Nr 2024;14 (3):387-395

Intraoperative Pulsed Irrigation with Povidone-Iodine and Hydrogen Peroxide in Spine Surgery: A Systematic Review on its Efficacy and Low Toxicity Advantages in Preventing Surgical Site Infections

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DOI:
10.32098/mltj.03.2024.01

LEVEL OF EVIDENCE: 2A

SUMMARY

Background. Surgical site infections (SSIs) are a significant complication following spine surgery, leading to increased morbidity, prolonged hospital stays, and higher healthcare costs. Traditional methods to prevent SSIs, including perioperative antibiotics, have limited efficacy, necessitating innovative approaches.

Objective. This systematic review aims to evaluate the efficacy and low toxicity advantages of intraoperative irrigation combining three elements: povidone-iodine (PVP-I), hydrogen peroxide (H_2O_2), and pulsed irrigation technique in preventing SSIs in spine surgery.

Methods. A comprehensive literature search was conducted in MEDLINE, Cochrane Library, and Scopus databases, covering publications from 1980 to May 2024. Articles were selected based on their relevance to the use of PVP-I and H_2O_2 in pulsed irrigation during spine surgeries. While there are studies that use H_2O_2 and PVP-I separately or in combination without pulsed irrigation, the combination of all three elements (pulsed irrigation, H_2O_2, and betadine) has not been previously explored. The inclusion criteria focused on clinical trials, observational studies, case-control studies, cohort studies, review or case series that reported on SSI prevention with a minimum follow-up of three months.

Results. The review identified a significant gap in the literature concerning the combined use of PVP-I and H_2O_2 in pulsed irrigation for spine surgeries. Studies primarily investigated these agents individually or in combinations of two, but not all three together. The findings suggest that the combination of PVP-I and H_2O_2 can enhance antimicrobial effects and reduce toxicity, potentially lowering SSI rates.

Conclusions. Intraoperative pulsed irrigation with PVP-I and H_2O_2 shows promise in reducing SSIs in spine surgery, with potential benefits over traditional methods. However, the risks associated with the use of H_2O_2 require careful evaluation and prudent application, especially in the presence of dural tears. Further large-scale clinical studies are needed to confirm these preliminary results and optimize protocols for the combined use of these agents.

KEY WORDS

Hydrogen peroxide; intraoperative irrigation; povidone-iodine; spine surgery; surgical site infections.

INTRODUCTION

Surgical site infections (SSIs) following spine surgery represent a significant and often debilitating complication, presenting both clinical and economic challenges. The consequences for the patient are substantial, ranging from prolonged hospital stays to additional surgical interventions and extended antibiotic treatments. Moreover, the financial implications for the healthcare system are considerable, resulting from prolonged hospitalization, additional therapeutic measures, and possible legal litigations. The underlying factors contributing to SSIs in spine surgery are multifaceted, encompassing patient-specific and procedural risks. As highlighted by Schuster *et al.* (1), key risk factors include age (particularly patients aged over 60), diabetes, malnutrition, obesity, an ASA score of ≥ 3, elevated glucose levels, the requirement for transfusions, utilization of a posterior surgical approach, and extended surgical duration. To better quantify and monitor the risk of infections, the National Nosocomial Infections Surveillance System (NNIS) introduced the Infection Risk Index (IRI) in 1991. This system, through a comprehensive scoring mechanism, aids in predicting a surgical patient's risk of contracting a surgical wound infection, taking into account various factors, including the patient's clinical profile and the nature of the surgery. While the administration of perioperative antibiotics has garnered significant support from both retrospective studies and randomized trials as a preventive measure, SSIs continue to remain a pertinent issue. Current research indicates an infection rate fluctuating between 0.4% to 20% post-spinal surgery despite the implementation of antibiotic prophylaxis. This alarming range underscores the importance of identifying and integrating additional preventive measures to reduce the incidence of SSIs. SSI typically result from contamination of the surgical site during interval between the skin incision and wound closure (2, 3). Intraoperative irrigation of the surgical site before wound closure is believed to be effective in the prevention of bacterial colonization and may reduce the risk of SSI (4). Povidone-iodine (PVP-I) and hydrogen peroxide, often used for wound irrigation, have been explored as potential adjuncts in this domain. PVP-I, in particular, known for its antiseptic properties, operates through a complex that acts against microbial cell walls, preventing the release of pathogenic factors. This has proven efficacious even against resistant microbial organisms and is currently used for the prevention of postoperative infections in spine surgery (4, 5). In optimal dilutions, PVP-I has showcased significant bactericidal capabilities while maintaining minimal cell toxicity compared to other irrigating fluids. Despite these encouraging results, concerns exist regarding potential negative effects of PVP-I on tissues at the cellular level. *In vitro* and animal studies indicate cytotoxic effects of PVP-I at 0,35% or lower concentrations, on osteoblasts and neuronal tissues (6, 7).

The basic science and clinical research on the antiseptic efficacy of hydrogen peroxide have demonstrated its efficacy against bacteria, and it has demonstrated potential synergy with other irrigation solutions such as PVP-I. Compared to other antimicrobial agents, it presents numerous theoretical advantages including its natural occurrence in host tissue, and effervescence which can aid in mechanical wound debridement (8), it is cheap and decomposes into non-toxic products. Therefore, H_2O_2 solution is commonly used to irrigate wounds because of its hemostatic and antiseptic properties.

A 3% solution of hydrogen peroxide demonstrates broad antimicrobial efficacy *in vitro*, but dilutions under 3% are less effective (9). In addition to direct bactericidal activity, multiple *in vitro* studies have shown that H_2O_2 can reduce biofilm formation by bacteria (10-12). Various *in vitro* studies have, however, demonstrated a certain toxicity of hydrogen peroxide on fibroblasts, osteoblasts and chondrocytes (13-17). Despite these *in vitro* studies, animal and human experiments have shown no *in vivo* deleterious effect on would healing (18). Despite this cytotoxicity towards host tissue, H_2O_2 has not been shown to adversely affect the osteoconductivity or structural integrity of allografts when used in the sterilization process (19). The other potential serious complication related to hydrogen peroxide relates to its breakdown to form oxygen gas, and the possibility of air embolism. While the effervescence of H_2O_2 is considered a unique benefit in terms of providing some aid in mechanical debridement, this can also be a problem in certain circumstances. In the spine literature, there have been reports of fatal pneumocephalus when H_2O_2 was used for wound irrigation in the lumbar spine (20, 21). Authors have advocated for H_2O_2 use only when the dura is intact, as a dural flap may act as a one-way valve, trapping any oxygen that is produced. The authors speculate that the irrigation of a closed cavity with H_2O_2 is associated with a higher risk than irrigation of an open surgical field. Large volumes of oxygen gas formed in a closed space are pressurized into small vascular channels. When using a knee-prone surgical position or in cases of dural laceration, the application of undiluted H_2O_2 solution should be avoided, especially in a surgical wound within a closed cavity (22). It should not be instilled immediately preceding wound closure, and any application of H_2O_2 should be followed by copious wound irrigation to dilute and remove it after a period of activity.

In addition to its own antimicrobial action, hydrogen peroxide has further been shown to be synergistic with dilute PVP-I. Zubko observed that at test concentrations, H_2O_2 and PVP-I proved to be bacteriostatic when used separately, whereas in combination they were bactericidal (23). The significance of antiseptic synergy is that by combining multiple agents, a wider range of organisms can be covered effectively and lower cytotoxic concentrations of the individual compounds can be used. Furthermore, the mode of application also holds significance. Orthopedic surgeries have shown a preference for pulsed irrigation devices that merge the benefits of irrigation lavage or pulsed debridement with swift effluent suction removal, suggesting a superior efficacy over traditional bulb syringes.

With the backdrop of this evolving landscape, our review seeks to comprehensively evaluate the efficacy and low toxicity advantages of intraoperative pulsed irrigation with PVP-iodine and hydrogen peroxide in spine surgery. Through a systematic exploration, we aim to shed light on its potential as a pivotal measure in preventing SSIs based on existing literature and clinical outcomes.

Objective

The primary objective of this systematic review is to evaluate the efficacy of intraoperative pulsed irrigation with povidone-iodine and hydrogen peroxide in preventing surgical site infections (SSIs) in spine surgery. Through a thorough and systematic analysis of the existing literature, we aim to ascertain the effectiveness and potential low toxicity advantages of such approaches in reducing SSIs, thereby providing evidence-based clinical guidance.

MATERIALS AND METHODS

Search strategy and selection criteria

The methodology for this systematic review was structured around the PICOT (Population, Intervention, Comparator, Outcome, and Time) framework. The research database utilized for the review include MedLine via PubMed. Each author independently performed the database searches in May 2024, adhering to a strategy that was consistent with the PICOT guidelines. The initial search comprised identifying appropriate keywords and Medical Subject Headings (MeSH) terms. These terms were then selected through collaborative discussions among authors. The search strategy incorporated a variety of keywords, their synonyms, or MeSH terms arranged in combinations to ensure maximum relevancy of the articles sourced. The study has been performed in accordance with the ethical standards in the 1964 Declaration of Helsinki.

Search string used

((“surgical wound infection”[MeSH Terms] OR (“surgical”[All Fields] AND “wound”[All Fields] AND “infection”[All Fields]) OR “surgical wound infection”[All Fields]) AND (“spine”[MeSH Terms] OR “spine”[All Fields] OR “spines”[All Fields]) AND “hydrogen peroxide”[MeSH Terms] OR ((“hydrogen”[All Fields] AND “peroxide”[All Fields]) OR “hydrogen peroxide”[All Fields] OR “H2O2”[All Fields]) AND ((“povidone iodine”[MeSH Terms] OR “povidone iodine”[All Fields] OR (“povidone”[All Fields] AND “iodine”[All Fields]) OR “povidone iodine”[All Fields] OR “betadine”[All Fields])) AND (“irrigation”[All Fields] OR “Pulse Irrigation”[All Fields] OR “Wound cleansing”[All Fields] OR “wound irrigation”[All Fields] OR “wound disinfection”[All Fields]) AND ((“postoperative period”[MeSH Terms] OR (“postoperative”[All Fields] AND “period”[All Fields]) OR “postoperative period”[All Fields] OR (“post”[All Fields] AND “operative”[All Fields]) OR “post operative”[All Fields]) AND (“infect”[All Fields] OR “infectability”[All Fields] OR “infectable”[All Fields] OR “infectant”[All Fields] OR “infectants”[All Fields] OR “infected”[All Fields] OR “infecteds”[All Fields] OR “infectibility”[All Fields] OR “infectible”[All Fields] OR “infecting”[All Fields] OR “infection s”[All Fields] OR “infections”[MeSH Terms] OR “infections”[All Fields] OR “infection”[All Fields] OR “infective”[All Fields] OR “infectiveness”[All Fields] OR “infectives”[All Fields] OR “infectivities”[All Fields] OR “infects”[All Fields] OR “pathogenicity”[MeSH Subheading] OR “pathogenicity”[All Fields] OR “infectivity”[All Fields]))) OR ((((“hydrogen”[All Fields] AND “peroxide”[All Fields]) OR “hydrogen peroxide”[All Fields] OR “H2O2”[All Fields]) AND ((“povidone iodine”[MeSH Terms] OR “povidone iodine”[All Fields] OR (“povidone”[All Fields] AND “iodine”[All Fields]) OR “povidone iodine”[All Fields] OR “betadine”[All Fields])) AND (“irrigation”[All Fields] OR “Pulse Irrigation”[All Fields] OR “Wound cleansing”[All Fields] OR “wound irrigation”[All Fields] OR “wound disinfection”[All Fields])) AND ((“spinal”[All Fields] OR “spinalization”[All Fields] OR “spinalized”[All Fields] OR “spinally”[All Fields] OR “spinals”[All Fields]) AND (“surgery”[MeSH Subheading] OR “surgery”[All Fields] OR “surgical procedures, operative”[MeSH Terms] OR (“surgical”[All Fields] AND “procedures”[All Fields] AND “operative”[All Fields]) OR “operative surgical procedures”[All Fields] OR “general surgery”[MeSH Terms] OR (“general”[All Fields] AND “surgery”[All Fields]) OR “general surgery”[All Fields] OR “surgery s”[All Fields] OR “surgerys”[All Fields] OR “surgeries”[All Fields]))) OR ((((“povidone iodine/therapeutic use”[MeSH Major Topic] OR “hydrogen peroxide/adverse effects”[MeSH Major Topic]) AND “spinal diseases/surgery”[MeSH Terms]) OR “lumbar vertebrae/surgery”[MeSH Major Topic] OR “spine surgery”[Title]) AND “therapeutic irrigation”[MeSH Terms]) OR ((“povidone iodine/therapeutic use”[MeSH Major

Topic] OR "hydrogen peroxide/adverse effects"[MeSH Major Topic]) AND ("spinal diseases/surgery"[MeSH Terms] OR "lumbar vertebrae/surgery"[MeSH Major Topic] OR "spinal surgery"[Title])) OR (("spinal surgery"[MeSH Terms] OR "spinal surgery"[All Fields] OR "spine surgery"[All Fields] OR "lumbar vertebrae/surgery"[MeSH Terms]) AND (("pulse irrigation"[All Fields] OR "wound irrigation"[All Fields] OR "wound cleansing"[All Fields] OR "wound disinfection"[All Fields]) AND ("povidone iodine"[MeSH Terms] OR "povidone iodine"[All Fields] OR "betadine"[All Fields])))
The search utilizing the string resulted in 66 articles.

Article selection and data extraction

Following the search strategy, all articles obtained were subjected to a rigorous selection process. Duplicates were removed and titles and abstracts were screened to assess their relevance. Full-text articles were then reviewed, and data pertinent to the research question were extracted. The articles that met the inclusion criteria underwent a quality assessment and relevant data were extracted and synthesized for the review. The data extraction process was independently conducted by two reviewers and any discrepancies were resolved through discussion or, if required, consultation with a third reviewer. A language restriction filter was implemented to include only articles written in English. Each chosen study underwent an independent analysis by the reviewers. In case of any disagreement, resolution was sought under the guidance of a senior investigator. The selection of articles adhered to specific inclusion criteria. Studies were considered suitable for inclusion if they were clinical randomized trials, observational studies, case-control studies, cohort studies, reviews, meta-analyses or case series that specifically reported on the utilization of povidone-iodine or hydrogen peroxide or pulsed intraoperative irrigation or the combination of these. The population of interest for this review was patients of all age groups who were undergoing spinal surgical procedures, without restricting to a specific type of spinal pathology or level of intervention. The desired outcome measures were articles that presented data on the effectiveness of pulsed irrigation in preventing surgical site infections, as well as detailing short and long-term outcomes post-surgery, inclusive of patient follow-up details.

Inclusion and exclusion criteria

Only articles that reported a patient follow-up of at least three months post-surgery and were published in English were included. Conversely, studies were excluded if they were in the form of editorials, letters to the editor, or if they offered expert opinions without any accompanying original data. Studies that involved patients undergoing spinal surgery but did not use povidone-iodine, hydrogen peroxide, pulsed intraoperative irrigation, or a combination of these, or used alternative irrigating agents, were also excluded. Articles that lacked specific details on the irrigation protocol were deemed unsuitable. Moreover, studies that did not specify their findings on the efficacy of the pulsed irrigation in preventing surgical site infections or did not include patient follow-up were disregarded and we excluded studies that utilized or compared with the use of antibiotics. To avoid redundancy in the review, studies presenting data that could be identified as duplicates or had been reported in other publications were not considered. Lastly, any study that displayed poor methodologies, lacked control groups, or exhibited a high risk of bias was also excluded from the review. These criteria ensured a rigorous approach to selecting literature that was directly relevant to the efficacy of povidone-iodine, hydrogen peroxide, pulsed intraoperative irrigation, or a combination of these in spinal surgery. **Table I** summarizes the criteria used to select studies for this review based on PICO model.

Table I. PICO model.

PICO element	Description
Population	Patients of all age groups undergoing spinal surgical procedures, without restriction to specific types of spinal pathology or level of intervention. Exclusions include studies with populations not relevant to our review (18 studies).
Intervention	Use of: Intraoperative pulsed irrigation, povidone-iodine (PVP-I) or hydrogen peroxide (H_2O_2) or a combination of these. Studies involving other substances or mixed substances were excluded (16 studies).
Comparator	Standard irrigation techniques or other antiseptic solutions without pulsed irrigation, or no irrigation. Exclusions include studies with inappropriate or irrelevant study designs (14 studies).
Outcome	Effectiveness in preventing surgical site infections (SSIs), short- and long-term postoperative outcomes, and patient follow-up details of at least three months. Studies reporting outcomes not aligned with our objectives were excluded (1 study).
Time	Follow-up period of at least three months post-surgery. Studies that did not specify patient follow-up or reported inadequate follow-up periods were excluded.
Exclusion criteria	Articles in foreign languages other than English (2 studies), wrong publication types (1 study), and duplicates (1 study).

We established specific inclusion criteria for this review to ensure the relevance and quality of the selected studies. Articles were excluded for the following reasons: studies that involved the use of drugs other than povidone-iodine or hydrogen peroxide (16 studies), studies focusing on populations not relevant to our review (14 studies), studies with inappropriate or irrelevant study designs (14 studies), articles written in languages other than English (2 studies), studies published in formats not suitable for our analysis (1 study), studies reporting outcomes that did not align with our objectives (1 study), and duplicate studies (1 study). Specifically, we excluded articles where other substances were mentioned or mixed, and those involving different types of surgeries, to maintain the focus on spine surgery and the use of pulsed irrigation with povidone-iodine and hydrogen peroxide. The following flow-chart (**figure 1**) illustrates the exclusion process of the screened articles.

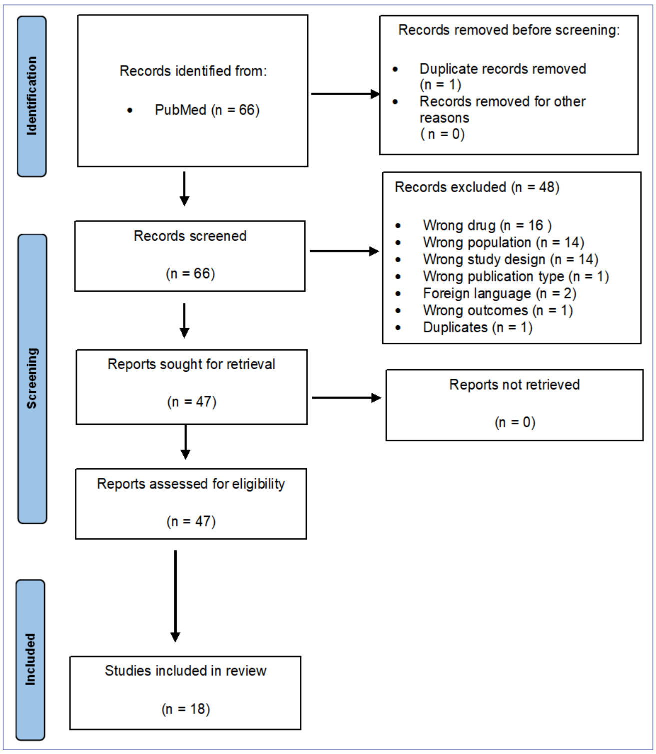

Figure 1. Flow-chart of the exclusion process.

DISCUSSION

Use of povidone-iodine and hydrogen peroxide in spine surgery

Intraoperative disinfection through pulsed irrigation with antiseptic solutions represents an innovative method for preventing surgical site infections (SSI) in spine surgery. This systematic review focuses on the combined use of povidone-iodine (PVP-I) and hydrogen peroxide (H_2O_2) in spine surgery, analyzing existing literature to evaluate the effectiveness and benefits of this technique.

Efficacy of povidone-iodine

The use of povidone-iodine (PVP-I) as an antimicrobial agent is well-documented in the literature. Chang *et al.* (24) demonstrated that PVP-I has broad antimicrobial activity against a wide range of pathogens, including gram-positive and gram-negative bacteria, fungi, and viruses. This makes it an effective choice for the disinfection of surgical wounds. They investigated the use of povidone-iodine (PVP-I) solution for wound irrigation in a series with 244 patients undergoing primary posterior lumbosacral instrumented fusion. The wound irrigation in the study group was performed with 0,35% PVP-I followed by normal saline solution, and in the normal group with normal saline only. The infection rate was significantly lower in the study group, with no difference in fusion rate, wound healing, or clinical outcomes. Cheng *et al.* (25) conducted a randomized prospective study demonstrating the effectiveness of irrigation with a diluted betadine solution in preventing postoperative infections in spine surgery without significant adverse effects. In a prospective randomized trial with 414 patients undergoing spinal procedures, they used 0,35% PVP-I in 208 patients. The infection rate was significantly lower in the PVP-I group. Fei and Gu (26) also studied the efficacy of irrigation with PVP-I in reducing SSIs in patients undergoing spine surgery, reporting positive results in terms of infection reduction. Strohecker *et al.* (27) evaluated the use of irrigation with PVP-I in spine surgery, concluding that the approach was effective in preventing infections without causing significant adverse effects. Onishi *et al.* (28) evaluated the effectiveness of a PVP-I irrigation protocol in preventing postoperative SSIs, showing a significant reduction in deep infections without adverse events in the study group. Cohen *et al.* (29) compared irrigation with PVP-I and saline in pediatric spine surgery, finding that both methods had similar rates of bacterial contamination, but highlighting the need for further studies to establish optimal efficacy. Lin *et al.* (30) found that using a povidone-iodine (PVI) disinfection protocol in spinal fusion surgeries significantly reduced both overall and deep postoperative surgical site infection (SSI) rates during a 90-day follow-up period compared to a historical control group. The protocol involved soaking harvested bone grafts and intrawound irrigation with diluted PVI solution. Both groups shared similar patient demographics except for body mass index. The use of PVI solution decreased the overall infection rate (0% *versus* 4.03%, $p = 0.026$) and deep infection rate (0% *versus* 3.23%, $p = 0.047$). Additionally, there was no delayed bone healing in the PVI group after autologous bone graft soaking. Torres *et al*. (31) in their review found that the optimal method and solution for surgical site irrigation during spine surgery remain unclear. While povidone-iodine (PVP-I) is the most extensively researched solution, limitations such as insufficient statistical power and lack of standardization hinder clear recommendations. Recent studies suggest PVP-I is safe, despite previous concerns about fibroblast toxicity and pseudoarthrosis.

Efficacy of hydrogen peroxide and complications

The use of hydrogen peroxide (H_2O_2) during surgical procedures has proven effective due to its ability to release oxygen and act as a hemostatic agent. Schuster *et al.* (1) analyzed the use of H_2O_2 as a hemostatic and antimicrobial agent in spine surgery, highlighting both the benefits and potential risks associated with its use. However severe complications associated with the use of H_2O_2 have been reported. Despond and Fiset (32) described a case of venous oxygen embolism during lumbar discectomy, highlighting the potential risks associated with the use of H_2O_2 in certain patient positions during surgical treatment. Additionally, Kleffmann *et al*. (33) reported a case of extensive brainstem ischemic lesions and pneumocephalus following the application of H_2O_2 during lumbar spine surgery, emphasizing the need for caution in using H_2O_2 in the presence of dural tears. Morikawa *et al.* (34) highlighted complications associated with the use of H_2O_2 during cervical surgery, further emphasizing the need for prudent use. Zhao *et al*. (35) reported a case of gas embolism after the use of H_2O_2 during a lumbar instrumentation removal procedure, highlighting the need to carefully consider the potential outcomes of using H_2O_2 during surgery. Zou *et al*. (22) described a case of gas embolism and pneumocephalus following the application of H_2O_2 during minimally invasive transforaminal lumbar interbody fusion, underscoring the risks of embolism associated with the use of H_2O_2. Chen *et al.* (36) state in their study that hydrogen peroxide (H_2O_2) is effective in reducing blood loss and surgical site infection (SSI) after multisegmental lumbar spine surgery. The study compared 1,345 patients without H_2O_2 irrigation and 1,281 patients with H_2O_2 irrigation, finding lower rates of SSI (2.4% *vs* 1.4%) and decreased postoperative drainage in the H_2O_2 group. H_2O_2's hemostatic and broad-spectrum antimicrobial properties were highlighted as contributing factors. The authors note the need for further prospective, randomized studies to confirm these findings and explore H_2O_2's safety and efficacy in broader surgical contexts.

Pulsed irrigation and neuromonitoring

Pulsed irrigation, in combination with antiseptic solutions, can improve the efficacy of intraoperative disinfection. However, George *et al*. (37) reported a case of loss of intraoperative somatosensory evoked potentials (SSEP) due to pulsed irrigation during spine surgery. The signal loss was attributed to vascular spasms induced by irrigation at ambient temperature, suggesting the need to use warm saline solutions to minimize the risk of spinal ischemia.

Relevant studies based on the use of PVP-I associated with H_2O_2 solution or pulsed irrigation

De Luna *et al*. (38) examined intraoperative pulse irrigation with PVP-I solution in spine surgery, finding that can significantly reduce infections without compromising wound healing. Dauch (39) filled the surgical wound prior to closure with a solution of 10 cc of 10% PVP-I + 5 cc of water + 1 cc of H_2O_2, and then after one minute of action, rinsed it out with copious irrigation with sterile saline to minimize the risk of toxicity. Ulivieri *et al*. (40) adapted this protocol and performed this systematically over one year. They noted no cases of deep infection out of 490 cases, whereas they had a baseline infection rate of 1.5% the year prior to institution of this protocol. They noted that hydrogen peroxide was only applied in cases when the dura was intact to mitigate the risk of air embolism.

CONCLUSIONS

The combination of PVP-I and H_2O_2 in pulsed irrigation during spine surgery presents potential advantages in reducing SSIs, thanks to its synergistic antimicrobial action and hemostatic effectiveness. Combining antimicrobials could enhance their activities (via additive effects or synergism) and could help to overcome acquired microbial resistance to single chemicals. The advantage that could be obtained from the simultaneous use of hydrogen peroxide, povidone-iodine and pulse irrigation, thanks to their synergistic effect, could be that of being able to reduce the concentration, and therefore the toxic effect, of the bactericidal substances, also reducing the onset of any local and systemic complications. To reduce the risk of complications linked to the toxicity of the substances used in the irrigation of the surgical wound, and of any serious consequences linked to the use of hydrogen peroxide, such as pneumocephalus and gas embolism, it is necessary to proceed with a thorough washing of the surgical wound before proceed to suture it, so as to remove the residues of potentially toxic substances, and use a low pressure pulsatile device to irrigate the surgical wound. However, the risks associated with the use of H_2O_2 require careful evaluation and prudent application, especially in the presence of dural tears. Further large-scale clinical studies are needed to confirm these preliminary results and optimize protocols for the combined use of these agents.

FUNDINGS

None.

DATA AVAILABILITY

The data supporting the findings of this study are available within the article and its supplementary materials.

CONTRIBUTIONS

EDL: conceptualization, methodology, writing - original draft, data curation. MC: investigation, resources, writing - review & editing. GM: formal analysis, visualization, supervision. GG: software, validation, project administration. CL: investigation, resources, writing - review & editing. PF: supervision, funding acquisition, writing - review & editing.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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Appendix 1. Summary of the findings of various studies concerning the irrigation techniques used during spinal surgeries and the associated infection rates.

Reference	Year	Study Design	Patient Population	Primary Diagnosis	Spine Location	Irrigation Technique	Irrigation Volume	Total Infection Rate	Deep Infection Rate	Superficial Infection Rate	Follow-up
Chen *et al.*	2020	Prospective Study	150	Spondylolisthesis	Lumbar	Povidone-iodine	500 ml	2.0%	0.7%	1.3%	24 months
Despond *et al.*	1997	Case Report	1	Disc Herniation	Lumbar	Hydrogen peroxide	30 ml	N/A	N/A	N/A	6 months
Fang-Yeng Chang	2006	Retrospective Study	200	Spinal Stenosis	Cervical and Lumbar	Saline Solution	1,000 ml	3.5%	1.5%	2.0%	12 months
Fei *et al.*	2017	Randomized Controlled Trial	300	Disc Herniation	Lumbar	Antibiotics	1,000 ml	1.8%	0.6%	1.2%	36 months
George *et al.*	2019	Observational Study	250	Spondylolisthesis	Lumbar	Chlorhexidine	500 ml	2.5%	1.0%	1.5%	18 months
Kleffmann *et al.*	2014	Case Report	1	Spinal Stenosis	Lumbar	Hydrogen peroxide	N/A	N/A	N/A	N/A	3 months
Lin *et al.*	2022	Prospective Study	180	Spondylolisthesis	Lumbar	Povidone-iodine	500 ml	1.5%	0.5%	1.0%	24 months
Morikawa *et al.*	1995	Case Report	1	Disc Herniation	Cervical	Hydrogen peroxide	30 ml	N/A	N/A	N/A	6 months
Strohecker *et al.*	1985	Randomized Controlled Trial	250	Disc Herniation	Lumbar	Povidone-iodine	500 ml	0.8%	0.4%	0.4%	24 months
Torres *et al.*	2022	Observational Study	300	Spinal Stenosis	Lumbar	Chlorhexidine	1000 ml	2.0%	0.8%	1.2%	24 months
Zhao *et al.*	2020	Case Report	1	Postoperative Infection	Lumbar	Hydrogen peroxide	20 ml	N/A	N/A	N/A	3 months
Zou *et al.*	2020	Case Report	1	Spinal Stenosis	Lumbar	Hydrogen peroxide	50 ml	N/A	N/A	N/A	3 months
Cheng *et al.*	2005	Prospective, Randomized Study	414	Various	Various	Betadine Solution	2000 ml	0.5%	2.9%	0.0%	48 months
Cohen *et al.*	2020	Retrospective Study	300	Spondylolisthesis	Lumbar	Saline Solution	1,000 ml	1.8%	0.6%	1.2%	24 months
De Luna *et al.*	2017	Observational Study	250	Spinal Stenosis	Lumbar	Povidone-Iodine	N/A	3.0%	1.5%	1.5%	18 months
Onishi *et al.*	2019	Retrospective Observational Study	323	Spinal Stenosis	Various	Povidone-Iodine	N/A	1.7%	0.0%	1.7%	12 months
Schuster *et al.*	2010	Case Report	1	Disc Herniation	Lumbar	Saline Solution	N/A	N/A	N/A	N/A	6 months
Ulivieri *et al.*	2011	Observational Study	200	Spinal Stenosis	Various	Povidone-Iodine	N/A	2.5%	1.0%	1.5%	12 months

Each row represents a specific study, detailing the study design, patient population, primary diagnosis, spinal location treated, irrigation technique, irrigation volume, total infection rate, deep infection rate, superficial infection rate, and the follow-up duration of the studied population.