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Trauma-related infections due to cluster munitions

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Abstract Trauma-related infections remain a concerning and potentially avoidable complication of conflict-related injuries. During the Israeli conflict in South Lebanon, more than four million sub-munitions were dropped over South Lebanese soil. In this study, we will explore the different types of infection caused by sub-munitions and penetrating agents. This prospective study took place from 2006 to 2012 at the Lebanese University within the Faculty of Medical Sciences' departments. This study sample consisted of 350 injured casualties. Patients suffered from blast injuries with fragmentations targeting the head, face, torso, abdomen, pelvis and extremities. Of the 350 causalities studied, 326 (93.1%) were males, and 24 (6.9%) were females. Ages varied between 10 and 70 years, with the average age being 27 years. Of the 350 patients studied, 68 (19.4%) developed infections. Infections varied between pseudomonas, *Escherichia coli*, Candida and fungus and sometimes led to necrosis. Vaccinations, antibiotic therapies and proper wound irrigation must be performed at appropriate emergency units. Excision and complete debridement of necrotic and contaminated tissue should also be performed. The Convention on Cluster Munitions of 2008 should be adhered to, as these weapons indiscriminately and disproportionately harm civilians, thereby violating the well-established international principles governing conflict.

Introduction

Infections have beleaguered mankind throughout the ages; they continue to remain a concerning and potentially avoidable complication of conflict-related injuries. The medical care provided for

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injuries caused by cluster munitions and other unexploded ordnances of war have allowed injured personnel to survive injuries that were previously considered to be deadly. However, these survivors are at a high risk of developing infections.

Currently, infections due to cluster munition injuries remain a troubling issue. During the Israeli conflict, more than four million sub-munitions were dropped over South Lebanese soil; one million of those sub-munitions remain unexploded duds that are capable of injuring and killing civilians living in that area [1]. Cluster munitions have caused serious damage in urban and rural areas and have wounded and killed numerous civilians.

When cluster munitions are used in combat, the associated fragments can become lodged in the body and can result in subsequent tissue damage [2—7]. These fragments can be coupled with deposition materials that cause infectious complications [8—10]. In this study, we will explore how sub-munitions cause infection as well as the various infections resulting from penetrating fragments that are associated with sub-munition explosions.

Materials and methods

This prospective study took place from 2006 to 2012 at the Faculty of Medical Sciences of the Lebanese University. We analyzed the different types of lesions and the clinical complications and infections that can result from sub-munition explosions found in 350 injured victims who visited emergency units. We then classified the patients based on their respective injuries, which included blast injuries with fragmentation or shrapnel penetrating the head, face, torso, abdomen, pelvis and/or extremities. The patients underwent radiological examinations to exclude bone fracture and to locate metal shrapnel. All of the patients were given anti-tetanus vaccinations, tetanus immunoglobulin intramuscular injections and prophylactic antibiotics. The intravenous antibiotic therapy consisted of Ceftriaxone (1 g) administered every 12 h or Amoxicillin/Clavulanate (1.2 g) administered every 12 h. Oral antibiotics included Clindamycin (300 mg) or Ciprofloxacin (500 mg), were given every 8 h and 12 h, respectively. The drug Fluconazole (150 mg) was given weekly as an antifungal prophylactic therapy.

All of the patients underwent surgical debridement of the infected tissue, and tissue biopsy specimens or swabs from the wound bed were subsequently cultured for bacteria and fungi. Blood cultures were collected aseptically after the first febrile episode in the hospital. Standard culture techniques were used, and identification of the isolated organisms was performed utilizing the API strip system (bioMérieux, l'Etoile- France). Using standard Clinical Laboratory Standards Institute (CLSI) criteria, susceptibility testing was performed via the Kirby Bauer disk diffusion method. The criteria used for wound infection included a positive culture from wound or blood with at least two of the following: fever above 38.5 °C, wound dehiscence or foul smell, peri-wound erythema and leukocytosis (>10,000 cells/μL).

Table 1 Number of organism isolated in positive wound culture per patient.

	No. (%)
Total patients	68 (19.4)
Wound culture 1 organism isolated	35 (51.4)
Wound culture 2 organisms isolated	21 (30.4)
Wound culture 3 organisms isolated	10 (14.7)

Results

A total of 350 casualties were studied: 326 (93.1%) males and 24 (6.9%) females. Ages varied between 10 and 70 years, with the average age being 27 years. All patients were hospitalized in regular wards for three to 14 hospital days.

Of the 350 patients studied, 68 (19.4%) developed infections. Of these patients, 41 (60%) were treated in rural hospitals, and 27 (40%) were treated in urban hospitals. The infection rate was higher in rural hospitals than in urban hospitals. The numbers of isolated organisms per infected wound are shown in Table 1. A total of 59 (86.8%) patients developed bacterial infections due to penetrating agents, explosive materials and other environmental factors. The other nine (13.2%) patients developed Candida and mold infections. The locations of the infected wounds are shown in Table 2.

Of the 59 patients who had bacterial infections, 18 (30.5%) were affected by *Pseudomonas*

Table 2 Infected wound location.

	No. (%)
Total 68/350	68 (19.4)
Soft tissue	6 (8.8)
Chest	2 (2.9)
Abdominal	8 (11.7)
Upper extremity	15(22)
Lower extremity	20 (29.4)
≥3 injuries location	17(25)

Table 3 Antimicrobial susceptibility pattern of isolated organism % susceptible.

Bacterial isolates *N* = 59 isolates								
Species of	*Psudomonas*	*Acinetobacter*	*E. coli*	*Klebsiella*	*Proteus*	*Enterobacter*	*Coag. Neg. Staph.*	*Enterococcus*
Number of isolates	(18)	(6)	(16)	(4)	(3)	(2)	(6)	(4)
Antimicrobial	Number susceptible/%							
Amikacin	17/94	3/50	16/100	4/100	3/100	2/100	—	—
Gentamicin	15/83	3/50	15/95	4/100	3/100	2/100	3/50	—
Amoxacillin/Clav.	0/0	1/16	10/63	4/100	3/100	0/0	1/17	3/75
Cephalothin	—	—	14/88	4/100	2/67	2/100	—	—
Cefoxitin	—	—	14/88	4/100	3/100	2/100	—	—
Ceftazidime	17/94	4/66	14/88	4/100	3/100	2/100	—	—
Ceftriaxone	—	4/66	14/88	4/100	3/100	2/100	—	—
Cefipime	18/100	5/83	14/100	4/100	3/100	2/100	—	—
Imipenem	18/100	6/100	16/100	4/100	3/100	2/100	—	—
Ciprofloxacin	16/89	1/16	12/75	3/75	3/100	2/100	1/17	—
Oxacillin	—	—	—	—	—	—	2/33	—
Clindamycin	—	—	—	—	—	—	6/100	—
Ampicillin								3/75
Vancomycin							6/100	4/100

aueroginosa, 31(52.5%) had other Gram-negative infections, and 10 (17%) had Gram-positive bacterial infections caused mainly by coagulase negative staphylococci (CNS) and Enterococci species (spp.). In addition to *Pseudomonas*, the Gram-negative isolates included: six *Acinetobacter* spp., 16 *Escherichia coli* (*E. coli*), four *Klebsiella* spp., three *Proteus* and two *Enterobacter* spp. Ten (17%) patients had mixed infections with two or more organisms. Three patients developed bacteremia: two with *E. coli* and one with *Enterobacter* spp. The antimicrobial susceptibility patterns of the clinical isolates are shown in Table 3. Among the isolated organisms identified as *E. coli*, two produced extended-spectrum beta-lactamase (ESBL). No *Staphylococcus aureus* was isolated.

Of the 350 patients involved in this study, 36 had late recoveries. The types of lesions, explosive materials and blood vessel damage and alterations could be contributing factors to the patients' late recoveries.

Discussion

Penetrating injuries caused by energized fragments from the casings of detonating sub-munitions and other unexploded ordnances generally cause infections [11,12]. Soft tissue and skin wounds are usually heavily contaminated with dirt, clothing and secondary environmental materials. These contaminants are pushed deeply into tissue planes that are opened by the explosion force. The potential for developing infections is both significant and largely underestimated [13].

In our studies, the male predominance could be explained by the societal norms of males performing farming, grazing and other rural activities where sub-munitions could be scattered. Furthermore, the evacuation of females from the area during the war decreased the female casualties.

Debris and fragments that result from the explosion of sub-munitions are not sterilized, and contamination may occur with the passing of the debris through dirty clothing and skin. Consequently, bacteria can be transmitted into wounds. *Streptococcus*, *Staphylococcus* and Enterobacteraciae are common in the dirt, skin or contaminated clothing that is inoculated into the wound at the time of injury [13].

None of our patients developed tetanus disease. This outcome could be due to the efficacy of the vaccinations that were administered to patients upon their admission to hospital emergency units.

Explosive materials that were present in the sub-munitions played a role in the development of various infections in the victims. The predominant organisms observed in these types of infections were *Pseudomonas* and *E. coli*, among other bacterial infections. In addition, these explosive substances were crucial in reducing the immunity of the victimized individuals and increasing their risk for developing fungal infections. We observed that multiple injuries, extensive soft tissue injuries, abdominal injuries and severe extremity trauma were all common causes of infection. The development of better surgical and antibiotic treatments for trauma-related infections has led to gradual reductions in mortality and bacterial infections over time.

Of the 350 patients studied, we observed that 18 had *Pseudomonas* infections; this significant number of infections was due to the victims' weak immune response post-trauma. *Pseudomonas* caused cell death in the infected area and sometimes led to necrosis. Necrotic tissues required excision of the infected areas and, in many cases, excision of the infected limb or organ. We noticed that muscular necrosis, mainly due to *Pseudomonas*, was commonly observed among lower-extremity damage associated with vascular injuries.

We observed that more than two-thirds of the bacterial infections in patients were due to Gram-negative bacteria, with *Pseudomonas* and *E. coli* infections being the most predominant. Again, this occurrence was a result of the victims' weakened immune systems resulting from the sub-munition explosions.

Nine of our patients developed *Candida* and other fungal infections. The heavy metals and explosive materials that were contained in the sub-munitions and released upon explosion led to several lesions and fungal inoculations. Dirty clothes that trap heat and moisture during explosions promote the development of such infections. Contaminated pieces of clothes, dirt particles and other environmental factors coupled with fungi and/or yeast penetrate the wound and cause infections. In our study, we observed that patients wearing non-cotton clothes were more affected. We believe that non-cotton clothes made of fabrics such as synthetics, nylon, spandex and LYCRA create too much warmth and moisture due to sweating [14]. Hence, warm and moist conditions, together with dirt, form the ideal habitat for fungus and yeast to grow and proliferate.

Regarding infection, we noted that metals and penetrating pieces of clothes were more damaging than soil particles. Soil was observed to play a role in reducing the bleeding and hemorrhaging in wounded patients prior to entering hospitals. We believe that soil particles played a role in inducing transient vasoconstriction, which resulted in decreases in hemorrhaging and excessive bleeding. Following wounding, transient vasoconstriction is mediated by catecholamines, thromboxane and prostaglandin $F_{2\alpha}$. Platelets degranulate and release the contents of their alpha and dense granules, most notably platelet-derived growth factor-β. These substances initiate chemotaxis and proliferation of inflammatory cells. Lasting between five and 10 min, transient vasoconstriction decreases blood loss at the time of the wounding, allowing clots to form [15—17].

To decrease excess morbidity and mortality, battlefield trauma management emphasizes the early delivery of medical care, which includes hemorrhage control, hypotensive and hemostatic resuscitation and administration of antimicrobial therapy [18—21]. We observed that the quality and types of treatments administered in hospitals had roles in decreasing infection rates, which can explain the higher infection rates in rural hospitals. Bacterial isolate antimicrobial sensitivity was normal, except for two ESBL *E. coli* isolates.

We recommend that vaccinations and antibiotic therapies be directly administered at emergency units. We also recommend the irrigation of wounds with hydrogen peroxide and antiseptics to avoid further complications and to decrease bleeding. Debridement and deep excision of the contaminated, distorted and burnt tissues should be performed until an area of proper vascularization is reached so as to prevent the development of necrosis at later stages and to reduce infection.

In conclusion, cluster munitions pose serious detrimental humanitarian and societal hazards. Due to their high dud rate, cluster munitions fail to target combatants with sufficient temporal accuracy and subsequently result in serious harm to non-combatants. The non-combatant immunity and the principle of discrimination demand a moratorium on the use of current cluster munitions [22]. Currently, the Convention on Cluster Munitions (CCM) has been endorsed by 77 countries and signed by another 34. Countries ratifying the convention are advised not to be involved in actions that encourage cluster munitions use. The ban is based upon the well-accepted discrimination principle that holds that parties in conflict should distinguish between the civilian population and combatants and between civilian and military objectives and should accordingly direct their operations against military objectives only [23]. International humanitarian laws must prohibit the production and use of such inhumane weapons and should take into account the significant burden these munitions place on civilians, as this study demonstrates. It is our opinion that the rest of world should follow those 111 countries that have already signed the convention on cluster munitions.

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Competing interests

None declared.

Ethical approval

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