Comprehensive Review on Postoperative Central Nervous System Infections (PCNSI): Causes, Prevention Strategies, and Therapeutic Approaches using Computer Based Electronic Health Record (EHR)

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The central nervous system is susceptible to various infections. Over centuries, bacterial infections have proven lethal in various surgical procedures. Infections that occur after craniotomy are often due to the reopening of operating wounds and past contamination of the scalp. Electronic health record (EHR) although provides programs to support surveillance efforts for these infections. However, the problem with these tools traditionally used is the lack of accuracy. Till now, the EHR systems are giving data to monitor and plan for these infections but this system needs more accuracy. The rate of postoperative infection in craniotomy ranges from 0.8% to 7% in patients who have received preoperative antibiotic prophylaxis. This rate increases significantly to about 10% in patients without antibiotic prophylaxis. Different types of bacteria manifest infections at different intervals after surgery. For instance, *Streptococcus pyogenes* infections typically appear within one or two days, Staphylococcal infections usually become evident after four to five days post-surgery, while gram-negative bacillary problems may arise within six or seven days. Resistance in bacteria contributes to the prevalence of postoperative infections, with examples such as Vancomycin Resistant *Streptococcus aureus* (VRSA), Vancomycin Resistant Enterococci (VRE), and Methicillin-Resistant *Streptococcus aureus* (MRSA). Given the high incidence of postoperative neurosurgical infections, there is a pressing need to manage such infections meticulously to reduce the risk of infections and associated fatalities. Treatment options include antibiotics and surgical practices aimed at minimizing pathogenic infections. Early and prompt recognition of bacterial infections after craniotomy is crucial, necessitating an understanding of both local and general infection symptoms. Additionally, cranioplasty can be considered as a means to address postoperative neurosurgical pathogenic infections.

Keywords: Craniotomy Infections, Bacterial Pathogens, Antibiotic Resistance, Cranioplasty, HER, Electronic data.

Introduction:

The nervous system plays a crucial role in coordinating and controlling bodily functions, including both voluntary and involuntary movements, sensory perception, and maintaining overall homeostasis [1]. It is essential for maintaining overall homeostasis, movement, cognition, sensory perception, and the body's survival. The brain or central nervous system is very susceptible and delicate tissue protected by various layers of coverings. It is defined as an immunological space, and the results are most alarming when suffering from infections [2]. Aspects that are important for the cooperation of the host defense system play a key role in initiating infections related to the brain after surgery, and such infections cannot be minimized or avoided. Over the centuries, such infections have been lethal. However, the use of newly effective antibiotics, enhanced bacteriological studies, recent imaging services, and more careful surgical methods have changed the outcomes [3]. The surgical process in which a part of the skull bone is removed to expose the central nervous system and brain is known as Craniotomy. The bone flap is removed and returned to its former position at the end of surgery to protect the brain and its structures. Mostly, metal plates are used to secure the bone flap in its position [4].

Objectives:

- To determine the causes and rate of surgical site infection (SSI).
- To screen pathogenic bacteria associated with surgical site wound infections after cranial surgery.

Novelty of the study:

- Conducting a study on the incidence of surgical site bacterial infections and other risk factors after cranial surgery (craniotomy) in hospitals of Lahore, Pakistan, is valuable research to find out the causative bacterial pathogens of surgical site infections after cranial surgery as the research is not conducted in Pakistan on this issue and relevant data is not available.
- This study is very useful in regard to checking the effect of different antibacterial agents other than antibiotics for the prevention of SSI infections which will be new findings in the field of medicine.
- It is helpful in reducing the mortality associated with post-operative bacterial infections after cranial surgery.

It plays a role in the scientific community and helps to drive further research and advancements in brain surgery.

Postoperative Central Nervous System Infection (PCNSI):

Postoperative Central Nervous System Infections (PCNSIs) are significant complications following brain surgery, leading to increased financial burdens and worse patient outcomes. Furthermore, there is a scarcity of scientific literature investigating the incidence and effects of PCNSI are modernized, resource-limited neurosurgical centers. Postoperative Central Nervous System Infection (PCNSI) is a major concern in the domain of neurosurgery. It describes infections that arise after surgery in the central nervous system, particularly the brain, spinal cord, or meninges. PCNSIs can develop as a result of postoperative difficulties or the development of pathogens during surgery. Patients who acquire these infections face a substantial risk of increased morbidity, prolonged hospital stays, and even mortality [5].

Postoperative CNS infection after cranial surgery remains a high risk despite the most attentive care during any operative process, and it demands immediate diagnosis and medical or surgical treatment. Once identified, postoperative infection can be treated with repeated surgery or the administration of subdural antibiotics [6]. Infections after Craniotomy may increase due to the reopening of operating wounds and past contamination of the scalp. Other factors also include multiple incisions, the location of a drain, the patient's immune deficiency, bone flap infection, cerebral abscess, and the long duration of surgery [7].

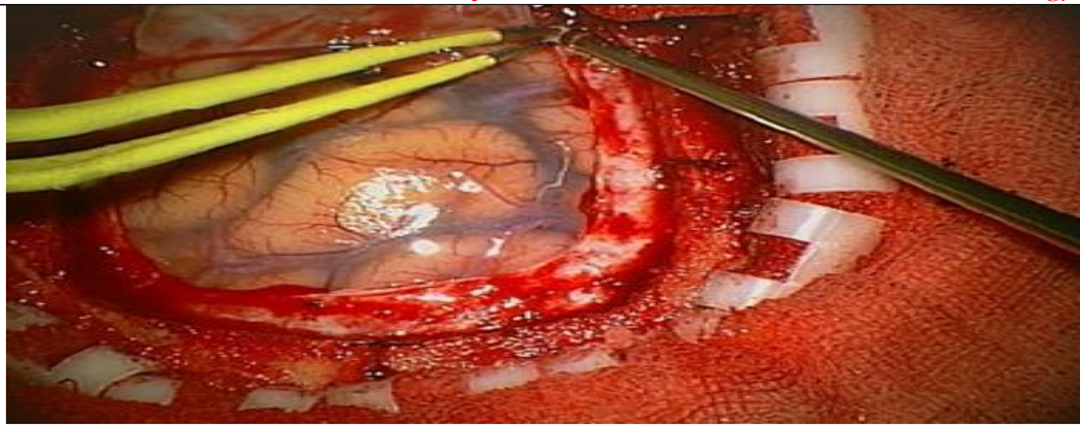


Figure 1: Computer Based Image of Postoperative Central Nervous System (PCNS) [8]

The choroid plexus is considered the first site of inflammation after a CNS infection, showing approximately 100,000 bacterial organisms per gram of tissue in cases of PCNSI. After brain surgery, the most common infections include Cerebrospinal Fluid (CSF) leakage, meningitis, epidural abscess, and subdural empyema of the brain. The rate of postoperative infection in craniotomy has been described as ranging from 0.8% to 7% in patients who receive preoperative antibiotic prophylaxis. Numerous randomized and retrospective studies have shown that the infection rate is considerably higher, around 10%, in patients without antibiotic prophylaxis [9].

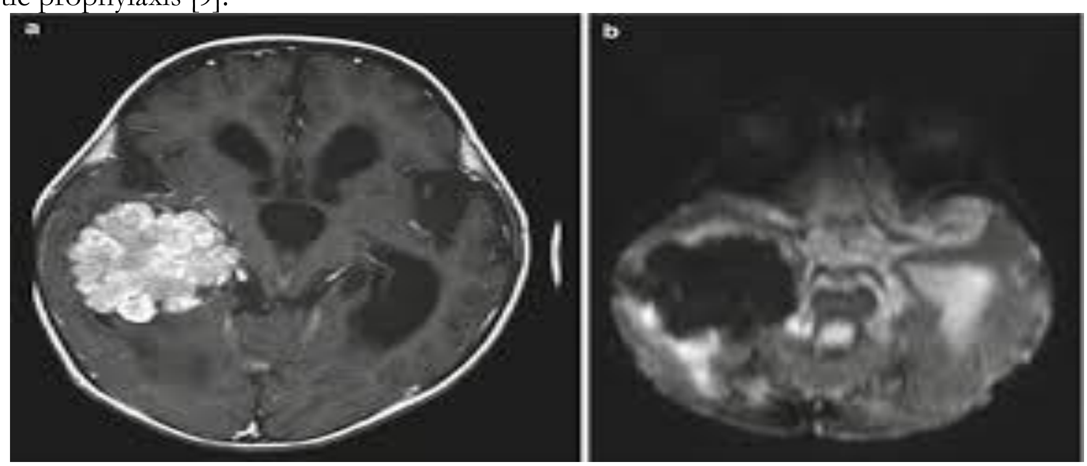


Figure 2: Choroid plexus [4]

Neurosurgeons' view on Postoperative Central Nervous System (PCNSI)

They have usually stated that postoperative wound infection rates after brain operations are considerably lower than those of other surgical procedures. However, the potentially distressing effects of postoperative Central Nervous System (CNS) infections have prompted current awareness and a better understanding of the issues that lead to wound infections after surgery. Potential risk factors for postoperative infections have been identified, but relatively few efforts to confirm the significance of each factor have been made in the literature [10]. Currently, no neurosurgical studies have attempted to evaluate the level of infection risk associated with specific factors. Although such data would be most consistently collected in a prospective manner, the outcomes of such studies would not be available for several years [11].

Postoperative Central Nervous System Infection (PCNSI) is recognized as a significant complication of neurosurgical treatments. PCNSIs can lead to increased morbidity, prolonged hospitalization, additional procedures, and potential mortality. Neurosurgeons take preventive measures such as administering preoperative antibiotics to patients, adhering to strict aseptic procedures during surgery, employing thorough surgical methods, and closely monitoring patients after surgery to reduce the risk of PCNSIs. For the effective management of PCNSIs, prompt diagnosis and tailored antimicrobial therapy are essential. Neurosurgeons prioritize controlling PCNSIs to enhance patient outcomes and minimize associated risks [12].

Surgical Site Infection (SSI)

A Surgical Site Infection (SSI) is an infection that develops at the location of an incision during surgery or in the tissue around it. It is one of the most frequent postoperative complications and can result in severe morbidity, extended hospital stays, and higher healthcare expenses. Bacteria can infiltrate the surgical site during the procedure or become contaminated afterward, leading to SSIs [13].

Factors contributing to SSIs and PCNSI:

Patient-related factors (including immune suppression, obesity, and diabetes), surgical factors (such as the type and duration of surgery), and poor adherence to infection prevention measures are all risk factors for SSIs. Preventive measures include observing aseptic technique, appropriate preoperative preparation, antimicrobial prophylaxis, and diligent postoperative wound care [14]. For the best possible outcomes for patients, early detection and timely treatment of SSIs are essential. The incidence of SSI following neurosurgery ranges from 0% within 30 days when no implants are involved, to potential occurrences over a year when external materials like hip prostheses or prosthetic heart valves are implanted. Postoperative wound infections are typically noticeable within a week of surgery [15]. Different types of bacteria manifest infections at different intervals; for example, *Streptococcus pyogenes* infections typically appear within one or two days, Staphylococcal infections usually become evident after four or five days post-surgery, while gram-negative bacillary problems may arise within six or seven days [16]. The most commonly isolated bacteria is S. aureus, which can cause infections such as pneumonia, endocarditis, septic arthritis, sepsis, and osteomyelitis when conditions such as temperature, pH, and nutrient availability change. Generally, SSI is initiated by mucous membranes or hollow viscera or the patient's skin. When the skin is cut, the underlying tissue is exposed, increasing the infection rate. Another factor in the spread of such organisms is the hospital environment, which can introduce pathogenic organisms into the patient's body through medical processes [11].

Although the type of pathogens depends on the surgical technique, current studies on postoperative infection have concluded that gram-positive bacteria have a higher rate of pathogenic infection compared to gram-negative bacteria associated with SSI. The most common pathogenic bacteria include Coagulase-Negative Staphylococci (CoNS), *S. aureus, Enterobacteriaceae, Pseudomonas aeruginosa*, and *Enterococci*. Furthermore, another factor that increases the prevalence of postoperative infection is antimicrobial-resistant bacteria such as Vancomycin-Resistant S. aureus (VRSA), Vancomycin-Resistant Enterococci (VRE), and Methicillin-Resistant S. aureus (MRSA). Besides pathogenic infections, factors such as the patient's healing duration, wound appearances, operative characteristics, bleeding, obesity, the need for drains in the wound, and diabetes mellitus also increase the rate of neurosurgical infections [9]. Various types and numbers of microbial pathogens, including fungi, bacteria, parasites, viruses, and mycoplasma, can cause post-operative wound infections. Organisms that generally cause abscesses and wound infections include species of *Enterococcus* sp., *S. aureus*, *Proteus* sp., *Streptococcus pyogenes*, *Escherichia coli*, *Clostridium* sp., and *Providencia* sp. Other uncommon pathogens causing SSI are *Mycobacterium chelonae* and *Mycobacterium fortuitum* [9].

Postoperative Central Nervous System Infection (PCNSI) can be linked to many reasons and contributing variables after neurosurgery procedures that lead to its development. Contamination of the surgery site is one of the main causes [17]. Numerous factors have contributed to diagnosing Central Nervous System (CNS) infections with a long lifespan, a high rate of solid-organ replacement, and better diagnostic facilities [18]. Despite new technology in postoperative and neurosurgical care, the rate of postoperative infections has not decreased as expected in modern times; in fact, it is increasing day by day. China has the largest number of neurosurgeons and neurosurgical procedures performed in the world; however, the rate of PCNSI is hardly recorded [19].

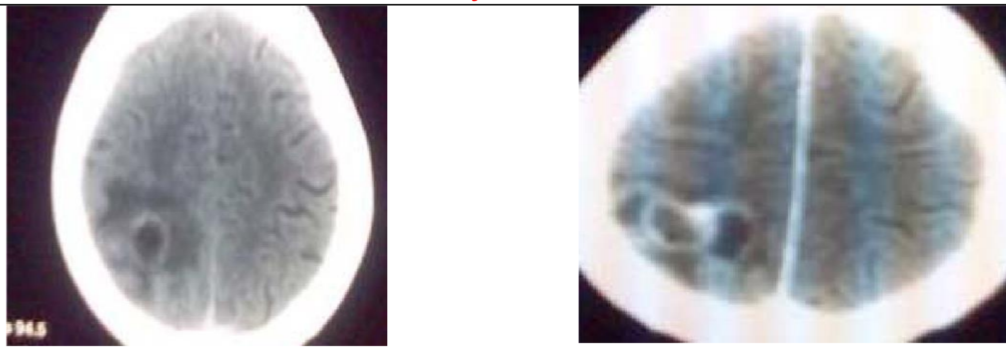
In the United States, Surgical site infections (SSIs) are now recognized as the most costly and common healthcare-related problems. The rate of postoperative infections is relatively variable, ranging from 0.5% to 18.8% as recorded after spine surgery, and from 1% to 8% after brain surgery. The range of infection varies depending on various operative factors such as the type of surgery, the use of surgical techniques, implantations, and the heterogeneity of the population. Due to the potentially distressing outcomes of infectious problems, studying their specific risk factors is of utmost importance to determine precise preventive approaches, especially since 60% of SSIs can be prevented by using evidence-based strategies. Although improvements have been made to control postoperative infections, there is also a need to improve sterilization procedures, operation theatre ventilation, barriers, surgical methods, and the use of antimicrobial prophylaxis [20].

PCNSI occurrence is also influenced by patient-related factors. Patients with immunosuppression, such as those whose immune systems have been compromised by underlying diseases or drugs, are more susceptible to infections. The incidence of PCNSIs is further increased by previous infections or microbial colonization [21]. An increased risk of infection can also be brought on by advanced age, malnutrition, systemic illnesses like diabetes or HIV, and the presence of foreign bodies such as shunts or implants. Another crucial factor is the duration of the operation. Longer operations increase the risk of contamination and eventual infection by exposing the surgical site to more potential microorganisms. Surgical teams strive to keep procedures brief while still being precise and thorough enough to lower this risk [22].

PCNSIs are influenced by the nasal carriage of infectious agents, primarily *Staphylococcus aureus*, including methicillin-resistant *Staphylococcus aureus* (MRSA). Bacteria from the nasal cavity can migrate to the operative site during surgery [22]. Preoperative testing for nasal pathogen carriage and the right preventative actions can help reduce this risk. PCNSIs can also be caused by factors like poor wound healing. When wound healing is compromised, pathogens have the opportunity to access the surgical site and cause infection, as is the case with surgical site dehiscence or wound breakdown [23]. The risk of PCNSI may be exacerbated by postoperative complications such as cerebrospinal fluid (CSF) leaks, meningitis, or the formation of cerebral abscesses. To reduce the frequency of PCNSIs, neurosurgeons implement preventive measures while taking these variables and causes into account. These efforts include appropriate preoperative screening and preventative measures, meticulous adherence to aseptic procedures during surgery, precise wound closure, and postoperative infection surveillance [23] [24].


(a)


(b)



(c) (d)

Figure 3: CT scan images showing smooth, thin, regular contrast-enhanced wall with a hypodense center, surrounded by edema. Cerebral abscess of the frontal (a and b) and parietal (c) lobes. Note the aerosol in (b), depicting the previous aspiration site, and the multiple cerebral abscesses in (d) [20].

Different Types of Post-Operative Infections:

Postoperative Meningitis (POM):

Postoperative Meningitis (POM) is an infection that develops after surgery and affects the meninges. It is linked to factors including contamination, prolonged surgical procedures, and immunocompromised status and can be caused by a variety of microorganisms. To manage POM and improve patient outcomes, early diagnosis, adequate antibiotic therapy, and preventive actions are crucial [25]. It is a life-threatening but rare issue in patients undergoing craniotomies. Advanced surgical and antimicrobial methods play an important role in reducing the rate of POM, but they still cause significant mortality and morbidity. The death rate can be minimized by using the best methodology for the diagnosis, prevention, management, and treatment of microbial infections after brain surgery. The prevalence of POM ranges from 0.3% to 8.9% according to various reports [26]. The risk factors range from 0.34% to 3.1% and include shaving of the scalp, Cerebrospinal Fluid (CSF) leakage, CSF shunts, emergency surgery, pathogenic infection at the surgical site, and surgery duration of about four hours. The rate of Surgical Site Infection (SSI) in neurosurgical procedures varies from 0% to 9.4% [17]. Pathogenic infections, such as Gram-negative bacilli and Gram-positive cocci, have an incidence of about 0.8% to 1.5%, which is considered very dangerous for postoperative problems after craniotomy. Infection varies according to factors like one-third of meningitis cases occurring almost within the first week of surgery, another one-third in the second week, while the remaining one-third develop after the second week or even many years later. Most infections occur within the first month after the operation, and the placement of catheters is also a very important factor in terms of timing and site of surgery [27]. Logistic regression studies indicate a roughly 3.7-fold increase in the likelihood of meningitis complications. Interestingly, the prevalence of Gram-negative bacteria such as *P. aeruginosa, K. pneumoniae*, and *A. baumannii* in brain meningitis is notably low. Another study finding reveals that the mortality rate in cases of Gram-positive meningitis is lower compared to Gram-negative cases. However, delayed identification of Gram-positive pathogens could contribute to faster patient mortality [28].

The analysis of nosocomial bacterial infection is done through the examination of Cerebral Spinal Fluid (CSF) in anaerobic and aerobic cultures, which are essential. However, cultures require lengthy incubation periods before definitively identifying pathogens as negative, and results may show negative in patients who have received prior antibacterial treatment. Among adults, gram-negative bacillary infections are mostly uncommon, especially in those with advanced age, neurosurgical procedures, and immunosuppression [29]. One factor contributing to late postoperative meningitis diagnosis and a high mortality rate is a lack of knowledge among patients. One major bacterial pathogen is *Acinetobacter baumannii*, which has become an epidemic in the Intensive Care Unit (ICU) of neurosurgical units in hospitals in recent years. The clinical presentations of *A. baumannii* are similar to Gram-negative bacillary infections, and confirmation of pathogens can only be done through bacterial culture [30].

Craniotomy or Neurosurgical Bacterial Meningitis:

Craniotomy or neurosurgical bacterial meningitis refers to the development of meningitis, an infection, following neurosurgical procedures or craniotomy. It can occur as a result of the introduction of microorganisms during surgery. Effective management of this disorder depends on early diagnosis, focused antibiotic therapy, and preventive measures [31]. It is a very complicated issue in craniotomy, with an infection rate of 0.8% to 1.5% in patients. The threat of postoperative brain infections can be lessened with the use of special neurosurgical methods, particularly by reducing the level of CSF leakage. In most cases, meningitis is caused by viral or bacterial infections of the cerebrospinal fluid (CSF) compared to other causes. This infection can be fatal, but efforts are being made to mitigate its impact through advanced antimicrobial techniques [32].

Types of Bacteria Causing Postoperative Infections

Postoperative infections can be caused by a variety of bacteria, and the specific pathogens implicated may vary depending on several factors. However, several common bacteria are typically associated with postoperative infections [3]. During brain surgery, the most commonly observed pathogenic bacteria are *P. aeruginosa*, *S. aureus*, and *Propionibacterium acnes*. None of these *S. aureus* infections are due to the methicillin-resistant type. Neurosurgical procedures associated with the highest rate of PCNSI are CSF pushing, followed by Ommaya reservoir placement (1.4%), and craniotomy for masses, tumors, and/or lesions. S. aureus is identified as the most prevalent pathogen, responsible for nearly 50% of infections based on previous data. *P. acnes* is also of great importance, with an observed infection rate of 25%, which is comparatively less threatening than *S. aureus* [33].

During brain surgery, the most commonly observed pathogenic bacteria are *P. aeruginosa* and *S. aureus*. The postoperative neurosurgical procedures that include CSF shunting, lesions, and mass craniotomy are linked to the highest rate of PCNSI. S. aureus bacteria account for 50% of infections, while *P. acnes* has a lower infection rate compared to *S. aureus*, at 25% [34]. Another interesting observation from various data-based research is that genera Proteus, Candida, Acinetobacter, or Enterobacter are not causes of PCNSI. Although infections are more common in younger patients compared to those without signs of infection, these observations may not be statistically significant. According to previous findings, CSF leakage, surgical procedures, male sex, and lack of antibiotic prophylaxis are major causes of brain infections after neurosurgery. In the United States, the rate of infection is 0.8% after cranial surgery, 0.4% after spinal surgery, and 0% after peripheral nerve surgery, based on data from 12,000 neurosurgeries. The prevalence of pathogenic infection after cranial surgery is about 16 times less than in newly recorded studies. Almost one-half of postoperative neurosurgical infections are related to the insertion of foreign bodies rather than CSF leakage, male sex, or diabetes issues [35].

A gram-negative bacterium called *Escherichia coli*, is frequently present in the digestive system and can result in urinary tract infections and infections at the surgical site. In postoperative complications such as wound infections and intra-abdominal infections, it is a frequent pathogen. Gram-positive bacteria often found in the gastrointestinal tract include members of the Enterococcus genus, such as *Enterococcus faecalis* and *Enterococcus faecium* [36]. They can infect the bloodstream, urinary system, and surgical sites, especially in medical settings. It's crucial to recognize that various healthcare settings and geographical regions may harbor different strains of bacteria responsible for postoperative infections. Identifying these causative microorganisms through laboratory testing and assessing their antibiotic susceptibility are essential steps in devising effective treatment strategies for these conditions [33].

Brain Abscess:

A brain abscess is a localized accumulation of pus in brain tissue, typically caused by bacteria or fungi. It can occur as a direct result of contamination during neurosurgical operations or as a result of infection spreading from other body regions, such as the heart or lungs. A wide variety of fungi, bacteria, and protozoa can lead to brain tissue death after neurosurgical procedures [37] [38]. Despite advancements in recognition and antibiotic treatment, the rate of brain abscess infections is increasing. Computerized Tomography (CT) is utilized to determine the size, location, and pattern of lesion infection. In recent years, there has been a gradual increase in the number of immunosuppressed patients and an increase in brain abscess cases due to pathogenic organisms, highlighting the need for current diagnostic and treatment efforts [39]."

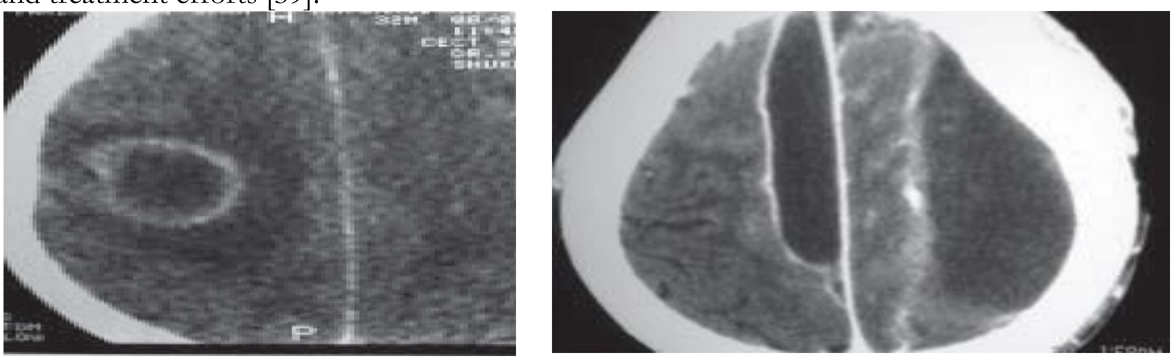


Figure 4: Brain Abscess with Computerized tomography (CT)

Postoperative Central Nervous System (CNS) infections are serious complications that can occur following surgical procedures involving the CNS. If these infections are not properly recognized and treated, they can cause considerable morbidity and mortality [40]. Here are some steps that patients can take to prevent and treat post-surgical CNS infections:

Preventions:

Postoperative Central Nervous System (CNS) infections are significant issues that necessitate careful treatment and prevention measures. Strategies for prevention are essential in reducing the incidence of these illnesses. This entails employing stringent sterile procedures during surgery, such as using clean tools, maintaining good hand hygiene, and sterile draping [41]. Additionally, crucial to preventing infections is antibiotic prophylaxis which is adapted to the particular surgical procedure and regional resistance patterns. In order to avoid postoperative CNS infections, proper wound management and surgical site care are essential. The risk of infections can also be decreased by improving the patient's general health and immune function prior to surgery through medical treatment, nutritional support, and, when possible, discontinuing immunosuppressive medicines [42].

Shaving a patient's scalp completely before cranial operations is a common procedure in China, intended to prevent surgical infection as well as to improve the surgical process. Various studies have been conducted to improve postoperative techniques as there is an increasing demand for addressing the social and psychological implications of neurosurgical infections after surgery. Many investigation outcomes have shown no significant change in the post-operative pathogenic infection percentage in patients with and without shaving before the operation, while other investigators found a greater threat of PCNSI [43].

Treatment:

Given the high incidence of postoperative neurosurgical infections, it is crucial to manage these infections meticulously to reduce associated risks and fatalities. Treatment strategies encompass various categories, such as antibiotics and surgical interventions, aimed at mitigating pathogenic infections following cranial surgery. After craniotomy, the risk of increasing infection is considered serious enough to warrant the administration of antibiotics before obtaining cultures. Early and quick recognition of bacterial infection after craniotomy is crucial for identifying local and general symptoms of infection. If an infection is recognized, the wound may need to be reopened, and standard methods are used for proper resolution of the infection. Cranioplasty is another alternative for addressing postoperative neurosurgical pathogenic infections, and it is typically performed at a later time [44].

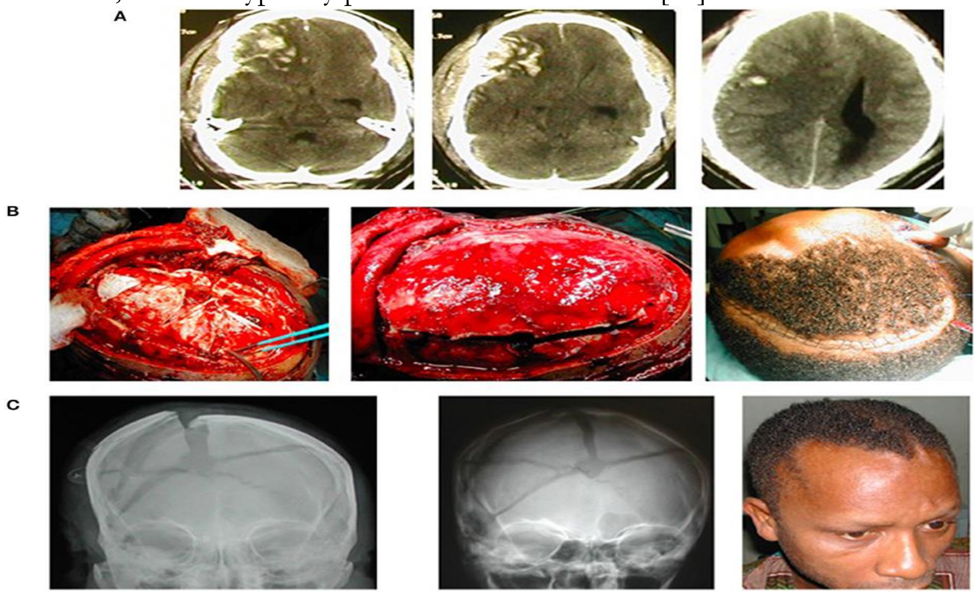


Figure 5: Cranioplasty Techniques after Cranial Surgery.

Early diagnosis is essential in the context of treatment to begin quick and effective therapies. It's critical to recognize the symptoms and warning signs of postoperative CNS infections. Assessment of the scope and location of the infection might be aided by diagnostic imaging techniques like computed tomography (CT) or magnetic resonance imaging (MRI) [45]. A multidisciplinary strategy is necessary for therapy after diagnosis. Empiric antibiotic therapy needs to start right away, taking into account local resistance trends and anticipated infections based on the surgical technique. To remove infected material and release pressure on the central nervous system, surgical intervention such as drainage or debridement may be required [46]. Future studies should also focus on enhancing preventative and treatment plans. This involves looking into advanced infection control procedures or antimicrobial coatings as revolutionary preventive measures. Postoperative CNS infections may be detected earlier and with more accuracy because of improvements in diagnostic methods, such as molecular diagnostics or imaging modalities [47]. Further research is needed in the areas of the involvement of immunomodulation and investigating innovative treatments for infections caused by biofilm [48]. We may work to decrease the occurrence of postoperative CNS Infections and enhance patient outcomes by continuously increasing our understanding and putting evidence-based practices into implementation.

Methodology:

Swab samples were collected aseptically using sterile cotton wool from post-operative wounds in the neurosurgery wards of the hospital's operation theatres. Following collection, pathogenic bacteria were isolated from these samples using nutrient agar media. To assess the pathogenicity of the isolated bacteria, Blood Agar Tests were conducted. Subsequently, the swab samples underwent evaluation for antibacterial activity. This assessment involved testing with a variety of agents, including different antibiotics, plant extracts, and nanoparticles, including those synthesized using green methods. These steps were crucial in understanding the effectiveness of these treatments against the isolated bacterial pathogens. Biochemical and molecular characterization of pathogenic bacteria was also done.

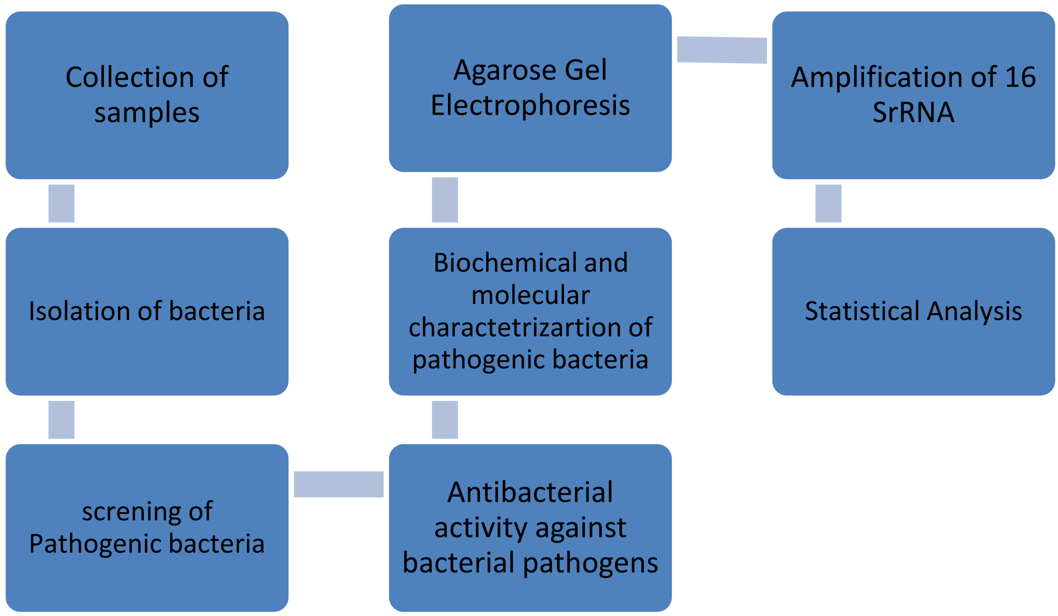


Figure 6: Flow chart showing methodology.

Results and Discussion:

This study provides valuable insights for planning research and control strategies, as well as for predicting surgical site bacterial infections following cranial surgery. Bacterial pathogens such as Pseudomonas aeruginosa, Staphylococcus aureus, and Streptococcus pyogenes were identified through ribotyping. These pathogens exhibited resistance to commonly used antibiotics, with resistance tested by measuring the zone of inhibition in centimeters (cm). Additionally, the antibacterial activity of nanoparticles was evaluated, revealing that these pathogens were resistant to control solutions of nanoparticles. A recent investigation identified bacterial pathogens from the air in operating rooms (OTs). Ideally, OT air should be sterile, but contamination remains an issue, particularly in regions with suboptimal hygiene conditions, such as Pakistan. This research aimed to examine prevalent pathogens found in both outdoor and indoor environments, including occupational therapy departments. Although bacterial infections are commonly isolated in hospitals, their presence in OT air remains uncertain. Airborne bacterial infections introduced during surgery significantly contribute to wound contamination.

The isolated bacterial strains included Pseudomonas aeruginosa, Streptococcus, and Staphylococcus aureus. Staphylococcus aureus is the most prevalent pathogen in the environment and is also the leading cause of infections in surgical and postoperative wounds. Pseudomonas aeruginosa is frequently found in hospital air and surrounding areas and is an opportunistic, oxidase-positive pathogen. The overuse of antibiotics in treating infectious diseases has led to increased resistance among bacteria and other microbes. Nanoparticles, known for their bactericidal properties, are often used in studies of antibacterial activity. Numerous investigations have demonstrated the efficacy of nanoparticle oxides, particularly zinc oxide and silver oxide, as bactericidal agents. Recent studies have shown that nanoparticles exhibit strong antibacterial activity against locally isolated common bacterial infections. Despite resistance to nearly all antibiotics, bacterial infections can still be susceptible to nanoparticles, as evidenced by clear inhibition zones. Consequently, nanoparticles hold promise as future bactericidal agents against antibiotic-resistant bacterial infections.

To mitigate the risk of surgical or postoperative infections, it is crucial to reduce bacterial contamination in OT air. Improving sterile procedures and maintaining hygienic conditions are essential steps in achieving this goal.

Future Research on Postoperative Central Nervous System Infections:

Future studies on postoperative infections of the Central Nervous System (CNS) should concentrate on filling in information gaps and improving our comprehension of these intricate illnesses. The development of efficient preventative measures is an essential area of research. This includes researching novel approaches to preoperative risk classification [56]. Additionally, more research into innovative surgical procedures, antiseptic solutions, and antimicrobial agents can aid in lowering the prevalence of postoperative CNS infections. Another crucial area for future study is improving diagnostic methods. The development of more precise and sensitive diagnostic tools, including biomarkers or imaging modalities, can help identify postoperative CNS infections early on. This may promote a swift beginning of focused treatment and enhance patient results. Research initiatives should also concentrate on comprehending the underlying mechanisms of postoperative CNS infections, especially the part played by biofilm development and microbial virulence factors [49]. Exploration and optimization are also necessary for treatment options. Treatment methods can be improved by researching the effectiveness of different antibiotic regimens, including combination therapy and novel antimicrobial drugs. Additionally, research should clarify how surgical procedures like drainage or debridement affect the results of postoperative CNS infections. It is necessary to conduct more research in the areas of long-term results and quality-of-life evaluations [50].

Treatment choices and patient care can be improved by being aware of how postoperative CNS infections affect morbidity and mortality in patients, neurologic sequelae, and functional outcomes [51]. Finally, to further our understanding of postoperative CNS infections, collaborative research initiatives including multidisciplinary teams of surgeons, infectious disease specialists, microbiologists, immunologists, and other relevant experts are essential. This cooperative method can encourage the development of thorough and efficient preventative and treatment plans [52]. In conclusion, future studies on postoperative CNS infections ought to concentrate on prevention, improvements in diagnosis, underlying processes, treatment optimization, long-term results, and interdisciplinary cooperation. We can improve patient care, increase results, and ultimately lessen the burden of postoperative CNS infections by focusing on these areas [53].

Conclusion:

Postoperative CNS infections indicate considerable obstacles to neurosurgical practice, advocating for further research and the use of evidence-based methods to enhance results. For prompt diagnosis and effective treatment, it's essential to have an in-depth understanding of the risk factors, pathophysiology, clinical manifestations, and management strategies associated with these illnesses. The prevalence of postoperative CNS infections can be lowered, resulting in better patient outcomes and lower healthcare expenditures, by following strict infection control guidelines and encouraging professional teamwork.

Conflict of interest:

There is no conflict of interest between the authors.

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REFERENCES

[1] I. Shah, M. A. Shaikh, and K. Mehmood, "Characteristics of Post-Neurosurgical Nosocomial Bacterial Meningitis in Adults: a retrospective Cross-Sectional Study," Pakistan J. Med. Heal. Sci., vol. 16, no. 11, pp. 397–397, Nov. 2022, doi:

10.53350/PJMHS20221611397.

[2] E. Journal et al., “Antibiotic therapy by intrathecal or intraventricular approach for postsurgical meningitis or ventriculitis: a systematic review and meta-analysis,” Egypt. J. Neurosurg. 2023 381, vol. 38, no. 1, pp. 1–11, May 2023, doi: 10.1186/S41984-023-00199-9.

[3] K. Hussein, R. Bitterman, B. Shofty, M. Paul, and A. Neuberger, “Management of post-neurosurgical meningitis: narrative review,” Clin. Microbiol. Infect., vol. 23, no. 9, pp. 621–628, Sep. 2017, doi: 10.1016/j.cmi.2017.05.013.

[4] R. N. Sahu, R. Kumar, and A. Mahapatra, “Central nervous system infection in the pediatric population,” J. Pediatr. Neurosci., vol. 4, no. SUPPL. 1, pp. 20–24, Jan. 2009, doi: 10.4103/1817-1745.49102.

[5] Y. F. Ma, L. Wen, and Y. Zhu, “Prospective study evaluating post-operative central nervous system infections following cranial surgery,” Br. J. Neurosurg., vol. 33, no. 1, pp. 80–83, Jan. 2019, doi: 10.1080/02688697.2018.1519112.

[6] W. Liang, Z. Yuan-Run, and Y. Min, “Clinical Presentations and Outcomes of Post-Operative Central Nervous System Infection Caused by Multi-Drug–Resistant/Extensively Drug-Resistant Acinetobacter baumannii: A Retrospective Study,” https://home.liebertpub.com/sur, vol. 20, no. 6, pp. 460–464, Aug. 2019, doi: 10.1089/SUR.2018.286.

[7] Y. J. Shi, G. H. Zheng, L. Y. Qian, R. A. Qsman, G. G. Li, and G. J. Zhang, “<p>Longitudinal Analysis of Risk Factors for Clinical Outcomes of Enterobacteriaceae Meningitis/Encephalitis in Post-Neurosurgical Patients: A Comparative Cohort Study During 2014–2019</p>,” Infect. Drug Resist., vol. 13, pp. 2161–2170, Jul. 2020, doi: 10.2147/IDR.S252331.

[8] “Craniotomy - Wikipedia.” Accessed: Jul. 23, 2024. [Online]. Available: https://en.wikipedia.org/wiki/Craniotomy

[9] R. Zhan et al., “Post-operative central nervous system infections after cranial surgery in China: Incidence, causative agents, and risk factors in 1,470 patients,” Eur. J. Clin. Microbiol. Infect. Dis., vol. 33, no. 5, pp. 861–866, Dec. 2014, doi: 10.1007/S10096-013-2026-2/METRICS.

[10] J. Wen et al., “Hypothalamus-Pituitary Dysfunction as an Independent Risk Factor for Postoperative Central Nervous System Infections in Patients With Sellar Region Tumors,” Front. Endocrinol. (Lausanne)., vol. 12, p. 661305, Apr. 2021, doi: 10.3389/FENDO.2021.661305/BIBTEX.

[11] E. Jiménez-Martínez et al., “Risk factors for surgical site infection after craniotomy: A prospective cohort study,” Antimicrob. Resist. Infect. Control, vol. 8, no. 1, pp. 1–8, May 2019, doi: 10.1186/S13756-019-0525-3/TABLES/4.

[12] L. Cheng et al., “Development and Validation of a Nomograph Model for Post-Operative Central Nervous System Infection after Craniocerebral Surgery,” Diagnostics 2023, Vol. 13, Page 2207, vol. 13, no. 13, p. 2207, Jun. 2023, doi: 10.3390/DIAGNOSTICS13132207.

[13] N. Cassir et al., “Risk factors for surgical site infections after neurosurgery: A focus on the postoperative period,” Am. J. Infect. Control, vol. 43, no. 12, pp. 1288–1291, Dec. 2015, doi: 10.1016/j.ajic.2015.07.005.

[14] S. M. Klimkiewicz et al., “Influence of the Built Environment on Airflow, Contamination, and Infection in the Operating Room: A Systematic Literature Review,” medRxiv, p. 2022.07.20.22277856, Jul. 2022, doi: 10.1101/2022.07.20.22277856.

[15] V. Pintado et al., “Staphylococcus aureus meningitis in adults: A comparative cohort study of infections caused by meticillin-resistant and meticillin-susceptible strains,” J.

Hosp. Infect., vol. 102, no. 1, pp. 108–115, May 2019, doi: 10.1016/j.jhin.2018.11.008.

[16] Archana et al., "Isolation and Characterization of Lytic Bacteriophage against Methicillin Resistant Staphylococcus aureus from Pyoderma in Dog," Indian J. Anim. Res., vol. 56, no. 7, pp. 873–879, Jul. 2022, doi: 10.18805/IJAR.B-4869.

[17] L. Prozan, N. Popovits, Z. Lidar, and R. Ben-Ami, "Risk Factors and Outcomes of Cutibacterium acnes Postoperative Central Nervous System Infection: A Case–Control Study," World Neurosurg., vol. 137, pp. e251–e256, May 2020, doi: 10.1016/J.WNEU.2020.01.161.

[18] R. A. Borchardt and D. Tzizik, "Update on surgical site infections: The new CDC guidelines," J. Am. Acad. Physician Assist., vol. 31, no. 4, pp. 52–54, Apr. 2018, doi: 10.1097/01.JAA.0000531052.82007.42.

[19] M. A. Smith and N. R. Dahlen, "Clinical practice guideline surgical site infection prevention," Orthop. Nurs., vol. 32, no. 5, pp. 242–248, Sep. 2013, doi: 10.1097/NOR.0B013E3182A39C6B.

[20] P. M. Spielmann, R. Yu, and M. Neeff, "Skull base osteomyelitis: current microbiology and management," J. Laryngol. Otol., vol. 127, no. S1, pp. S8–S12, Jan. 2013, doi: 10.1017/S0022215112002356.

[21] H. Zhou and X. Zhang, "Intracranial malignant lesions correlate with the requirement for a long treatment course in postoperative central nervous system infection," Neuropsychiatr. Dis. Treat., vol. 10, pp. 2071–2077, Nov. 2014, doi: 10.2147/NDT.S71836.

[22] "(PDF) Preventing Surgical Complications During Microscopic Fenestration in Middle Fossa Arachnoid Cysts: A Retrospective Study for 38 Cases and Literature Review." Accessed: Jul. 06, 2024. [Online]. Available: https://www.researchgate.net/publication/354138379_Preventing_Surgical_Complications_During_Microscopic_Fenestration_in_Middle_Fossa_Arachnoid_Cysts_A_Retrospective_Study_for_38_Cases_and_Literature_Review

[23] M. Liu et al., "A retrospective study of prevalence and antibiotic resistance of bacteria isolated from the cerebrospinal fluid of neurosurgical patients in a Shanghai tertiary hospital," Feb. 2020, doi: 10.21203/RS.2.23500/V1.

[24] I. Martin-Loeches, A. Blake, and D. Collins, "Severe infections in neurocritical care," Curr. Opin. Crit. Care, vol. 27, no. 2, pp. 131–138, Apr. 2021, doi: 10.1097/MCC.0000000000000796.

[25] H. D. Mollman and S. J. Haines, "Risk factors for postoperative neurosurgical wound infection: A case-control study," J. Neurosurg., vol. 64, no. 6, pp. 902–906, Jun. 1986, doi: 10.3171/JNS.1986.64.6.0902.

[26] S. McClelland and W. A. Hall, "Postoperative central nervous system infection: Incidence and associated factors in 2111 neurosurgical procedures," Clin. Infect. Dis., vol. 45, no. 1, pp. 55–59, Jul. 2007, doi: 10.1086/518580/2/45-1-55-TBL002.GIF.

[27] W. Ma, C. Li, and L. Cong, "Dynamic Curve Analysis of Indicators Related to Lumbar Cistern Drainage for Postoperative Meningitis," World Neurosurg., vol. 151, pp. e299–e307, Jul. 2021, doi: 10.1016/J.WNEU.2021.04.031.

[28] T. A. M. Radwan, R. S. Fahmy, and B. N. Hanna, "Surveillance of the incidence and causative pathogens of meningitis and surgical site infection after craniotomies for brain tumors in neurosugical ICU and ward: a cohort study," Ain-Shams J. Anesthesiol. 2018 101, vol. 10, no. 1, pp. 1–7, Oct. 2018, doi: 10.1186/S42077-018-0010-X.

[29] K. Singh, S. Lohiya, R. Chaudhary, M. Lakra, and S. Damke, "A Rare Case of Guillain-Barré Syndrome with Signs of Meningeal Irritation and Treatment-Related Fluctuations/Relapse," J. Pediatr. Neurol., vol. 21, no. 6, pp. 434–436, Jan. 2022, doi:

10.1055/S-0042-1750790/ID/JR2200005-16/BIB.
[30] C. Moon, Y. G. Kwak, B. N. Kim, E. S. Kim, and C. S. Lee, "Implications of postneurosurgical meningitis caused by carbapenem-resistant Acinetobacter baumannii," J. Infect. Chemother., vol. 19, no. 5, pp. 916–919, Jan. 2013, doi: 10.1007/s10156-013-0608-7.
[31] J. B. Chang et al., "Combined Strategy for Post-Operative Patients with Central Nervous System Infections Caused by Extensively Drug-Resistant/Pan-Drug–Resistant Acinetobacter baumannii: A Retrospective Study," https://home.liebertpub.com/sur, vol. 21, no. 10, pp. 853–858, Nov. 2020, doi: 10.1089/SUR.2019.341.
[32] R. Moorthy, V. Job, G. Rebekah, and V. Rajshekhar, "Cerebrospinal Fluid Procalcitonin - A Potential Biomarker for Post-Craniotomy Bacterial Meningitis," Neurol. India, vol. 70, no. 2, pp. 721–725, Mar. 2022, doi: 10.4103/0028-3886.344643.
[33] R. N. Montalvo et al., "Variations in the Organisms Causing Deep Surgical Site Infections in Fracture Patients at a Level i Trauma Center (2006-2015)," J. Orthop. Trauma, vol. 32, no. 12, pp. E475–E481, 2018, doi: 10.1097/BOT.0000000000001305.
[34] C. Mayslich, P. A. Grange, and N. Dupin, "Cutibacterium acnes as an Opportunistic Pathogen: An Update of Its Virulence-Associated Factors," Microorg. 2021, Vol. 9, Page 303, vol. 9, no. 2, p. 303, Feb. 2021, doi: 10.3390/MICROORGANISMS9020303.
[35] L. Zhu et al., "The Diagnostic and Antibiotic Reference Values of Procalcitonin for Intracranial Infection After Craniotomy," World Neurosurg., vol. 126, pp. e1–e7, Jun. 2019, doi: 10.1016/J.WNEU.2018.10.241.
[36] R. E. Balch, "Wound Infections Complicating Neurosurgical Procedures," J. Neurosurg., vol. 26, no. 1part1, pp. 41–45, Jan. 1967, doi: 10.3171/JNS.1967.26.1PART1.0041.
[37] J. W. Alexander, J. S. Solomkin, and M. J. Edwards, "Updated recommendations for control of surgical site infections," Ann. Surg., vol. 253, no. 6, pp. 1082–1093, Jun. 2011, doi: 10.1097/SLA.0B013E31821175F8.
[38] K. Y. Yang, W. N. Chang, J. T. Ho, H. C. Wang, and C. H. Lu, "Postneurosurgical nosocomial bacterial brain abscess in adults," Infection, vol. 34, no. 5, pp. 247–251, Oct. 2006, doi: 10.1007/S15010-006-5607-5/METRICS.
[39] N. Lange et al., "Clinical Characteristics and Course of Postoperative Brain Abscess," World Neurosurg., vol. 120, pp. e675–e683, Dec. 2018, doi: 10.1016/J.WNEU.2018.08.143.
[40] T. Niu, X. Bao, J. Wei, Y. Shi, W. Ma, and R. Wang, "Impact of Penicillin Allergy–Based Alternative Antibiotics on the Risk of Postoperative Central Nervous System Infection: A Retrospective Cohort Study," World Neurosurg., vol. 171, pp. e745–e751, Mar. 2023, doi: 10.1016/J.WNEU.2022.12.102.
[41] R. M. Antonello and N. Riccardi, "How we deal with Staphylococcus aureus (MSSA, MRSA) central nervous system infections," Front. Biosci. - Sch., vol. 14, no. 1, p. 1, Jan. 2022, doi: 10.31083/J.FBS1401001/1945-0524-14-1-001.PDF.
[42] M. Weller et al., "Diagnosis and management of complications from the treatment of primary central nervous system tumors in adults," Neuro. Oncol., vol. 25, no. 7, pp. 1200–1224, Jul. 2023, doi: 10.1093/NEUONC/NOAD038.
[43] J. M. Lemée, M. V. Corniola, M. Da Broi, K. Schaller, and T. R. Meling, "Early Postoperative Complications in Meningioma: Predictive Factors and Impact on Outcome," World Neurosurg., vol. 128, pp. e851–e858, Aug. 2019, doi: 10.1016/J.WNEU.2019.05.010.
[44] M. Meschiari et al., "Ceftazidime/avibactam and ceftolozane/tazobactam for the

treatment of extensively drug-resistant Pseudomonas aeruginosa post-neurosurgical infections: three cases and a review of the literature," Infection, vol. 49, no. 3, pp. 549–553, Jun. 2021, doi: 10.1007/S15010-020-01539-9/TABLES/1.

[45] E. R. Bader, A. J. Kobets, A. Ammar, and J. T. Goodrich, "Factors predicting complications following cranioplasty," J. Cranio-Maxillofacial Surg., vol. 50, no. 2, pp. 134–139, Feb. 2022, doi: 10.1016/J.JCMS.2021.08.001.

[46] A. Soriano, Y. Carmeli, A. S. Omrani, L. S. P. Moore, M. Tawadrous, and P. Irani, "Ceftazidime-Avibactam for the Treatment of Serious Gram-Negative Infections with Limited Treatment Options: A Systematic Literature Review," Infect. Dis. Ther., vol. 10, no. 4, pp. 1989–2034, Dec. 2021, doi: 10.1007/S40121-021-00507-6/TABLES/6.

[47] G. L. Daikos et al., "Review of Ceftazidime-Avibactam for the Treatment of Infections Caused by Pseudomonas aeruginosa," Antibiot. 2021, Vol. 10, Page 1126, vol. 10, no. 9, p. 1126, Sep. 2021, doi: 10.3390/ANTIBIOTICS10091126.

[48] N. Rattanachak et al., "High-Throughput Transcriptomic Profiling Reveals the Inhibitory Effect of Hydroquinine on Virulence Factors in Pseudomonas aeruginosa," Antibiotics, vol. 11, no. 10, p. 1436, Oct. 2022, doi: 10.3390/ANTIBIOTICS11101436/S1.

[49] F. Ciummo, P. Srinivas, and J. Biedny, "Antimicrobial use in central nervous system infections," Curr. Opin. Infect. Dis., vol. 34, no. 3, pp. 255–263, Jun. 2021, doi: 10.1097/QCO.0000000000000721.

[50] R. Nau, F. Sörgel, and H. Eiffert, "Central nervous system infections and antimicrobial resistance: an evolving challenge," Curr. Opin. Neurol., vol. 34, no. 3, pp. 456–467, Jun. 2021, doi: 10.1097/WCO.0000000000000931.

[51] G. G. Zhanel et al., "Real-life experience with ceftolozane/tazobactam in Canada: results from the CLEAR (Canadian LEadership on Antimicrobial Real-life usage) registry," J. Glob. Antimicrob. Resist., vol. 25, pp. 346–350, Jun. 2021, doi: 10.1016/J.JGAR.2021.03.025.

[52] S. Dubler et al., "Off-Label Use of Ceftolozane/Tazobactam for the Successful Treatment of Healthcare-Associated Meningitis Caused by Extensively Drug-Resistant Pseudomonas aeruginosa in a Polytraumatized Patient—A Case Report," Reports 2022, Vol. 5, Page 33, vol. 5, no. 3, p. 33, Aug. 2022, doi: 10.3390/REPORTS5030033.

[53] W. Baharoon, J. Shamou, and L. Layqah, "A Fatal Case of Meningitis Complicating Chronic Otitis Media and Base of Skull Osteomyelitis due to Carbapenemase (OXA-48)-Producing Klebsiella pneumoniae," Dr. Sulaiman Al Habib Med. J. 2022 51, vol. 5, no. 1, pp. 23–28, Dec. 2022, doi: 10.1007/S44229-022-00024-9.