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Operation-Related Infection Prevention in Neurosurgical Procedures - A Review

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ABSTRACT

Similar to other medical procedures, neurosurgical operations carry a risk of complications, especially infections, which occur in 0.7% to 12% of cases. Such complications increase morbidity rates across patients, prolong hospital stays, and incur unnecessary costs for hospitals. A comprehensive knowledge of the characteristics of the etiology of such infections, methods of prophylaxis, as well as antibiotic treatment, is crucial in preventing infections and making the procedures safer for patients. Currently, prevention of post-surgical infections relies on antibiotic prophylaxis, utilizing medications such as intravenous cefalosporins (cefazolin, ceftriaxone) or powdered vancomycin – data show that such treatment significantly reduces infection rates post-surgery. High-grade data also reveal that intraoperative wound irrigation with antibiotic or antiseptic solutions helps reduce such complications. The purpose of this study is to analyse the most common methods for preventing infection in neurosurgery, compare the effectiveness of different approaches, and highlight areas for further research.

Keywords: Neurosurgery, infection, prevention, antibiotics

1. INTRODUCTION

Neurosurgical procedures carry a risk of infection – including that of surgical site infections (SSIs), which occurs in 1% to 5% of craniotomies (Fei et al., 2016) and 0.7% to 12% of spinal operations (Koutsoumbelis et al., 2011). These complications result in higher morbidity and mortality, prolonged hospitalizations, and increased healthcare costs (Scala-Bertola et al., 2025).

In the United States, SSIs related to spinal and cerebral procedures are most commonly caused by Gram-positive bacteria, such as *Staphylococcus aureus* and *Staphylococcus epidermidis*, which are part of the skin's natural microbiota (Sasso and Garrido, 2008).

SSIs pose a significant clinical risk in neurosurgical operations, since they can be life-threatening (Scala-Bertola et al., 2025), with estimated morbidity rates of 1.2% to 5.3% in craniotomies, 3% to 15% in post surgical meningitis (PNM) and around 10% after ventricular drainage (Zheng et al., 2023; Magni et al., 2024). The purpose of this

review is to present current knowledge regarding infection prevention methods for neurosurgical procedures and to highlight their limitations.

2. REVIEW METHODS

An electronic literature search was conducted using PubMed for studies published through August, 2025. The following mix of keywords was used: “neurosurgery”, “antibiotic”, “prophylaxis”, “infection”, “prevention”, and their derivatives. To be included in this study, articles had to be related to the area of interest and published in English. Exclusion criteria consisted of: articles that did not cover the area of interest (prevention methods of neurosurgery-related infections), and articles written in a language other than English. Any redacted studies were excluded from this review. The publication date was set between January 1995 and August 2025. This approach allowed for a comprehensive understanding of the background, as well as current knowledge regarding infection prevention methods in neurosurgical procedures (Figure 1).

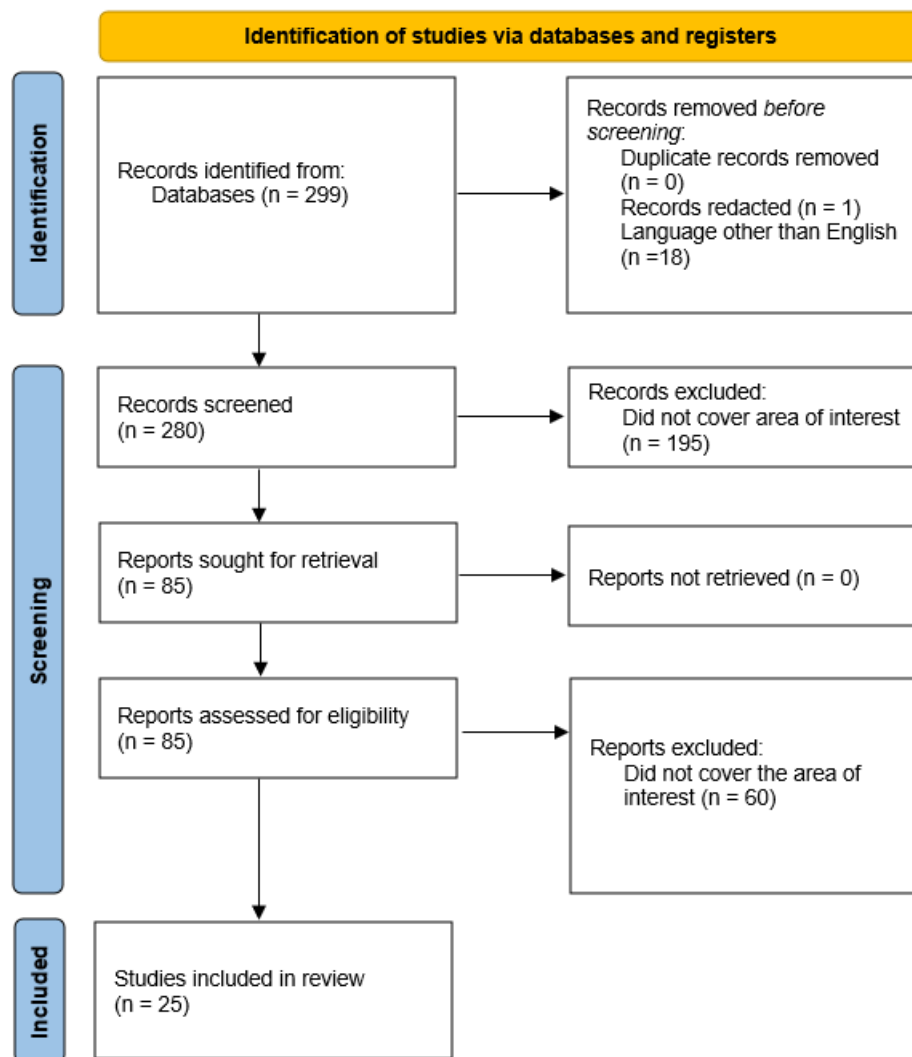


Figure 1. Studies included in the review – selection flow chart

3. RESULTS

Antibiotic prophylaxis

The use of cefazolin and other broad-spectrum antibiotics has been the standard prevention method in neurosurgical procedures (McLeod et al., 2013). Below, we propose a review of antibiotics used for neurosurgical infection prophylaxis, organized by their international name.

Cefazolin – a first-generation cephalosporin and an effective treatment for infections caused by Gram-positive bacteria, with a limited Gram-negative coverage. It is widely used as prophylaxis in various surgical procedures, including neurosurgical procedures, due to its low cost, broad spectrum of activity, and good tissue penetration (Kim et al., 2022). The standard dose of cefazolin is 2 grams administered 60 minutes before the first incision for patients weighing under 120kg, and 3 grams for patients weighing over 120 kg, with a maintenance dose of an additional 1 gram every 4 hours (Scala-Bertola et al., 2025).

A recent study by Nagy et al., (2025) revealed that the perioperative use of cefazolin in instrumented lumbar spine procedures was superior to clindamycin. In the study, the use of a single dose of 1g or 2g cefazolin administered intravenously was associated with an SSI occurrence of 10.6% to 11.52%, compared with 21.67% in the single-dose clindamycin group; therefore, decreasing the risk by nearly 50%. The study also revealed that the differences between single-dose administration and 72h were not statistically significant, and therefore, single-dose or short-term prophylaxis may be preferable. However, a meta-analysis by Liu et al., (2014) revealed that the use of third-generation cephalosporins was not superior to alternative regimens, such as first-generation cephalosporins (cefazolin and cefuroxim), glycopeptides (vancomycin), and aminoglycosides (gentamycin).

Ceftriaxone, a third-generation cephalosporin and a broad-spectrum medication, effective against Gram-positive, Gram-negative, and some anaerobic bacteria, was also used in studies. A study by Zhao et al., (1995) included 343 patients who underwent neurosurgical procedures. It revealed that the use of a regular prophylaxis of penicillin and gentamycin administered intravenously for 5 to 7 days twice a day resulted in 7.2% risk of post-operative infection. In contrast, one or two doses of perioperative ceftriaxone (1g of ceftriaxone in 5ml of saline, administered intravenously over 5 minutes, 30 minutes before the first incision, with an additional dose administered in case of surgeries lasting longer than 4 hours) reduced the incidence of such complications to 1.75% in the same hospital department.

Vancomycin is a glycopeptide antibiotic that inhibits the synthesis of the bacterial cell wall, used in the treatment of gram-positive bacterial infections, including those caused by methicillin-resistant *Staphylococcus aureus* (MRSA) as well as methicillin-susceptible *Staphylococcus aureus* (MSSA) (Patel et al., 2026). Powdered vancomycin was used perioperatively as a method of infection prevention in numerous studies. A systematic review and a meta-analysis by Texakalidis et al., (2019) revealed that the use of powdered vancomycin significantly decreased the risk of SSIs (especially the deep SSIs) in patients undergoing spinal and cranial surgeries. The study included a total of 16,369 participants. In the case of patients who underwent spinal surgeries, powdered vancomycin prophylaxis resulted in the occurrence of SSI in 1.9% of patients, in comparison to 4.9% of patients who did not receive such treatment. In cranial surgery patients, the occurrence was 1.9% and 5% in the powdered vancomycin and non-vancomycin group, respectively. The differences in vancomycin doses (1 gram vs 2 grams vs composite dose) were not statistically significant.

A meta-analysis by Alotaibi et al., (2016) which included 2365 participants in total, revealed that antibiotic prophylaxis (using vancomycin, cloxacillin, oxacillin, piperacillin, clindamycin, or cefotiam) reduces the risk of meningitis post-craniotomy by 66% compared to placebo. In that study, whether the antibiotic displayed Gram-negative coverage and surgery duration were not statistically significant.

Irrigation

Prophylactic intraoperative incisional wound irrigation (pIOWI) is a known method for preventing infections intraoperatively. Various solutions can be used to irrigate the wound before suturing, helping remove potential contaminants, such as metabolic waste, pathogens, or debris (Papadakis, 2021).

A recent meta-analysis by Groenen et al., (2024) revealed high GRADE analysed the effectiveness of wound irrigation using antiseptic (0.1% to 10% aqueous iodine, polyhexanide, chlorhexidine, hydrogen peroxide, and strongly acidic aqueous electrolyzed solutions), antibiotic (cefazolin, gentamicin, rifampicin, imipenem, clindamycin, ceftriaxone, metronidazole, and bacitracin), saline solutions as well as no irrigation at all. It was concluded that wound irrigation using antiseptic solutions was associated with a decreased risk of SSIs in comparison to no irrigation. Use of antibiotic and antiseptic solutions was superior to the use of saline and no irrigation. The study revealed high-certainty data indicating that the use of antiseptic solutions decreased the risk of SSI by 40% in comparison to no irrigation. In the study, the use of antibiotic solutions reduced the risk of SSI by 54% compared with no irrigation; however, the certainty level was low. Use of saline irrigation was not superior to no irrigation, and the differences between antibiotic and antiseptic solutions were not statistically significant. The summary of the prevention methods mentioned is provided in Table 1.

Table 1. Summary of the most important infection prevention methods used in neurosurgery procedures

Study	Publication year	Study type	Type of prevention method	Type of surgery	No. of patients (N)	Findings
Nagy et al.,	2025	Retrospective patient data analysis	Cefazolin – 1g or 2g vs Clindamycin - single dose vs 72h	Instrumented lumbar spine surgery	N = 915	SSI occurred in 11.2% of patients overall. Infection rates were significantly lower in the Cefazolin group, regardless of the length of administration.
Liu et al.,	2014	Analysis of 5 randomized control trials	Third-generation cephalosporins vs. conventional antibiotic regimen*	Cranial, spinal, burr-hole, shunt, transsphenoidal	N = 2209	No significant difference in the rates of SSIs between third-generation cephalosporins and conventional antibiotic regimen.
Zhao et al.,	1995	Open - label study	Ceftriaxone vs. Penicillin and Gentamycin	Various neurosurgical procedures (tumors, aneurysms, AVM, drainage of subdural hematoma, etc)	N = 343 (Ceftriaxone) N = 361 (Penicillin and Gentamycin)	The incidence of meningitis in the Ceftriaxone group was 1.75% compared to 7.2% in the Penicillin and Gentamicin group (the prior year). The department and the staff remained the same.
Texakalidis et al.,	2019	Systematic Review and Meta-Analysis	Powdered vancomycin vs non-vancomycin group	Spine surgery (fusion, decompression, osteotomy, resection)	N = 16 369	Incidence of overall SSI was significantly lower in the vancomycin group. Differences between doses (1g vs 2g) were not statistically significant.
Alotaibi et al.,	2016	Meta-Analysis	Various antibiotic regimens	Craniotomy	N = 2365	The odds of meningitis were reduced by 66% in the prophylaxis group vs. the placebo group.
Groenen et al.,	2024	Systematic Review and Meta - Analysis	Irrigation with antiseptic solutions vs irrigation with antibiotic solutions vs saline irrigation vs no irrigation	All types of surgeries, including some neurosurgical procedures	N = 17,188	Irrigation with antiseptic (high level of certainty) and antibiotic solutions (low level of certainty) was associated with a significant reduction in the incidence of SSI in comparison to no irrigation at all. Saline was not significantly superior to no irrigation at all.

*ie. Trimethoprim-sulfamethoxazole, Gentamycin and Vancomycin, Ampicillin-Sulbactam, Cefazoline

4. DISCUSSION

Infection risk assessment

In certain groups of neurosurgical patients, preventing infections may be especially important to consider. For example, patients undergoing a second craniotomy were more likely to suffer from a systemic infection than patients undergoing a craniotomy for the first time (Chang et al, 2003). Well-known risk factors of SSIs in spinal surgery include: BMI over 30, diabetes mellitus, immunodeficiency, smoking, malnutrition (preoperative albumin below 3.5 mg/dL), posterior spinal fusion, and duration of surgery

over 3 hours (Liu et al., 2018; Fei et al., 2016). In case of patients undergoing craniotomies as a treatment of brain neoplasms, SSIs are more likely to develop in patients displaying the following characteristics: male gender, older age, history of wound infection, and significant length of operation (McCutcheon et al., 2016). It is crucial that, before surgery, a thorough examination and history are obtained in order to identify the possible risk factors and plan an appropriate prophylactic approach.

Antibiotic prophylaxis in the context of bacterial resistance

Even though antibiotic prophylaxis is currently the most common way of preventing infection in neurosurgery, the rise of antibiotic resistance is a global problem that necessitates implementing more responsible approaches to such procedures. A tool, potentially able to aid this issue, could be a microbiological or molecular analysis of the patient's skin microbiota performed before the surgery. Identifying the bacterial species colonizing the skin affected by the surgery and the consequent antibiogram could give the clinician a clear idea of which antibiotic to use as an infection prophylaxis, thereby preventing a further increase in bacterial resistance. However, this approach may not be ideal in every case. For example, in time-sensitive and emergency surgeries, there often is not enough time for proper microbiological or molecular analysis of such samples. Also, despite the most common etiology of neurosurgery-related SSIs being bacteria residing in the patient's own microbiota (such as *S. aureus* or *S. epidermidis*), the infections may be caused by other pathogens, especially those found in the hospital environment, which can display various mechanisms of antibiotic resistance. Therefore, pre-surgery microbiological analysis aimed in identifying the bacteria colonising the patient and their antibiotic resistance profiles may prove to be an interesting tool for research and statistical purposes, rather than being used in everyday clinical practice.

Antiseptic irrigation – the ‘solution’ to microbial resistance?

The use of antiseptic wound irrigation is a potential alternative approach to standard antibiotic prophylaxis. High-grade data indicates that such a course of action is more likely to decrease the risk of infection in comparison to no irrigation (Groenen et al., 2024). The use of commonly used antiseptics in clinical practice, such as iodine, chlorhexidine, or hydrogen peroxide, could reduce the amount of antibiotics used, potentially mitigating the effects of bacterial resistance. More research comparing the effectiveness of antiseptics vs. antibiotics or the use of both in neurosurgical practice is needed to verify that claim.

Antibiotic allergies – potential alternatives

Antibiotic allergies are a well-known clinical challenge that creates a need for a highly individualized approach in the prevention of perioperative infections, such as SSIs. Their clinical presentation can be varied, from mild symptoms such as a rash or discomfort to life-threatening systemic reactions, anaphylactic shock, or even death. In the process of selecting the most suitable infection prevention method, identifying such allergies through an extensive history is crucial, as well as a proper annotation in the documentation, to prevent adverse reactions, ensure the patient's comfort without compromising the effectiveness of the treatment (Dhole et al., 2023). In the case of an antibiotic allergy, the most common course of action is to recommend an alternative antibiotic. That is why research comparing the effectiveness of different groups of antibiotics, or the aforementioned antiseptic solutions, could provide a list of alternative methods that combine patient safety with clinical efficacy.

Cost-benefit analysis

Finding a balance between maximizing patient outcomes and the economic aspects of treatment is a necessary skill for healthcare institutions all over the world. However, preventing infections may allow for shorter hospital stays, reduce medication use, require fewer diagnostic tests, and, therefore, generate lower costs for hospitals. For example, the use of powdered vancomycin in the prevention of SSIs in neurosurgical procedures resulted in savings of \$244,402 to \$433,675 USD per 100 spinal fusion procedures (Theologis et al., 2014). While enticing, irresponsible antibiotic use may exacerbate microbial resistance and undermine long-term savings in the long run (Allen et al., 2018). Antibiotic prophylaxis alternatives, as well as new technologies (i.e. bacteriophages, personalized medicine, immunomodulatory therapies), can potentially help mitigate the risks of standard treatment and lower overall treatment costs.

Future of infection prevention

In light of antibiotic resistance, efforts are made to develop alternative methods of preventing perioperative infections. Using personalized medicine, the patient's risk factors, genetic predispositions, bacterial colonization, biomarkers, as well as immunological

factors can be taken into consideration, providing a tailored program which maximises the effectiveness of preventing infection while mitigating the risks associated with a standard approach, such as microbial resistance (Dhole et al., 2023). Recent research on bacteriophages created a promising perspective of potentially utilising them in surgical infection prevention. Such viruses can be genetically modified in a way that could target the specific bacteria causing such infections without significant disruptions to the symbiotic microbiota (Opperman et al., 2022). That way, the need for antibiotics could potentially be reduced. In cases of surgeries requiring the use of implants or instruments, antibacterial coatings prove to have potential to prevent SSIs (Li et al., 2021). Such coatings disrupt and prevent the formation of biofilms and reduce bacterial colonization through the gradual release of active substances, consequently lowering the risk of post-surgical complications.

Immunomodulation is another tool gaining the interest of researchers. Instead of fighting pathogens directly, it focuses on boosting the patient's immune response in order to help them fight off a potential infection. This solution can be especially useful in immunocompromised patients, who are at increased risk of infections caused by opportunistic bacteria, a more severe course of the disease, and higher mortality rates (Coccolini et al., 2021). It is essential that such tools are being researched and their effectiveness tested in clinical settings, in order to ensure their safety and infection-prevention capabilities.

Limitations

This review has its limitations. Since it is limited to studies published in English, it is possible that articles in other languages existed and were not included in this study. Due to the fact that the studies were searched using PubMed, as well as Google Scholar, it is possible that there were other papers unavailable on those websites and, therefore, omitted from this review. It is crucial that future reviews include as many applicable studies as possible to ensure a comprehensive understanding of the infection prevention methods in neurosurgical procedures. Systematic reviews as well as meta-analyses, including a significant amount of available data on the topic, especially those analysing patients' outcomes from different countries and regions of the world, will be especially helpful in drawing accurate, high-quality conclusions.

The studies included in the review also have their limitations. Since the meta-analyses relied primarily on study-level data, it is possible that patients' health status could have had an impact on the proposed methods of infection prevention, due to the inaccessibility of data on patients' age, comorbidities, etc, in many of the studies. The results could also have been affected by variations in antibiotic dosages used in the primary research or follow-up intervals.

5. CONCLUSION

Antibiotic pre-surgical prophylaxis (such as intravenous cefazolin), as well as wound site irrigation, are valuable tools in decreasing the risk of infections after neurosurgical procedures. More research is needed, especially high-quality, randomized clinical studies comparing the effectiveness of various prevention methods. Conducting more meta-analyses, including more patients from different countries, will allow for a more comprehensive understanding of the effectiveness of varying infection prevention methods.

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Authors' Contributions

Maja Czerniachowska – Project administration, conceptualization, review and editing, investigation, methodology

Maja Kondratowicz- Methodology, investigation, visualization, supervision

Kamila Kałamarz- Conceptualization, visualization, resources

Kinga Żmuda- Review, data curation, investigation

Maciej Świerczyna- Resources, writing- rough preparation, data curation

Aleksandra Figzał - Visualization, data curation, investigation

Marcin Kaniewski- Review, visualization, formal analysis

Martyna Wojnowska- Supervision, writing- rough preparation, data curation

Wiktoria Polkowska- Review and editing, formal analysis, supervision

Michał Grabek- Resources, writing- rough preparation, formal analysis

Informed consent

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Ethical approval

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Conflict of interest

The authors declare that they have no conflicts of interest, competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data and materials availability

All data associated with this study will be available based on the reasonable request to corresponding author.

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