Interventions for treating phosphorus burns (Review)

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[Intervention Review]

Interventions for treating phosphorus burns

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ABSTRACT

Background

Phosphorus burns are rarely encountered in usual clinical practice and occur mostly in military and industrial settings. However, these burns can be fatal, even with minimal burn area, and are often associated with prolonged hospitalisation.

Objectives

To summarise the evidence of effects (beneficial and harmful) of all interventions for treating people with phosphorus burns.

Search methods

We searched the Cochrane Wounds Group Specialised Register (searched 30 September 2011); the Cochrane Central Register of Controlled Trials (CENTRAL) (*The Cochrane Library* 2011, Issue 3); Ovid OLDMEDLINE (1947 to 1965); Ovid MEDLINE (1950 to September Week 3 2011); Ovid MEDLINE (In-Process & Other Non-Indexed Citations 29 September 2011); Ovid EMBASE (1980 to 2011 Week 38); EBSCO CINAHL (1982 to 23 September 2011) and Conference Proceedings Citation Index - Science (CPCI-S) (1990 to 30 September 2011).

Selection criteria

Any comparisons of different ways of managing phosphorus burns including, but not restricted, to randomised trials.

Data collection and analysis

We found two non-randomised comparative studies, both comparing patients treated with and without copper sulphate.

Main results

These two comparative studies provide no evidence to support the use of copper sulphate in managing phosphorus burns. Indeed the small amount of available evidence suggests that it may be harmful.

Authors' conclusions

First aid for phosphorus burns involves the common sense measures of acting promptly to remove the patient's clothes, irrigating the wound(s) with water or saline continuously, and removing phosphorus particles. There is no evidence that using copper sulphate to assist visualisation of phosphorus particles for removal is associated with better outcome, and some evidence that systemic absorption of copper sulphate may be harmful. We have so far been unable to identify any other comparisons relevant to informing other aspects

of the care of patients with phosphorus burns. Future versions of this review will take account of information in articles published in languages other than English, which may contain additional evidence based on treatment comparisons.

PLAIN LANGUAGE SUMMARY

Interventions for treating phosphorus burns

Phosphorus is a chemical element sometimes used in a military or industrial context. Phosphorus burns resulting from military or industrial injuries are chemical burns that can be fatal. Although rare, these burns are serious, often very deep and painful, and can be associated with lengthy periods of time in hospital for patients.

The usual procedure for dealing with phosphorus burns is to remove any affected clothing and wash the wounds with water or saline solution. In addition, copper sulphate can be used to make the particles of phosphorus more visible and easier to remove, however, copper sulphate is poisonous and can in itself be fatal if absorbed into the body. This review found two retrospective studies (88 patients) that compared burns treated with or without copper sulphate. The review found no evidence that using copper sulphate improves the outcome of the burn, indeed, based upon the limited available evidence, the review authors suggest that copper sulphate should not be used in the treatment of phosphorus burns.

No other studies were identified that could be used to assess other treatments for this type of burn.

BACKGROUND

Description of the condition

Clinical reports of phosphorus burns have been appearing for more than half a century (Rabinowitch 1943). These burns are sustained by people injured by bombs or other weapons containing phosphorus, or during the manufacture of munitions or fireworks. For example, in a major study of 276 burned patients treated in US military units over 51 years, white phosphorus was the cause in half of the cases (Barillo 2004). Phosphorus is a component of insecticides and fertilisers, and burns from these sources have also been reported**.**

White phosphorus is used as a smoke-producing flare and is a waxy, yellow transparent combustible solid (Al Barqouni 2010). In the presence of oxygen, white phosphorus ignites spontaneously with a yellow flame and dense smoke and remains ignited until either deprived of oxygen or burned out (Eldad 1991).

Description of the intervention

Phosphorus burns result from industrial and military injuries therefore they are thankfully rarely encountered in usual clinical practice. These chemical burns are sometimes fatal, however, and often associated with significant morbidity and prolonged hospitalisation (Davis 2002).

White phosphorus burns are extremely painful (Chou 2001). They affect areas of exposed skin and typically appear as yellowish, necrotic, full-thickness burns resulting from both chemical and thermal effects. The high lipid solubility (the ability of the phosphorus to penetrate the fatty tissues easily) of phosphorus can result in deep extension of the burn injury into the fatty subcutaneous tissues, and this can substantially delay wound healing. Phosphorus can be lethal if inhaled. It may also be absorbed systemically and this can result in multiple organ dysfunction due to its haemolytic effects on erythrocytes and toxic effects on organs, including the kidneys, liver and heart (Davis 2002; Eldad 1991; Souba 2007).

Most of the available options for treating phosphorus burns depend on the usual practice of clinician rather than the evidence-based practice; these include:

Initial management

A patient's clothes must be removed immediately, as they may ignite or re-ignite. During transportation of the burned person, the burn wound should be covered with a saline or water-soaked dressing until the patient reaches the hospital or other place of treatment (Al Barqouni 2010). On arrival, continuous irrigation of the burn site with copious amounts of saline or water is used to minimise any complications of phosphorus burns and pain control provided as needed (Eldad 1991; Kaufman 1988).

Identification and removal of phosphorus particles

Large, easily identifiable particles of phosphorus must be removed. Ultraviolet light or a solution of copper sulphate is sometimes used to facilitate the identification and removal of smaller or embedded particles. However, the use of copper sulphate may also have adverse effects, such as intravascular haemolysis and renal failure (Davis 2002).

Excision of the necrotic tissue

Excision involves removal of all dead, non-viable tissues.

Systemic support of the burned patient

In critically ill patients with phosphorus burns, practice frequently involves appropriate fluid replacement, with close monitoring of electrolyte concentrations (mainly serum calcium and phosphorus) and electrocardiograms (ECGs) to identify and reduce predictable complications such as hypocalcaemia, hyperphosphataemia and cardiac arrhythmia (Eldad 1955).

Long-term management

After completion of the initial treatment period, patients are discharged and followed up in an outpatient setting where further wound care (including pain management), physiotherapy, rehabilitation and psychiatric care should be given. In some patients, skin grafting and specific measures to prevent scar formation and contractures is required (Spanholtz 2009).

Why it is important to do this review

Despite the limited treatment options available in the management process for phosphorus burns, there is no clarity regarding the most effective treatment approaches, either for their immediate or the ongoing management. No systematic review has been undertaken to summarise evidence of the effects of alternative approaches for managing phosphorus burns. The circumstances in which phosphorus burns occur influence the types of studies likely to be possible. Phosphorus burns from causes other than munitions are likely to be isolated single case reports of industrial or other accidents. Although many more patients suffer burns from bombs and other weapons used during wars, these circumstances may not be conducive to carefully controlled comparisons of alternative management strategies. This reality has prompted some controlled experiments to be done in animals and we are currently preparing a completely separate systematic review of these animal studies.

These methodological challenges cannot alter the reality that people have sustained phosphorus burns over a period of more than 60 years, and that it is unfortunately the case that phosphorus burns will continue to occur accidentally and deliberately in the future. The responsibility of this review is therefore to provide information that will assist in the management of future burns, however they occur, using the results of research, while drawing attention to the important questions that remain inadequately addressed.

OBJECTIVES

To summarise the evidence for the effects (beneficial and harmful) of all interventions for treating people with phosphorus burns.

METHODS

Criteria for considering studies for this review

Types of studies

We considered any comparisons of different ways of managing phosphorus burns, including randomised trials where possible.

Types of participants

Studies involving people of any age and gender with phosphorus burns. We considered studies involving people with any percentage of total body surface area burned (%TBSA). The identification of phosphorus as the causative burn agent depended on the history of phosphorus exposure, and we accepted study authors' definitions of phosphorus burns. We have excluded studies involving non-human participants.

Types of interventions

Studies of all types of interventions, either topical or systemic, for the treatment of phosphorus burns. The review distinguished between emergency and post-emergency interventions. Eligible interventions included (but were not limited to) wound irrigation with saline or water, ultraviolet light, copper sulphate, surgical debridement (removal of dead tissues) and systemic support including fluid and electrolyte replacement and antibiotic therapy.

Types of outcome measures

Primary outcomes

1. Death
2. Time to complete wound healing/proportion of burns completely healed in a specified period of time

Secondary outcomes

1. Change in wound surface area over time/proportion of wounds partly healed in a specified time period
2. Complications, for example, intensive care unit admission, wound infection
3. Pain
4. Patient satisfaction (cosmetic appearance and/or function)
5. Quality of life
6. Length of hospital stay

Search methods for identification of studies

Electronic searches

We searched the following databases:

- the Cochrane Wounds Group Specialised Register (searched 30 September 2011);
- the Cochrane Central Register of Controlled Trials (CENTRAL) (*The Cochrane Library* 2011, Issue 3);
- Ovid OLDMEDLINE (1947 to 1965);
- Ovid MEDLINE (1950 to September Week 3 2011);
- Ovid MEDLINE (In-Process & Other Non-Indexed Citations 29 September 2011);
- Ovid EMBASE (1980 to 2011 Week 38);
- EBSCO CINAHL (1982 to 23 September 2011);
- Conference Proceedings Citation Index - Science (CPCI-S) (1990 to 30 September 2011).

We searched the Cochrane Central Register of Controlled Trials (CENTRAL) using the following search strategy:

#1 MeSH descriptor Phosphorus explode all trees
#2 MeSH descriptor Burns, Chemical explode all trees
#3 (#1 AND #2)
#4 phosphorus NEAR/5 burn*:ti,ab,kw
#5 “white phosphorus”:ti,ab,kw
#6 “red phosphorus”:ti,ab,kw
#7 “yellow phosphorus”:ti,ab,kw
#8 (#3 OR #4 OR #5 OR #6 OR #7)

The search strategies used in Ovid MEDLINE, Ovid EMBASE and EBSCO CINAHL can be found in Appendix 1, Appendix 2 and Appendix 3 respectively. We did not apply any methodological filters or restrictions on the basis of study design, language, date of publication or publication status.

Searching other resources

We handsearched the *Journal of the Royal Army Medical Corps* from 1939 to 1948. We also searched the World Health Organization (WHO) International Clinical Trials Registry Platform Search Portal (www.who.int/trialsearch). We checked the reference lists of all included studies to identify reports that had not been found using the methods outlined above.

Data collection and analysis

Selection of studies

We selected studies in two stages. First, based on the title and abstracts of reports, two review authors (LB, KE) independently selected those that were judged potentially relevant. To decide on eligibility we obtained the full texts of articles written in English that potentially matched our inclusion criteria, and which required further scrutiny. Secondly, two review authors (LB, KE) independently assessed the full texts of potentially eligible reports against the pre-determined eligibility criteria. A third review author (NS) arbitrated any disagreement.

Data extraction and management

Two review authors (LB, NS) independently extracted data from the included studies using a pre-determined data extraction sheet. The information extracted included study population (age, gender, setting); information on the location, severity and extent of the burn; the nature of the interventions; analysis; outcomes; and the characteristics of the study (source of funding, country, setting).

Assessment of risk of bias in included studies

We intended that two review authors would independently assess each included study using the Cochrane Collaboration tool for assessing risk of bias (Higgins 2011a). This tool assesses the risk of bias in six specific domains: sequence generation, allocation concealment, blinding, incomplete outcome data, selective outcome reporting and other issues (likely to be if the timing of outcome assessments are similar). Each criterion was to be judged using: low risk of bias, high risk of bias or at unclear risk of bias (see Appendix 4 for details of criteria on which the judgement was to be based). We intended to complete a ’Risk of bias’ table for each eligible study. We planned to discuss any disagreement amongst all review authors to achieve a consensus.

Measures of treatment effect

We planned to report the quantitative data in individual trials for outcomes listed in the inclusion criteria using risk ratios (RR) with corresponding 95% confidence intervals (CIs) for dichotomous outcomes, mean differences (MD) with 95% CIs for continuous outcomes, and hazard ratios (HR) and 95% CI for time to event outcomes (e.g. time to healing).

Unit of analysis issues

The unit of randomisation is the individual patient. If RCTs with a cluster-randomised design had been identified, to avoid unit of analysis errors in cluster-randomised trials we planned to re-analyse these studies by calculating the effective sample sizes where possible, according to the methods outlined in Higgins 2011b and, if necessary, we would have incorporated an estimate of the intra-cluster coefficient (ICC) using external estimates obtained from similar studies.

Dealing with missing data

Where data were missing from published reports, we intended to contact authors for further information. If these data were not available we would have made explicit the assumptions of any methods used to cope with missing data, performed sensitivity analyses to assess how sensitive results are to reasonable changes in the assumptions that are made, and addressed the potential impact of missing data on the findings of the review in the Discussion.

Assessment of heterogeneity

We planned to assess the studies for clinical heterogeneity by checking the inclusion criteria, exclusion criteria, differences in the intervention, differences in the control and differences in the definition used for outcomes. We planned to assess heterogeneity in the effect estimates by visually examining the forest plots, by the Cochrane Q statistic and the I^2 statistic values. The I^2 statistic examines the percentage of total variation across studies due to heterogeneity rather than due to chance. Values of I^2 over 75% indicate a high level of heterogeneity (Higgins 2003). Statistically significant values would have been interpreted in accordance with recommendations outlined by Deeks 2009.

Assessment of reporting biases

We planned to assess publication bias by preparing a funnel plot and examining it either visually or quantitatively by the rank correlation test and/or the graphical test with or without heterogeneity.

Data synthesis

We planned to pool the results of clinically homogenous groups of studies using the fixed-effect model for meta-analysis. If there had been evidence of some clinical and statistical heterogeneity (I^2 over 50%), we would have used a random-effects model. We would not have pooled studies if statistical heterogeneity (I^2 over 75%) was high. We presented results in a narrative format by type of intervention.

Subgroup analysis and investigation of heterogeneity

We planned to consider subgroup analyses according to the setting (i.e. evaluations of those with burns because of being in a conflict zone versus those exposed to phosphorus as an occupational hazard).

Sensitivity analysis

We planned to conduct a sensitivity analysis to investigate how conclusions might be affected if studies at high risk of bias (trials that did not report adequate allocation concealment or do not have blinded outcome assessment) are excluded from the analyses.

RESULTS

Description of studies

See: Characteristics of included studies; Characteristics of excluded studies; Characteristics of studies awaiting classification.
See: Characteristics of included studies; Characteristics of excluded studies.

Results of the search

Our searches identified 373 reports, and scrutiny of the titles and abstracts identified 23 of these that were potentially relevant. Two authors (LB and KE) obtained the full texts of these 23 records for detailed examination. We identified no further studies by searching the reference lists of selected studies or by handsearching. Of these 23 reports, we excluded 11 (see Excluded studies below) and 5 are awaiting further assessment after translation. This left only two reports in English in which different management strategies were compared.

Included studies

We identified no RCTs or quasi-randomised RCTs (the eligible designs pre-specified in our protocol). At this point we made a collective decision to deviate from our protocol to include any comparative studies in an effort to find any evidence, however weak.

The two included studies were both retrospectively assembled case series reporting comparisons of different ways of managing phosphorus burns. The first involved 77 of 96 patients treated at the US Army Institute of Surgical Research between 1950 and 1986 (Curreri 1970), and the second 11 patients treated at the US Army Surgical Research Unit in 1965 and 1966 (Summerlin 1967). In both these reports, comparisons were made between patients in whom copper sulphate had been used and patients in whom it had not been used before, during and after debridement.

Excluded studies

Eleven studies did not meet the inclusion criteria for the review and we excluded them for various reasons, the most common being that no treatment comparison had been reported. In summary there were three retrospective surveys (Barillo 2004; Chou 2001; Mozingo 1988) and eight case reports with no comparison group (Al Barqouni 2010; Conner 2007; Davis 2002; Frank 2008; Karunadasa 2010; Konjoyan 1983; Loveall 2007; Song 1985);see Table 1 and Table 2 for additional information.

Risk of bias in included studies

Both included studies were at high risk of bias. Firstly both were at high risk of selection bias since the comparison groups were not prospectively assembled at random; neither of the included reports described how patients had been selected for treatment with copper sulphate. Curreri 1970 stratified analyses by the %TBSA burned, but not in terms of other factors, such as co-morbidities, or type of treatment. Furthermore there is attrition bias: in Curreri 1970, only 77 out of 96 patients were included in the study report; the remaining 19 patients were not accounted for.

Effects of interventions

In the report of Curreri 1970, copper sulphate was used in 40 patients with phosphorus burns and not used in 37 patients. In the report by Summerlin 1967, copper sulphate was used in eight patients and not used in three patients.

Outcomes

Neither study reported the primary outcome of wound healing. Curreri 1970 stratified their analysis by the percentage of total body surface area (%TBSA) burned. The average duration of hospitalisation among patients with 0% to 20% TBSA burned was 101 days after treatment with copper sulphate and 97 days if copper sulphate had not been used. Average duration of hospitalisation among patients with 2% to 40% TBSA burned was 135 days after use of copper sulphate and 112 days among patients in whom copper sulphate had not been used. Neither of these differences between the two groups were statistically significant. No differences were observed in the time to eschar (a dry dark scab) separation or in residual contractures. The primary outcome of death was reported only in relation to the total number of patients who had burns resulting from chemical agents, this includes phosphorus, 5.6% (6/111). It was not reported how many of these deaths were in patients with phosphorus burns.

In Summerlin 1967, haematuria, haemoglobinuria, mild to severe hypocalcaemia, high level of copper in urine, oliguria and finally renal failure 20 to 72 hours after injury developed in three of the eight patients treated with copper sulphate, and one of them required haemodialysis. It was stated that all patients recovered, therefore there were no deaths reported. None of the three patients who did not receive copper sulphate experienced any of these complications.

DISCUSSION

It is a challenge to review evidence relevant to the management of phosphorus burns, as most of the cases occur in acute conflict circumstances, in which doing carefully designed research will be extremely difficult or impossible. We did not expect to find randomised trials. We found only reports in which different management strategies had been compared after assembling case series retrospectively. These provide little assurance that selection and measurement biases had been adequately controlled. It is possible that more and better evidence is contained in the reports awaiting translation from languages other than English.

However, the restricted evidence we have identified so far provides no support for the use of copper sulphate in the management of phosphorus burns, and some evidence of the serious complications that may follow its use. On the basis of possible harmful adverse events of copper sulphate, we suggest the use of alternative approaches, such as ultraviolet light (Wood's lamp), which are likely to be a safer option for identifying and removing small phosphorus particles.

We will update this review when reports published in languages other than English have been translated and assessed. We have also embarked on an analysis of potentially relevant animal research.

AUTHORS' CONCLUSIONS

Implications for practice

The treatment of people with acute phosphorus burns is based on clinical experience, custom and practice rather than research evidence (which is lacking). Removal of patients' clothes, continuous irrigation of their wounds with cold solutions and removal of phosphorus particles are the most important elements of the management of phosphorus burns. Beyond these common sense first

aid measures, the research we have reviewed provides little guidance on subsequent management. However, the evidence we had analysed so far suggests that copper sulphate should not be used for visualisation of phosphorus particles as what evidence there is suggests a possible association with adverse outcomes. Ultraviolet light can be used to assist the visualisation of phosphorus particles during the process of debridement as a safer alternative.

Implications for research

The conduct of high-quality randomised controlled trials to address the uncertainties around the management of people with phosphorus burns, is highly desirable, but would be extremely difficult given the context in which such burns occur.

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* *Indicates the major publication for the study*

CHARACTERISTICS OF STUDIES

Characteristics of included studies *[ordered by study ID]*

Curreri 1970

Methods	Retrospectively assembled case series based on the clinical records of all 111 patients admitted to the US Army Institute of Surgical Research between 1950 and 1986
Participants	77 out of a total of 96 patients with phosphorus burns
Interventions	**Without copper sulphate**: 37 patients: wounds irrigated with copious amounts of water or saline, debridement with removal of phosphorus particles at least once, and application of wet dressing with thick gauze pads, and irrigation with water or dilute solution of sodium bicarbonate **With copper sulphate:** 40 patients treated as above, plus application of copper sulphate before, during and after debridement
Outcomes	Average length of hospitalisation, the time required for eschar separation and incidence if residual contractures
Notes	USA

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	High risk	Not randomised
Allocation concealment (selection bias)	High risk	No allocation concealment

Summerlin 1967

Methods	Retrospective survey of the clinical records of patients admitted to the US Army Surgical Research Unit between 1965 and 1966
Participants	11 patients with phosphorus burns
Interventions	**Without copper sulphate**: 3 patients with phosphorus burns treated without copper sulphate **With copper sulphate:** 8 patients with phosphorus burns treated with copper sulphate
Outcomes	**Without copper sulphate:** no complications had been experienced **With copper sulphate:** haematuria, haemoglobinuria and mild to severe hypocalcaemia, high level of copper in urine, oliguria and finally renal failure 20 to 72 hours after injury developed in 3 patients out of 8. One required haemodialysis. Eventually all recovered
Notes	USA

Summerlin 1967 (*Continued*)

Risk of bias		
Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	High risk	Not randomised
Allocation concealment (selection bias)	High risk	No allocation concealment

Characteristics of excluded studies *[ordered by study ID]*

Study	Reason for exclusion
Al Barqouni 2010	Methodologically inappropriate, case report (Table 2)
Barillo 2004	Methodologically inappropriate, non-comparative retrospective study (Table 1)
Chou 2001	Methodologically inappropriate, non-comparative retrospective study (Table 1)
Conner 2007	Methodologically inappropriate, case report (Table 2)
Davis 2002	Methodologically inappropriate, case report (Table 2)
Frank 2008	Methodologically inappropriate, case report (Table 2)
Karunadasa 2010	Methodologically inappropriate, case report (Table 2)
Konjoyan 1983	Methodologically inappropriate, case report (Table 2)
Loveall 2007	Methodologically inappropriate, case report (Table 2)
Mozingo 1988	Methodologically inappropriate, non-comparative retrospective study (Table 1)
Song 1985	Methodologically inappropriate, case report (Table 2)

Characteristics of studies awaiting assessment *[ordered by study ID]*

Bonelli 1971

Methods	
Participants	
Interventions	
Outcomes	
Notes	Awaiting translation - study language: Italian

Broekhuizen 1982

Methods	
Participants	
Interventions	
Outcomes	
Notes	Awaiting translation - study language: Dutch

Carras 1993

Methods	
Participants	
Interventions	
Outcomes	
Notes	Awaiting translation - study language: French

Fang 1987

Methods	
Participants	
Interventions	
Outcomes	
Notes	Awaiting translation - study language: Chinese

Weinberger 1978

Methods	
Participants	
Interventions	
Outcomes	
Notes	Awaiting translation - study language: Hebrew

DATA AND ANALYSES

This review has no analyses.

ADDITIONAL TABLES

Table 1. Retrospective surveys with no treatment comparison

Study	Type	Participants	Interventions	Outcome	Other
Chou 2001 Taiwan	Retrospective survey of hospital clinical records between 1984 and 1998	7 out of 326 chemical burn patients resulted from white phosphorus, and 2 of these were presented	**Irrigation and dressing** Copious normal saline irrigation dressing with saline-soaked pads **Identification and removal of phosphorus particles** Identification of phosphorus particles **Use of copper sulphate or ultraviolet light** 1% copper sulphate solution for neutralisation **Systemic support** Monitoring for electrolytes and cardiac function **Long-term management** No details provided **Others** - none	1 of the 7 died from inhalation injury Of the 7 patients, 5 required skin grafting when wounds had not healed within 14 days of presentation. Hypocalcaemia was commonly encountered	Mentioned the use of cold solution in irrigation
Mozingo 1988 USA	Retrospective survey of clinical records in US Army Institute of Surgical Research between 1969 and 1985, mostly in Vietnam	49 out of 87 chemically burned patients were burned with white phosphorus	**Irrigation and dressing** Removal of clothes and copious water irrigation done as soon as possible **Identification and removal of phosphorus particles** Removal of particles from the skin surface **Use of copper sul-**	Cases of white phosphorus burns remained in hospital longer	Noticed the importance of not liquidising the phosphorus particles **Ref. 11, 13**

Table 1. Retrospective surveys with no treatment comparison (*Continued*)

			phate or ultraviolet light Copper sulphate solution (1% or less) or Woods lamp (ultraviolet light) used **Systemic support** No details provided **Long-term management** No details provided **Others** The report does not allow disaggregation of the management of the 49 patients with white phosphorus burns		
Barillo 2004 USA	Retrospective survey of clinical records in US Army Institute of Surgical Research between 1950 and 2000	146 out of 276 chemically burned patients were burned with white phosphorus	**Irrigation and dressing** Wounds thoroughly irrigated and then covered with saline or saline-soaked pads **Identification and removal of phosphorus particles** Visible particles of white phosphorus removed and placed in cold water to prevent re-ignition Immediate surgical debridement necessary and repeated until all phosphorus particles have been removed Debrided wounds examined at least twice daily for new particles or smoking areas, which would indicate the need for re-operation	Mortality increased from 5.4% between 1950 and 1968 to 13. 8% between 1969 and 1985. Mortality from 1986 to 2000 was 0% Hospital length of stay decreased from a mean of 90 days in the first 19 years of the study to a mean of 15 days in the most recent 15-year period. The chemical responsible for injury was white phosphorus in 146 cases	

Table 1. Retrospective surveys with no treatment comparison (*Continued*)

			Use of copper sulphate or ultraviolet light No details provided **Systemic support** No details provided **Long-term management** No details provided **Others** - none		

Table 2. Case reports, with no treatment comparisons

Study	Type	Participants	Interventions	Outcome	Other
Frank 2008 Germany	4 cases	German civilians picking up phosphorus (sometimes mistaken for amber) from North German sea beach	**Irrigation and dressing** Submerging affected skin in cold water. Saline used for irrigation **Identification and removal of phosphorus particles** Phosphorus particles removed, debridement of necrotic tissue (sometimes under general anaesthesia) **Use of copper sulphate or ultraviolet light** No details provided **Systemic support** No details provided **Long-term management** Defects in skin covered by allogenic grafts in one case. Vacuum-assisted closure in one case **Others** - none	All survived. First case discharged home after 4 weeks; 2nd after 12 days; 3rd after 20 days; 4th after 11 days	Refers to the use of white phosphorus in World War I, and to the military jargon 'willie pete' Emphasised the use of cold rather than warm water for irrigation
Karunadasa 2010 Sri Lanka	2 cases	2 soldiers injured by an exploding rocket-propelled grenade	**Irrigation and dressing** Clothes were not removed, with resulting	Both survived. Referred to aggressive rehabilitation after 13 weeks. No contracture observed at	

Table 2. Case reports, with no treatment comparisons (*Continued*)

			deep burns. Saline used for irrigation **Identification and removal of phosphorus particles** Serial excisions and debridement **Use of copper sulphate or ultraviolet light** No details provided **Systemic support** Intravenous antibiotics and blood transfusion **Long-term management** Grafting **Others** - none	12 months	
Davis 2002 USA	1 case	50-year old male worker at munitions manufactory suffered 36% total body surface area burns	**Irrigation and dressing** Clothes were removed. Water used for irrigation. **Identification and removal of phosphorus particles** Debridement and removing of phosphorus particles by metal forceps **Use of copper sulphate or ultraviolet light** No details provided **Systemic support** No details provided **Long-term management** 2 skin grafts were placed **Others** - none		
Konjoyan 1983 USA	1 case	21 year old male soldier injured after explosion of a defective mortar in an armed personnel carrier. Another soldier was killed by the blast	**Irrigation and dressing** Wounds irrigated and dressed with silver sulphadiazine **Identification and re-**	Survived. After 23 days, transferred to another government health facility to be closer to his home.	

Table 2. Case reports, with no treatment comparisons (*Continued*)

			moval of phosphorus particles Debridement of wounds on the left knee, with removal of all visible phosphorus particles **Use of copper sulphate or ultraviolet light** No details provided **Systemic support** Resuscitation with intravenous fluids, analgesics, oxygen and blood transfusion **Long-term management** Closure of wounds that were not healed. **Others** - none		
Song 1985 China	1 case	41-year old male patient 7% of surface area, 2nd degree burn on lower extremities	**Irrigation and dressing** Wound rinsed and cleaned with water, covered with wet gauze pad. **Identification and removal of phosphorus particles** No details provided **Use of copper sulphate or ultraviolet light** 0. 4% copper sulphate applied immediately and with wet gauze pads **Systemic support** No details provided **Long-term management** No details provided **Others** - none	The patient gets worse at night, developing nausea and vomiting, haematuria, jaundice and hepatomegaly On the 11th day the patient died of acute renal failure as result of copper ion absorption	Conclusion to use the silver nitrate solution instead, as it can make phosphorus particles non-flammable for 6 months or more, and also use of wet compress of 3% to 5% sodium bicarbonate
Conner 2007 USA	1 case	A 19-year-old man presented burns after exposure to an incendiary agent	**Irrigation and dressing** Burns irrigated with copious saline		

Table 2. Case reports, with no treatment comparisons (*Continued*)

			Identification and removal of phosphorus particles Remaining phosphorus particles removed. Surgical debridement if still present **Use of copper sulphate or ultraviolet light** Examination under ultraviolet light if required **Systemic support** No details provided **Long-term management** No details provided **Others** - none		
Loveall 2007 USA	1 case	Patient with hand actively burning	**Irrigation and dressing** Hand rinsed in warm tap water for an hour, then wrapped with gauze, and soaked in sterile water. Hand later submerged in vegetable oil **Identification and removal of phosphorus particles** Surgical excision **Use of copper sulphate or ultraviolet light** Examination under ultraviolet light **Systemic support** Inpatient intensive care unit management **Long-term management** No details provided **Others** - none		
Al Barqouni 2010 Palestine	1 case	18-year old male patient with 30% surface area burned	**Irrigation and dressing** Irrigation with dilute sodium bi-	8 days after admission, the patient was discharged relatively well,	

Table 2. Case reports, with no treatment comparisons (*Continued*)

			carbonate, wet dressing applied **Identification and removal of phosphorus particles** Debridement and removal of phosphorus particles **Use of copper sulphate or ultraviolet light** No details provided **Systemic support** Monitoring of electrolytes and cardiac function **Long-term management** No details provided **Others -** none	and after 16 months of follow-up no permanent complications	

HISTORY

Protocol first published: Issue 11, 2010

Review first published: Issue 3, 2012

CONTRIBUTIONS OF AUTHORS

Loai Barqouni conceived, designed and co-ordinated the review, extracted and checked quality of extracted data, undertook quality assessment, analysed and interpreted data, performed and checked statistical analysis, completed first draft of the review, performed part of writing or editing the review, made an intellectual contribution, approved final review prior to submission, advised on the review, secured funding, performed previous work that was the foundation of the current review, wrote to study authors/experts/companies, and is guarantor of the review.

Khamis Elessi conceived the review, extracted data, checked quality of data extraction, undertook quality assessment, analysed data, checked quality assessment, performed part of data analysis or interpretation, performed and checked quality of statistical analysis, advised on the review, and secured funding.

Nafiz Abu Shaaban conceived the review, analysed or interpreted data, checked quality assessment, performed part of data analysis or interpretation, advised on the review, secured funding and performed previous work which was the foundation for the current review.

Contributions of editorial base:

Nicky Cullum: edited the review, advised on methodology, interpretation and review content. Approved the final review prior to submission.
Sally Bell-Syer: co-ordinated the editorial process. Advised on methodology, interpretation and content. Edited and copy edited the review.
Ruth Foxlee: designed the search strategy, ran the searches and edited the search methods section.

DECLARATIONS OF INTEREST

No conflict of interest.

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DIFFERENCES BETWEEN PROTOCOL AND REVIEW

The eligibility criteria for type of studies were relaxed to include any comparative studies given the absence of any prospective, controlled trials. The absence of randomised or quasi-randomised evidence can be attributed to the circumstances in which phosphorus burns occur which make the possibility of conducting a randomised controlled trial (RCT) unlikely. However, despite the rarity of such RCTs, phosphorus burns will continue to occur and such a systematic review will provide the practitioner with the best available evidence in treating phosphorus burns.