen identified among tsunami survivors, accounting for over 20 % of infections [14]. Other, mostly Gram-negative bacteria [6] were also common, particularly *E. coli* and *Klebsiella pneumoniae*, as well as *S. aureus*, *Proteus vulgaris*, and *P. aeruginosa* [6].

Sepsis with or without necrotizing fasciitis was frequently seen following flood and tsunami wounds [10, 15], and it was associated with more than doubling of mortality (OR 2.45, 95 % confidence interval [CI] 1.52–3.96) [11].

Crush syndrome

Nine review articles and three descriptive studies each addressed crush syndrome, which is acute renal failure secondary to hypovolemia and rhabdomyolysis from muscle damaged at any of three different times: the time of the initial mechanical crushing force, during periods of ischemia, and during reperfusion [9, 16–18]. While skeletal muscle was thought to be relatively tolerant of ischemia for 2–4 h without permanent injury, it is likely that irreversible changes that limit functional recovery start to occur in as little as 1 h [18], especially when there is concurrent tissue damage and other injuries. Death often ensues due to hypovolemia and hyperkalemia [9].

Among earthquake survivors [3], the reported incidence of crush syndrome was 2–15 % [3, 9]. Entrapped time under the debris, multiple crush injuries, male gender, presence of infection, and creatinine kinase (CK) level were all predictive of acute renal failure [19]. Survival depended on limiting the degree of renal dysfunction and supporting organ function, and mortality was reported to be up to 48 % [9, 17, 20].

Management

The panel agreed on the principles of basic wound care in disasters, which are presented in Table 3. These highlight the importance of meticulous wound care even when resources and expertise are limited, recognizing that poorly managed wounds are associated with high mortality from sepsis and crush syndrome.

Initial patient management

Protocols for field-based triage and initial assessment of injured patients should prioritize identification and management of life-threatening conditions [21]. Early maneuvers to secure the airway, ensure adequate ventilation, and stop bleeding must take precedence over assessment and management of a non-bleeding extremity wound. Of course, wounds may compromise the airway, ventilation, cardiac function, or cause substantial hemorrhage, of which the latter may need to be addressed through application of direct pressure or a temporary tourniquet.

Basic wound assessment and management

Injuries to extremities should be addressed after initial assessment for life-threatening injuries and resuscitation has taken place [21]. Wounds must be carefully inspected, and assessment must be made for associated injuries, distal function, bone and soft tissue injury, and underlying neurovascular injury. In major earthquakes these types of injury occur in approximately 1 in 20 patients sustaining limb injury [9]. Assessment of the degree of contamination, devitalized tissue, presence of foreign bodies, and integrity of underlying structures may require wound extension and formal exploration, under anesthesia if it is available.

After adequate assessment, aggressive cleaning and debridement are required [6, 22]. Foreign bodies should be removed, and obvious embedded ones should be scrubbed before exploration, wound debridement, and removal [22] if possible. Devitalized tissue needs appropriate debridement by trimming or excising around the wound edge [22]. In one study of contaminated wounds, debridement was associated with reduced wound infection rates from 62.5 to 2 % [23].

Irrigation can be done with isotonic saline, distilled water, boiled and cooled water, dilute antiseptic solution, sterile water, or drinkable/potable tap water, with similar efficacy [24]. Untreated river water and seawater have high levels of contaminants and should not be used [25]. Dilute antiseptics, such as 1 % povidone–iodine or a 5 % solution of sodium benzyl penicillin have been shown to decrease infection rates and can be used in addition to water or normal saline [26–28].

Value of delayed primary closure

All primary and review articles confirmed that wounds sustained in disaster events are contaminated, especially when presentation is delayed, and that early primary wound closure causes high rates of serious wound infection eventually requiring much more extensive debridement and sometimes leading to the death of the patient [4, 6, 15, 29]. Such wounds should therefore be closed in a delayed fashion, which is associated with much lower infection rates. The only exception, for which initial wound closure has provided acceptably low rates of subsequent wound infection, is when primary closure followed wound assessment, meticulous debridement of all foreign material and devitalized tissue by an experienced surgeon within 6 h of injury [30].

Delayed primary closure consists of initial adequate debridement followed by wound dressing, careful wound reassessment at 48 h, repeat debridement and dressing if necessary, and, finally, closure 48 h or longer after initial inspection, but only if the wound is clean and free of foreign material and contaminated and devitalized tissue [31]. Simple closure techniques using strips, sutures, or staples can be employed if the wound edges can be brought together without undue tension. Delayed primary suturing gives similar cosmetic outcomes to immediate suture, even when closure is achieved 2–5 days after wounding. Wounds that cannot be closed without tension will need to be left open to heal by secondary intention or closed by skin graft or flap as appropriate.

Dressings

A clean, dry, absorbent dressing is usually sufficient to minimize ongoing contamination. Our search identified three systematic reviews [27, 32, 33], two randomized controlled trials [34, 35], and two other review articles [15, 36] that sought to determine whether any particular type of dressing was associated with superior outcomes compared to another.

It appears that an absorbent gauze dressing or saline-soaked gauze dressing and coverage with dry gauze are sufficient [15, 22, 34, 37]. Occlusive dressings have not been shown to further reduce infection, hasten healing, or be associated with less pain [34]. There is little evidence to support superior results over simple gauze dressings from the use of antibiotic or silver impregnated dressings and gels [33, 36, 38, 39], or antibiotic beads [40]. Medical-grade honey is reported to have peroxide and antibacterial activity, but little evidence of better outcomes exists to support its use [41, 42]. In patients with properly debrided wounds, there is also little evidence of reduction in mortality or severe infection with the additional use of advanced technologies, such as negative pressure wound therapies or hyperbaric oxygen, which may mitigate anaerobic infection by promoting a hyperoxic wound environment [9, 43]. There is some evidence that, where available, negative pressure wound therapies, which likely reduce tissue edema [44], allow earlier delayed primary closure [32, 35, 45]. However, such advanced technologies are unlikely to be available early on in the setting of a disaster when wounds are fresh.

Systemic antibiotics

While topical antibiotics have not been shown to significantly influence wound infection rates [38], systemic antibiotics play an adjunct role to proper initial wound care and delayed primary closure [21, 46]. Their availability at the time of initial wound care is the main limitation for prophylaxis. Various prophylactic regimens have been recommended, ranging from a single dose of beta-lactam penicillin in patients with mildly contaminated wounds [22] or in operations for the treatment of closed fracture [47], to longer durations in wounds affecting the hands [21] and feet, as well as in all open fractures [25]. Antibiotic use has had protective effects against early infection in open fractures of the limb [46]. In established infections, antibiotics are an essential component of wound care.

A variety of oral and parenteral agents have been recommended. Initial prophylaxis with fusidic acid, flucloxacillin, or erythromycin were generally effective in preventing skin and soft tissue infections [48–50]. However, antibiotic resistance is prevalent, particularly to commonly used agents such as amoxyl–clavulanate, ceftriaxone, and cloxacillin [6, 13]. More infecting bacteria were susceptible to aminoglycoside (gentamicin, amikacin), piperacillin–tazobactam, third and fourth generation cephalosporins, quinolones (ciprofloxacin), imipenem, and meropenem [3, 8, 12, 14, 25]. Broad-spectrum antibiotic prophylaxis has been shown to decrease infection rates [22, 23] and therefore benefit wound healing [6]. Similarly, if initial antimicrobial agents are ineffective, broadening therapy with quinolones such as ciprofloxacin and gentamicin to cover Gram-negative bacteria is indicated [25].

Tetanus prophylaxis

Tetanus prophylaxis or mass vaccination campaigns have been rolled out in disaster settings [9, 21], and have shown that unnecessary vaccination is unlikely to cause harm [51]. Tetanus-prone wounds are those that are stellate in shape or longer than 1 cm, more than 6 h old, that contain devitalized tissue or gangrene, or are contaminated with dirt, saliva, or feces [5]. Avulsion injuries are also prone to tetanus. Proper initial wound care and debridement are critical for tetanus prevention [51].

The need for post-exposure prophylaxis for tetanus depends on each patient's previous immunization status. When immunization status is unknown, or if the patient has received fewer than three previous doses of tetanus toxoid, both tetanus toxoid and tetanus immunoglobulin should be administered. A second dose of toxoid should be given within the next 2 months, followed by a third dose in the following 6–12 months [5, 50, 51]. In cases of completed immunization within 5 years, it appears unnecessary to give either tetanus toxoid or immunoglobulin. If completed immunization was longer than 5 years before injury, patients should be given a single dose of tetanus toxoid [5, 50, 51]. Pediatric patients (under 7 years of age), can be given the diphtheria, pertussis, tetanus (DPT) vaccine instead of tetanus toxoid [5, 51].

Documentation

Although none of the articles reviewed made specific reference to the need for appropriate documentation, the panel regarded clear, concise documentation of wound management to be crucial to monitoring and follow-up of each wound.

Details to be recorded include (1) the mechanism of injury (e.g., penetrating, laceration, abrasion, blast); (2) a description of the wound, including the location of the injury on the body; (3) the wound size, depth, margins, and base, and any neurovascular structures involved; and (4) any management that has been undertaken and any further action required, making clear the date and time of planned wound review.

Special situations (Table 4)

Entrapment and extrication

The entrapped victim presents the concurrent challenges of time-critical life-saving interventions and freeing the victim, followed by prevention and minimization of the harmful systemic effects of crush injury and the management of wounds and other injuries. Primary management of

Table 4 Special cases

1. Splinting
Preferably use a splint in cases of suspected or confirmed fractures
Wounds on the limb: test distal function
2. Definitive fracture management
Soft tissues are best treated by fracture stabilisation
3. Amputate
Remove devitalised and mangled tissue/limbs in unsalvageable cases
Is surgical input to decision-making possible?
4. Fasciotomy
Consider if distal pulses absent or other signs of distal limb ischaemia
Clinical examination and objective measures should both be used to make decision
5. Delayed primary closure (2–5 days) where tissue defect
Alternative closure technique with skin graft or flap (local or free)
Secondary closure (>5 days)
6. Crush injury
Aggressive fluid resuscitation
Alkalinisation with bicarbonate
Serum CPK and electrolyte monitoring at 6-hourly intervals
7. Blast injury
8. Extrication
Amputation indicated when alternative retrieval failed, for life-saving purposes only
Amputation by specialised team in coordinated effort
Maximum limb preservation must be considered

the entrapped victim consists of early fluid administration and coordinated extrication; however, if an entrapped limb is preventing early extrication, then amputation at the scene may be a life-saving measure [18, 44].

While limb amputation before release of the crushing force may prevent the sequelae of the reperfusion syndrome and minimize the systemic insult, it is also associated with substantial morbidity and should be done only if other options for preserving crushed limbs have been exhausted [18]. Surgical expertise is often required to remove and safely extricate an injured survivor from the scene of a disaster [9, 16, 21, 44, 52], and medical expertise is often needed immediately afterwards to manage the complications of prolonged entrapment and reperfusion injury.

Crush injury, compartment syndrome, and avoidance of fasciotomy

Crushing of a limb often leads to swelling, painful tense compartments, altered sensation, and sometimes absent distal pulses. In civilian settings a limb with these signs would usually be treated with resuscitation, limb immobilization, fracture fixation, and fasciotomy to reduce compartment pressures and restore capillary circulation.

In disaster settings, it is unclear whether the benefits of fasciotomy outweigh the risks associated with further wounds, which may act as a portal for infection of underlying devitalized muscle. In one study of earthquake victims, 81 % of fasciotomies became infected, and fasciotomy was therefore a significant factor in sepsis ($p < 0.001$) and mortality ($p < 0.0001$ [9]).

A reasonable strategy that balances potential benefits and harms in limbs with viable musculature, as indicated by responsiveness to mechanical or electrical stimulation, is for fasciotomy to be performed only if intra-compartment pressures are greater than 40 mmHg [17] or distal pulses are absent [18, 44]. Salvage of muscle is likely to be futile in limbs that have been crushed for a prolonged period and show evidence of devitalized muscle by lack of responsiveness to stimulation. In this situation, debridement of devitalized tissue should be the priority.

Systemic effects of crush injury, especially rhabdomyolysis, should be expected [19]. A urine dipstick to detect myoglobin and subclinical rhabdomyolysis can be useful in the field to triage patients; however, the serum CK level is a more sensitive biochemical marker once pathology services are available [9]. A serum CK level greater than 5,000 U/L has been shown to be the best predictor of acute renal failure in crush-injured patients, with mortality in the range of 14–48 % [9]. Urgent treatment and critical care monitoring are almost always needed if the serum CK level reaches 20,000 U/L [16]. Electrolyte abnormalities are common, and hyperkalemia and hypovolemia can be fatal, so serum potassium levels, CK level, cardiac status, and arterial pH should be measured three to fours times daily in the first few days [9, 17, 18].

Early intravenous fluid administration prior to extrication can help prevent acute renal failure due to rhabdomyolysis [9, 17, 20]. Treatment of crush syndrome usually requires early aggressive hydration and forced diuresis (urine output of 100–200 mL/h), alkalinization of urine (pH 6.5 or more), and maintenance of arterial pH <7.5 [16, 20, 53]. Hemodialysis, if available, will often be initiated if the serum creatinine is greater than 1.5 mg/dL [16, 53].

Fractures

Basic principles of fracture management should be followed, which include temporary splinting to minimize pain and bleeding and prevent further soft tissue or neurovascular injury during transportation to more specialized services [53]. Patients with open fractures should receive early systemic antibiotic treatment and tetanus vaccination [53]. External fixation is often a mainstay of early management of the mangled limb, allowing wounds and soft tissues to be properly assessed and managed even when definitive fracture fixation is unavailable [54]. Early referral should be planned to a facility capable of managing fractures and other needs of the victims.

Delayed amputation

Other than as a life-saving procedure to extricate a trapped person where other options have been exhausted, amputation of a mangled or devitalized limb should only be performed by a suitably qualified person after careful evaluation of the limb and the patient [9, 16, 21, 44, 52]. Aids to assessment, such as the Mangled Extremity Severity Score (MESS), have been developed to guide decision making [52]. The main indications for amputation have been irreparable vascular injury, completion of partial amputation and, as a last resort in patients with severe soft tissue damage, with or without fractures and deteriorating renal and cardio-respiratory function, as well as overwhelming sepsis [21].

Wounds of the head, neck, face, hands, and feet

In disaster settings wounds on the face, neck, hands, and feet should be managed according to the same principles, as they have early wound infection rates exceeding 50 % [2, 4, 37, 54, 56].

Although it may be technically challenging to treat injuries to these sites, adequate debridement and delayed primary closure are still key to preventing severe wound infection. In one series the infection rates among patients who had and had not undergone wound debridement were 2 and 62.5 %, respectively [23]. Where there are cosmetically challenging wounds, early referral to an experienced surgeon may reduce the risk of eventual disfigurement or loss of function. In any wounds of the head, neck, or face early consideration needs to be given to the possibility of brain or airway injury.

Discussion

Through this systematic review we provide an evidence-based overview of the clinical challenges of managing wounds among survivors of natural and man-made disasters. We also provide evidence of suboptimal wound management in recent disasters, noting that these wounds could have been better managed with adherence to some key principles. The review and the deliberations of the international panel have clarified and redefined these key principles, distilled from a variety of sources, that together comprise the necessary aspects of good wound care in austere environments. It is anticipated that adherence to these practices will minimize preventable deaths and improve the outcomes and quality of life among survivors.

The most critical step is avoiding premature closure of contaminated and inadequately cleaned and debrided wounds. Simple cleaning, dressing, and review of wounds at 48 h allows identification and adequate management of the vast majority of wound infections that could otherwise be life-threatening or limb-threatening. When the open wound is re-inspected, the presence of erythema, purulent exudate, necrotic core, and tissue edema are all signs that the wound should not yet be closed, that further cleaning and debridement should performed, and that antibiotic therapy should be considered. The wound should then be redressed and inspected another 48 h later.

The review and deliberations also highlighted the challenges faced in standardizing these practices. In disaster settings health care services are usually overburdened, first responders are often inexperienced in wound care, and resources are mostly inadequate. Experienced surgeons who can manage complex wounds are usually a scarce resource, and crucial strategies, such as delaying wound closure, may be unfamiliar to those immediately responsible for care of the victims.

The consensus panel acknowledged that promoting practice improvements among dispersed, relatively unskilled personnel working at unpredictable times in austere environments with few of the usual clinical resources is a very challenging task. We regarded a wide dissemination strategy and endorsement by relevant clinicians and their representative organizations to be essential. With this in mind, our panel developed a simple generic poster that provides guidelines for wound care in disaster settings (Fig. 1). It is anticipated that the poster would be useful for promoting discussion about optimal wound management, for education, and for field-based guidance in the acute aftermath of a disaster. It is presented as a simple A, B, C, D, E, F, G *aide de memoir* for easy reference and to facilitate recollection. This poster can be modified for local use if necessary, and included in disaster management equipment packs, and in emergency care facilities during disaster situations. It was launched at the joint meeting of the RACS International Committee and the Alliance for Surgery and Anesthesia Presence at the Royal Australasian College of Surgeons and Australian and New Zealand College of Anaesthetists Annual Scientific Congress in Singapore on 5 May 2014, and it is likely to be made available for download from many surgical college websites.

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