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Experimental Comparison of Efficiency of First Aid Dressings in Burning White Phosphorus on Bacon Model

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Study Design A
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Statistical Analysis C
Data Interpretation D
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Background: The aim of this study was to determine effectiveness of first aid dressings in extinguishing burning white phosphorous (WP), eliminating WP pieces from the surface, inhibiting re-ignition on the model (fresh bacon covered with military uniform), and preventing from late re-ignition caused by persistent WP pieces.

Material/Methods: Burning WP was extinguished with several dressings: tactical Military Dressing (WJ10), wet gauze, 2 hydrocolloids, and 3 prototypes of hydrocolloids developed by the authors.

Results: All examined dressings were effective in extinguishing WP provided that the entire area of the burning substance was completely covered. Moist gauze was especially effective in extinguishing WP, and also removed and absorbed the majority of the WP mass, preventing deeper penetration of WP particles. The immediate re-ignition was observed when all the remaining examined dressings were removed from the bacon. A stream of water was dangerous, as it splashed and transferred pieces of WP around.

Conclusions: Moist gauze placed on burning WP for approximately 3 min was most effective in extinguishing WP and removing most of the WP pieces. We recommend moist gauze, used once or twice, as the best primary means for WP elimination and preventing tissue penetration. As a dressing used for medical evacuation (MEDEVAC), or as a second step after complete removal of visible WP, innovative hydrocolloid or hydrogel dressings should be used.

MeSH Keywords: **Bandages, Hydrocolloid • Burns, Chemical • Chemical Warfare Agents**

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Background

The aim of the study was to determine the effectiveness of various first aid dressing in extinguishing flame, eliminating phosphorus pieces from the surface, and preventing re-ignition, as well usefulness in military applications.

White phosphorus (WP) is a chemical warfare agent that, although prohibited by the Geneva Conventions, is still in use as a smoke-screen, in signaling, for illumination, and as a highly destructive weapon. In military jargon it is known as “Willy Pete” or “shake and bake” as phosphorus missiles flash, produce smoke and crumble into highly destructive pieces, the trajectory of which is unpredictable. Contact with white phosphorus leads to deep skin and inhalation burns, whereas exposure is toxic to other organs. Recent military usage of phosphorus bombs was reported in Libya, Israel, Iraq, Afghanistan and Syria. Thousands of civilians suffered from phosphorus burns.

On the military field it is used as an incendiary factor when mixed with napalm or other flammable agents, for production of ammunition, as a smoke-screen, in signaling, or for illumination. In industry it is used in production of fertilizers, matches, fireworks, and poisons. White phosphorus is highly destructive and toxic. The lethal dose is estimated to be 50–100 grams [1].

WP is a solid substance similar to a piece of chalk. It is characterized by a garlic-like smell. WP should be stored under water. Its melting temperature is approximately 44°C. It reacts with oxygen in the air and water and burns out within minutes, but when covered with a protective layer, it can last for several years in water and soil. When dried, it ignites spontaneously [1–9]. WP ignites spontaneously if the temperature exceeds 34°C.

WP is dangerous when inhaled, ingested, or absorbed through burned skin. White phosphorus injuries are due to its thermal and chemical features [1–10]. WP burns are unpredictable, and are mainly second- and third-degree. The mechanism of action of WP is corrosion, as it denatures tissues [8]. The eschar is yellowish, extremely painful, and smells like garlic. WP is fat-soluble, and even low doses penetrate deep into tissues, bloodstream, and organs [8,10,11]. The metabolism of phosphorus in humans is still unknown. In high concentration, it leads to multi-organ dysfunction, most severely affecting the liver, kidneys, and heart. There are no biomarkers for WP intoxication.

Material and Methods

Seven first aid dressings were studied: hydrogel tactical Burn Dressing Military (WJ10), Water Jel Technologies, USA; simple moistened gauze dressing, Matocomp, TZMO, Poland; 2

Hydrocolloids (Aqua-Gel and BurnTec), Kikgel, Poland; and 3 prototypes: hydrocolloid containing glycerin, hydrocolloid containing 2% NaHCO₃, and semi-liquid hydrocolloid containing 1,2% PVP, 0,3% polyethylene glycol, 0,2% agar, 4% NaHCO₃, Kikgel, Poland.

As a consequence of the low ignition temperature of WP, the study was carried out in a air-conditioned laboratory at 22°C. WP was stored and cut into 400-mg pieces and subsequently weighed under water. All experiments were performed in a well-ventilated area (under the fume hood) with all necessary personal protective gear. WP placed on the substrate was burned in porcelain dishes placed on bricks. White phosphorus burns with bright light, immediately turning into liquid. When completely burned, it becomes phosphorus pentoxide P₂O₅, which is extremely hygroscopic and easily dissolved in water.

WP pieces were placed on bacon covered with military uniform, ignited, and covered with a dressing under study. A medical dressing was applied typically just after WP started to burn. The remaining WP was measured qualitatively. The absence of re-ignition was not regarded as absence of WP.

We performed 1100 individual experiments with the use of different types of first aid dressings during a 2-year period (2012–2013). First, the time to extinguish burning WP was examined. WP was burned and covered with the investigated dressing. The efficiency in extinguishing WP was examined in 5 time periods: after 1, 3, 5, 7, and 10 min. Then, each dressing was kept on the model, and after 40 or 60 min it was removed and we looked for re-ignition of WP. The remaining WP was burned out and washed from the surface. The last step was to verify if there was any WP remaining. Every piece of bacon was incised 24 h after burning with WP. The presence of smoke, fumes, and sparks was regarded as the evidence of WP penetration to deeper structures of the bacon.

Photos and film material were recorded for all experiments in this study. The research was approved by the Bioethics Commission of the Warsaw Military Institute.

Results

Every examined dressing type was found to be effective in extinguishing burning phosphorus, provided that the entire area of the burning substance was covered. However, the tactical NATO dressing (WJ10) has fine holes through which the phosphorus could escape and burn. NATO tactical dressing contains an oily emulsion. The substance was still present on the bacon even after 24 h. The oily emulsion penetrated the uniform and enabled WP to burn under the fabric. The dressing did not absorb the WP mass, and when removed, spontaneous

Figure 1. The gauze dressing with a stain of solidified WP after usage of moist gauze to extinguish WP on a military uniform. Extinguishing burning on fresh bacon (pol. “BOCZEK”) covered with field uniform (pol. “MUNDUR”) with moist gauze, description in text.

Figure 2. (A–C) Three stages of phosphorous combustion on a military uniform. Stages of WP burning on fresh bacon (pol. “BOCZEK”) covered with field uniform (pol. “MUNDUR”), description in text.

Table 1. The impact of the time of the application of dressing on bacon wounds.

The dressing	Time, min.				
	1	3	5	7	10
Moist gauze	0 mm	0 mm	1±0.5 mm	1±0.5 mm	1±0.5 mm
Aqua gel	4±0.5 mm	5±0.5 mm	5±0.5 mm	5±0.5 mm	8±0.5 mm + smoke
WJ10	4±0.5 mm	4±0.5 mm	4±0.5 mm	4±0.5 mm	4±0.5 mm
Hydrocolloid with glycerin	5±0.5 mm + smoke	6±0.5 mm + smoke	6±0.5 mm + smoke	6±0.5 mm +smoke	6±0.5 mm + smoke
Hydrocolloid with NaHCO ₃	5±0.5 mm + smoke	5±0.5 mm + smoke	5±0.5 mm +smoke	5±0.5 mm +smoke	5±0.5 mm + smoke

re-ignition was immediate. Moist gauze is very efficient in extinguishing burning phosphorus. It also removes and absorbs major parts of the WP mass, preventing deep burns. Figure 1 shows a spot of WP on the moist gauze 1 hour after application of the moist gauze dressing on burning WP on the warm bacon covered by a military uniform. No penetration of liquid

WP across the fabric was observed. After gauze removal, most of the WP was retained on the dressing. Liquid colloids were troublesome in usage, and covering the entire area of the phosphorus proved to be difficult. Solid colloids did not prevent re-ignition and when removed, intensive flame was immediately observed.

Figure 3. The depth of WP penetration examined after 24 h. Impact of the examined dressing on bacon burns, in all samples above, the dressings were taken off after 5 minutes. (A) Control “healthy”. (B) Moist gauze. (C) Aqua Gel. (D) Hydrocolloid with NaHCO_3 . (E) Control “burned”. (F) WJ10. (G) Glycol hydrocolloid.

Figure 2 shows the 3 stages of phosphorous burning on a military uniform. After setting WP on fire (Figure 2A), it burned on the surface of the uniform, but some amount of liquid WP went through the fabric even though the fire was out (Figure 2B).

The uniform removal caused the flow of oxygen and immediate re-ignition (Figure 2C). The removal of WP by streaming water was also examined. The stream of water splashes and transfers pieces of burning phosphorus, and the WP splashes into pieces, the trajectory of which is unpredictable.

Only the moist gauze prevented WP from penetrating. When the bacon was incised after 24 h, there were no signs of residual WP. In contrast, bacon samples treated with other investigated dressings, had a characteristic smell after making an incision, with smoke and, in some cases, sparking. Only the samples covered with moist gauze and WJ10 did not show bacon injury. In every other case, the bacon surface was injured and, in comparison with controls, which were unburned (“healthy bacon” and “burned bacon” on which WP was burned without any dressing), all dressings occluded the burn area and worsened the injury. Table 1 presents the influence of time during the dressing covered WP on damage to fresh bacon (Figure 3).

Discussion

Removal of toxic agents and contaminated clothing is crucial in the first aid, as the duration of contact with chemicals determines the extent of skin injury and organ toxicity. Our study proved that the best way to eliminate WP pieces from the body surface is to cover the burned area with moist gauze. The dressing should be pressed and kept in place for 3–5 min. The gauze eliminates most WP from the surface. The WP pieces stay on the dressing and when exposed to oxygen they immediately re-ignite. This reaction could cause additional burns during first aid and could be dangerous for rescuers or even later for caregivers. That is why the removed dressing should be kept a safe distance from the rescuers. When needed, another moist gauze piece to remove the remaining WP should be used. In our opinion, if rescuers do not have gauze, any other wet garment available in the field can be used to remove WP from the victim. To minimize the depth of injury, the burned area should be then protected with hydrocolloid or hydrogel dressing. As a result of our study, we recommend Water Jel WJ10, as is it covered with an oily substance that protects from WP penetration into the skin. WJ10 is efficient even beyond 24 h of application and is the best product to use for transport. Hydrocolloid dressings are also useful for transport, provided that all WP is eliminated, because those materials create occlusion and can worsen the injury. Extinguishing burning phosphorus with a stream of water is dangerous and ineffective. The stream of water splashes and

transfers pieces of burning phosphorus, which might contaminate the surroundings and be dangerous for rescuers, unlike the treatment used for other chemical burns. It is important to realize that, while burning, WP splashes into pieces, the trajectory of which is unpredictable.

If the WP pieces penetrated deep into the skin, it is advisable to eliminate the contaminated tissues using a sharp tool, such as a knife. The victim should be immediately transported to the closest burn unit or hospital (MEDEVAC).

Early gentle debridement should be performed, remembering that persistent pieces of WP are dangerous for the medical staff [9]. Even after 24 h after burning, the remaining WP in tissues has the capacity for spontaneous re-ignition [6], which was also observed during our experiments. A Wood's lamp is useful in finding WP burned areas or WP particles on skin surface or deeper [10]. Several treatment protocols have been proposed for phosphorus burns [3–10,12]. The main goal is always the removal or neutralization of active phosphorous from the burn site. Removal of stained phosphorus particles on the wounds is essential for prevention from further re-ignition, absorption into the circulation, and possible systematic effects. The medical staff is obliged to protect their own safety. WP should not be touched without special protective clothing and glasses, as the substance is highly toxic and even small amounts of WP can lead to serious burns. The cleared wound should be treated as a burn wound, but a temporary wound cover is needed prior to final wound closing. Burned patients require intensive treatment and constant monitoring, bearing in mind possible organ dysfunctions.

Conclusions

The moist gauze prevented spontaneous re-ignition and penetration of WP into bacon. It also eliminated large amounts of unburned WP. Moist gauze or any field-available wet garment should be used, pressed once or twice for 3–5 min, to remove WP from the victim. After removal of WP, we recommend Water Jel WJ10 as a secondary dressing ideal for medical transport. Hydrocolloid dressings are also useful for transport, provided that all WP is eliminated, because those materials create occlusion and can worsen the injury.

Conflict of interest

The authors have declared no conflict of interest.

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