PYROTECHNIC SIGNAL FLARE ['MINIFLARE'] INJURIES

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Introduction

Miniflares are compact signalling devices used in both combat and recreational maritime environments. They consist of an aerial flare cartridge that is primed by screwing it onto a handheld spring-loaded pen ejector. In ideal conditions a deployed miniflare attains a height of at least 60m and is visible for about six seconds. The pyrotechnic composition burns at greater than 2200°C and has a luminous intensity of 3000 candelas or more. During Operation HERRICK 9, a series of seven International Security Assistance Force (ISAF) and Afghan National Army (ANA) personnel were injured following the accidental deployment of miniflares. This case series illustrates the range and potential severity of the injuries that they can cause and discusses their composition.

Case Series

During one week four ISAF / ANA personnel presented to the Emergency Department of the Role Two (Enhanced) [R2E] facility at Camp Bastion following injuries caused by miniflares. The miniflares had all been primed prior to patrolling and had been stored on body armour. All were ignited inadvertently. Injuries sustained were: a highly contaminated penetrating injury of a limb, a relatively uncomplicated finger pulp laceration, a deep contact burn of the lower lip, and a full-thickness contact burn of the columella and ala nasi. Following these incidents, local Standard Operating Procedures were revised so that miniflares were neither primed nor carried on body armour. Despite this, a further three personnel subsequently presented with similar injuries. Three selected cases are used to illustrate the range of injuries that miniflares can cause.

Case One

A marine sustained a penetrating injury of his medial left thigh when a primed miniflare on his combat body armour was accidentally fired. The miniflare embedded in his medial thigh and continued to burn while he tried to brush it away with his left hand. In the Emergency Department, a 10mm diameter wound was identified, surrounded by carbon deposits and mixed depth dermal burns (Figure 1a). Superficial dermal burns of his left middle and ring fingers were also identified. Radiographs showed a cavity within his medial thigh and multiple radiopaque deposits in the wound [Figure 1b]. Advice from the ammunition technical officer (ATO) was that these munitions contained white phosphorus, and therefore the wound was irrigated and a moist dressing applied. Exploration under general anaesthetic was performed with copious irrigation with normal saline and S10 respirators to hand. The skin wound was excised and extended. The cavity was located superficial to the deep fascia and was coated with metallic particles. Significant damage to vastus medialis was found (Figure 2a). Fragments of the flare were removed and the cavity was formally excised and irrigated. Removal of all radiopaque particles was confirmed radiologically (Figure 2b). The marine was evacuated to the UK where delayed primary closure was performed at five days. Subsequent rehabilitation was unremarkable and he has since returned to full duties.

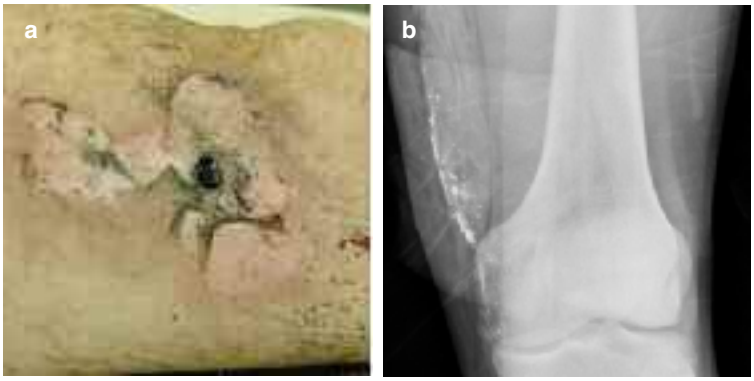

Figure 1. Miniflare injury of the left medial thigh. *(A) The small penetrating injury surrounded by mixed depth burn appears relatively innocuous. (B) The presence of a subcutaneous cavity and multiple radiopaque fragments can be seen in the Emergency Department radiograph.*

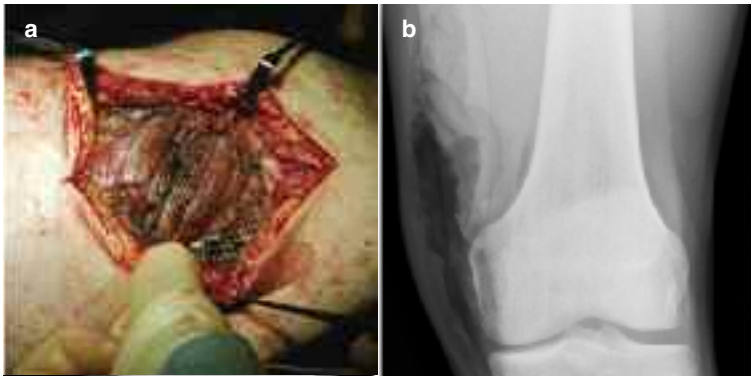

Figure 2. *(A) Under general anaesthetic, a large cavity was identified with extensive contamination by multiple metallic fragments and elements of the pyrotechnic composition. The wound was extended, the cavity was excised and the resultant defect was irrigated. (B) All contamination has been removed after wound excision and large volume irrigation*

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Case Two

An Afghan soldier sustained an isolated injury of his face when a primed miniflare in his body armour was triggered during a firefight. The flare ricocheted off his lower lip. He presented more than 24 hours later with a deep eschar of his right lower lip surrounded by carbon deposits (Figure 3). There was a fracture of the right mandibular first bicuspid tooth associated with an adjacent mucosal contusion. Exploration under a mental nerve block showed no intraoral communication or retained fragments. The eschar was excised, revealing burns deep to orbicularis oris, and the dental surgeon removed the damaged tooth. The wound was left open and the patient was prescribed oral antibiotics. He elected to let the wound heal by secondary intention.

Figure 3. Miniflare injury of the lower lip. *Although the contact time was extremely short for this particular injury a deep burn requiring debridement was identified.*

Figure 4. Miniflare injury of the hand. *There is extensive soft tissue trauma and multiple radiopaque fragments in the second webspace, including the percussion cap of the miniflare (circular opacity).*

Case Three

A US marine sustained a complex injury of his right palm while holding a primed miniflare that was accidentally ignited. He presented in severe pain with gross swelling of the dorsum of his hand and absent sensation to the ulnar aspect of the thumb, the entire volar index finger and the radial aspect of the middle finger. There were no other associated injuries. A 10mm diameter wound was identified associated with full thickness burns and a visible foreign body. Radiographs identified radiopaque fragments in the palm, extending distally into the flexor sheath of the index finger and proximally towards the carpal tunnel (Figure 4). Exploration under general anaesthetic identified extensive tissue necrosis, a large metal fragment and generalised wound contamination with a metallic substance. The common digital nerve to the second web space had been obliterated along with the palmar digital nerve to the radial border of the index finger. The wound was extensively debrided and large volume irrigation used to remove all contamination. The marine was evacuated to the USA for further care.

Discussion

Miniflares do not contain phosphorus. The pyrotechnic composition is a magnesium-strontium nitrate mixture, a combination often used in ammunition tracer rounds and in signalling flares.[1] The pyrotechnic composition of a red miniflare is specifically formulated to generate strontium monochloride which emits light at a wavelength of 620-680nm. This pure red light provides good contrast against blue sky and green foliage. Organic binders such as alloprene, a chlorinated latex rubber, influence the performance characteristics including burn rate, light output and ignition temperature. The pyrotechnic composition is not usually hazardous to human health although systemic absorption of perchlorates, added as an oxidiser and chlorine donor, can theoretically interfere with iodine uptake by the thyroid gland.[2]

The luminous intensity is a measure of the visible light perceived by human eyes. The SI unit is the candela [cd], which is very roughly the light emitted by a single candle. The burning rate and light intensity of the flare are adjusted by varying the particle size of the magnesium powder.[3] Magnesium burns at a temperature in excess of 2200°C and has an autoignition temperature in air of 473°C. Magnesium-containing pyrotechnics have a maximum-attainable adiabatic flame temperature in excess of 3000°C.[4] Once ignited, magnesium is extremely difficult to extinguish and can ignite just as readily in a nitrogen or carbon dioxide atmosphere. Miniflares will generally burn to completion unless smothered under sand or suppressed with a Class D (combustible metal) fire extinguisher. In contrast to burning phosphorus, water should not be used to extinguish burning magnesium because it is immediately hydrolysed and produces highly explosive hydrogen gas.

As case two illustrates, even brief contact with an ignited miniflare will cause a profound burn. At temperatures in the region of 2200°C a contact time measured in hundredths of a millisecond generates sufficient heat flux to burn the full thickness of the skin.[5] The initial velocity of a miniflare is approximately $40ms^{-1}$ although this rapidly decreases due to drag forces. Penetration of the skin may occur despite this low velocity because of the high temperature of the burning flare.[6] These cases, and one previously-reported civilian case,[7] show that penetration will commonly lead to the formation of a large cavity and the passage of material along tissue planes. It is hypothesised that this is due to the rapid expansion of gases released during the highly energetic deflagration of the pyrotechnic composition. This is in contrast to the temporary displacement of tissues ('cavitation') seen in a high-energy

gunshot wound. Burned and unburned elements of the pyrotechnic composition, including various organic chlorine compounds and perchlorates, as well as parts of the flare casing, clothing or other environmental contaminants can be embedded in the wound. Clinicians treating miniflare injuries must have a high index of suspicion and the wounds should be treated as highly contaminated thermal injuries. All devitalised tissue must be excised followed by copious irrigation and radiological confirmation that all particulate matter has been removed.

Miniflare injuries are preventable and education is a vital part of the management of these injuries. The pen ejector should not be primed unless it is about to be used, as inadvertent ignition can be devastating in an austere combat environment. It is also recommended that they are not worn on exposed parts of the webbing or combat body armour where they can potentially be activated. Awareness of the pyrotechnic compositions of standard issue ordnance ensures timely and appropriate intervention. This recommendation should also extend to the ATOs in theatre, upon whose advice the R2E facility was in one case erroneously primed for chemical protection from a high-risk phosphorus injury.

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