

Surgical site infections in neurosurgical patients following cranial surgery: An integrative review



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Abstract

Aim: To synthesise the literature pertaining to surgical site infections (SSIs) in neurosurgical patients following cranial surgery.

Background: SSIs in neurosurgical patients following cranial surgery present a major healthcare problem for healthcare providers worldwide. The most widely reported outcomes following SSIs include increased length of inpatient stay, morbidity, mortality, higher treatment costs and increased care burden for families and caregivers.

Design: Integrative review.

Methods: Using an integrative review framework, electronic database searches were conducted in CINAHL, Embase, Medline and ProQuest from 2012 - 2022. The search was limited to peer reviewed full text publications. Reference lists of identified studies were reviewed, and additional articles were accessed. Methodological rigour for included studies was evaluated using Critical Appraisal Skills Program tools.

Results: Twenty articles were reviewed, and four themes emerged relating to: preoperative patient preparatory practices and SSIs; risk factors for developing SSIs post cranial surgery; patient-reported outcomes and healthcare implications; and strategies for preventing SSIs within hospital settings.

Conclusion: Surgical site infections post cranial surgery among neurosurgical patients can be contained through administration of pre-surgical prophylactic antibiotics, adhering to aseptic hand hygiene, utilising evidence based infection control protocols, educating neurosurgical nurse clinicians in post cranial surgical wound care, and providing tailored education for patients and families in postoperative cranial surgical wound care.

KEYWORDS:

surgical site infections, neurosurgical patients, cranial surgery, integrative review

Introduction

Patients who present with head trauma or disorders affecting the brain may require surgical intervention for treatment. A surgical procedure known as cranial surgery is often performed to enable clinical management for cerebral bleeds, removal of brain tumours, evacuation of extradural or subdural haematomas, treatment for hydrocephalus, or decompression of cranial nerves (Abecassis & Kim, 2017). A major complication that occurs following cranial surgery is widely reported to

be in the form of surgical site infections (SSIs) (Abu Hamdeh et al., 2014; Kose et al., 2016, Kraft et al., 2022). SSIs are infections that develop within either thirty days following surgery or a year if an implant remains in-dwelling post operatively (Bhatti & Leach, 2013).

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DOI: 10.21307/ajon-2023-015

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SSIs are common nosocomial infections among neurosurgical patients, and they account for approximately 5% of all nosocomial outbreaks (Abu Hamdeh et al., 2014; Bekelis et al., 2016). The most widely reported pathogens that cause SSIs include *Staphylococcus aureus*, *Enterococci*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Streptococci*, *Enterobacter species*, *Proteus species*, and *Serratia species* (Garner & Anderson, 2016; Seidelman & Anderson, 2021).

Within the hospital setting, SSIs post cranial surgery are associated with high morbidity among patients and increased hospital resource utilisation (Davies et al., 2016; Mann et al., 2021; Riordan et al., 2016; Patel et al., 2019). SSIs result in increased length of hospital stay, prolonged use of antibiotics, and inpatient mortality (Fiani et al., 2020). Patients who develop SSIs after discharge from hospital may require readmission for further corrective treatment, heightening family strain and caregiver burden. (Royle et al., 2023; Sebastian, 2012).

A review of published statistical data revealed that the overall estimated SSI rate in Australian public hospitals equated to 66 cases per 100,000 population and 16,541 cases were recorded annually at a treatment cost of A\$323.50 million (Royle et al., 2023). The burden of SSIs for both public and private hospitals was estimated to be A\$6.8 billion (Royle et al., 2023). The lack of a centralised or national surveillance system to track SSIs in both public and private healthcare settings in Australia encumbers the computation of the true burden of SSIs. In the United States of America (USA), approximately 300,000 SSIs occur each year and between 1% to 5% of inpatients develop SSIs post operatively (Seidelman & Anderson, 2021). The estimat-

ed annual healthcare expenditure associated with SSIs ranges from US\$3.5 to US\$10 billion depending on the surgical site and wound classification (Khan et al., 2020; Seidelman & Anderson, 2021). In Europe, SSIs constitute up to 19.6% of all Hospital Acquired Infections (HAIs) (Badia et al., 2017). Across a sample of 12 European nations, an estimated incidence rate of SSIs ranging from 0.6% to 9.5% was established from as cohort of 1.2 million surgical cases (European Centre for Disease Prevention and Control [ECDC], 2023). The global incidence for SSIs varied from 0.5% to 11% among patients who underwent cranial surgery (Ehrlich et al., 2016; Fiani et al., 2020). Low and middle income countries have the highest incidence rates for SSIs ranging from 1% to 24% (Seidelman & Anderson, 2021). The general signs and symptoms for SSIs include pain, swelling, redness, purulent discharge, wound dehiscence, foul odour, local erythema and delayed healing (Harrington, 2014; Hweidi et al., 2018; Schuderer et al., 2022; Seidelman & Anderson, 2021).

The clinical manifestation of post cranial SSIs poses a major global public health care problem (Abu Hamdeh et al., 2014). However, to date, a broad review of the literature pertaining to neurosurgical patients following cranial surgery has not been explored. Hence to address this gap in literature, this integrative review was warranted. The review outcomes will generate information that can inform and guide neurosurgical nurses in the clinical nursing management of post cranial surgical patients.

The review

Aim

The aim of this integrative review was to synthesise the literature pertaining to SSIs in neurosurgical patients following cranial surgery. The review was guided by the question: What is known about SSIs among neurosurgical patients who undergo cranial surgery?

Design

The Whittemore and Knafl (2005) integrative review framework was used to allow for inclusion of empirical studies of diverse research designs. A five-stage approach was applied addressing elements relating to problem identification, literature search, data evaluation, data analysis, and presentation. The problem was identified as SSIs in neurosurgical patients following cranial surgery. The literature search terms used are contained in the search strategy illustrated within Table 1. Data evaluation involved assessing the quality of each included study for methodological rigour using Critical Appraisal Skills Programme tools (CASP, 2018). The data analysis involved extraction of data from selected papers into a tabular form for conceptualisa-

tion and categorisation (Table 2). Data presentation portrayed a broad synthesis of results that integrated data from all the reviewed studies. The primary author (SK) performed the study selection, screening for eligibility, data extraction, and data synthesis.

Search methods

Electronic searches were conducted from databases that included CINAHL, Embase, Medline and ProQuest for pertinent articles published between 01 January 2012 and 31 December 2022. Table 1 illustrates the keywords, additional search terms, and search limits that were used to explore the four databases. Boolean operators “OR” and “AND” were applied to search terms in multiple combinations. Reference lists of the identified articles were also explored, and additional articles were extracted, reviewed and included in the review process. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram was used to illustrate the search process and indicate the number of studies that were screened, assessed for eligibility, and included (Figure 1) (Moher et al., 2009).

Table 1 The search strategy

Databases	Keywords	Additional search term	Search limits
CINAHL Embase Medline ProQuest	Surgical site Wound infection Neurosurgical patients Cranial surgery Causes Preventing Managing Nursing practice Hospital setting	Craniotomy site; craniectomy site Wound infection*; surgical site infection* Neurosurg*; patient* Brain surgery; head surgery; craniotomy Cause*; outcome* Prevent*; prevention* Manage*; management Nurs* practice; nurse* practice* ; nursing practice* Hospital*; acute care ; inpatient* setting*	English Language publications, peer reviewed papers, patients aged 18 years or above, full text papers, and studies centred on human subjects

The following inclusion and exclusion criteria were applied:

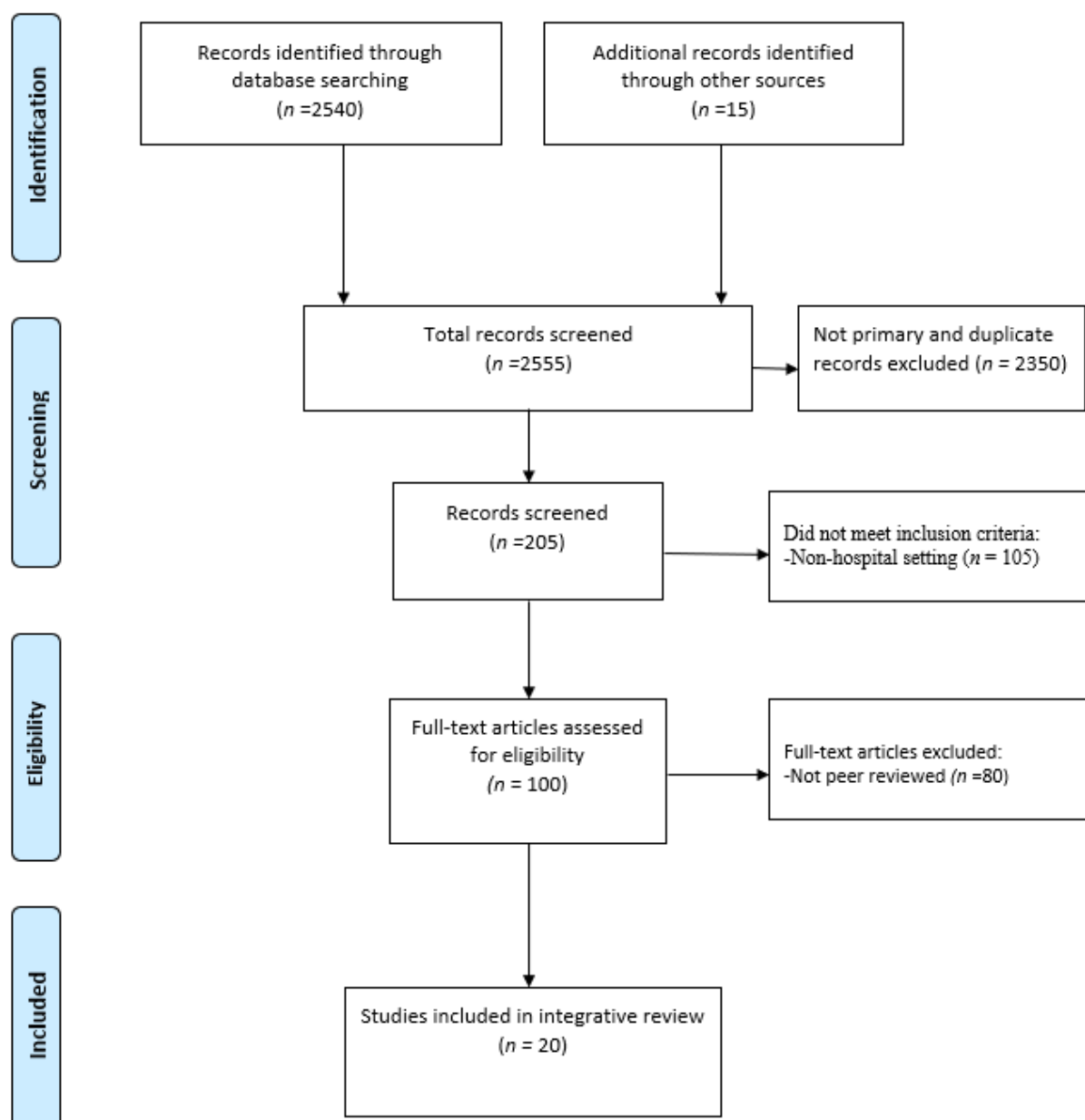
Inclusion criteria

- Studies focusing on SSIs in neurosurgical patients post cranial surgery
- Publications in English language published in peer reviewed journals
- Studies with patients aged 18 years or older

Exclusion criteria

- Studies where data specific to neurosurgical patients could not be identified
- Grey literature, abstracts and opinion papers

Figure 1 PRISMA Flow diagram illustrating the search process (Moher et al., 2009)



Search outcomes

A total of 2540 studies that were pertinent to the review were identified. Fifteen papers were further identified following a manual search for the literature from the reference lists of initial articles. From a total of 2555 studies, 2350 records that were duplicates or not-primary studies were further removed. The screening of the remaining 205 studies was undertaken against the inclusion and exclusion criteria. A further 105 studies were removed as these did not meet the selection criteria. Full text extraction of 100 studies was undertaken and upon further review for eligibility, 80 articles were further excluded as they were not peer reviewed publications. A total of 20 studies were included in the final review (Figure 1) and a summary of these studies is provided in Table 2.

The 20 included papers were from eleven different countries. These were distributed as follows ; five from the USA (Bekelis et al., 2016; Fiani et al., 2020; Luther et al., 2020; Riordan et al., 2016; Wathen et al., 2016), three from England (Davies et al., 2016; Patel et al., 2019; Tanner et al., 2012), two from France (Cassir et al., 2015; Salle et al., 2021), two from Japan (Haruki et al., 2017; Shibahashi et al., 2017); two from China (Shi et al., 2017; Yao & Liu, 2019), and one from each of the following six countries, Wales (Bhatti & Leach, 2013), Norway (Golebiowski et al., 2015), Sweden (Abu Hamdeh et al., 2014), Australia (Honeybul & Ho, 2014), Turkey (Kose et al., 2016), and Spain (Jiménez-Martínez et al., 2021). The study designs included ten prospective studies, eight retrospective studies, one randomized control trial, and two qualitative studies.

Quality appraisal

The quality appraisal for the studies included in the review was performed using Critical Appraisal Skills Programme tools (CASP, 2018). The quality appraisal involved a comprehensive evaluation of the studies for methodological rigour following key CASP tools questions that were scored out of computed totals specific to the applied tool (Table 2). For example, out of 10 and 12 for qualitative studies and out of 11 for quantitative studies (CASP, 2018). The CASP tools enabled the critical examination of the methodological rigour of the selected studies taking into consideration the sampling, setting, aim, design, data collection, data analysis, researcher-participant relationship, ethical considerations, clarity of findings and contribution of study findings to clinical practice (CASP, 2018). All the studies included in the review had a high-quality appraisal score and had received Human Research Ethics Committee approval.

Data synthesis

The structure for data synthesis was based on the Whitemore and Knafl (2005) framework and the following four steps were applied during this phase. Firstly, a table was constructed, and key data were extracted from each of the included articles. The data extracted related to author, country of study, aims, design, sample, setting, data collection, data analysis and pertinent findings (Table 2). Secondly, the extracted data were displayed in the table, examined, and iteratively compared to identify common relationships and differences. Thirdly, categories were identified, and examined for common meanings which enabled the emergence of themes.

Fourthly, primary sources were revisited and reviewed to ensure that the conceptualised themes that emerged were congruent with those in the primary sources. The process involved re-reading each primary study to compare reported results with the themes that emerged.

Results

The four main themes that emerged included: (1) preoperative patient preparatory practices and SSIs; (2) risk factors for developing SSIs post cranial surgery; (3) patient-reported outcomes and healthcare implications, and (4) strategies for preventing SSIs within healthcare settings. These themes are presented below in detail:

Preoperative patient preparatory practices and SSIs

Five studies explored preoperative patient preparatory practices and examined how these practices were associated with post-operative SSIs (Bhatti & Leach, 2013; Fiani et al., 2020; Jiménez-Martínez et al., 2021; Kose et al., 2016; Luther et al., 2020). A key finding indicated that the practice of administering prophylactic antibiotics prior to cranial surgery reduced the risk for acquiring SSIs (Jiménez-Martínez et al., 2021). Also, shaving of patients' hair prior to cranial surgery was a widely used practice (Bhatti & Leach, 2013). However, there was no conclusive evidence that hair removal decreased the risk for developing SSIs (Bhatti & Leach, 2013; Luther et al., 2020). Bhatti and Leach (2013) cautioned that shaving of patients' hair pre-operatively may instead heighten the risk for developing SSIs. The practice of shaving patients' was reported to have negative outcomes for patients including emotional, psy-

chological and behavioural transformations. These were associated with struggling to adapt to living with a changed personal appearance as a result of having shaven hair post cranial surgery (Kose et al., 2016; Luther et al., 2020). Hair sparing techniques enhanced self-image among patients (Luther et al., 2020).

Risk factors for developing SSIs post cranial surgery

The most common risk factors reported for developing SSIs post cranial surgery included the presence of cerebrospinal fluid (CSF) leakage from the cranial surgical wound; having an indwelling surgical wound drain, and the use of staples for wound closure (Abu Hamdeh et al., 2014; Cassir et al., 2015; Golebiowski et al., 2015; Haruki et al., 2017; Jiménez-Martínez et al., 2021; Patel et al., 2019; Yao & Liu, 2019). Additional risk factors for developing SSIs were associated with being diabetic and having an external CSF monitoring device in situ (Haruki et al., 2017; Wathen et al., 2016). The risk for developing SSIs also increased when patients had cranial surgical procedures that lasted longer than four hours (Allegranzi, 2014; Patel et al., 2019). Further risk factors were dehiscence at the cranial-surgical wound site and having an inhibited immune system (Riordan et al., 2016). The location of brain tumours was also reported as a risk factor, particularly for patients who had infratentorial or intraventricular tumours (Shi et al., 2017). Having a high rate of staff turnover within the operation theatre was associated with an increased risk for developing SSIs as contamination of the sterile surfaces was likely to occur during the process of gowning or scrubbing to permit staff rotation (Wathen et al., 2016).

Patient-reported outcomes and healthcare implications

Patients reported outcomes included feeling fearful of living with cranial wound infections, having physical impairments, and having psychological and emotional changes (Tanner et al., 2012). Some patients reported having difficulty adjusting to living with SSIs, while others felt relief post cranial surgery given that they had survived what they perceived to be a major life threatening disease that had prompted for surgical intervention (Tanner et al., 2012). Patients who developed SSIs following cranial surgery required lengthy hospital stay for further treatment or undergo additional surgery and were faced with increased treatment costs (Haruki et al., 2017). These patient-reported outcomes highlight the need for neurosurgical nurses to be vigilant about SSIs in order to achieve positive post-cranial surgical outcomes. Fifty percent of patients with a tumour malignancy developed SSIs post cranial surgery and the causative micro-organism was identified as *Propionibacterium acnes* (Haruki et al., 2017). While *P. acnes* outbreaks were reported as being non-fatal for this patient cohort, they did contribute to longer hospital stays. For healthcare providers, the healthcare implications for neurosurgical patients contracting SSIs were associated with increased operational costs associated with the need for further antibiotics usage, surgery and or alternative treatments (Abu Hamdeh et al., 2014).

Strategies for preventing SSIs within hospital settings

The fundamental strategies for preventing SSIs within hospital settings were reported to include enacting SSI infection surveillance, observing effective infection control

measures post operatively, and providing evidence-based education of nurses in the care for patients post cranial surgery (Cassir et al., 2015, Salle et al., 2021). The administration of antimicrobials post operatively was reported as a positive strategy that can prevent SSIs post cranial surgery (Shi et al., 2016), maintaining optimal blood sugar levels for patients living with diabetes (Bekelis et al., 2016; Salle et al., 2021). Maintaining staff stability in the operating room can promote stable healthcare practices, support skill mastery and reduce the risk for SSIs (Davies et al., 2016; Wathen et al., 2016).

Discussion

This integrative review synthesised the literature pertaining to surgical site infections in neurosurgical patients following cranial surgery. The four main themes that emerged pertained to preoperative patient preparatory practices and SSIs; risk factors for developing SSIs post cranial surgery, patient-reported outcomes and healthcare implications; and strategies for preventing SSIs within hospital settings. Shaving of patients' hair before cranial surgery was a major practice in many neurosurgical hospital settings but critical evidence suggested that the practice can alter normal skin-flora and consequently heighten the risk for developing SSIs (Bhatti & Leach, 2013). However, this finding was derived from a prospective study that recruited participants at a single research site (Bhatti & Leach, 2013) and a larger study may be warranted to consolidate clinical evidence. Additional findings indicated that hair shaving can also alter the skin bacterial composition through exposing the scalp to microscopic trauma and result in patients being more prone to SSIs (Kerk et al., 2018).

Comparable studies reported that hair removal had no benefit for patients in terms of reducing SSIs (Çelik, 2004; Shi, Yao & Yu, 2017). Thus, there appears to be an imperative prerequisite for neurosurgical nurses to exercise clinical judgement when considering whether to shave or not to shave patients' hair when preparing for cranial surgery as the consequences from the practice could outweigh the benefits. There is a gap between neurosurgical clinical nursing practice and theoretical knowledge around shaving patients' hair prior to cranial surgery and this is an area that can benefit from further empirical research.

Another finding from the review was that cranial surgical procedures that took longer periods to complete increased the risk for developing SSIs (Bekelis et al., 2016; Patel et al., 2019). Of specific note was that cranial surgical procedures that lasted longer than four hours enhanced the risk for post-operative SSIs (Jeong & Yee, 2018; Patel et al., 2019). Similarly, longer cranial surgeries provided an avenue for infective microorganisms from external sources such as surgical instruments and healthcare personnel to colonise the surgical site (Golebiowski et al., 2015). In consideration of these findings, shorter periods for cranial surgeries were advised as they were more likely to yield positive outcomes for patients post operatively (Abu Hamdeh et al., 2004). Unforeseeable organisational factors such as the lack of adequate clinical and support resources can also influence the duration of cranial surgery (Storey, 2013). However, these findings highlight the potential downside of prolonged cranial procedures which nurses can monitor and manage when fulfilling the role of being patient-advocates.

The risk factors for developing SSIs comprised of patient-specific and external factors. The patient-specific factors which heightened the risk for acquiring SSIs included having comorbidities or other diseases such as diabetes, and malignant tumours (Cassir et al., 2015). Having diabetes increased the risk for developing SSIs by up to 60% (Coleman et al., 2010). A major uncontrollable external factor was described as having a redo or repeat cranial surgery in the absence of any other non-invasive interventional alternatives (Cassir et al., 2015; Abu Hamdeh et al., 2004; Wathen et al., 2016). The modifiable external risk factors included shaving of hair prior to cranial surgery, using staples for wound closure; and having indwelling devices such as wound drains (Jiménez-Martínez et al., 2021; Abu Hamdeh et al., 2004; Yao & Liu, 2019). Considering that the external risk factors are modifiable, neurosurgical nurses should aim to address them in order to enhance positive outcomes for patients post cranial surgery. For instance, ensuring timely administration of antimicrobial prophylaxis was a key modifiable risk factor that was associated with a decrease in SSIs (Harrington, 2014). However, neurosurgical nurses should exercise caution with antimicrobial administration as excessive usage can lead to antimicrobial resistance (Velez & Sloand, 2016). There are a number of interventions that can be initiated by neurosurgical nurses to prevent the spread of SSIs for inpatients post cranial surgery. For instance, the implementation of well-coordinated SSIs surveillance practices such as performing daily wound assessments, and enacting SSIs prevention control measures such as keeping blood glucose levels under control for patients with diabetes (Cassir et al., 2015; Erman et al., 2007; Harrington, 2014; Honeybul & Ho,

2016; Hweidi et al., 2018; Moorthy, Sarkar, & Rajshekhar, 2013; Odom-Forren, 2006; Shi et al., 2017). Other strategies that can assist in the prevention of SSIs include practicing regular hand hygiene and applying aseptic precautions when attending to surgical site care (Smith & Dahlen, 2013). In addition, providing patient education regarding surgical wound care, performing accurate wound assessments using a structured wound assessment tool and maintaining proper wound care documentation can assist in curbing SSIs through supporting vigilance and informing multidisciplinary team wound management (Chen et al., 2013; Gillespie et al., 2014; Murakami et al., 2013). Preventing cranial SSIs in hospital settings necessitates working within an initiative-taking multidisciplinary team environment with the aim of enhancing positive post-operative outcomes for patients (Lailama et al., 2021).

Limitations

The primary limitation for this integrative review is that only peer reviewed studies that were published in English were considered and there is a possibility that some pertinent studies may have been missed. The review was dependent on the search terms applied along with the databases accessed and therefore it is possible that studies indexed elsewhere were omitted. Larger reviews should aim to incorporate studies from other languages and diverse databases in order to broaden the understanding of SSIs post cranial surgery.

Conclusion

This integrative review synthesised the literature pertaining to surgical site infections in neurosurgical patients following cranial sur-

gery. The key findings indicate that risks for developing SSIs in neurosurgical patients remains a major health problem for patients, families and healthcare providers. Preoperative patient preparatory practices such as shaving patient hair can contribute to heightening the risk for contracting SSIs. The risks for developing SSIs were categorised as modifiable and non-modifiable. Patient-reported outcomes reflected on the burden that contracting SSIs bears on patients and their families. Healthcare providers and neurosurgical nurses in particular play a major role in preventing SSIs among individuals who present for cranial surgery in hospital settings. Future research should expand the findings of this review and explore how neurosurgical nurses can empower patients to become self-reliant in managing modifiable risk factors in order to prevent SSIs post cranial surgery.

Funding

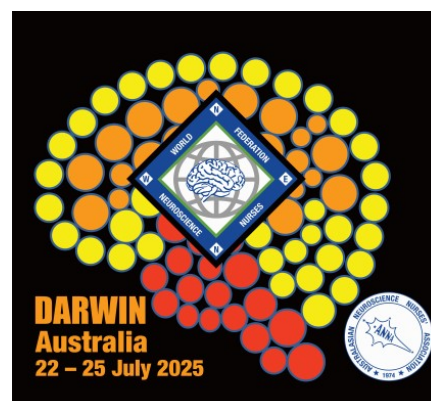
There was no external funding for this review.

Contributions

SK: Study design, data collection, data analysis and manuscript preparation.

Conflict of interest

No conflict of interest has been declared by the author.



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Table 2 Summary of included studies

Author & country of study	Aims	Design	Sample & setting	Data collection & analysis methods	CASP Tool Score	Key findings
1. Abu Hamdeh et al. (2014) -Sweden	To prospectively record the prevalence of SSI three months after standard intracranial neurosurgical procedures and analyse the incidence, impact and risk factors of SSI	Prospective study	Convenience sample of 448 patients -Neurosurgical ward at a tertiary hospital	- Data were collected using the electronic patient journal system. - Analytical and descriptive statistics were explored	9/10 Transferability of research findings to other populations was not considered	-Risk factors for SSI were meningioma, longer operation time, craniotomy as method of surgery, and staples in wound closure. -Patients with SSI had longer hospital stay - Longer and more complicated procedures heightened risk for SSI - The prevention of SSI was multidisciplinary
2. Bekelis et al. (2016) -USA	To investigate the association of operative duration in neurosurgical procedures with the incidence of SSI	Retrospective cohort study	94,744 patients who underwent a neurosurgical procedure - Database consisting of private hospitals	-Retrospective cohort study involving patients who underwent neurosurgical procedures from 2005 to 2012 -Statistical analyses were performed	11/12 Inadequate discussion regarding participant consent process	- Longer operative duration was associated with increased incidence of SSI for neurosurgical procedures. -The results can be used to stratify patients regarding SSI risk.
3. Bhatti & Leach (2013) -Wales	To look at the infection rate in adults undergoing craniotomies without hair removal and compare the results with the usual practice of pre-operative shaving or clipping	Prospective study	100 adults who had elective supra-tentorial craniotomy for tumour removal -University hospital	Patients were followed up prospectively to look for surgical site infection. The rate of infection was determined, and the results were compared with the published data on similar procedures where hair removal was carried out before surgery	9/10 Lack of details relating to the process of obtaining participant consent	-Cranial surgery with hair left in place did not pre-dispose to an increased infection risk for adults undergoing tumour surgery. -There was no convincing evidence that pre-operative shaving led to a decrease in the incidence of post-operative wound infections - Removing hair before surgery dislodges resident micro-organisms on the skin from their normal location resulting in alteration of flora, colonization of micro-traumatized epidermal layers, enhancement of microbial growth and increases predisposition to infection post-surgery

4. Cassir et al. (2015) -France	To analyse the rates, types, and main risk factors for SSIs after neurosurgical procedures with a focus on the postoperative period	Prospective cohort study	849 adult patients undergoing neurosurgery -University hospital	- A systematic review of the medical records of neurosurgical patients was undertaken from 2009 - 2010. -Key statistical analyses were performed	11/12 Recommendations were not supported by other robust evidence	-The rate for SSI was 4.5% and active surveillance reduced this rate to 3.0% - The independent risk factors for SSI postcranial surgery included: previous surgery at the same site; intensive care unit (ICU) length of stay >7 days; duration of drainage >3 days; cerebrospinal fluid leakage - Active surveillance with regular feedback was effective in reducing SSI rates. - The postoperative period was associated with overlooked risk factors for neurosurgical SSI.
5. Davies et al. (2016) -England	To review the effectiveness of SSI surveillance guidelines and consider their appropriateness	Qualitative study	2375 patients undergoing cranial neurosurgery -Public hospital	- Prospective follow up of all cranial neurosurgery procedures between October 2011 – February 2013 - Descriptive data analysis was undertaken	9/10 Inadequate details pertaining to the relationship between researcher and participants	-Active monitoring of inpatients and readmissions was considered vital for cranial neurosurgical SSI programmes.
6. Fiani et al., (2020) -USA	To conduct a retrospective analysis of neurosurgical patients following a contemporary wound closure	Retrospective study	1184 patients who underwent cranial and spinal surgery -Regional medical center	-Retrieval of data pertaining to 1184 cases. Data were extracted from a centralised patient database and analysed using Ms Excel and retrieval software	10/10	-Intrinsic risk factors for SSIs: CSF leak, prolonged duration of operation >4hrs, implantation of foreign material, -Factors lowering SSIs: use of antibiotic impregnated sutures, use of 5% chlorhexidine hair wash, lack of hair shaving -Extrinsic factors: male gender, tobacco smoking, diabetes, obesity BMI>35, UTI, hypertension
7. Golebiowski et al. (2015) -Norway	To explore the possible impact of duration of surgery on the risk of developing extracranial complications and surgical site infections following intracranial tumor surgery	Retrospective study	1000 records of patients who underwent intracranial tumour operations -University hospital	- Retrospective review of patients who underwent planned surgery for intracranial tumors -Statistical analysis was performed	9/10 Researcher and participant relationship was inadequately addressed	- Duration of surgery together with comorbidity and acquired neurological deficits were independent risk factors for cranial complications after brain tumour surgery. -Longer duration of surgery was associated with higher risk for developing SSWIs. -The risks associated with prolonging brain surgery should be considered preoperatively

8. Haruki et al. (2017) -Japan	To investigate the risk factors for <i>Propionibacterium acnes</i> infection after neurosurgery and to evaluate the prognosis for <i>P. acnes</i> -associated post-cranioplasty neurosurgical infection	Retrospective case control study	42 patients divided into 2 groups (14 cases and 28 control) -Community hospital	-Medical records were retrospectively reviewed to assess the patients' baseline characteristics and risk factors from January 2004 to March 2016	10/11 Outcome measures were from one single study site	- <i>Propionibacterium acnes</i> was a prominent causative organism for post-neurosurgical infection - Craniotomy, malignancy, and prolonged operation time were identified as risk factors for the <i>P. acnes</i> infection
9. Honeybul & Ho (2014) -Australia	To assess the impact that injury severity has on complications in patients who have had decompressive craniectomy for severe traumatic brain injury (TBI).	Prospective observational cohort study	270 patients who underwent decompressive neurosurgery - Two major adult hospitals	- The clinical and radiological data of patients on initial presentation were entered into a web-based prognostic model from 2004 to 2012. Data were prospectively examined to obtain the predicted risk of an unfavourable outcome which was used as a measure of injury severity	12/12	-There was no associations between timing of cranioplasty after severe TBI and risk of infection or resorption of bone flap after cranioplasty.
10. Jiménez-Martínez et al. (2021) -Spain	To evaluate the care bundle intervention to prevent surgical site infections after craniotomy	Historical control study	- 1017 Adult patients who underwent craniotomy between 2013 - 2017 -Public hospital	-Reviewing electronic clients' charts, checking re-admissions, post discharge surveillance -Statistical analysis was performed	9/10 Relationship between researcher and participants was not clarified	-The care bundle included: pre-operative shower with 4% chlorhexidine soap, hair removal, antibiotic prophylaxis, sterile wound dressing -The care bundle was effective in reducing SSIs post craniotomy
11. Kose et al. (2016) -Turkey	To investigate the effects of different types of shaving on body image and surgical site infection in elective cranial surgery	Randomised-controlled design	200 patients who underwent elective cranial surgery between March 2013–August 2014 -Neurosurgery department at a military hospital	-Patients were randomised to two groups: strip shaving and hair shaving using a randomisation block method and computer programme. - Statistical data analysis was performed	11/11	-There is no difference between strip shaving and regional shaving in the development of surgical site infection after cranial surgery. -Regional hair shaving negatively affects the patients' body image after cranial surgery.

12. Luther et al. (2020) -USA	To evaluate the rate of SSIs and perioperative complications associated with using an absorbable intradermal barbed suture for skin closure in hair-sparing supratentorial craniotomies for tumor in order to prove non-inferiority to traditional methods	Retrospective study	-446 records of patients post craniotomy for brain tumors were reviewed -University Hospital	-Retrospective review of patient records who underwent supratentorial craniotomies for brain tumors between 2011 to 2017 -Statistical analysis was performed	10/10	-Hair sparing approaches to craniotomies are safe, equally effective and result in greater patient satisfaction, excellent cosmesis, quicker return to normal daily activities, and improved self-image prospectively. -Hair shaving techniques were recommended in combination with absorbable intradermal sutures to facilitate early discharge and return to normalcy for patients
13. Patel et al. (2019) -England	To determine the rate of SSIs requiring re-operation and identify factors leading to an increased risk	Retrospective analysis	16,513 patients at a single centre over a period of seven years	- A single centre retrospective analysis -Multivariate binary logistic regression was used to analyse risk for developing SSIs	10/10	Risk factors for SSIs included: Wound lead, dexamethasone use, instrumentation, operation duration > 3hrs, drain use, and diabetes
14. Riordan et al. (2016) -USA	To determine which patient characteristics and operative factors lead to post cranioplasty infections	Retrospective chart review	186 patients who underwent cranioplasty procedures -Level one trauma centre	A single-center, retrospective chart review of patients who underwent cranioplasty procedures	9/10 No critical examination for researcher influence, role or choice of study location	-Wound dehiscence and presence of a postoperative fluid collection was associated with a high rate of infection -The use of autologous bone flap and a state of immunosuppression trended toward statistical significance -There was no clear association between CSF Ventriculoperitoneal shunting in relation to cranioplasty infection
15. Salle et al. (2021) -France 55	To evaluate the impact of SSI on the survival of glioblastoma patients	Retrospective multi-centred study	- 64 patients from 14 neurosurgical centers	-Data from SSI cases after glioblastoma surgeries between 2009-2016 were collected from multiple neurosurgical centers	12/12	Recommendations to reduce rate of SSIs: Follow strict aseptic techniques in operating rooms, control risk factors such as monitoring for diabetes perioperatively, establish guidelines for management

16. Shi et al. (2017) -China	To determine the risk factors for and the incidence, outcomes, and causative pathogens of post-craniotomy intracranial infection (PCII) in patients with brain tumors	Retrospective cohort study	5723 patients with brain tumors who underwent elective craniotomy -Public hospital	-Retrospective review of medical records of patients with brain tumors who had craniotomy - Statistical analysis was performed	11/12 Results were in relation to only one study center	-Postoperative administration of antibiotics reduced the incidence of PCII -Risk factors included: prolonged operation (>7 h), external Cerebrospinal fluid (CSF) drainage, monitoring device placement, and postoperative CSF leakage. - Tumors located in the infratentorial or intraventricular regions were more vulnerable to PCII. - Gram-positive bacteria were the most common causative pathogens accounting for 82.0% of the PCII cases.
17. Shibahashi et al. (2017) -Japan	To review all post-operative complications and identify the risk factors for developing surgical site infection (SSI) after primary cranioplasty	Retrospective study	155 patients who underwent cranioplasty - Metropolitan Hospital	-Retrospective chart review of patients who had undergone craniectomy due to intracranial hypertension at a single institution.	10/10	-There was a significant relationship between operative time and SSI - A long operative time was a significant risk factor for SSI after cranioplasty - 8.4% of cases reviewed had SSI post cranioplasty
18. Tanner et al. (2012) -England	To explore the effect of SSIs on patients using qualitative methods to provide an in-depth understanding of the lived experience of suffering an SSI	Qualitative study	- 50 patients identified through a surveillance programme - Three public hospitals	- Audio taped unstructured interviews were conducted and transcribed - Thematic content analysis was performed	8/10 Researcher - participant relationship was not clarified	-The lived experiences of patients suffering with SSI were described as: living in horror; having physical effects e.g feeling weak, having pain; having psychological effect; feeling of relief for having survived surgery

19. Wathen et al. (2016) -USA	To identify the impact of workflow and personnel-related risk factors contributing to the incidence of SSIs in a large sample of neurological surgeries	Prospective study	12528 cases consisting of neurological patients -Neurological clinic	-SSI data were obtained from prospective surveillance by infection preventionists using Centers for Disease Control and Prevention definitions. - Statistical analysis was performed	10/10	- Patient body mass index and male sex were associated with an increased risk of SSI - Operating room personnel turnover was an independent variable that positively correlated with SSI.
20. Yao & Liu (2019) -China	To study the risk factors of intracranial infection after traumatic craniotomy in multiple trauma to provide references for clinical prevention and control of intracranial infection	Logistic regression analysis	94 multiple trauma patients with craniotomy (34 complicated with intracranial infection & 60 who had no infection post craniotomy -Public hospital	Logistic regression analysis was undertaken. Statistical data analysis was performed.	11/11	-Factors associated with SSI included: Surgical duration greater than 4hrs, postoperative CSF leak, external drainage, using the posterior fossa surgical approach

CASP, Critical Appraisal Skills Programme Tool; CSF, Cerebrospinal fluid; ICU, Intensive Care Unit; SSI, Surgical site infections; PClI, Post-craniotomy intracranial infection