HEALTH, ENVIRONMENT, DEVELOPMENT

THE IMPACT OF PHOSPHORUS WEAPONS DURING A FULL-SCALE WAR

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Summary

Due to military actions, there is destruction of Ukraine's ecosystems, deterioration of sanitary and hygienic indicators of drinking water, air, and soil. With the onset of full-scale war, the negative impact of harmful and dangerous substances (the use of chemical, phosphorus bombs, and other weapons) prohibited by the Geneva Convention leads to unforeseen consequences for the environment of Ukraine. The purpose of the study is to analyze injuries resulting from the action of white phosphorus of various types of phosphorus weapons, namely explosive weapons with a wide area of effect, mines, ammunition, long-range missiles; artillery, mortar shells, various types of grenades in the conditions of russian aggression against Ukraine. The following methods were used in the work: content analysis, comparative analysis, and systematization of the researched material. Research of scientific publications by domestic and foreign scientists using the PubMed and Google Scholar databases for the period 2001-2023 was conducted. Phosphorus munitions such as WP are known for their high effectiveness in combat operations, but also lead to serious injuries, both traumatic and post-traumatic psychological changes. White phosphorus (explosive bombs) causes burns of human body tissues upon contact with burning material, as well as burns of the upper respiratory tract due to inhalation of smoke or gases emitted during combustion.

The article analyzes the regulatory framework prohibiting the use of phosphorus munitions in armed conflicts. Clinical cases of gunshot combined injuries of limbs with massive soft tissue defects, gunshot fractures, and the presence of multiple foreign bodies of metal density due to the use of phosphorus munitions are considered. An analysis of scientific research by foreign scientists on this issue was conducted. The article provides algorithms for providing first aid due to the action of phosphorus munitions, as well as methodological recommendations of the Ministry of Health of Ukraine (Order of the Ministry of Health of Ukraine No. 506 of March 20, 2022) for providing medical assistance at the prehospital stage in case of phosphorus munition injuries, burns, enteral poisoning, exposure to white phosphorus in the eyes.

Key words: white phosphorus, phosphorus shells, treatment of burns from phosphorus shells, military operations.

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1. Introduction

As a result of hostilities and the use of a large number of chemical and phosphorus weapons, which cause the destruction of Ukraine's ecosystem, deterioration of sanitary and hygienic indicators of soil, drinking water, and air. With the outbreak of a full-scale war, the negative impact of harmful, hazardous substances (use of chemical, phosphorus bombs and other weapons) prohibited by the Geneva Convention, which leads to unforeseen consequences for the environment of Ukraine, is considered in *(Bosak, 2023: 6).*

White phosphorus (WP) was first used as a weapon in the nineteenth century by Irish nationalists in a form that went down in history as "Fenian fire". There is evidence that a solution of phosphorus and carbon disulfide was used in arson attacks in Australia. In 1916, British troops used the first white phosphorus (WP) grenades. In general, World War I laid the foundation for the use of phosphorus in future military conflicts. During the Second World War, the range of WP military applications expanded significantly: mines, shells, grenades, bombs, and rockets. The use of WP shells not only caused great destruction, but also exerted psychological pressure on the enemy, instilling fear and frustration. In addition to the world wars, phosphorus shells were also used in local armed conflicts: by American troops in Syria and Afghanistan, in Iraq, by Russian troops in Grozny, and by Ethiopian groups in Mogadishu. At the end of 2020, Azerbaijani forces used phosphorus ammunition against the Armenian military on the front in Nagorno-Karabakh. Unfortunately, Ukraine also had the opportunity to experience the explosions of phosphorus shells. In March 2022, the Russian aggressors used phosphorus shells in the battles for Kyiv and Kramatorsk, as well as against defense groups at the Azovstal steel plant in Mariupol. In 2023, WP ammunition reappeared on the military and political scene: Israeli forces used white phosphorus in military operations in Lebanon and Gaza.

History shows us that WP projectiles, like any other type of weapon, cause severe traumatic effects on civilians and soldiers on the battlefield. Barillo D. *(Barillo, 2004: 448)* claimed that injuries caused by chemical burns accounted for 2.1% of all hospitalizations in the periods 1969 and 1985, and 1986 and 2000. The average body surface area involved in treatment was 19.5% over the 19 years of the study, compared to 8.6% over the past 15 years. Mortality rates increased from 5.4% to 13.8% over these periods. The length of stay in the hospital decreased from an average of 90 days to 15 days during these periods. In 146 cases, the chemical responsible for the injuries was WP, as discussed in.

Phosphorus munitions are a type of incendiary or smoke munitions containing white phosphorus. This substance is toxic to humans and ignites directly on contact with oxygen, so it is considered a self-igniting material. The combustion temperature exceeds 800 °C, which provides a thermal component in the event of phosphorus burns. At night, the phosphorus charge glows noticeably as a result of the explosion, which is primarily used to illuminate the battlefield. In contrast, during daylight hours, the effect of a phosphorus charge can be distinguished from other munitions by the appearance of thick, acrid white smoke with a pungent garlic smell and the flying of bright sparks. A phosphorus bomb causes large-scale fires that are very difficult to extinguish due to the chemical characteristics of this compound. WP is dangerous in terms of:

1. Chemical property – on contact with air, it is self-igniting, forming phosphorus oxides, which are very toxic. The interaction of white phosphorus with strong bases leads to the formation of toxic gases, in particular phosphine, which is toxic to humans;
2. Explosive property – reacts violently with oxidizing agents, halogens, nitrites, sulfur, metals, which lead to a fire with large amounts of heat and emission of hazardous gases;
3. Extremely spontaneous combustible property – white phosphorus tends to burn spontaneously on contact with air at room temperature. This means that even small particles of phosphorus can cause a fire at the slightest contact with oxygen.
4. Potential radioactivity – in some cases, phosphorus munitions may contain radioactive substances that add to their hazard. As a result, contact with them may pose a risk of radiation contamination.

2. Materials and Methods is to analyze the impact of white phosphorus on various types of phosphorus weapons, namely explosive weapons with a wide area of impact, mines, ammunition, long-range missiles; artillery, mortar shells, various types of grenades in a full-scale war in Ukraine. The following methods were used in the work: content analysis, comparative analysis and systematization of the studied material. A study of scientific publications of domestic and foreign scholars was conducted using PubMed and Google Scholar databases for the period 2001–2023.

3. Results

Summary of the main research material

In general, the use of phosphorus bombs is prohibited by the Geneva Convention and other legal acts (Table 1).

Table 1

Legal framework prohibiting the use of phosphorus munitions in armed conflicts

№	Name of the normative document	№/date of the document	QR code
1	Article 1 Protocol on Prohibitions or Restrictions on the Use of Incendiary Weapons (Protocol III)	October 10, 1980.	

2	Article 2 Protocol on Prohibitions or Restrictions on the Use of Incendiary Weapons (Protocol III)	October 10, 1980.	
3	Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons Which May Be Deemed to Be Excessively Injurious or to Have Indiscriminate Effects	October 10, 1980.	
4	Article 35 basic rules protocol additional to the geneva conventions of august 12, 1949, and relating to the protection of victims of international armed conflicts (protocol i)	June 8, 1977.	
5	Article 8(2)(b)(i), (ii) or (v) of the Rome Treaty	July 17, 1998	

The technical characteristics of the phosphorus bomb's radius of destruction are 150 meters, which means a potential threat to a large area. The phosphorus bomb ignites on contact with air, so it must be stored in water or other neutral liquids to prevent accidental combustion. In contact with human skin, the WP contained in ammunition causes severe chemical burns. WP is toxic to humans and the lethal dose is 0.05-0.15 g. This substance can cause damage to bones and bone marrow, tissue necrosis, as a person receives not just burn injuries, but deep wounds.

WP is used in the following projectiles:

- Bombs – M47A1, AN-M47A2, AN-M47A3, CBU-55/B, CBU-78/B, etc.
- Missiles – M156, M259, Mk 67 Mod 0, etc.
- Artillery shells – M825/M825A1, M110A1, M110A2, M104, etc.
- Mortar shells – M106 4.2-inch mortar smoke shell, M68 120 mm Smoke White Phosphorus, M929 120 mm Smoke White Phosphorus, etc.
- Various types of grenades – M34, No. 77 Mk1, No. 80 Mk1, No. 81 Mk 1 – white phosphorus hand grenades, etc.

A phosphorus projectile spreads the incendiary compound over a large area, which can be hundreds of square meters, causing catastrophic consequences for the ecosystem of Ukraine. The combustion ends when the source, i.e. phosphorus, is exhausted or oxygen is cut off. Such weapons cause mutilation; their effects can lead to slow martyrdom. Treatment of this type of injury requires qualified medical personnel and specialized equipment. In addition, providing assistance to the victims can also pose a high risk to the medical personnel themselves, who may be injured while treating the wounded.

WP burns at temperatures up to 2760 degrees Celsius. The hot particles of BP cause quite deep, limited or extensive burns. Indeed, they are a harbinger of death due to the absorption of phosphorus into the body through the wound surface, which can lead to liver, heart and kidney damage, and in some cases, multiple organ failure. Weapons with phosphorus-impregnated felt submunitions are particularly dangerous, as they may not burn completely, leaving up to 15% of the phosphorus content. Such ammunition is capable of spontaneous re-ignition, especially as a result of some kind of pressurization effect, for example, caused by the transportation of such weapons. As a rule, damage caused by high explosives is limited to areas of exposed skin, as smaller particles do not burn through clothing.

The combustion of WP results in the formation of phosphorus (V) oxide in the form of an aerosol. Field concentrations are usually harmless, but in the case of large concentrations, the fume can cause temporary irritation of the eyes, nasal mucous membranes and respiratory tract. The Agency for Toxic Substances and Disease Registry has set a minimum inhalation risk level of 0.02 mg/m^3 for white phosphorus fume, as well as fuel oil vapor. Higher concentrations of smoke, for example, in enclosed spaces, can cause asphyxiation and lead to irreversible changes in the upper and lower respiratory tract. The concentration of smoke created by a phosphorus projectile for camouflage purposes is toxic.

The pathogenesis of WP exposure is very serious and leads to injury and death through various mechanisms. First of all, it is important to note three main ways:

1. **Penetration into deep tissues**: is a serious threat because the toxic substances penetrate deep into the body through skin contact. This leads to severe chemical burns and damage to internal organs, which in turn can cause internal bleeding and tissue necrosis. Significant damage by any means can be fatal.

2. **Smoke Inhalation**: During combustion, WP emits thick white smoke containing toxic gases and vapors. Inhalation of this smoke can damage the lungs, cause chemical burns to the respiratory tract and lead to asphyxiation.

3. **Intra-body ingestion**: WP is ingested through open wounds or contact with internal organs during an explosion, which in turn leads to internal organ burns, systemic poisoning, and other serious complications.

Primary blast injury occurs when a blast wave interacts with a body or tissue, producing two types of energy: stress waves that cause compression and stretching of tissue and shear waves that cause tissue displacement and tearing (Figures 1, 2).

The stress waves generated by the interaction of the blast wave and the body surface are supersonic longitudinal pressure waves that cause microvascular injuries. Organs with increased air permeability, such as the lungs, hearing aid, and gas-filled intestines, are the most sensitive. Stress wave injuries are caused in several ways. Pressure drops in structures; rapid compression and subsequent re-expansion of gas-filled structures; reflection of the compression stress wave component; and a spalling effect characterized by the "boiling" effect observed at the air-water interface after an underwater explosion. That is, the above mechanisms lead to damage to open mucous membranes and submucous membranes due to damage to microvessels. Shear waves cause damage to muscles and bones, which may depend much more on the tertiary and quaternary effects of the explosion than on the blast wave alone.

Specifics of the explosion:

1. The basic mechanism of the explosion causes injuries as the only consequence of the interaction between the blast wave and the body;

Figure 1, 2. Traumatic injuries to the lower extremities caused by the explosion of a phosphorus shell by an AFU serviceman during a full-scale war

2. The second mechanism of explosion is caused by the fragments being pushed apart by the explosion and connecting with the body, causing penetrating or blunt wounds;

3. The third explosion mechanism is caused by the acceleration and deceleration of a body or body part when the energy released during the explosion pushes the body or body part (acceleration phase), and then the body or body part suddenly stops when it hits the ground or a surrounding object;

4. The fourth explosion mechanism involves flash burns caused by short-term but intense heat of the explosion (Fig. 3), known from [3].

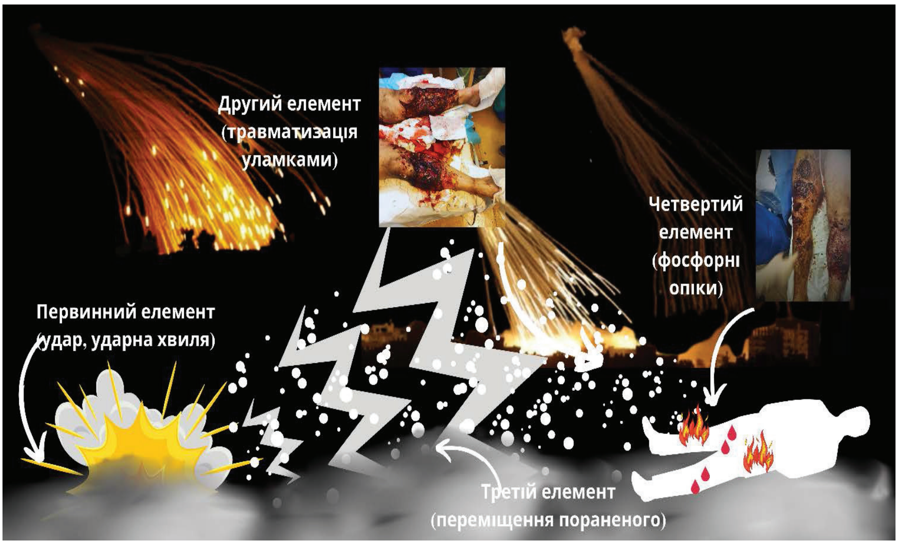

Figure 3. Features of the traumatic effect of a phosphorus projectile

WP intoxication causes several signs and symptoms, which are divided into the following stages:

Stage I – General symptoms occur within the first 24 hours after WP ingestion per os, respiratory tract and are characterized by abdominal pain in the epigastric region, profuse diarrhea, nausea, vomiting and in some cases fever. Breath, vomit and belching have a garlic odor. Laboratory data at this stage are normal.

Stage II – asymptomatic, which occurs between 24 and 72 hours after WP exposure. This is an asymptomatic period; however, liver histology at this stage shows early changes of toxic hepatitis, and laboratory data show a moderate increase in aminotransferases and bilirubin.

Stage III – advanced: occurs 72 hours before symptoms disappear or death. This stage is characterized by multisystem organic failure. The patient has signs of acute hepatitis; liver histology reveals steatohepatitis and necrosis are discussed in *(Santos, 2009: 162; Şamdanci, 2016: 51)*.

WP is lipid-soluble, and this allows it to penetrate deeply through the fatty subcutaneous tissue. Hot WP particles can cause significant, deep (second and third degree) painful burns (Fig. 4). The burns themselves are very severe, usually full-thickness, with necrotic changes. This is the result of both the thermal and chemical effects of burning phosphorus. Tissue damage also occurs due to the corrosive effects of phosphoric acids (which are produced during combustion), the heat of the chemical reaction that produces phosphorus pentoxide, and the hygroscopic effects of phosphorus pentoxide itself. These burns heal much more slowly than typical thermal burns.

Figure 4. Gunshot combined wound of both lower extremities with a massive soft tissue defect of the left tibia, gunshot fracture of the fibula and the presence of multiple foreign bodies of metallic density due to the use of phosphorus ammunition by a serviceman of the Armed Forces of Ukraine during a full-scale war

When providing first aid, there are general guidelines NATO STANDARD AMedP-7.1 MEDICAL MANAGEMENT OF CBRN CASUALTIES (Edition A Version 1 JUNE 2018) and methodological recommendations (Order of the Ministry of Health of Ukraine "On Approval of Methodological Recommendations for the Organization of Emergency Medical Care for Victims of Phosphorus Ammunition" No. 506 of March 20, 2022). Separately, a systematic review of white phosphorus "White Phosphorus: Systemic Agent" (last revised: October 20, 2021) by the National Institute for Occupational Safety and Health, which, in addition to the toxic effects of white phosphorus, describes options for providing first aid and treatment to victims of this compound in any form (Table 2).

Table 2

Regulatory documents on first aid as a result of phosphorus munitions

NATO STANDARD AMedP-7.1 MEDICAL MANAGEMENT OF CBRN CASUALTIES (Edition A Version 1 JUNE 2018)	**Methodological recommendations on the organization of emergency medical care for victims of phosphorus munitions (Order of the Ministry of Health of Ukraine No. 506 of March 20, 2022)**	**"White Phosphorus: Systemic Agent" by the National Institute of Occupational Safety and Health**

4. Discussion

Analysis of recent studies and publications According to Brutyan S. *(Brutyan, 2021: 1100)*, during the Nagorno-Karabakh war of 2020, the average total area of the affected body surface was 14.1%. The head and neck were affected in 79.3% of cases, the upper limbs and hands in 90.2% of cases, the torso in 26.8% of cases, and the lower limbs in 46.3% of cases. The eyes and eyelids were affected in 20.7% of patients, the upper respiratory tract in 30.5% of patients, the external ears and ear canal in 50.0% of patients, and the lungs in 15.9% of patients. Concomitant multi-fragment wounds were detected in 37.9% of patients. Intensive care was required for 28.7% of patients with full-thickness burns, including 10.3% of patients who died within a week of hospitalization.

Phosphorus munitions, such as WP, are known for their high effectiveness in combat operations, but also cause serious injuries, both traumatic and post-traumatic psychological changes. White phosphorus (WP) bombs cause burns to human body tissue when in contact with burning material, as well as burns to the upper respiratory tract through inhalation of smoke or gases released during combustion. According to the results of the study, Khurshid R. et al. *(Khurshid, 2022: 172)* found that contact with phosphorus shells led to various psychological injuries, namely insomnia in the first days, fatigue and stress, fear of noise; traumatic brain injuries, head injuries are discussed in.

Absorption of highly fat-soluble white phosphorus leading to necrosis of soft tissues, liver or kidneys is one of the most common complications arising from contact with this toxic substance. WP can cause pathological changes, primarily in electrolyte metabolism, including hypocalcemia, hyperphosphatemia with calcium-phosphate shifts, within 1 hour after the burn, as discussed in *(Barillo, 2004: 448).*

Xie W.G. *(Xie, 2008: 36)* found an average burn rate of 9%, with an average area of II B degree/III degree burns of 7%. The majority of patients had symptoms and signs of phosphorus poisoning, 33% had liver dysfunction, 18.5% had kidney damage, and 52% had electrolyte imbalance.

Lakota J. *(Lakota, 2023: 276)* provides a pathophysiological explanation of hypocalcemia: phosphoric acid (H3PO4) is the end product of the reaction of phosphorus pentoxide P4O10 (empirical formula P2O5) with water (H2O). Calcium (and possibly magnesium) is used to "neutralize" the phosphoric acid. The end product – calcium (and magnesium) salts of phosphoric acid – are very poorly soluble in water. However, the only source of calcium (and magnesium) is the "free" calcium (and magnesium) in the patients' blood plasma. In essence, the drop in calcium ions reflects the amount of this ion that was needed to neutralize phosphoric acid. Calcemia and phosphatemia in the patient's blood reflect the "amount" of "burned" phosphorus discussed in.

The rapid development of hypocalcemia and hyperphosphatemia is responsible for cardiac arrhythmias with abnormalities after a burn, including QT prolongation, ST-T wave changes, and progressive bradycardia. The scientist also noted early metabolic changes due to the effects of WP in the patient's body, discussed in *(Chou, 2001: 492).*

Rabinowitch I. M *(Rabinowitch, 1943)* reports that burns from WP are intensely painful and similar to burns from hydrofluoric acid, which are more serious than burns caused by caustic soda and sulfuric acid.

WP smoke irritates the eyes and nose in moderate concentrations. Intense exposure may cause intense coughing. However, no casualties were reported during the hostilities due to exposure to WP smoke alone, and to date there are no confirmed cases of deaths due to exposure to phosphorus smoke.

The effects of WP on the central nervous system are mainly mental changes with irritability, confusion, psychosis, hallucinations, and coma. Patients may also develop arterial hypotension, tachycardia, arrhythmias, and cardiogenic shock.

Austin E.B. *(Austin, 2016)* describes that absorbed phosphorus can cause intoxication of many organs. On the part of the central nervous system, the manifestations of intoxication are delirium, psychosis, convulsions, and coma. Symptoms of gastrointestinal tract damage include abdominal colic, melena, as well as hepatomegaly and jaundice. The urinary system also has certain changes: proteinuria and acute tubular necrosis of the kidney. The cardiovascular system also undergoes changes: ventricular extrasystole and myocarditis are present. The blood composition changes, as thrombocytopenia and hypoprothrombinemia are observed, as described in.

The specifics of emergency medical care are almost identical in these two guidelines, but there is a major difference: the use of copper sulfate, which is not mentioned in the guidelines *(Order of the Ministry of Health of Ukraine No. 506 of 20.03.2022).*

The first step in providing medical care at the pre-hospital stage is to remove all contaminated clothing. Due to the chemical characteristics of phosphorus, it is necessary to deprive the area of oxygen as soon as possible by immersing it in the WP or applying a bandage soaked in water/saline solution. Karunadasa K. and co-authors *(Karunadasa, 2010)* advocate the use of saline-soaked gauze to cover the wound, which facilitates oxygen depletion by any residual phosphorus particles discussed in.

It should be noted that white phosphorus particles become liquid at a temperature of 44 °C, so the use of warm or hot water will only worsen the patient's condition by diluting it, leading to spreading and, accordingly, a larger burn area. Instead, intensive irrigation with water can lead to splashing of white phosphorus particles and spread to intact tissue, as discussed in *(Aviv, 2017)*.

Witkowski W. and co-authors *(Witkowski, 2015)* suggested that when providing first aid due to the effects of WP, the use of wet gauze, which was applied to the burning WP for about 3 minutes, was most effective in extinguishing WP and removing most pieces of WP. They recommended that using wet gauze once or twice is the best basic means of eliminating the effects of BC and preventing penetration into tissue. The dressing used for medical evacuation of the patient (MEDEVAC), or as a second step after complete removal of visible WP, should use innovative hydrocolloid or hydrogel dressings are discussed in.

Based on the results of the study by Lakota J. *(Lakota,2023),* Phoenix E. *(Phoenix, 2024),* Phoenix, T., *(Phoenix 2024),* it is known from that a medical care algorithm was proposed (Figure 1):

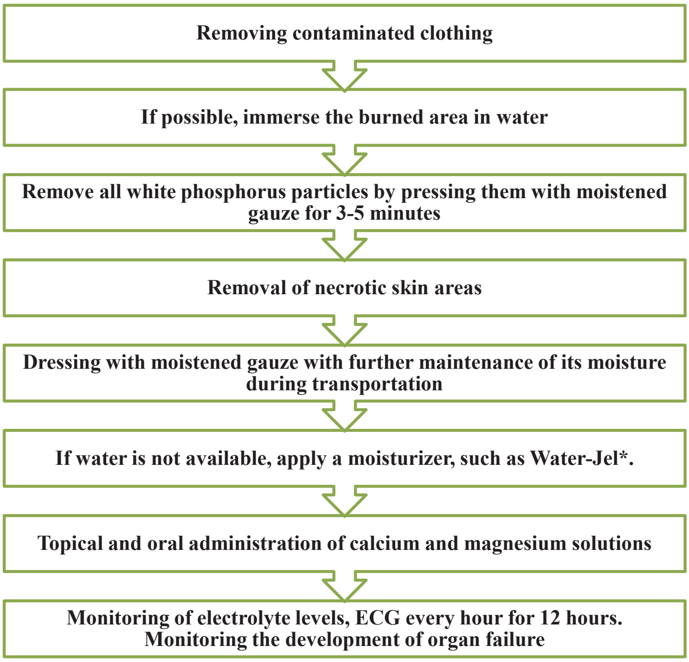

Figure 1. Algorithm for providing medical care to victims with white phosphorus burns

*This gel consists of 96% water and has the same cooling effect as water, but because of its thickness it stays on the burn and does not evaporate. Water-Jel also contains a small amount of natural extract of Melaleuca alternifolia, better known as tea tree. It has antibacterial antibacterial activity that helps prevent infection. Water-Jel also contains thickeners and preservatives to maintain the gel's viscosity.

The Ministry of Health of Ukraine provides general guidelines for first aid in the event of a phosphorus munition injury (Figure 2):

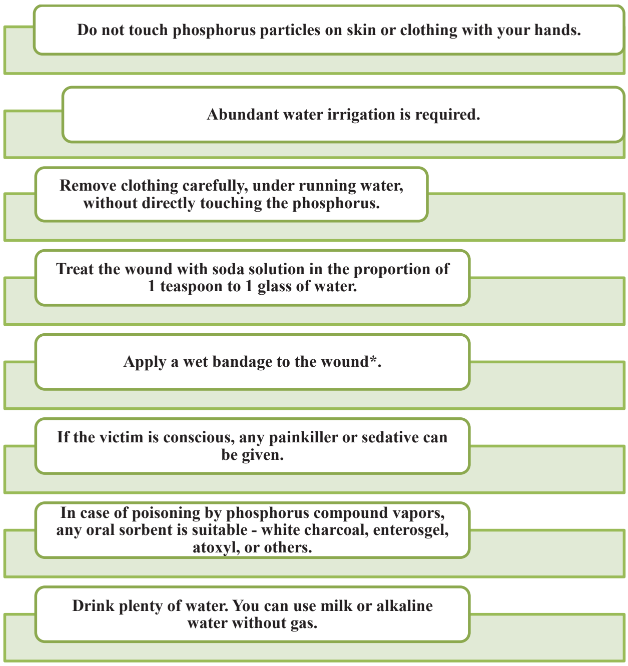

Figure 2. General provisions for providing first aid in case of phosphorus shell injury

*The use of cotton wool and hydrogen peroxide is prohibited. Hydrogen peroxide releases free oxygen during decomposition, which prolongs the combustion of phosphorus.

In the case of phosphorus burns at the prehospital stage, the actions of the rescuer should be directed to (Figure 3):

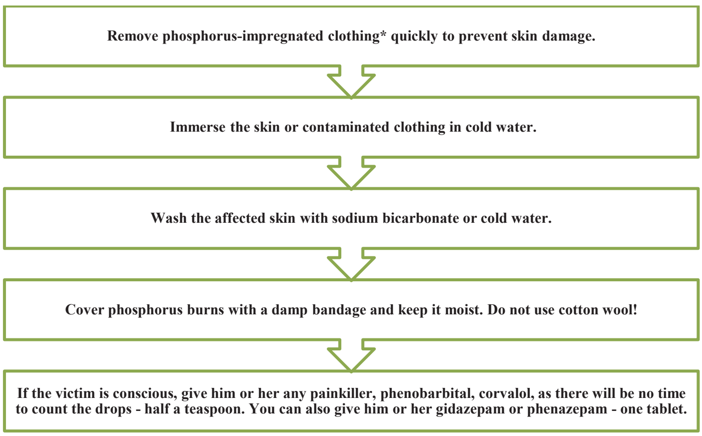

Figure 3. Peculiarities of first aid in case of phosphorus burns

*Remove visible phosphorus particles (preferably under water) with a non-sharp object (knife handle, etc.) or tweezers. Do not touch the phosphorus with your fingers! Immerse the removed phosphorus or clothing with phosphorus in water or allow it to burn in a suitable place.

There are some peculiarities in providing first aid to a person who has swallowed or inhaled white phosphorus (Figure 4):

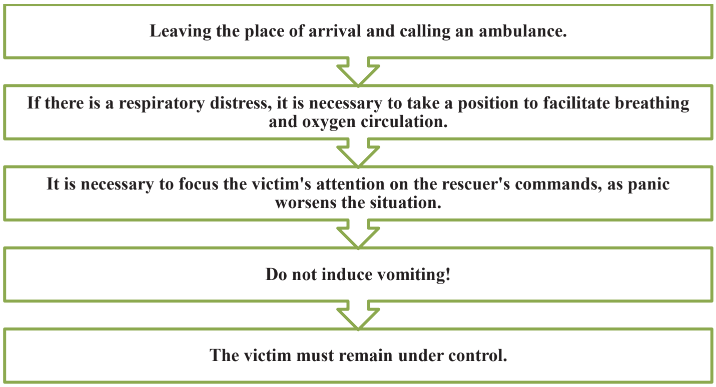

Figure 4. Peculiarities of first aid in case of exposure to phosphorus smoke or enteric poisoning

*Do not give water, as white phosphorus particles can cause severe burns to the mucous membranes, mouth and stomach.

Contact with white phosphorus in the eyes requires a slightly different approach to first aid (Figure 5):

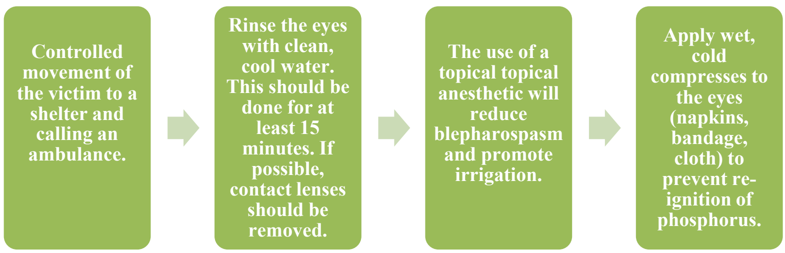

Figure 5. Features of first aid in case of contact with white phosphorus in the eyes

When providing first aid, it is extremely important to remember that in the absence of treatment, the victim is likely to develop systemic toxicity. The chemical aspect of treatment is aimed at neutralizing white phosphorus, which is realized through the external use of a bicarbonate solution. For identification purposes, a physical method is often used – Wood's lamp (ultraviolet light lamp), which is an alternative to the chemical method, namely the use of a solution of copper sulfate. Early signs of systemic phosphorus intoxication include abdominal pain, jaundice, and garlic breath. Prolonged inhalation of vapors can cause anemia, as well as cachexia and phosphorus necrosis of the lower jaw ("phosphorus jaw" or "Lucifer's jaw"), and bone necrosis. The shortest period of exposure to phosphorus fumes that led to bone necrosis was 10 months, the longest was 18 years.

Conclusions

1. Human exposure to white phosphorus can cause injury and death in three ways: by penetrating deep into tissues, ingestion, and inhalation of smoke. The main pathogenesis of white phosphorus burns is electrolyte imbalance, which must be immediately corrected during medical care.

2. Requires attention and further research to develop effective approaches to medical care due to the lack of a unified protocol for the treatment of burns caused by white phosphorus – phosphorus weapons. There is a need to improve the system of emergency response and medical care to effectively address the consequences of white phosphorus use in the conflict zone.

3. To develop and implement rehabilitation systems for victims with burns caused by white phosphorus (phosphorus weapons) to help them return to normal life.

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