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Evidence Review

# A Systematic Review of Methods of Eye Irrigation for Adults and Children with Ocular Chemical Burns

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## ABSTRACT

**Aim:** To present the best available research evidence on eye irrigation methods for ocular chemical burns to facilitate better-informed clinical decisions.

**Methods:** Randomized, quasi-randomized controlled trials and observational studies comparing the effectiveness of eye irrigation methods among adults or children as an active form of emergency treatment for ocular chemical burns were reviewed. Electronic databases in English and Chinese were searched from inception to June 2010. Two reviewers made independent decisions on whether to include each publication in the review and critically appraised the study quality independently. Given the clinical and methodological diversity among the studies, the review findings are presented in a narrative form.

**Results and Discussion:** Four studies involving 302 adults and children were identified. The results of this review indicate that patients who underwent irrigation with tap water immediately following alkali burns at the scene of injury had significantly better clinical and ocular outcomes. The evidence also suggests that in hospital settings, more patients preferred balanced saline solution (BSS) plus than other irrigation fluids. Irrigation with diphoterine was found in one study that resulted in better ocular outcomes following grade 1 and 2 ocular burns. With regard to duration of eye irrigation, patients with ocular chemical burns treated with prolonged irrigation reported shorter duration of treatment at hospital and absence from work. The results should be treated with caution, as there were significant differences between the comparison groups in some studies.

**Implications and Conclusions:** As prompt eye irrigation with tap water immediately after alkali burns had better outcomes, it would be important to commence eye irrigation immediately after burns are sustained. In this review, irrigating fluids including normal saline, lactated Ringer's, normal saline with sodium bicarbonate added, BSS Plus, and diphoterine solutions all yielded positive ocular outcomes suggesting for its use in hospital settings.

**KEYWORDS** eye irrigation, eye burns, chemical burns, systematic review

## BACKGROUND

### Ocular Chemical Burns

Eye injuries are medical emergencies that occur mostly at home, or at work, or are associated with assaults (May et al. 2000; Fea et al. 2008). Ocular chemical burns are one of the frequently reported causes of eye injuries (Yu et al. 2004; McGwin & Owsley 2005; Xiang et al. 2005). Ocular chemical burns are commonly sustained after exposure to acids or alkalis found in cleaning agents, fertilizers, bleaches, or plaster (Hoyt & Haley 2005). The chemicals that commonly cause alkali burns are ammonia, sodium hydroxide, ammonia hydroxide, potassium hydroxide, and calcium hydroxide, while those that most often cause acid burns are sulfuric, sulfurous, hydrofluoric, hydrochloric, nitrous, and acetic acids

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The severity of an ocular burn depends on the type, volume, temperature, pH, and concentration of the causative agent, impact force, and duration of exposure (Schrage et al. 2000; Pokhrel & Loftus 2007). Alkalis such as ammonium hydroxide and strong acids such as hydrofluoric acids are particularly hazardous, as they penetrate more rapidly into the anterior chamber of the eye and cause further damage (Kuckelkorn et al. 2002; Peate 2007). Although acids penetrate the cornea much less readily than do alkalis, the corrosive damage to the cornea is equally serious (Saini & Jain 2003; Duffy 2008).

Clinical signs of ocular chemical burns include reflex blepharospasm, conjunctival injection, limbal ischemia, corneal opacification, and periocular damage (Onofrey et al. 2005). After sustaining ocular chemical burns, patients often complain of pain, photophobia, blurred vision, and a foreign body sensation (Pokhrel & Loftus 2007). Sight-threatening complications include corneal or conjunctival scarring; corneal erosion, perforation or calcification; visual acuity deterioration; and permanent loss of vision (Kuckelkorn et al. 2002; Onofrey et al. 2005). These complications may have profound health and economic implications such as loss of income and increased medical costs (Islam et al. 2000). Providing effective treatment for ocular chemical burns is thus crucial to the optimization of client outcomes and prognosis.

## Management

Copious eye irrigation with water performed by bystanders, patients, or emergency response personnel at the scene of injury is a widely accepted immediate treatment for ocular chemical burns (Khaw et al. 2004; Duffy 2008). Eye irrigation helps to reduce the exposure time to the chemicals, to remove the chemical burden through elimination, dilution, and pH neutralization, and to reduce the incidence of corneal or conjunctival scarring, visual acuity deterioration, and permanent loss of vision (Rihawi et al. 2006; Xue 2008).

## Eye Irrigation

Effective eye irrigation is important to the accomplishment of therapeutic goals. Previous evidence suggests that eye irrigation should be initiated immediately or even before comprehensive ocular assessment (Hooper 1997; Ikeda et al. 2006), to ensure a decisive influence on clinical course and prognosis (Schrage et al. 2000; Rihawi et al. 2007).

Normal saline and tap water are the irrigating fluids frequently used for ocular chemical burns because of their low cost (Boyd-Monk 2005). However, normal saline might cause a stinging and burning sensation, resulting in further discomfort (Hooper 1997). Water is hypotonic to the corneal stroma and rinsing with water dilutes the corneal tissue and might lead to an increased uptake of water and diffusion of the chemical agents into the cornea. Irrigating the eyes with a fluid of higher osmolarity is sometimes recommended to mobilize water and corrosives out of the burnt tissue (Kuckelkorn et al. 2002). Other types of fluids suggested for eye irrigation include isotonic solutions such as lactated Ringer's solution, phosphate buffer solution, balanced saline solution, and fluids of high osmolarity such as diphoterine. Each of these fluids has its advantages and disadvantages (Gerard et al. 2002; Kuckelkorn et al. 2002).

Agreement has yet to be reached on the optimal duration of eye irrigation. Some authors have suggested the decision to cease eye irrigation be based on pH measurements of the tear film in the conjunctival fornices reaching a value between 7.3 and 8.0 (Onofrey et al. 2005; Duffy 2008), whereas others have proposed that irrigation to continue for a specific minimum period such as 15 or 30 minutes (McConnell 1991; Hoyt & Haley 2005).

There is little consensus on the volume of irrigating fluid that should be used to ensure effective treatment. Some authors have suggested the use of copious fluid volume (McConnell 1991; Khaw et al. 2004) until ocular pH reaches a neutral level, whereas others have suggested a specific amount of fluid ranging from 500 to 1,000 ml (Kuckelkorn et al. 2002; Boyd-Monk 2005). The suggested flow rate of irrigating fluids also varies from a maximum flow via an intravenous set (Webb 2004) to a constant and gentle flow (Kuckelkorn et al. 2002).

Eye irrigation can be an uncomfortable procedure, especially when prolonged. Fear of blindness or ocular-related complications is common (Kelch 2000). Topical anesthetics are sometimes used to facilitate irrigation and relieve pain (Hoyt & Haley 2005; Peate 2007). However, repeated application could result in dose-related toxicity in the corneal epithelium (Duffy 2008). Others have suggested continuous eye irrigation with a lidocaine-saline solution and a Morgan lens or using warmed saline (between 90°F and 100°F) for eye irrigation to promote comfort (Ernst et al. 1998; O'Malley et al. 2008).

In summary, it is clear from the existing evidence that many factors can influence the effectiveness of eye irrigation for patients with ocular chemical burns. Inconsistencies in practice have been found concerning the types, volume, and flow rate of eye irrigating fluids used, the duration of eye irrigation, and interventions aimed at promoting patient comfort during treatment. There has been no systematic review of eye irrigation methods for patients with ocular chemical burns.

## AIM

The aim of the review was to present the best available research evidence on eye irrigation methods for ocular chemical burns to facilitate better-informed clinical decisions.

## METHODS

### Selection Criteria

***Types of studies.*** All randomized and quasi-randomized controlled trials comparing the effectiveness of eye irrigation methods as an active form of emergency treatment for ocular chemical burns were considered. In the absence of randomized trials, retrospective and prospective observational studies that observed the course of events and outcomes for patients receiving different eye irrigation methods were included.

***Types of participants.*** Studies involving adults (aged 18 years and over) or children (aged 0 through 18 years) with ocular chemical burns were included.

***Types of interventions.*** Studies were eligible for inclusion if methods of eye irrigation were examined within the following comparison categories:

- Time to commence first eye irrigation.
- Types of eye irrigating fluids.
- Volume of eye irrigating fluids.
- Duration of eye irrigation.
- Flow rate of eye irrigating fluids.
- Temperature of eye irrigating fluids.
- Addition of anesthetics during eye irrigation.
- Use of eye irrigating delivery system.

***Types of outcome measures.*** The primary outcomes of interest included:

- Immediate ocular outcomes: pH value of tear films, severity of symptoms (e.g., pain, injection), visual acuity, intraocular pressure.

The secondary outcomes included:

- Ocular complications: corneal erosion, corneal calcification, corneal opacification, conjunctival scarring.
- Self-reported outcomes: satisfaction, comfort level, preference.
- Clinical outcomes: time to visual recovery, time elapsed to corneal reepithelialization, length of hospital stay.
- Cost: working days lost.

***Exclusion criteria.*** The systematic review excluded studies of these types:

- Single-case reports, narrative reports, literature reviews, systematic reviews, clinical guidelines, protocols, editorials, or expert opinion articles.
- In vitro or ex vivo studies.
- Those involving animal experiments and healthy volunteers as study participants.

### Search Strategies

Studies published in English or Chinese from inception of databases to June 2010 were considered for review. Electronic bibliographic databases were searched to identify keywords used in titles and abstracts, index terms, and subject headings. An extensive search of databases was performed using the search strategies developed to identify potential studies for inclusion. Hand searching was performed to identify studies or additional relevant source materials overlooked by the search strategies. The reference lists and bibliographies of all articles retrieved were scrutinized to identify further studies. A forward search on the authors of the studies identified was also performed. Electronic databases searched for primary publications written in English and Chinese, databases searched for gray literature or unpublished studies, and a typical search strategy are presented in Additional Material 1 (see journal's Web site).

### Study Selection

Two reviewers independently assessed the titles and abstracts of all publications identified during the search process. A study eligibility verification form was developed for the assessment. Full text of all articles deemed relevant to the systematic review or having inconclusive titles or abstracts were retrieved for further assessment. The two reviewers made independent decisions on whether to include each publication in the systematic review. Any disagreement was resolved by discussion with close attention to the selection criteria.

### Methodological Quality Assessment

The two reviewers independently assessed the methodological quality of the studies included in the review using the Joanna Briggs Institute critical appraisal checklists for randomized and pseudorandomized studies and descriptive/case series studies. Any disagreement was resolved by discussion.

### Data Extraction

Data from the included studies were extracted by one reviewer and checked by the other reviewer for accuracy. Data extraction was performed using a standardized form specifically developed for the systematic review.

### Data Synthesis

The included studies were categorized according to eye irrigation method, including the time to commence first eye irrigation, the types of the eye irrigating fluids used, and the duration of eye irrigation. The included studies were assessed for clinical and methodological heterogeneity by considering their study designs, settings, populations, samples, interventions, and outcomes. Meta-analysis was not undertaken due to heterogeneity of the studies, therefore findings are presented in a narrative summary.

## RESULTS

### Search Results

A total of 8,899 citations (1,943 in English and 6,956 in Chinese) were identified from the databases and 115 potentially relevant studies were retrieved. One hundred were excluded due to nonempirical nature of study, duplication, irrelevant topic or study design. In addition, three relevant studies published in English were excluded as there was no information about the type of eye irrigating fluid used (Kuckelkorn et al. 1995), and had unclear description of the outcomes (La Lau 1979; Watts & Mulira 1989). In another study, the outcomes of using a continuous corneal irrigation system for chemical burns were unclearly reported (Yamabayashi et al. 1990). Attempts made to contact these authors for further information were unsuccessful. Furthermore, seven studies published in Chinese (Wang et al. 1990; Shen 1994; Chen 1995; Keung & Fung 1997; Keung & Chien, 2000; Cheung et al. 2004; Huang et al. 2008) were excluded as there were insufficient details about the types of interventions, outcome measurement, methods of data analysis, and effectiveness of the eye irrigation methods. The reasons for exclusion of the 111 studies were presented in Additional Material 2 (see journal's Web site). Four studies in English were included in the systematic review. A flow chart of the study retrieval and selection is presented in the Figure 1.

### Methodological Quality

Incomplete details on methods of random assignment and a small sample size were issues of concern in one study (Herr et al. 1991). A post hoc power analysis indicated that the sample size was inadequate to detect significant differences in the outcome measures of preference and discomfort level. Neither did this study report the validity and reliability of the outcome measure of discomfort (Herr et al. 1991). Another major concern was the limited detail on confounding factors affecting the outcomes and the strategies to deal with them. For example, there were significant differences between the two comparison groups in the time between injury and initial hospital visit (Ikeda et al. 2006), and the delay in administering the first irrigation (Merle et al. 2005). The condition of patients receiving prolonged eye irrigation was more severe than those receiving conventional irrigation (Saari et al. 1984). In several instances, these confounding factors were not taken into account in the final analysis. All four studies did not report patients' existing ocular conditions that might affect the clinical outcomes after eye irrigation. Only one study reported the exclusion of patients with mental impairment that might preclude their determination of eye comfort associated with irrigating fluids (Herr et al. 1991). The strengths and limitations of these four studies were summarized in Additional Material 3 (see journal's Web site).

### Details of the Included Studies

A total of four studies involving 302 patients with ocular chemical burns were included. One study adopted a prospective, double-blind, randomized crossover design (Herr et al. 1991). Two observational descriptive studies involved retrospective analyses of medical records (Saari et al. 1984; Ikeda et al. 2006), and the other was a prospective, observational study (Merle et al. 2005).

The total number of patients and eyes burned ranged from 11 (12 eyes) (Herr et al. 1991) to 172 (194 eyes) (Saari et al. 1984). The patients ranged in age from 2 to 75 years in the study of Saari et al. (1984) and 17 of them were less than 19 years old. The patients' mean age in Merle et al. (2005) and Ikeda et al. (2006) ranged from 30 to 53 years. Herr et al. (1991) did not provide any information about the patients' age. The causative chemicals, major causes and severity of the ocular chemical burns, design, sample, interventions, and findings were summarized in Additional Materials 4–6 (see journal's Web site).

## TYPES OF INTERVENTIONS

Ikeda et al. (2006) determined the effects of prompt eye irrigation with tap water at the scene of injury in 53 patients with alkali burns. Three studies examined the irrigation methods in hospital settings including ophthalmology departments of university hospitals (Saari et al. 1984; Merle et al. 2005) and an emergency department (Herr et al. 1991). Two studies involving 77 patients examined the effectiveness of the types of eye irrigating fluids on ocular chemical burns (Herr et al. 1991; Merle et al. 2005). Saari et al. (1984) compared the effects of prolonged irrigation and conventional irrigation on ocular chemical burns among 172 patients. Various outcome measures adopted in these studies were summarized in Additional Materials 7 (see journal's Web site).

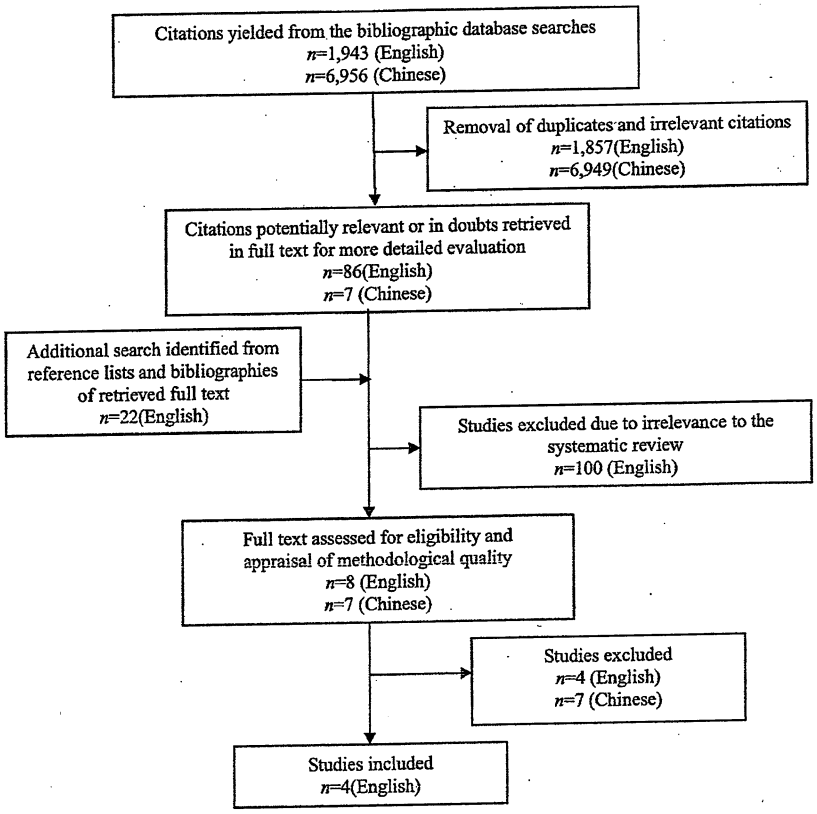


**Figure 1. Flow chart of the study retrieval and selection.**

## EFFECTS OF INTERVENTIONS

### Time to Commence First Eye Irrigation

In the study of Ikeda et al. (2006), 36 patients (49 eyes) had prompt eye irrigation at the scene of injury following alkali burns and 17 patients (29 eyes) did not have immediate eye irrigation. The range of duration of irrigation was 5–20 minutes for 26 patients and 30–60 minutes for 10 patients. All 53 patients were admitted to the emergency rooms and eye clinics in the hospital and received further irrigation for 30–60 minutes with 500 to 1,000 ml of physiological saline. The patients in the irrigation group were significantly younger than those without immediate irrigation (mean age: 30 vs. 53 years), and had significantly shorter mean time between injury and initial hospital visit (1.8 vs. 4.2 hours).

The ophthalmic examination following in-hospital irrigation showed a significantly lower prevalence of erosion of the eyes in the irrigation group (24%) than the no-irrigation group (86%). Not all patients underwent examination of the pH of the conjunctival sac following the in-hospital irrigation. All 34 eyes examined in the irrigation group showed a pH within normal range, while 21 eyes examined in the no-irrigation group had pH levels of 7.8 to 8.4 that required further irrigation with physiological saline. The intraocular pressures of all eyes examined were within normal range. The prevalence of good visual acuity after in-hospital irrigation was significantly greater in the irrigation group than the no-irrigation group (92% vs. 21%). Three eyes in the no-irrigation group had cataracts with poor visual acuity. The study also showed that the group with immediate irrigation had significantly fewer grade 2 injuries according to Hughes' classification than the no-irrigation group (24% vs. 86% of the eyes). No patients with immediate irrigation required hospitalization, but six patients (35.3%) without immediate irrigation were hospitalized and received further treatment. The mean time from injury until corneal wound healing was significantly shorter in the irrigation group

than the no-irrigation group (8 vs. 29 days) (Ikeda et al. 2006).

**Types of Eye Irrigating Fluids**

Eleven patients with chemical burns (12 eyes) in Herr et al.'s (1991) study acted as their own controls. Each underwent crossover irrigation of 500 ml of normal saline, lactated Ringer's, normal saline with sodium bicarbonate added, and balanced saline solution plus (BSS Plus, Alcon, Fort Worth, TX, USA), respectively, in a random order upon admission to the emergency department. A Mediflow lens (Morgan therapeutic lens, MorTan Inc., Torrington, WY, USA) was inserted and the irrigating fluids were run at a wide-open rate through an intravenous line. The results showed that more patients preferred BSS Plus. Normal saline had the lowest preference ranking. Both lactated Ringer's and normal saline with sodium bicarbonate added were intermediate in preference ranking. Seven out of 11 patients were asked to rate their discomfort. BSS Plus was identified as causing the least discomfort and scored significantly better than normal saline. Both lactated Ringer's and normal saline with sodium bicarbonate added were intermediate. More positive comments were obtained from patients rinsed with BSS Plus, and more patients gave negative comments about normal saline irrigation. All four irrigating fluids were found resulting in normalization of conjunctival pH. There was no change in conjunctival injection between irrigating fluids. Irritation caused the suspension of irrigation in two occasions with normal saline, and on one occasion using normal saline with sodium bicarbonate added. None of the patients could tolerate fluids other than BSS Plus.

Merle et al. (2005) involved 66 adult patients (104 eyes) with alkaline ocular burns. Of them, 48 eyes (46%) were rinsed with 500 ml normal saline (physiological solution) and 56 eyes (54%) with 500 ml diphoterine (Laboratories Prevor, Valmondois, France). Anesthetic eye drops were administered before irrigation. No information was given about the type of anesthetic eye drops. All 66 patients underwent immediate eye irrigation using water or mineral water at the scene of injury. The mean time between chemical exposure and irrigation at hospital was $4.7 \pm 7.3$ hours. The result showed that the time elapsed to reepithelialization was significantly shorter in the diphoterine group when compared with the normal saline group for grade 1 burns; and grade 2 burns. For grade 3 burns, there was no significant difference between the two groups. All injured eyes with grade 4 burns were rinsed with normal saline, so no comparison could be made. No significant differences were found between the two groups in final visual acuity for grade 1, 2, and 3 burns, and in the prevalence of corneal opacity for grade 2 and 3 burns.

**Duration of Eye Irrigation**

In Saari et al. (1984), 53 patients (30.8%) received prolonged irrigation and 119 patients (69.2%) underwent conventional irrigation. All patients immediately washed their eyes with water at the scene of injury, underwent eye irrigation with physiological saline at the local health centre or at the outpatient department, and had eye irrigation with physiological saline once again after being admitted to the two eye hospitals. Those appeared more severe on admission and within 6 hours after chemical exposure received prolonged irrigation with 1,000 ml of physiological saline over 1 to 2 hours through an intravenous line at the eye hospitals.

Of the 57 patients with acid burns, 27 received prolonged irrigation. The mean duration of treatment at hospital after prolonged and conventional irrigation, respectively, was 4.8 and 9.5 days, and that of absence from work was 7.7 and 16.9 days. For patients receiving prolonged irrigation and with burns caused by AIV solution and inorganic acids, the final visual acuity was good except the eye injured after car battery explosion. No data were provided about the final visual acuity of patients who received conventional irrigation.

Of the 64 patients with alkaline burns, 22 received prolonged irrigation. The mean duration of treatment at hospital after prolonged and conventional irrigation, respectively, was 5.4 and 7.8 days, and that of absence from work was 8.4 and 15 days. For patients receiving prolonged irrigation and with burns caused by sodium hydroxide, mortar and cement, the final visual acuity was good. For patients receiving conventional irrigation, one patient whose burns caused by mortar and cement had final visual acuity below 0.1, while the injured eye became blind in two patients whose burns were caused by sodium hydroxide. No data were provided about the final visual acuity of patients with burns caused by other alkali chemicals.

Of the 51 patients with other ocular chemical burns, four received prolonged irrigation. No data were provided on the differences in duration of treatment at hospital and absence from work between patients receiving prolonged irrigation and conventional irrigation. The final visual acuity of patients receiving prolonged irrigation and conventional irrigation was good.

## DISCUSSION

This systematic review was to determine the effectiveness of eye irrigation methods for ocular chemical burns in enhancing patient outcomes. These studies suffered from a number of methodological weaknesses that could have biased the results.

In the study of Ikeda et al. (2006), the group that underwent immediate irrigation with tap water at the scene of injury had a significantly lower prevalence of corneal and conjunctival erosion and all eyes examined showed a pH within normal range. The prevalence of good visual acuity determined following in-hospital irrigation or second visit was significantly greater in the irrigation group. The study also showed that the patients with immediate irrigation had significantly fewer grade 2 injuries and did not require hospitalization. The mean time from injury until corneal wound healing in the irrigation group was significantly shorter. However, the results should be treated with caution, as there were significant differences between the two comparison groups. The mean time between injury and the initial hospital visit was significantly shorter in the irrigation group (a difference of 2.4 hours). The patients in the irrigation group were also significantly younger than those in the no-irrigation group (a difference of 23 years in mean age). These confounding factors were not taken into account in the final analysis. Moreover, information about the concentration and amount of causative chemicals, and duration of chemical exposure was not provided in the study. It is difficult to estimate the severity of ocular burns and determine the effectiveness of immediate eye irrigation on ocular outcomes. Furthermore, not all patients underwent pH examination of the conjunctival sac following in-hospital irrigation. Since the major purpose of copious immediate irrigation of the affected eyes is to remove the chemical burden through elimination, dilution, and pH neutralization, all studies examining the benefits of immediate eye irrigation should obtain pH measurement of the tear films to determine its effectiveness. In the irrigation group, no information was given regarding the volume of fluids used during immediate irrigation.

There is insufficient evidence on the effectiveness of different types of eye irrigating fluids in ocular and clinical outcomes. The results in Herr et al.'s (1991) study found more patients preferred BSS Plus to normal saline, lactated Ringer's, and normal saline with sodium bicarbonate added. BSS Plus was identified as causing the least discomfort among the four irrigating fluids. More positive comments were obtained from patients rinsing with BSS Plus, and more patients gave negative comments about normal saline irrigation. All four irrigating fluids resulted in normalization of conjunctival pH and there was no change in conjunctival injection between irrigating fluids. However, it should be noted that incomplete details on methods of random assignment and a small sample size were issues of concern. Only 7 of the 11 patients recruited were asked to rate their discomfort level. Neither did Herr et al. (1991) report on the validity and reliability of the outcome measure of discomfort. No information was provided about the time between chemical exposure and irrigation at hospital and details on immediate irrigation at the scene of injury. In this study, 11 adult patients acted as their own controls, and each underwent irrigation of four irrigating fluids. The washout period between administrations of each irrigating fluid was not mentioned. The total volume of irrigating fluids administered amounted to 2,000 ml and the cumulative effects on dilution and pH neutralization were possible.

In the study of Merle et al. (2005), the results showed that for patients with grade 1 and 2 burns, the time elapsed to reepithelialization was shorter in the diphoterine group compared with the normal saline group. Caution should be taken in interpreting the results, as there were significant differences between the two comparison groups. There was a delay in administering the first irrigation in the group receiving normal saline (an average of 76.3 minutes in the group rinsing with normal saline vs. 33 minutes in the group rinsing with diphoterine). Although the results showed the healing time of corneal scarring for grade 1 and 2 burns was shorter with diphoterine, there was no significant difference between the two groups for grade 3 burns. No significant differences in final visual acuity were found among patients rinsing with diphoterine or normal saline for grade 1, 2, and 3 burns. There were also no significant differences in the prevalence of corneal opacity between the two groups for grade 2 and 3 burns.

There is also insufficient evidence to draw conclusion on the optimal duration of eye irrigation for ocular burns. The investigation of Saari et al. (1984) is the only study that included children in their study populations. However, limited information was provided regarding the nature and severity of the injuries, and whether the treatments for children and adults were the same. It is unclear that the prescription of prolonged irrigation with 1,000 ml of physiological saline over 1 to 2 hours was based on clinical judgment (those appears to be more severe), or rather the decision should be based on pH measurements of the tear films. The results demonstrated that patients mostly with alkaline and acid burns treated with prolonged irrigation reported shorter duration of treatment at the hospital and absence from work. However, no inferential statistics were employed to determine differences between groups. Furthermore, the patients' visual acuity was described in general terms such as "good final visual acuity" in selected cases. It is impossible to compare the visual acuities between groups. No data were provided about the final visual acuity of patients with burns other than acids and alkalis who underwent conventional irrigation (Saari et al. 1984).

The severity of ocular burns depends on the type, volume, temperature, pH, and concentration of the causative agents, impact force, and duration of exposure (Schrage

et al. 2000; Pokhrel & Loftus, 2007). All included studies failed to provide this crucial information to assist in clinical decision-making. Our search identified no clinical trials or comparative studies of patients with ocular chemical burns that determine the effectiveness of different volume, flow rate, temperature of eye irrigating fluids, and comfort measures used during eye irrigation.

This systematic review had several limitations. Only one study was identified that included children in their study populations. Due to limited information provided regarding the children's demographic and clinical data, it was impossible to draw conclusion on the effectiveness of prolonged irrigation on the outcomes. A final limitation is that we only consider articles published in English and Chinese, which could lead to language bias.

## IMPLICATIONS FOR PRACTICE AND RESEARCH

Currently, there is insufficient evidence to recommend practice of eye irrigation among adults or children as an active form of emergency treatment for ocular chemical burns. As prompt eye irrigation with tap water immediately after alkali burns had better ocular outcomes, it would be important to commence eye irrigation immediately after burns were sustained. In this review, irrigating fluids including normal saline, lactated Ringer's, normal saline with sodium bicarbonate added, BSS Plus, and diphoterine solutions all yielded positive ocular outcomes suggesting for its use in hospital settings. The current limited evidence suggests that health care professionals need to continuously update themselves about the latest evidence on the optimal methods of eye irrigation in enhancing patient outcomes.

Better-designed, randomized, and quasi-experimental trials are needed to further examine the effective eye irrigation methods for ocular chemical burns. Future studies should provide sufficient information about the demographic and clinical data including the types and severity of ocular injuries, causative chemicals, first-aid management, and time elapsed to eye irrigation. Standardized outcome measures such as pH measurement of tear films, visual acuity, and comfort level should be used. A clear description of the eye irrigation protocol is crucial to facilitate comparisons across studies. Future research could consider using stratified random sampling to examine the differential effect of eye irrigation methods among patients with acid, alkali, or other types of chemical burns.

## CONCLUSIONS

To conclude, there is insufficient evidence to determine the optimal eye irrigation methods to improve ocular and clinical outcomes. Further trials should consider the potentially confounding factors such as the time to commence eye irrigation and cumulative effects of irrigating fluids that might affect the outcomes and adopt strategies to deal with them.

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## Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1: Search srategies
Table S1: Reasons for exclusion of the 111 excluded English and Chinese studies
Table S2: Summary of the strengths and limitations of the four included studies
Table S3: Summary of the type of causative chemicals
Table S4: Summary of the causes and severity of chemical burns
Table S5: Summary of design, sample, country, interventions, and findings of the four included studies
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