Maggot Debridement Therapy in Disaster Medicine

Frank Stadler, BSc Hon;[1] Ramon Z. Shaban, RN, EMT-P, PhD;[2,3] Peter Tatham, PhD[1]

1. Department of International Business and Asian Studies, Griffith University, Gold Coast, Queensland, Australia
2. Menzies Health Institute Queensland, School of Nursing and Midwifery, Griffith University, Gold Coast, Queensland, Australia
3. Department of Infection Control and Infectious Diseases, Gold Coast University Hospital and Health Service, Gold Coast, Australia

Correspondence:
Frank Stadler, BSc Hon
Griffith Business School
Department of International Business and Asian Studies
Gold Coast Campus
Griffith University
Queensland, Australia 4222
E-mail: f.stadler@griffith.edu.au

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MDT: maggot debridement therapy
VAC: vacuum-assisted closure
WRAIR: Walter Reed Army Institute of Research

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Abstract

Background: When disaster strikes, the number of patients requiring treatment can be overwhelming. In low-income countries, resources to assist the injured in a timely fashion may be limited. As a consequence, necrosis and wound infection in disaster patients is common and frequently leads to adverse health outcomes such as amputations, chronic wounds, and loss of life. In such compromised health care environments, low-tech and cheap wound care options are required that are in ready supply, easy to use, and have multiple therapeutic benefits. Maggot debridement therapy (MDT) is one such wound care option and may prove to be an invaluable tool in the treatment of wounds post-disaster.

Discussion: This report provides an overview of the wound burden experienced in various types of disaster, followed by a discussion of current treatment approaches, and the role MDT may play in the treatment of complex wounds in challenging health care conditions. Maggot debridement therapy removes necrotic and devitalized tissue, controls wound infection, and stimulates wound healing. These properties suggest that medicinal maggots could assist health care professionals in the debridement of disaster wounds, to control or prevent infection, and to prepare the wound bed for reconstructive surgery. Maggot debridement therapy-assisted wound care would be led by health care workers rather than physicians, which would allow the latter to focus on reconstructive and other surgical interventions. Moreover, MDT could provide a larger window for time-critical interventions, such as fasciotomies to treat compartment syndrome and amputations in case of life-threatening wound infection.

Recommendations: There are social, medical, and logistic hurdles to overcome before MDT can become widely available in disaster medical aid. Thus, research is needed to further demonstrate the utility of MDT in Disaster Medicine. There is also a need for reliable MDT logistics and supply chain networks. Integration with other disaster management activities will also be essential.

Conclusions: In the aftermath of disasters, MDT could play an important role facilitating timely and efficient medical treatment and improving patient outcomes. Existing social, medical, and logistic barriers will need to be overcome for MDT to be mainstreamed in Disaster Medicine.

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Introduction

In modern clinical practice within developed regions, patients with traumatic injuries can look forward to good outcomes thanks to high-quality care. However, the picture is quite different in developing countries, especially when natural or man-made disasters strike. They easily can overwhelm already fragile health care systems and challenge the capacity of national and international aid agencies to provide humanitarian relief. For example, six of the seven most deadly earthquakes between 2001 and 2011 occurred in low- or middle-income countries, directly affecting 58.2 million people.[1] The global trend toward urbanization means that, in the event of disasters such as earthquakes, tsunamis, floods, or storms, a large number of people may be affected in a given locality. Typhoon Yolanda made landfall on November 8, 2013 and devastated Leyte, a relatively confined region of the Philippines, killing 6,293 and injuring another 28,689.[2] Similarly, when a magnitude 7.0 earthquake leveled Port-Au-Prince (Haiti) on January 12, 2010, three million people were killed, injured, displaced, or otherwise affected.[3] These statistics highlight an important consideration for the management and development of disaster relief medical surge capacity. There are, on average, approximately three times more injured than dead in an earthquake, and this may be similar in other disasters depending on circumstances.[4] Self-evidently, it is the living wounded that require immediate attention and medical care.

Natural disasters damage a country's built infrastructure including transport, communication, utility, and medical infrastructures.[5] The resultant interruptions to the supply chains for medications and consumables can severely influence the care that is provided.[6,7] Indeed, even if regional clinics are operational, the patient burden may stretch resources beyond the breaking point, as exemplified by the 2004 tsunami in Thailand where those impacted were treated in hospitals that were unaffected structurally but lacked sufficient operating facilities, human resources, and equipment.[8]

Thus, despite a rapid and comprehensive deployment of national and international medical assistance teams, the number of patients requiring treatment can be overwhelming – even for the most experienced and best resourced agencies. Médecins sans Frontières (MSF; Geneva, Switzerland) treated over 55,000 Haitians in the 10 weeks after the 2010 earthquake, a figure that includes over 4,000 surgical interventions.[6] Indeed, although the total injury figures for this disaster vary widely, they are estimated by Doocy and colleagues to lie somewhere between 110,000 and 300,000.[9] In such compromised health care environments, wound care options are required that are relatively cheap, in ready supply, easy to use, and have multiple therapeutic benefits. Maggot debridement therapy (MDT), also known as larval debridement therapy, is one such option which may prove to be an invaluable tool in the treatment of complex wounds in the aftermath of disasters.

Current MDT practice employs the larvae of the green bottle blowfly *Lucilia* (*Phaenicia*) *sericata* Meigen (Diptera: Calliphoridae) to remove necrotic tissue from wounds, to control infections, and to stimulate tissue regeneration and wound healing; although, other species have been used successfully.[10,11] In the 1930s and 1940s, MDT was used for the treatment of intractable wounds and osteomyelitis, but it fell out of fashion with the advent of sulphonamides, penicillin, and new antiseptics.[12] Over the past three decades, however, MDT has emerged once again as a treatment for chronic non-healing wounds, necrotic and infected trauma injuries, burns, and post-operatively complicated wounds.[13-17] Maggots are applied either in cage-like containment dressings that cover the wound and permit maggots direct access to necrotic tissue (free-range), or in small sealed pouches made of a porous material such as polyvinyl alcohol that allow maggots to feed and debride but not explore the wound freely.[18]

Some of the earliest accounts of beneficial wound infestations by maggots come from the battle fields of Napoleon's Egyptian expedition in Syria (1798-1801) and the First World War (Europe; 1914-1918).[10] The US Army Special Forces Medical Handbook from 1982 describes under the heading of "Primitive Medicine" how to use wild flies for infection control and debridement in the field;[19] although, the use of wild unsterilized fly eggs and maggots is a measure of last resort in the total absence of medical care, and under austere conditions. While modern military medical science has not yet refined and operationalized this therapy for deployment in the theatre of war, recent research at the Walter Reed Army Institute of Research (WRAIR; Silver Spring, Maryland USA), and elsewhere, is addressing this knowledge gap. For example, Heitkamp and colleagues surveyed 180 US Army physicians, and although 83% were aware of MDT, only 10% of them had ever used it.[20]

In parallel, Peck and Kirkup investigated the effect of antimicrobials, including antibiotics and antifungals, on medicinal maggots.[21] These researchers found that antimicrobials can be used in combination with MDT without diminishing the therapeutic activity of the medicinal maggots. Most relevant to the application of MDT in Disaster Medicine is the latest research emerging from the WRAIR where Peck and colleagues tested the resilience of medicinal maggots during transport in US military aircraft.[22] The authors have shown that medicinal maggots can withstand conditions that exist during military evacuation and transfer flights and could, therefore, be used in the treatment of wounds during the evacuation process. These results also suggest that medicinal maggots could be sent to disaster zones on a needs basis using military and other aircraft.

Given that military medical innovation often paves the way for civilian applications,[23] the research conducted at the WRAIR supports the fundamental contention of this report that the use of MDT in disaster medical aid has potential merit. Furthermore, a review of the literature, using five electronic databases (PubMed (National Center for Biotechnology Information; Bethesda, Maryland USA), CINAHL Plus with full text (EBSCO Information Services; Ipswich, Massachusetts USA), SCOPUS Life Sciences & Health Sciences (Elsevier; Amsterdam, Netherlands), ProQuest (Ann Arbor, Michigan USA), and Web of Science BIOSIS (Thomson Reuters; New York, New York USA)) from inception to December 2014, suggests that MDT in disaster medical aid has not been investigated previously.

Aim

With this introduction in mind, the aim of this study was to demonstrate how medicinal maggots could contribute to the treatment of intractable wounds in Disaster Medicine. To achieve this aim, the report consists of an overview of the wound burden of natural disasters, followed by a discussion of current treatment approaches for various injury categories, and the role medicinal maggots could play in their treatment. The report concludes with research gaps emerging from this initial investigation.

Report/Discussion

Disasters reflect a broad range of causalities that include the impact of earthquakes, tsunamis, floods, cyclones, typhoons and hurricanes, and man-made technology-related events. Wounds are a common consequence of disasters. Table 1 presents a summary of such disasters, their injury mechanisms, and resulting wound types.[24-52]

The presence of necrotic devitalized tissue and wound infection are prime indications for the use of MDT in the clinical setting. It is safe to assume that this is also the case in an austere health care setting such as in the aftermath of disasters and other emergencies. Indeed, the ability of medicinal maggots to control the microbial burden in wounds under the most extreme conditions is remarkable, it suggests that MDT can debride wounds and stimulate wound healing under such circumstances, and it's without the need to close wounds for fear of infection. For example, Terterov and colleagues document a case of human cerebral myiasis which, in all likelihood, saved the life of an assault victim.[53] The patient lay abandoned in a ditch for two weeks with severe facial injuries,

Disaster or Emergency	Injury Mechanisms	Wound Types
Earthquakes [24-25]	Falling buildings, rubble, and debris.	Musculoskeletal and soft tissue injuries, open wounds, lacerations, fractures and crush injuries - often requiring fasciotomies and amputation.
Tsunamis and Floods [8,26-28]	Impact force of fast-moving water and suspended debris, water-borne pathogens.	Lacerations, abrasions, fractures, wounds, wound and skin infections, and musculoskeletal injuries.
Storms [29]	High-energy events mobilizing objects, demolition of infrastructure.	Lacerations, abrasions, cuts, scratches, blunt trauma, penetrating trauma, spinal injuries, and burns.
Post-disaster Activity [8,27,30-32]	Medical interventions, rescue, and clean-up related accidental injury.	Minor scratches to more serious injuries, surgical interventions; high incidence of acute wound infections, abscesses, and other infections appearing weeks and months after disaster.
Mass-gathering Events [33-34]	Fire, crushing, trampling, smoke inhalation, and drowning.	Burns, trauma wounds, wounds resulting from surgical treatments such as fasciotomies and the setting of fractures.
Industrial Disasters [34,35-40]	LPG explosions, oil and petroleum explosions, fire.	Extensive burns.
Nuclear Warfare and Terrorism [41-49]	Heat, physical impact, flying debris, and radiation exposure.	Extensive burns, trauma, radiation illness, bone marrow syndrome, and infections.
Pressure Wounds in the Aftermath of Disaster [31,50-52]	Prolonged immobilization and incapacitation, unsuitable surfaces and bedding.	Pressure ulcers.

Table 1. Common Disaster and Emergency Categories, Their Injury Mechanisms, and Resulting Wound Types
Abbreviation: LPG, liquefied petroleum gas.

including a skull fracture and maggot infestation of the left frontal lobe. To the surprise of the authors, the patient did not succumb to meningitis or encephalitis, and this they attributed to the antimicrobial properties of the maggots. It should be stressed, however, that the infestation of wounds by wild flies should be avoided, particularly if treating physicians are not familiar with medical entomology and alternative MDT species. This is because some fly species, like the New World screwworm *Cochliomyia hominivorax,* feed on living flesh, and if left in the wound, they would cause further harm.[54] Myiasis can also lead to additional contamination of the wound with fly-borne pathogens.[55]

Natural Disasters

In response to the devastating 2010 earthquake in Haiti, a US medical team sponsored by the nongovernmental organization "Partners in Health" (Boston, Massachusetts USA) was assigned to Hospital St. Nicholas in St. Marc, 80 miles outside the capital. In the first seven to eight days post-injury, the team performed critical soft tissue interventions and amputations. From day nine to day 14 after the quake, external fixations of fractures were undertaken. Surgical debridement and amputations were performed from day seven onward, as many patients had developed critical wound infections. Wound closures were performed from day 11 onward. Sepsis, compartment syndrome, and the presence of necrotic wounds were significant indicators of amputation.[51]

In extremity crush and compartment syndrome, the decision to perform a fasciotomy appears to be influenced, in part, by the actual and perceived risk of wound infection and the danger of necrosis and muscle damage if the fasciotomy is not performed. Following the 1999 Marmara earthquake in Turkey, trauma to the extremities, and particularly the lower limbs, was most common.[56] Crush syndrome resulted in high incidence of fasciotomy and amputation, but 24.8% of fasciotomies developed sepsis, while 13% of non-fasciotomized injuries also suffered sepsis. Moreover, late fasciotomies often have poor outcomes resulting in high infection and amputation rates.[57] Follow-up complications from infection in a crushed limb after fasciotomy are considered worse than muscle fibrosis and contracture.[51,58] Fasciotomy is contraindicated when compartment syndrome in closed lower limb injuries exists for more than eight to 10 hours. Instead, conservative treatment of late compartment syndrome is recommended to preserve skin and avoid infection. Any corrective surgery and late excision of necrotic muscle can occur at a later date.[58] However, experience with combat patients suggests that fasciotomy revisions and delayed compartment release is associated with a significant increase in mortality, a two-fold increase in amputation, and a three-fold mortality rate.[57] With respect to the management of a fasciotomy wound, Duman and colleagues advocate monitoring for infection, timely debridement, antibiotic treatment, and amputation if necessary,[59] while the consensus view advises against amputation of crushed limbs.[60]

Maggot debridement therapy can control some wound infections and associated necrosis successfully and could play an important part in the prevention of amputation when fasciotomy has been performed. MacDougall and Rodgers document the successful treatment of a non-healing fasciotomy wound with MDT in the community setting.[61] Maggot debridement therapy also has been highly successful in the treatment of postsurgical wound infection after scoliosis correction.[62] Consequently, infection concerns may not influence the decision to perform a fasciotomy if MDT was freely available to treat some wound complications. It follows that MDT could support both the decision to perform an emergency or a delayed fasciotomy. This is because infections can be treated successfully with MDT, as well as tissue necrosis in compartment syndrome, where fasciotomy has been performed too late or not at all. Indeed, compartment syndrome may no longer be considered a limb-threatening injury because the window for effective surgical treatment and limb salvage has become much larger with MDT.

The option to apply maggots directly or in bags also allows for a tailored application, depending on which wound closure strategy is used. Vacuum-assisted closure (VAC) has been used to assist in the closure of fasciotomy wounds.[63] However, it is unlikely that VAC will be available widely to responders of mass-casualty disasters unless they receive patients in well-equipped regional hospitals; even there, the high patient load may outstrip the availability of specialized equipment. Other standard treatment modalities are saline-soaked gauze packing and the application of dermatotraction,[64,65] and it appears that maggots are quite compatible with the latter treatment options. Indications for the use of bagged maggots suggest they may be used in open fasciotomy wounds either in combination with, or in place of, saline-soaked gauze. Debridement of necrotic tissue and control of infection in wounds obstructed by dermatotraction systems is probably best achieved with maggots that are applied directly into the wound (free-range) and are contained by a cage-like dressing. In this case, periodic removal of maggots would be simply a matter of irrigating the wound with saline. Furthermore, free-range MDT would allow the dermatotraction device to remain in place and maintain wound closure gains while necrosis and infection is treated. In addition, free-range maggots have been shown to be more effective in debriding necrotic tissue, particularly in wounds with uneven wound edges, undercuts, and a complex mix of necrotic and viable tissue.[66,67]

The limb-saving potential of MDT is not restricted to fasciotomy wound management. Severe injuries to limbs are often deemed unsalvageable under austere conditions, but case reports of successful interventions with MDT, including extreme degloving injuries[68,69] and chronic infections,[70] demonstrate that MDT can debride extensive necrosis and effectively control wound infections and save limbs. Consequently, MDT has the potential to reduce the amputation rate in victims of disasters.

Premature closure of wounds sustained in disasters is not desirable but happens too often.[8,31,71] For example, many of the Swedish citizens injured in the 2004 tsunami required further corrective treatment upon their return to Stockholm (Sweden). Primary closure performed in Thailand had to be reversed, and wounds had to be excised and left open for delayed closure.[31] Because MDT targets only dead necrotic tissue, it ideally is placed to precisely debride complex wounds with a mixture of viable and necrotic tissue in the case of unsuccessful premature closure.[72]

Moreover, the effects of natural disasters typically impact survivors many months after. Latent or complicating infections with progressing and migrating abscesses have occurred due to mycobacterial and fungal infection.[31] While large wounds pose the highest risk of infection, small scratches, punctures, pricks, and lacerations also allow bacterial and fungal pathogens to pass the skin barrier, and these can cause severe infection of underlying tissues. Such minor wounds can deteriorate within days and become life-threatening sources of sepsis.[8] Maggot debridement therapy has been used successfully in the treatment of such cases in a non-disaster context. For example, Chaffey documents the treatment of a small insect bite that deteriorated and led to a severe infection and tissue necrosis on the leg.[73] Maggot debridement therapy successfully debrided the wound and promoted granulation and healing.

Pressure wounds are a little-recognized, secondary injury source in sudden-onset disasters and may affect the geriatric population, the disabled, and the immobilized wounded. Impaired mobility is the primary cause for pressure ulcers.[50] Victims of disasters that suffer spinal cord injuries, or any other injury that restricts mobility, are also at high risk of developing pressure ulcers.[31] Moreover, because of the austere conditions prevailing in the aftermath of disasters, the immobilized victims may necessarily rest on hard and unsuitable surfaces which can contribute to the development of pressure ulcers.[51]

This potential source of injury is exacerbated by the likelihood of interruptions to power supplies and supply chains for health care provision. This was evident in the aftermath of the Great East Japan (Fukushima) Earthquake in 2011 when there was a surge of elderly people in home care and evacuation centers developing pressure ulcers. Alternating-pressure air mattresses failed without power, and other devices for pressure ulcer prevention could not be distributed in time.[52] Of course, the best treatment for pressure ulcers is prevention, but it appears unlikely that pressure ulcers can be avoided altogether when disaster strikes.

Maggot debridement therapy should be considered for the treatment of pressure ulcers in austere settings and in response to a surge in the incidence of pressure ulcers in the community. Sherman reports complete debridement in 80% of pressure wounds treated with MDT, while in the same study, only 48% debridement was achieved with traditional wound care methods. Sherman also notes the rapid growth of granulation tissue, which is a vital sign of healing and tissue regeneration.[74] Importantly, in a disaster situation, it is unlikely that pressure ulcers will receive focused attention from surgeons who would, in all probability, be concerned with more pressing interventions. Access to MDT would, thus, allow non-physician health care workers to take the lead in debridement of pressure ulcers and infection control.

Technological Disasters

As far as technological disasters, such as building collapses and mass transport accidents, are concerned, many of the injuries are likely to be similar to those sustained in natural disasters. However, there are injury categories unique to particular human activities. Some of the most catastrophic man-made disasters involve industrial explosions - particularly gas, oil, and petroleum explosions.[35,36,38] Likewise, the impact of the two atomic bombs detonated over Hiroshima and Nagasaki (Japan) suggests that a thermo-nuclear attack on any densely populated center would have catastrophic consequences with thousands of victims suffering from severe burns and complex trauma.

Burns are among the most challenging injuries encountered and demand significant health care resources if the patients' clinical needs are to be met and suffering is to be minimized.[75] Of immediate concern are fluid-loss or shock, as well as airway obstruction and immune-compromise, and coincidental trauma, while escharotomies may be necessary to prevent further tissue damage.[76] The risk of bacterial and fungal infection of burn wounds is also significant.[77,78] The disaster impact itself introduces dirt and debris into the wound and leaves large amounts of dead tissue. Extensive burns continue to be vulnerable to contamination during first aid, emergency fasciotomy or escharotomy,[79] and during burn care at the hospital.[80] Once the patient is stabilized, infection prevention is initiated and includes whole body cleaning, shaving, and microbiological monitoring. Surgical debridement under general anaesthesia is performed to prepare the wound for skin grafting.[78] After a pipeline explosion in Abule-Egba, Nigeria, badly burnt patients were treated at Lagos State University Teaching Hospital (Ikeja, Lagos, Nigeria). Wound care included escharectomies and escharotomies, scrubbing, closed wound dressings, monitoring of microbial load, tailored antibiotics, skin grafting, and contracture release.[40]

In mass burn disasters, analgesics, anaesthetics, and antibiotics may not be available, or may be in short supply, particularly in austere health care settings and resource-constrained, low-income countries. In such settings, patients may benefit from MDT as it has proven to be effective in the treatment of burns.[81-83] The ability of maggots to perform extensive debridement equal to surgical intervention has been demonstrated by Akhtar and colleagues who had success in debriding full thickness burns in patients that were not fit for anaesthesia and surgery.[84] Likewise, Namias and colleagues achieved remarkable recovery of fourth degree burns to both legs with MDT.[82] In China, MDT has been used to treat a patient with horrendous hot-crush injuries,[85] where Li and colleagues used *Musca domestica,* a species of fly not normally used in MDT, but achieved good results with complete debridement and wound closure.

The affected body surface area in disaster burn victims is often extensive, which makes the application of MDT dressings difficult. To overcome this problem, Felder and colleagues modified VAC technology to accommodate medicinal maggots.[86] According to these authors, this technology allows coverage of irregular and extensive wound areas and may be used for the removal of extensive burn eschar. Moreover, they suggest that such a combined VAC/MDT dressing may be applied to wounds without prior sharp debridement due to the unique wound-healing properties of medicinal maggots. This would facilitate the rapid treatment of mass casualties in burn disasters greatly. However, the use of VAC technology might be problematic in austere environments due to the need for reliable power supply to run vacuum pumps.

Conclusion

Natural and man-made technological disasters will remain an ongoing concern for the international emergency and disaster management community. Such events frequently lead to a surge of casualties that can overwhelm first responders and medical assistance teams. While waiting for treatment, patients can deteriorate rapidly and limbs may be amputated prematurely for fear of sepsis. Victims may also present late with neglected and infected wounds. The standard approach to such complex traumatic wounds and wound infection is surgical debridement, but this is time consuming and has to be performed by trained physicians. Furthermore, antibiotics may not be effective in controlling resistant infections. Consequently, wound care options are needed that are efficacious, can free up physicians to perform vital surgical interventions, and allow nurses to manage wound debridement and infection control – regardless of the clinical environment, location, or patient burden.

With this in mind, it is suggested that MDT could play a significant role in meeting this wound care need in disaster medical aid. Maggot debridement therapy is highly precise, provides infection control against a broad spectrum of microbes, stimulates healing, and prepares the wound bed for grafting or closure. In addition, MDT can be performed by nurses without the need of a physician.

However, there are social, medical, and logistic hurdles to be overcome before MDT can be added to the tool box of disaster medical aid teams. For instance, there remains an aversion among the medical profession to the use of maggots in wound care, and a belief that current approaches to wound care are appropriate.[20] Therefore, it is argued that the benefits of MDT in trauma care should be further explored. To this end, physicians and nurse practitioners are encouraged to publish case reports of successful maggot therapy in trauma care. In addition, research is needed to support the establishment of reliable supply chain networks for MDT and to understand (and, where possible, overcome) the logistic barriers that may prevent the successful use of MDT.

References

1. Zhang L, Zhang Y, Liu Z, et al. Emergency medical rescue efforts after a major earthquake: lessons from the 2008 Wenchuan earthquake. *Lancet*. 2012;379(9818): 853-861.
2. Republic of the Philippines. NDRRMC Update - SitRep No. 108 Effects of Typhoon "Yolanda" (Haiyan). http://reliefwebint/sites/reliefwebint/files/resources/NDRRMC%20Update%20-%20Sitrep%20No%20108%20re%20TY%20Yolanda%20-%2003%20April%202014pdf. Accessed February 18, 2014.
3. Jobe K. Disaster relief in post-earthquake Haiti: unintended consequences of humanitarian volunteerism. *Travel Med Infect Dis*. 2011;9(1):1-5.
4. Phalkey R, Reinhardt JD, Marx M. Injury epidemiology after the 2001 Gujarat earthquake in India: a retrospective analysis of injuries treated at a rural hospital in the Kutch district immediately after the disaster. *Glob Health Action*. 2011;4:7196-7199.
5. Chapin E, Daniels A, Elias R, et al. Impact of the 2007 Ica earthquake on health facilities and health service provision in southern Peru. *Prehosp Disaster Med*. 2009; 24(4):326-332.
6. Chu K, Stokes C, Trelles M, et al. Improving effective surgical delivery in humanitarian disasters: lessons from Haiti. *PLoS Med*. 2011;8(4):e1001025.
7. Missair A, Pretto EA, Visan A, et al. A matter of life or limb? A review of traumatic injury patterns and anesthesia techniques for disaster relief after major earthquakes. *Anesth Analg*. 2013;117(4):934-941.
8. Prasartritha T, Tungsiripat R, Warachit P. The revisit of 2004 tsunami in Thailand: characteristics of wounds. *Int Wound J*. 2008;5(1):8-19.
9. Doocy S, Jacquet G, Cherewick M, et al. The injury burden of the 2010 Haiti earthquake: a stratified cluster survey. *Injury*. 2013;44(6):842-847.
10. Baer WS. The classic: the treatment of chronic osteomyelitis with the maggot (larva of the blow fly). *Clin Orthop Relat Res*. 2011;469(4):920-944.
11. Sherman RA, Hall MJ, Thomas S. Medicinal maggots: an ancient remedy for some contemporary afflictions. *Annu Rev Entomol*. 2000;45:55-81.
12. Whitaker IS, Twine C, Whitaker MJ, et al. Larval therapy from antiquity to the present day: mechanisms of action, clinical applications, and future potential. *Postgrad Med J*. 2007;83(980):409-413.
13. Church JCT, Courtenay M. Maggot debridement therapy for chronic wounds. *Int J Low Extrem Wounds*. 2002;1(2):129-134.
14. Church JCT. The traditional use of maggots in wound healing, and the development of larva therapy (biosurgery) in modern medicine. *J Altern Complement Med*. 1996; 2(4):525-527.
15. Kruglikova AA, Chernysh SI. Surgical maggots and the history of their medical use. *Entomological Review*. 2013;93(6):667-674.
16. Pechter EA, Sherman RA. Maggot therapy: the surgical metamorphosis. *Plast Reconstr Surg*. 1983;72(4):567-570.
17. Wollina U, Karte K, Herold C, et al. Biosurgery in wound healing - the renaissance of maggot therapy. *J Eur Acad Dermatol Venereol*. 2000;14(4):285-289.
18. Čičková H, Čambal M, Kozánek M, et al. Growth and survival of bagged Lucilia sericata maggots in wounds of patients undergoing maggot debridement therapy. *Evid Based Complement Alternat Med*. 2013. DOI: 10.1155/2013/192149.
19. US Army. ST 31-91B US Army Special Forces Medical Handbook. Boulder, Colorado: Paladin Press; 1982; 22-1 to 22-4.
20. Heitkamp RA, Peck GW, Kirkup BC. Maggot debridement therapy in modern army medicine: perceptions and prevalence. *Mil Med*. 2012;177(11):1411-1416.
21. Peck GW, Kirkup BC. Biocompatibility of antimicrobials to maggot debridement therapy: medical maggots Lucilia sericata (Diptera: Calliphoridae) exhibit tolerance to clinical maximum doses of antimicrobials. *J Med Entomol*. 2012;49(5):1137-1143.
22. Peck G, Helgeson SM, Powell ED, et al. Airworthiness testing of medical maggots. *Mil Med*. 2015;180(5):591-596.
23. Glassberg E, Nadler R, Erlich T, et al. A decade of advances in military trauma care. *Scand J Surg*. 2014;103:126-131.

24. Clover AJP, Jemec B, Redmond AD. The extent of soft tissue and musculoskeletal injuries after earthquakes; describing a role for reconstructive surgeons in an emergency response. *World J Surg*. 2014;38:2543-2550.
25. Doocy S, Daniels A, Packer C, et al. The human impact of earthquakes: a historical review of events 1980-2009 and systematic literature review. *PLoS Currents*. 2013;5. DOI: 10.1371/currents.dis.67bd14fe457f1db0b5433a8ee20fb833
26. Doocy S, Daniels A, Dick A, et al. The human impact of tsunamis: a historical review of events 1900-2009 and systematic literature review. *PLoS Currents*. 2013;5. DOI: 10.1371/currents.dis.40f3c5cf61110a0fef2f9a25908cd795.
27. Ciottone GR, Elsevier. *Disaster Medicine*. Philadelphia, Pennsylvania USA: Elsevier/Mosby; 2006.
28. Tempark T, Lueangarun S, Chatproedprai S, et al. Flood-related skin diseases: a literature review. *Int J Dermatol*. 2013;52(10):1168-1176.
29. Doocy S, Dick A, Daniels A, et al. The human impact of tropical cyclones: a historical review of events 1980-2009 and systematic literature review. *PLoS Currents*. 2013;5. DOI: 10.1371/currents.dis.2664354a5571512063ed29d25ffbce74
30. Benedict K, Park BJ. Invasive fungal infections after natural disasters. *Emerg Infect Dis*. 2014;20(3):349-355.
31. Edsander-Nord Å. Wound complications from the tsunami disaster: a reminder of indications for delayed closure. *Eur J Trauma Emerg Surg*. 2008;34(5):457-464.
32. Garzoni C, Emonet S, Legout L, et al. Atypical infections in tsunami survivors. *Emerg Infect Dis*. 2005;11(10):1591-1593.
33. Turris SA, Lund A, Bowles RR. An analysis of mass-casualty incidents in the setting of mass gatherings and special events. *Disaster Med Public Health Prep*. 2014;8(2):143-149.
34. Wachira BW, Smith W. Major incidents in Kenya: the case for emergency services development and training. *Prehosp Disaster Med*. 2013;28(2):170-173.
35. Arturson G. The tragedy of San Juanico-the most severe LPG disaster in history. *Burns Incl Therm Inj*. 1987;13(2):87-102.
36. Dechy N, Bourdeaux T, Ayrault N, et al. First lessons of the Toulouse ammonium nitrate disaster, 21st September 2001, AZF plant, France. *J Hazard Mater*. 2004; 111(1-3):131-138.
37. Woltering HP, Schneider BM. Great damage event of the Dutch Enschede on May 13th, 2000. *Unfallchirurg*. 2002;105(11):961-967.
38. Kumar P. Fire disaster following LPG tanker explosion at Chala in Kannur (Kerala, India): August 27, 2012. *Burns*. 2013;39(7):1479-1487.
39. Carlson LC, Rogers TT, Kamara TB, et al. Petroleum pipeline explosions in sub-Saharan Africa: a comprehensive systematic review of the academic and lay literature. *Burns*. 2015;41(3):497-501.
40. Fadeyibi IO, Omosebi DT, Jewo PI, et al. Mass burns disaster in Abule-egba, Lagos, Nigeria from a petroleum pipeline explosion fire. *Ann Burns Fire Disasters*. 2009;22 (2):97-103.
41. Goffman TE. Nuclear terrorism and the problem of burns. *Am J Emerg Med*. 2011; 29(2):224-228.
42. Knebel AR, Coleman CN, Cliffer KD, et al. Allocation of scarce resources after a nuclear detonation: setting the context. *Disaster Med Public Health Prep*. 2011;5(Suppl 1):S20-S31.
43. Hammond E, Shaban RZ, Holzhauser K, et al. *An Exploratory Study to Examine the Phenomenon and Practice of Ambulance Ramping at Hospitals within the Queensland Health Southern Districts and the Queensland Ambulance Service*. Queensland, Australia: Griffith University & Queensland Government – Report; 2011.
44. Matsunari Y, Yoshimoto N. Comparison of rescue and relief activities within 72 hours of the atomic bombings in Hiroshima and Nagasaki. *Prehosp Disaster Med*. 2013; 28(6):536-542.
45. Kartchner K, Larsen J. *Stanford Security Studies: On Limited Nuclear War in the 21st Century*. Redwood City, California USA: Stanford University Press; 2014.
46. Radchuk A. The great nuclear game of the 21st century: disarmament or war? *Security Index: A Russian Journal on International Security*. 2010;16(4):19-43.
47. Ross JR, Case C, Confer D, et al. Radiation injury treatment network (RITN): health care professionals preparing for a mass casualty radiological or nuclear incident. *Int J Radiat Biol*. 2011;87(8):748-753.
48. Williams G, O'Malley M. Surgical considerations in the management of combined radiation blast injury casualties caused by a radiological dirty bomb. *Injury*. 2010; 41(9):943-947.
49. Wolbarst AB, Wiley AL Jr., Nemhauser JB, et al. Medical response to a major radiologic emergency: a primer for medical and public health practitioners. *Radiology*. 2010;254(3):660-677.
50. Health Quality. Management of chronic pressure ulcers: an evidence-based analysis. *Ont Health Technol Assess Ser*. 2009;9(3):1-203.
51. Smith RM, Dyer GSM, Antonangeli K, et al. Disaster triage after the Haitian earthquake. *Injury*. 2012;43(11):1811-1815.
52. Sato T, Ichioka S. Pressure ulcer occurrence following the Great East Japan Earthquake: observations from a disaster medical assistance team. *Ostomy Wound Manage*. 2012;58(4):70-75.
53. Terterov S, Taghva A, MacDougall M, et al. Posttraumatic human cerebral myiasis. *World Neurosurg*. 2010;73(5):557-559.
54. Lindsay R, Stancil J, Ray JM. Myiasis of facial wounds by Cochliomyia hominivorax sustained in a natural disaster in Haiti. *Otolaryngol Head Neck Surg*. 2010;143(4):595-596.
55. Roudiere L, Jean-Pierre H, Comte C, et al. Isolation of Schineria sp. from a man. *Emerg Infect Dis*. 2007;13(4):659-661.
56. Sever MS, Erek E, Vanholder R, et al. Clinical findings in the renal victims of a catastrophic disaster: the Marmara earthquake. *Nephrol Dial Transplant*. 2002; 17(11):1942-1949.
57. Ritenour AE, Dorlac WC, Fang R, et al. Complications after fasciotomy revision and delayed compartment release in combat patients. *J Trauma*. 2008;64(2):S153-S162.
58. Finkelstein JA, Hunter GA, Hu RW. Lower limb compartment syndrome: course after delayed fasciotomy. *J Trauma*. 1996;40(3):342-344.
59. Duman H, Kulahci Y, Sengezer M. Fasciotomy in crush injury resulting from prolonged pressure in an earthquake in Turkey. *Emerg Med J*. 2003;20(3):251-252.
60. Greaves I, Porter KM. Consensus statement on crush injury and crush syndrome. *Accid Emerg Nurs*. 2004;12(1):47-52.
61. MacDougall KM, Rodgers FR. A case study using larval therapy in the community setting. *Br J Nurs*. 2004;13(5):255-260.
62. Hwang JH, Modi HN, Suh SW, et al. Maggot debridement therapy for postsurgical wound infection in scoliosis: a case series in five patients. *Spine (Phila Pa 1976)*. 2011;36(4):313-319.
63. Saziye K, Mustafa C, Ilker U, et al. Comparison of vacuum-assisted closure device and conservative treatment for fasciotomy wound healing in ischaemia-reperfusion syndrome: preliminary results. *Int Wound J*. 2011;8(3):229-236.
64. Eid A, Elsoufy M. Shoelace wound closure for the management of fracture-related fasciotomy wounds. *ISRN Orthop*. 2012;6. DOI: 10.5402/2012/528382
65. Matt SE, Johnson LS, Shupp JW, et al. Management of fasciotomy wounds - does the dressing matter? *Am Surg*. 2011;77(12):1656-1660.
66. Steenvoorde P, Jacobi CE, Oskam J. Maggot debridement therapy: free-range or contained? An in-vivo study. *Adv Skin Wound Care*. 2005;18(8):430-435.
67. Thomas S, Wynn K, Fowler T, et al. The effect of containment on the properties of sterile maggots. *Br J Nurs*. 2002;11(12):S21-S28.
68. Chan QE, Hussain MA, Milovic V. Eating out of the hand, maggots - friend or foe? *J Plast Reconstr Aesthet Surg*. 2012;65(8):1116-1118.
69. Husain ZS, Fallat LM. Maggot therapy for wound debridement in a traumatic foot-degloving injury: a case report. *J Foot Ankle Surg*. 2003;42(6):371-376.
70. Mumcuoglu KY, Ingber A, Gilead L, et al. Maggot therapy for the treatment of intractable wounds. *Int J Dermatol*. 1999;38(8):623-627.
71. Doung-ngern P, Vatanaprasan T, Chungpaibulpatana J, et al. Infections and treatment of wounds in survivors of the 2004 tsunami in Thailand. *Int Wound J*. 2009;6(5):347-354.
72. Fenn-Smith P. Case study: maggot debridement therapy. *Wound Practice & Research*. 2008;16(4):169-170.
73. Chaffey R. Case study: larval therapy for an infected insect bite. *World Wide Wounds*. 1997; http://www.worldwidewounds.com/1997/october/LarvalTherapy/LarvalCaseStudy.html. Accessed February 18, 2014.
74. Sherman RA. Maggot versus conservative debridement therapy for the treatment of pressure ulcers. *Wound Repair Regen*. 2002;10(4):208-214.
75. Atiyeh B, Gunn SW, Dibo S. Primary triage of mass burn casualties with associated severe traumatic injuries. *Ann Burns Fire Disasters*. 2013;26(1):48-52.
76. Jeng J, Gibran N, Peck M. Burn care in disaster and other austere settings. *Surg Clin North Am*. 2014;94(4):893-907.
77. Branski LK, Al-Mousawi A, Rivero H, et al. Emerging infections in burns. *Surg Infect (Larchmt)*. 2009;10(5):389-397.
78. Struck MF, Gille J. Fungal infections in burns: a comprehensive review. *Ann Burns Fire Disasters*. 2013;26(3):147-153.
79. Kennedy P, Brammah S, Wills E. Burns, biofilm, and a new appraisal of burn wound sepsis. *Burns*. 2010;36(1):49-56.
80. Hassen AF, Khalifa SB, Raddaoui K, et al. Risk factors for nosocomial infection in pediatric burn patients. *Ann Fr Anesth Reanim*. 2012;31(7-8):591-595.
81. Edwards J. Larval therapy in full thickness burns. *Journal of Community Nursing*. 2006;20(10):33-38.
82. Namias N, Varela JE, Varas RP, et al. Biodebridement: a case report of maggot therapy for limb salvage after fourth-degree burns. *J Burn Care Rehabil*. 2000;21(3):254-257.
83. Thornton D, Berry M, Ralston D. Case report: maggot therapy in an acute burn. *World Wide Wounds*. 2002; http://www.worldwidewounds.com/2002/august/Thornton/LarvalTherapyAcuteBurn.html. Accessed February 18, 2014.
84. Akhtar N, Abdel-Rehim S, Rodrigues J, et al. The use of larvae therapy to debride full thickness burns in the anaesthetically unfit patient: the Nottingham experience. *Burns*. 2011;37(6):e44-e49.
85. Li Q, Lu R, Huo R, et al. Maggots of musca domestica in treatment of acute intractable wound. *Surgery*. 2009;145(1):122-123.
86. Felder JM 3rd, Hechenbleikner E, Jordan M, et al. Increasing the options for management of large and complex chronic wounds with a scalable, closed-system dressing for maggot therapy. *J Burn Care Res*. 2012;33(3):e169-e175.