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Medical Consequences and Treatment of Injuries Caused by White Phosphorus Munitions

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White phosphorus (WP) has been used in hand grenades, mortar and artillery shells, and aerial bombs since World War I. Recently it has been used in combat operations in Iraq, Syria, Afghanistan, Yemen, Nagorno-Karabakh and is used during the Palestinian-Israeli conflict in Gaza. Burns caused by WP usually result in death or disability. *The purpose of the work* is to analyze and summarize the data of the scientific literature on the medical consequences and treatment of lesions caused using ammunition with WP. *Materials and methods.* For the analysis, we used available scientific publications describing the consequences of WP burns received during hostilities. The method of analysis is descriptive. The following tasks were solved: the properties of WP as a damaging agent were studied; materials on the medical consequences of WP lesions and methods of treatment of such lesions were summarized. *Discussion of the results.* WP is highly reactive, highly toxic and ignites in air as early as 35°C. The severity of WP lesions is the result of both the thermal and chemical effects of combustion. Fatalities among humans from WP burns have occurred involving less than 10% of the total body surface area. Burns caused by WP heal more slowly than thermal burns. WP penetrates deeply through the fatty subcutaneous tissue. Therefore, the burns are full-thick, necrotic. The absorbed WP acts as a cellular poison and causes damage to the central nervous system, liver, kidneys, myocardium, and other organs. Any WP particles trapped in the wound may re-ignite. *Conclusion.* At the pre-hospital stage, the first thing to do is to wash off the wounds with cool water and remove the pieces of WP that have fallen into the skin with forceps. The light from the UV lamp can help to visualize the small particles of WP. Cleaning exfoliated skin and removing visible WP particles from the skin are critical methods for limiting wound severity and systemic WP absorption. It is advisable to excise the burned area within an hour after the lesion and repeat surgical procedures until all phosphorus particles have been removed; to control during the first 48 hours for the content of calcium and phosphorus in the blood serum with appropriate correction. In the future, skin grafting and treatment with allogeneic mesenchymal stem cells are advisable.

Keywords: *chemical effects; thermal effects; treatment plan; white phosphorus; WP burns.*

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Медицинские последствия и лечение поражений, вызванных применением боеприпасов с белым фосфором

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Белый фосфор (white phosphorus, WP) используется в ручных гранатах, минометных и артиллерийских снарядах, авиационных бомбах с Первой мировой войны. Его применяли в боевых действиях в Ираке, Сирии, Афганистане, Йемене, Нагорном Карабахе и применяют в ходе палестино-израильского конфликта в Газе. Ожоги, вызываемые WP, обычно приводят к смерти или к инвалидности. *Цель работы* – анализ и обобщение данных научной литературы по медицинским последствиям и лечению поражений, вызванных применением боеприпасов с WP. *Материалы и методы.* Для анализа использовались доступные научные публикации, описывающие последствия ожогов WP, полученные в ходе боевых действий. Метод анализа – описательный. Решались следующие задачи: изучались свойства WP, как поражающего агента; обобщались материалы по медицинским последствиям поражения WP и методам лечения таких поражений. *Обсуждение результатов.* WP высоко реакционен, высокотоксичен и воспламеняется на воздухе уже при температуре 35 °C. Тяжесть поражений WP – результат как термического, так и химического воздействия горения. Смертельные случаи среди людей от ожогов WP происходили при участии менее 10 % кожи. Ожоги, вызванные WP, заживают медленнее термических ожогов. WP глубоко проникает через жировую подкожную клетчатку. Поэтому ожоги полнослойные, некротические. Поглощенный WP действует как клеточный яд и вызывает поражение ЦНС, печени, почек, миокарда и других органов. Любые частицы WP, попавшие в рану, могут повторно возгораться. *Заключение.* На догоспитальном этапе прежде всего необходимо смыть WP прохладной водой и удалить щипцами кусочки WP, попавшие в кожу. Свет от УФ-лампы может визуализировать мелкие частицы WP. Очистка отслоившейся кожи и удаление видимых частиц WP с кожи являются важнейшими методами ограничения тяжести ран и системной абсорбции фосфора. Целесообразны иссечение обожженного участка в период до часа после поражения и повторные оперативные процедуры до тех пор, пока все частицы фосфора не будут удалены; контроль в течение первых 48 ч за содержанием кальция и фосфора в сыворотке крови с соответствующей коррекцией. В дальнейшем целесообразны пересадка кожи и лечение мезенхимальными стволовыми клетками.

Ключевые слова: *белый фосфор; ожоги белым фосфором; схема лечения; термические эффекты; химические эффекты.*

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Phosphorus (P) is a chemical element with the atomic (protonic) number 15. Elemental phosphorus can exist in several allotropes, the most common of which are white and red solids. From the perspective of applications and chemical literature, the most important form of elemental phosphorus is white phosphorus (often abbreviated as WP). In WP, phosphorus atoms are arranged in groups of 4 as tetrahedra (see later text). White phosphorus emits a faint glow when exposed to oxygen – hence the name, taken from Greek mythology, Φωσφόρος («Fosfóros») meaning 'light-bearer' (Latin Lucifer), referring to the "Morning Star", the planet Venus. The glow of phosphorus is caused by oxidation of the white (but not red) phosphorus – a process now called chemiluminescence. (By the 18th century, it was known that in pure oxygen, phosphorus does not glow at all. The Nobel prize in chemistry in 1956 to sir Cyril Norman Hinshelwood (1897–1967) and academician Nikolai Nikolayevich Semenov (1896–1986) «for their research into the mechanism of chemical reactions» was mainly for the explanation of this phenomena. Semenov investigated the matter and found that it really was so that a mixture of phosphorus vapor and oxygen did not react at all if the gas pressure was too small or too great, but that at intermediate pressures the mixture exploded[1]. WP is the least stable, the most reactive, the most volatile, the least dense and the most toxic of the allotropes. The density of WP is 1.823 g/cm^3, its melting point is 44.1 °C. WP gradually changes to red phosphorus. This transformation is accelerated by light and heat, and samples of WP almost always contain some red phosphorus and accordingly appear yellow. For this reason, WP that is aged or otherwise impure (e.g., weapons-grade, not lab-grade WP) is also called yellow phosphorus. When exposed to oxygen, WP glows in the dark with a very faint tinge of green and blue. Owing to its pyrophoricity, white phosphorus is used as an additive in napalm. The odor of combustion of this form has a characteristic garlic smell,

[1] The Nobel Prize in Chemistry 1956. Award ceremony speech. https://www.nobelprize.org/prizes/chemistry/1956/ceremony-speech/ (date: 10.01.2023).

and samples are commonly coated with white phosphorus pentoxide (empirical formula, P_2O_5), which consists of P_4O_{10} tetrahedra.

WP is used «routinely» in many military munitions to include hand grenades, mortar rounds, artillery, and bombs. It has been involved in many other recent conflicts. Over the past 15 years alone, it has been used in Iraq, Syria, Afghanistan, Yemen, Azerbaijan, and Gaza.

Purpose of the work – Analysis and synthesis of data from the scientific literature on the medical consequences and treatment of injuries caused using munitions with WP.

Materials and methods. For the analysis, we used available scientific publications describing the consequences of WP burns received during hostilities. The method of analysis is descriptive.

The following tasks were solved: the properties of WP as a damaging agent were studied; materials on the medical consequences of WP lesions and methods of treatment of such lesions were summarized.

Phosphorus chemistry

The electron configuration of the phosphorus atom can be represented by $1s2^2s2^2p6^3s^23p^3$. The outer shell arrangement therefore resembles that of nitrogen, with three half-filled orbitals each capable of forming a single covalent bond and an additional lone pair of electrons[1]. Depending on the electronegativity of the elements with which it combines, phosphorus can therefore exhibit oxidation states of +3 or −3, just as does nitrogen. The principal differences between nitrogen and phosphorus are that the latter is of considerably lower electronegativity and has larger atoms, with outer d orbitals available. For these reasons, the similarities between nitrogen and phosphorus chemistry are largely formal ones, tending to conceal the actual, wide differences. The outer d orbitals in phosphorus permit an expansion of the octet, which leads to the +5 state, with five actual covalent bonds being formed in compounds, a condition impossible for nitrogen to achieve. The first striking difference in chemistry of the two elements is that elemental phosphorus exists under ordinary conditions in any of 10 modifications, or allotropic forms, all of which are solid; the three major allotropes are white, red, and black. Phosphorus molecules of formula P2, structurally analogous to N2 molecules and evidently also triply bonded, exist only at very high temperatures. These P2 molecules do not persist at lower temperatures—below about 1,200 °C because of the fact that three single bonds in phosphorus, in contrast to the situation with nitrogen, are energetically favored over one triple bond. On cooling, the triply bonded P2 molecules condense to form tetrahedral P4 molecules, in which each atom is joined to three others by single bonds (Figure 1).

White phosphorus has two allotropes: the alpha form, which is stable at ordinary temperatures, has a cubic crystal structure; the beta form, which is stable below −78 °C, has a hexagonal crystal structure. Because of the relatively weak intermolecular attractions (van der Waals forces) between the separate P_4 molecules, the solid melts easily at 44.1 °C and boils at about 280 °C. Formation of tetrahedra requires bond angles of 60° instead of the preferred 90°–109° angles, so that white phosphorus is a relatively unstable, or metastable, form. It changes spontaneously, but slowly, at temperatures around 200 °C or higher, to a polymeric form called «red phosphorus.» This substance is amorphous when formed at lower temperatures, but it can become crystalline, with a melting point of about 590° C. At higher temperatures and pressures, or with the aid of a catalyst, at ordinary pressures and a temperature of about 200 °C, phosphorus is converted to a flaky black crystalline form, which somewhat resembles graphite. This may prove to be the most stable form of phosphorus, despite the relative difficulty in its preparation. In both the red and the black forms, each phosphorus atom forms three single bonds, which are spread apart sufficiently to be relatively strain free (Figure 2).

Consistent with the metastable condition of the white modification, and the crowding of its covalent bonds, this form is far more reactive chemically than the others. It is highly toxic, reacts vigorously with most reagents, and inflames in air at only 35° C, so it must be stored under water or other inert liquid. White phosphorus dissolves readily in solvents such

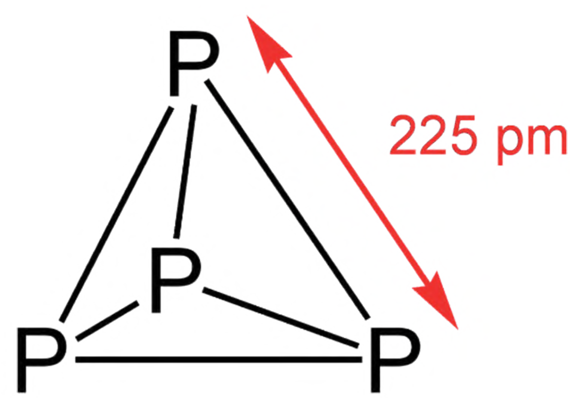

Figure 1 – *Tetraphosphorus molecule*

[1] Phosphorus. https://www.britannica.com/science/phosphorus-chemical-element/Properties-and-reactions (date: 02.01.2023).

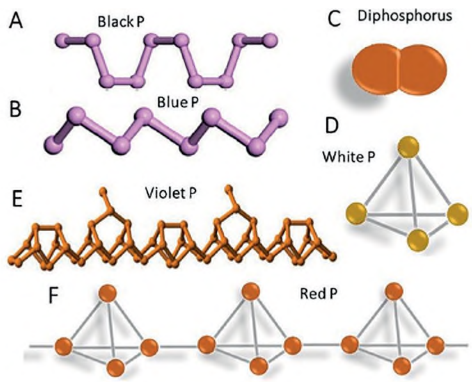

Figure 2 – *Diverse allotropes of phosphorus. (A) Side view of black phosphorus. (B) Side view of blue phosphorus. (C) Gaseous form of phosphorus (named diphosphorus P 2). (D) Unit cell of white phosphorus (P 4). (E) Side view of violet phosphorus. (F) Side view of red phosphorus [1]*

as carbon disulfide, in which it maintains the composition P_4. White phosphorus has been used for military purposes as a source of smoke and to fill incendiary shells and grenades. In contrast, red phosphorus is insoluble and relatively inert, although large quantities of the usual commercial form can ignite spontaneously in air and react with water to form phosphine and phosphorus oxyacids. Red phosphorus is used in preparing the striking surface for safety matches. Black phosphorus is more inert and is capable of conducting electricity. Both these polymeric forms are insoluble and are very much less volatile than white phosphorus.

Military use

White phosphorus (WP) has been used in hand grenades, mortar and artillery shells, and aerial bombs since World War I. More data about the military use and characteristics of WP including the properties can be found[1]. WP exposures, be they dermal, inhalational, or enteral, are associated with severe systemic toxicity. The exact mechanisms underlying the systemic toxic effects of phosphorus, however, are not entirely clear [2].

Phosphorus is often cited as being a «general protoplasmic poison.» Much of this reputation is based on electron microscopy observations in a 1969 study in which the earliest morphologic changes were noted in the rough endoplasmic reticulum, before any changes were observed in the nucleus or mitochondria [3–5], lipoperoxidation [6] and triglyceride secretion [7]. On histology, one sees intracellular lipid accumulation in multiple organs, namely, the liver, heart, brain, and kidneys [8].

Absorbed phosphorus can cause intoxication of many organs [9]:

- Central nervous system – delirium, psychosis, convulsions, coma.
- Gastrointestinal tract – abdominal colic, melena.
- Liver – hepatomegaly, jaundice.
- Kidneys – proteinuria, acute tubular necrosis.
- Blood – thrombocytopenia, hypoprothrombinemia.
- Myocardium – ventricular extrasystole, myocarditis.

White phosphorous ignites in air (i.e. «in oxygen»), and it is burning as a bright yellow flame. Some people have described it as smelling like garlic, which could be confused with the chemical warfare agent sulfur mustard, which is also described as smelling like garlic, onions, or mustard. In the presence of oxygen white phosphorus continues to burn until it has completely consumed itself. Any phosphorus particles embedded in a wound may continue to oxidize and lead to ongoing tissue injury even after the initial exposure has ended [10].

The burns themselves are very severe. They are typically full-thickness, necrotic. This results from both thermal and chemical effects of the phosphorus burning. Tissue damage also occurs secondary to the corrosive action of phosphoric acids (which form during combustion), from the heat of the chemical reaction producing phosphorus pentoxide, and from the hygroscopic actions of the phosphorus pentoxide itself (Figure 3).

These burns heal much slower than typical thermal burns. White phosphorus is highly

Figure 3 – *Typically full-thickness, necrotic [11]*

[1] Summary and Evaluation for White Phosphorus Remediation: A Literature. https://archive.org/details/DTIC_ADA317393/page/n3/mode/2up (date: 02.01.2023).

lipid-soluble, and this allows it to penetrate deeply through fatty subcutaneous tissue [12] (Figures 4, 5).

A 12 to 15% white phosphorous total body surface area burn (TBSA) can be fatal in experimental models [15]. However, in humans' fatalities from white phosphorus burns have occurred with less than 10% TBSA involvement [16].

All contaminated clothing needs to be removed as soon as possible. To extinguish the ignited white phosphorous, it needs to be deprived of oxygen as soon as possible. This is best done with immersion in cool water or covering the burning area with water / saline moistened dressings. It should be noted that white phosphorus particles become liquid at 44 degrees Celsius. Therefore, warm, or hot water will exacerbate the wounds by liquifying it, causing it to run over a larger surface (and volume) area, thereby increasing the amount of burned tissue. Similarly, aggressive water irrigation can splash the white phosphorous particles to unburned tissue and rescuers only to ignite once the particles dry out [17].

Some have stated that «extinguishing burning phosphorous with a stream of water is dangerous and ineffective.» [18]. However, tap water irrigation, best performed in the field, is the only treatment consistently documented to decrease death from white phosphorus burns, the severity of the burn, and length of hospitalization [19].

Figure 4 – *18-year-old male with white phosphorous burns from an artillery shell detonation. Photo A and B are during initial care. Photo C and D after 16 months follow up [13]*

Figure 5 – *Cavity burn lesions on the left thigh of an Armenian soldier during the 2020 Nagorno-Karabakh war [14]*

These factors would seem to indicate there is a role for irrigation, but perhaps after moistened gauze was used to extinguish the burning particles. Caution would still be needed to decrease a splash risk to the casualty and rescuers. There is a documented case when during wound debridement, a white phosphorous particle dislodged and burned a nurse's neck [13].

Traditionally, usually 1–3% copper sulfate ($CuSO_4$) solution was used on the burns to help identify small particles of embedded WP to better facilitate removal. However, a Cochrane Systematic Review looked at two retrospective case series which showed no benefit to copper sulfate use and the potential harm from copper absorption. It is no longer recommended [12]. Copper sulfate solution is easily absorbed through the wound and may cause intravascular hemolysis and acute renal and cardiovascular failure [19].

Ultraviolet light, from a UV (Wood's) lamp (maybe) can help to visualize small particles (Figure 6).

Debridement of sloughed skin and removal of obvious phosphorous particles from the skin are crucial techniques to limit wound severity and systemic absorption of phosphorus and should be best performed prehospital. Nevertheless, an excision of the burned area one hour after exposure has not been shown to decrease mortality, suggesting it should be done even sooner after injury to be beneficial [21].

There is speculation the increased mortality, compared to a similarly sized thermal burn, is secondary to absorption of phosphorus, which can result in elevated phosphorus levels, decreased calcium, and subsequent cardiac rhythm abnormalities. In the study of New Zealand white rabbits, they checked these levels and EKGs every hour for the first twelve hours [16] (Figure 7).

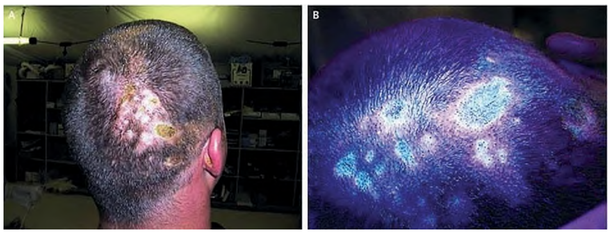

Figure 6 – *Scalp of a 18-year-old with WP burns on his scalp. As his bandages were removed the wound began to smoke. Photo on the right fluoresces with ultraviolet light (Wood's lamp) [20]*

The pathophysiological explanation of the author of this article for the hypocalcemia can stand as follows: Phosphoric acid (H_3PO_4) is the final product of the reaction of phosphorus pentoxide P_4O_{10} (empirical formula P_2O_5) with water (H_2O). The «neutralization» of phosphoric acid is calcium (and probably magnesium) «consuming». The final product – calcium (and magnesium) salts of phosphoric acid are very poorly (almost not) soluble in water. However, the only source for calcium (and magnesium) is the «free» calcium (and magnesium) in the human plasma. Basically, the drop of calcium ions (magnesium ions were not estimated) reflects the amount of this ion which was necessary to neutralize the phosphoric acid. This idea is supported by the «parallel» levels of phosphate in the serum. In other words, both calcemia and the phosphatemia reflect the «amount» of «burned» phosphorus. Therefore, in the «Treatment plan»

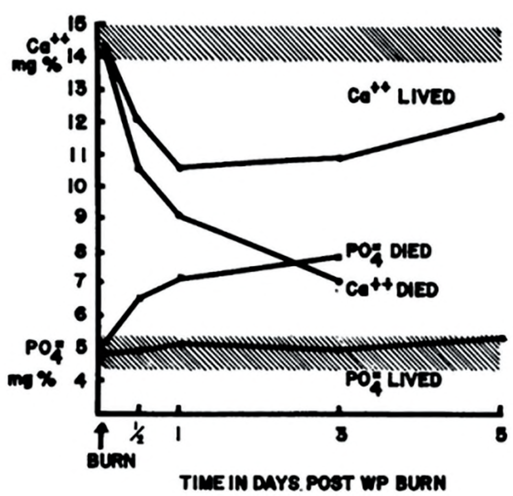

Fig. 2. Mean serum calcium and phosphorus values for Test Group 1 animals that lived and those that died are compared after the SWPB.

Figure 7 – *Standardized fatal white phosphorous burns on New Zealand while rabbits showed significant hypocalcemia and hyperphosphatemia as early as one-hour post-burn. The whole figure (Figure 2 in the original article) is taken from [16]*

we added the point 7: «Use effervescent calcium and magnesium tablets immediately after the burns. They should be used locally and orally.»

Additionally, the phosphorus can cause liver necrosis and direct renal damage ultimately resulting in kidney failure. In a Chinese study of 81 casualties from a yellow phosphorus explosion, where the average TBSA burn was 9%, the mean burn surface area of III degrees/ IV degrees was (7%) TBSA. Most of the patients showed the symptoms and signs of phosphorus poisoning, 33% had liver dysfunction, 18.5% kidney injury, and 52% electrolyte disturbances [22]. In a study of 87 soldiers injured by white phosphorous from the Nagorno-Karabakh war in 2020, between Azerbaijan and the Republic of Artsakh, the average TBSA burned was 14%. Head and neck burns occurred in nearly 80% of casualties. Upper extremities and hand burns in 90% [14].

We would like to suggest a treatment plan which is shown below. The seven points can be considered as «First aid» the 8th point is mandatory in the hospital.

Possible Treatment ("First aid") Plan: An ideal scenario is shown below. (This is an ideal treatment plan, recognizing in conflict zones.)

Step 1: Remove all contaminated clothing.

Step 2: Submerge or immerse white phosphorus burn in cool water (if possible).

Step 3: Remove all embedded white phosphorus particles by pressing moistened gauze for 3–5 minutes; (obvious particles will need to be removed with forceps)

Step 4: Debride all sloughed skin.

Step 5: Dress all burns with cool, moistened gauze, keep wet during transport.

Step 6: Water-Jel WJ110 (or other commercial equivalent) could be placed on the wound for transport, if keeping the gauze wet is not possible. (This gel consists of 96% water and has the same cooling effects as water, but because it is thick, it stays on the burn and doesn't evaporate. Water-Jel also contains a small amount of the natural extract Melaleuca alternifolia, better known as Tea Tree. This has anti-bacterial activity to help prevent infection. Water-Jel also contains thickening agents and preservatives to maintain the gel's viscosity)

Step 7: Use effervescent calcium and magnesium tablets immediately after the burns. They should be used locally (dissolved in water) and perorally.

Step 8: Monitor calcium, phosphorous levels, EKG changes, hourly for the first 12-hours, and watch for organ failure.

Here we will show an example of handling of a victim (non-military) of the burns of the WP [23].

We report a case of a white phosphorus burn that has a unique mechanism of injury involving a 40-year-old woman with her 7-year-old daughter who were collecting rocks on a beach in Tel Aviv. Upon returning home, the daughter washed the rocks of sand with tap water and immediately wrapped them in a paper towel. According to her anamnesis, the daughter presented her mother an unusual appearing, yellow translucent colored rock covered by a wet paper towel. As she commenced unwrapping the paper towel, white smoke emanated from the rock that was followed by ignition of flames and accompanied by a severe burning sensation in her hands. Subsequently, she dropped the rock which contacted her right calf and then landed on her right foot that was covered by a sock and ignited. The patient then proceeded to put out the flames in the bathroom shower. Upon return to the living room, the piece of white phosphorus had ignited the couch which took hold, and the entire apartment was gutted with fire. Both mother and child were safely evacuated from the apartment with no further injuries sustained. Upon arrival at the Emergency Department, within 1 h of the burn injury, the patient presented as conscious and talking with no evidence of an inhalation injury. Assessment revealed chemical burns from contact with what was suspected to be white phosphorus. No adequate first aid was administered at the time of the injury. First aid was commenced, and the burns underwent decontamination, irrigation and debridement of devitalized tissue. Her wounds were thoroughly irrigated with water and then covered with saline soaked pads and was subsequently admitted to our Burns Center for further treatment. Scattered partial thickness burns were sustained on bilateral hands to the dorsum and palms aspects of 0.5% Total Body Surface Area (TBSA), deep dermal burns to her right medial calf of 1% TBSA and full thickness burns were sustained to her right foot dorsum aspect calculated to be 0.5% TBSA (see Figure 8).

Figure 8 – *White phosphorus burns on presentation to the Emergency Department: Partial thickness burns sustained to palmer surface of bilateral hands (A); Deep dermal to full thickness burns sustained to right medial calf (B); Full thickness burns sustained to dorsum of right foot (C) [23]*

Due to the small surface area involvement and our department's experience with conservative non-surgical approach for minor burn care, the patient's burns were treated with mafenide acetate (*Mafenide is a sulfonamide-type medication used as an antibiotic. Mafenide is used to treat severe burns. It is used topically as an adjunctive therapy for second- and third-degree burns. It is bacteriostatic against many gram-positive and gram-negative organisms, including Pseudomonas aeruginosa.*) on the right medial calf and dorsum of foot and Flaminal Forte (*Flaminal® Forte is composed of hydrated alginate polymers with a biologic enzyme system that is based on glucose oxidase and lactoperoxidase stabilized by guaiacol. Due to its composition, Flaminal® Forte is expected to have an antimicrobial and continuous debriding effect.*) for the palmar wounds. Vital signs were all within normal limits, bloods were unremarkable and electrocardiogram abnormalities were not observed. Throughout the hospitalization period, blood tests were routinely taken twice weekly. The phosphorus level increased gradually from 2.90 mg/dL on day 1 to 4.40 mg/dL on day 14 (normal range 2.5–4.5 mg/dL). C-reactive protein (CRP) levels increased throughout the first 5 days and reached 122.21 mg/L, then gradually decreased to normal parameters (normal range 0–5 mg/L). During the admission period, occupational therapy and physiotherapy were provided to facilitate full range of motion to the hands and right leg. The patient was discharged 22 days after admission and followed up in the outpatient clinic. Pressure garments were provided; however, hypertrophic scars began to develop on the dorsum of her right foot. silicone sheets were provided under the pressure garment and the patient was educated on the importance of adherence to burn care therapy. The patient was again followed up 7 months post injury where digital images were once again obtained with the consent of the patient (see Figure 9).

Immediate surgical debridement is often necessary and is followed by repeated operative procedures until all phosphorous particles have been removed. Debrided wounds should be examined at least twice daily for new particles or smoking areas, which would indicate the need for re-operation. Debrided areas can be covered in aqueous 5% mafenide acetate solution between operative procedures to facilitate examination. Definitive wound closure should be deferred until adequacy of debridement is assured, at

Figure 9 – *Plates A, B and C 7 months post burn injury from white phosphorus. Scarring seen on right medial calf c hypertrophic scarring evident on right foot (B) [23]*

which point split thickness skin grafts can be applied [23].

The summary of a treatment procedure in the hospital can be summarized as follows [24]:

1. Under general or regional anesthesia, thoroughly irrigate the burn area with large amounts of 0.9% NaCl solution. To facilitate mechanical elimination of phosphorus particles, we use a water flosser.

2. Avoid using a brush to remove the phosphorus particles. In most instances, such attempts might result in further embedding of the phosphorus into the injured tissue.

3. Delicately remove the black particles by means of a metal forceps. Not infrequently these particles are located deep in the tissue; identification could be made easier by locating the origins of the slim smoking points. Larger and more superficial particles can be visualized by a fluorescent (i.e. ultraviolet) Wood's lamp.

4. If the injury is extensive and deep, consider the need for prompt excision to the fascia and skin grafting.

5. Dress the wound with dressings soaked with 5% mafenide solution or any other antimicrobial agent.

6. Inspect the wound at least twice per day. Should new particles or smoking areas be identified, surgical removal as previously described is mandatory.

7. After successfully eliminating the phosphorus particles, treat the burn wound conservatively or surgically, according to its estimated depth.

8. During the first 48 hours after the injury, be aware of serum electrolyte levels, with special attention to calcium and phosphorus levels. Replace intravenous fluids to all patients. In addition, ECG, hemodynamic, and cardiovascular state monitoring is recommended, especially in patients with extensive phosphorus burns.

Finally, we can add the following: according to previous data [25, 26] it is highly recommended to the surgeon (point 7) to use the freshly prepared («off the shelf») allogeneic mesenchymal stem cells. The effect of this novel therapy is astonishing.

Conclusion

At the pre-hospital stage, the first aid consists of washing off the WP with cool water and removing the pieces of WP that have fallen into the skin with forceps. If possible, use effervescent calcium perorally and for the wounds to wash. In the hospital the cleaning of exfoliated skin and removing visible WP particles from the skin are critical methods for limiting wound severity and systemic phosphorus absorption. The light from the UV lamp can visualize small particles of WP. It is advisable to excise the burned area within an hour after the lesion and to repeat surgical procedures until all phosphorus particles have been removed; the control during the first 48 hours for the content of calcium and phosphorus in the blood serum with appropriate correction is mandatory. Further treatment, consisting of skin grafting and the local treatment with «off the shelf» allogeneic mesenchymal stem cells are advisable.

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Информация о конфликте интересов / Conflict of interest statemen

Я заявляю, что подготовил статью из источников, находящихся в свободном доступе в Интернете, а также свободно доступных публикаций, рисунков и других возможных легальных источников. Я, как единственный автор, заявляю, что исследование проводилось при отсутствии каких-либо коммерческих или финансовых отношений, которые могли бы быть истолкованы как потенциальный конфликт интересов / I am declaring that I prepared the article from sources freely available on the Internet and free available publications, figures, and other possible legal sources. I, as a sole author declare that the research was conducted in the absence of any commercial or financial relationship that could be construed as a potential conflict of interest.

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