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Postoperative Infections: Risk Factors, Prevention, and Management Strategies

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Abstract: Postoperative infections pose a significant concern within the healthcare field due to their potential to profoundly impact patient outcomes and escalate healthcare costs. Among the common types of postoperative infections are surgical site infections, urinary tract infections, pneumonia, and bloodstream infections. These infections can result in substantial rates of morbidity and mortality,as well as prolonged hospital stays and increased healthcare expenses. Various risk factors have been identified that can heighten the likelihood of postoperative infections. These include underlying medical conditions such as diabetes or immune suppression, the duration of the surgical procedure, the presence of foreign bodies like catheters or implants, and inadequate infection control practices. Furthermore, certain patient characteristics, including older age, obesity, and smoking status, have also been linked to an elevated risk of postoperative infections. To mitigate their incidence, healthcare providers can employ a range of strategies. These may encompass the administration of prophylactic antibiotics, the implementation of proper wound care techniques, adherence to infection control protocols, and the optimization of patient outcomes. Additionally, educating patients and involving them in infection prevention practices can play a pivotal role in reducing the risk of postoperative infections.

I. Introduction

Post-operative infections are infections that occur after a surgical procedure in the area where the surgery was performed [1,2]. Theseinfections can occur within 30 days following the surgical procedure, either while still in the hospital or once the patient has returned home. However, it can also appear several months or even years later if a prosthesis or foreign body has been implanted[1]. It has been classified by the Centers for Disease Control and Prevention into Superficial infections, deep infections, and organ/space infections. The severity of the infection varies depending on the case. They can affect one or multiple layers of tissue in the surgical area. Similarly, diagnostic signs can range from simple pus secretion to a generalized infection of deep subcutaneous tissues [1,2].

The consequences of a post-operative infections are manifold and can range in severity from mild to potentially fatal.It could lead to a prolonged hospital stay, management may involve repeated interventions by the surgeon,, and in rare situations, it can even pose a risk to the patient's survival.

Common types of postoperative infections include surgical site infections, pneumonia, urinary tract infections, and bloodstream infections. These infections are typically caused by bacteria, viruses, or fungi that enter the body during the surgery or develop after the procedure due to improper wound care, compromised immune system, or inadequate sterilization of surgical equipments [1,2]. The origin of these germs can be endogenous (an infectious focus near the surgical area) or, less commonly, exogenous (the environment, the operating room, the personnel, the instruments, etc.). It is important to follow proper infection control measures before, during, and after surgery to reduce the risk of developing postoperative infections.

- Surgical site infections: Infections that occur at the site of a surgical incision, leading to redness, swelling, and discharge [2,3].
- Urinary tract infections: Infections that occur in the bladder or urethra, often as a result of catheterization during surgery [4–6].
- Pneumonia: Infections of the lungs that occur in the lungs, often as a result of breathing difficulties or prolonged bed rest after surgery [7–9].
- Sepsis: A potentially life-threatening infection that occurs when bacteria enter the bloodstream and spread throughout the body [10,11].
- Wound infections: Infections that occur in a wound or incision site, leading to delayed healing and increased risk of complications [1,3].
- Bloodstream infections: Infections that occur when bacteria enter the bloodstream, often as a result of poor hygiene practices during surgery [12,13].
- Meningitis: Infections that occur in the membranes lining the brain and spinal cord, often as a result of contamination during surgery or from an existing infection spreading [14–16].
- Catheter-related infections: Infections that occur due to the presence of a catheter, leading to urinary tract infection, bloodstream infection, or sepsis [17–19].

The risk of infection can vary depending on the specific organ that the surgeon operates on. In cases where the chosen treatment involves accessing a hollow organ such as the respiratory, digestive, or urinary system, there is a potential for the contents of the organ to spread, thereby increasing the risk of infection[1]. Additionally, the likelihood of postoperative infection is influenced by the patient's overall health condition, nutritional status and medical background. Factors such as diabetes mellitus, smoking habits, age, and obesity can all contribute to the risk of infection following surgery [1,2,20,21].

Postoperative infections can have significant impacts on patient outcomes and healthcare systems. Some of the key effects include:

- Increased morbidity and mortality: Postoperative infection can lead to prolonged hospital stay, increased pain and discomfort, and in severe cases, can result in mortality. Patients who develop infections are at higher risk of complications and may require further medical interventions or surgeries to address the infection[1,2].
- Increased healthcare costs: Patients who develop postoperative infections require additional medical care and treatment, including antibiotics, wound care, and possible surgical interventions. This can result in increased healthcare costs for both the patient and the healthcare system. In some cases, patients may need to be readmitted to the hospital, further increasing costs[22].
- Prolonged hospital stays: Patients who develop postoperative infection often require longer hospital stays to address the infection and recover [22–24]. This can result in increased strain on hospital resources, including beds, staff, and medical supplies. Prolonged hospital stays can also impact on patient comfort and well-being, as they may be separated from their families and support systems for longer periods of time.
- Impaired quality of life: Postoperative infections can have long-term effects on a patient's quality of life, including physical and emotional impacts. Patients may experience chronic pain, scarring, reduced mobility, and decreased overall well-being as a result of the infection and its treatment[1].
- Increased antibiotic resistance: The overuse of antibiotics to treat postoperative infections can contribute to the development of antibiotic-resistant bacteria. This can make infections more difficult to treat in the future and may require the use of stronger, more expensive antibiotics [25,26].

In this review, we will outline the various types of postoperative infections that are most common as well as their prevalence; we will specifically examine the risks most often associated with this type of infection. In a second section, a comprehensive list of prevention methods [pre, intra, and post-operative] will be presented along with strategies for diagnosing and treating post-operative infections. The final section will discuss the latest advances in the management of postoperative infections and the future directions to reduce their prevalence.

II. Methodology

This extensive search was conducted utilizing the PubMed and Google Scholar databases to identify English-language studies focusing on the pathogenesis, clinical presentation, guidelines, and prevention of postoperative infections. Each selected article's references were meticulously examined and compared with other sources to validate the accuracy of pertinent information.

III. Discussion

I. Epidemiology of Postoperative Infections

Postoperative infections are categorized based on the type of wound and its level of severity.

[1,27]. These categories include clean wounds, which involve sterile tissue with a low risk of infection; clean-contaminated wounds, resulting from exposure to mucous membranes; contaminated wounds, which are associated with open trauma, contamination from the intestinal tract, or failure to maintain sterility during surgery; and heavily contaminated or infected wounds, which have come into contact with pus or perforated intestines. Additional classes pertain to wounds that arise within the subsequent month following a surgical procedure. These encompass superficial wound infections, which affect the skin or subcutaneous tissues and result in the generation of pus. Additionally, they encompass wounds that have been opened or drained, or where bacteria have been isolated from the fluid of a wound prior to the primary suturing. On the other hand, deep wound infections can manifest up to a year after the implantation of medical foreign bodies such as prostheses or metal wires. These infections are localized in deeper tissues, such as intramuscular, arthritis, or intra-abdominal regions, and are characterized by the production of pus and/or the spontaneous opening of the wound due to the accumulation of pus. Symptoms may include localized pain or the development of an abscess[28].

The incidence of postoperative infections is heavily influenced by the nature of the surgical procedure, particularly in gastrointestinal surgeries, as well as the overall quality of the healthcare facility, including factors such as the number of beds, nurses, specialists, and the training and equipment available to the surgical team [1,29]. On average, postoperative infections affect between 0.5% to 3% of patients who undergo surgery [30,31], resulting in a significant financial burden on the US healthcare system, ranging from $3 to $10 billion annually [2,32]. In the majority of cases (>70%), these infections can be attributed to intestinal bacteria such as Staphylococcus aureus (24%), coagulase-negative Staphylococcus, or Escherichia coli (10%) [31,33]. In a recent prospective study involving a cohort of 44,814 patients from various countries, it was found that 6.5% of the patients developed postoperative infections. Among those infected, 3.4% succumbed to the infection [34].

A comprehensive analysis conducted on a total of 2027 patients who underwent surgical procedures in India revealed the varying prevalence rates for different types of operations[35] (see Table 1).

Lower segment cesarean section	2.2%
Sphincterotomy	4.6%
Knee replacement	8.5%
Appendectomy	**15.6%**
Cholecystectomy	17.9%
Hernia repair	18.6%
Exploratory laparotomy	18.6%
Hip replacement	19.3%

Table 1: Prevalence of postoperative infections according to the operation type.[35]

III. Risk Factors for Postoperative Infections

a. Patient-related risk factors

The likelihood of a postoperative infection in a patient is influenced by a wide range of factors, including both patient-related (endogenous) and process/procedural-related (exogenous) variables. While certain variables like age and gender cannot be changed, there are several other factors that can be addressed to improve the chances of a successful surgical outcome. These include nutritional status, smoking habits, the proper use of antibiotics, and the surgical technique employed [1,2]. A detailed list of patient-related risk factors helps to understand the key elements that play a significant role in determining the risk of postoperative infections.

- Diabetes: Elevated levels of blood glucose , referred to as hyperglycemia, can have adverse impact on the body's innate immune system, which serves as its natural defense mechanism [20,36,37]. Additionally, hyperglycemia plays a role in the glycosylation process of proteins, which further impedes the proper healing of wounds [38,39]. Moreover, individuals with diabetes commonly encounter heightened glucose levels in the perioperative phase, posing greater difficulties in effectively managing hyperglycemia.
- Obesity: Impaired blood circulation within the adipose tissue leads to a reduction in the supply of oxygen and antibiotics, thereby exerting a substantial impact on the healing process of wounds and increasing the vulnerability to infections [40–42].
- Malnutrition: Poor nutrition can lead to a decline in collagen production, obstruct the formation of granulation tissue in surgical wounds, and impede the overall tissue healing process [43,44]. Lowered albumin levels may compromise the body's natural defense mechanisms by inducing macrophage death and diminishing their effectiveness. Moreover, decreased albumin levels can facilitate fluid leakage from surrounding tissues into the surgical site, resulting in increased tissue swelling.
- Smoking: Tobacco consumption has been associated with the induction of vasoconstriction, leading to changes in collagen metabolism, decreased inflammatory response, and a state of relative ischemia [45–47].
- Poor hygiene: Individuals who do not comply with the suggested hygiene measures both before and after a surgical intervention are at a heightened risk of experiencing postoperative infections [1,2].
- Immunocompromised conditions: Patients diagnosed with HIV/AIDS, those receiving immuno-suppressive drugs such as post-transplant patients, or patients receiving chemotherapy treatment face an increased susceptibility to postoperative infections as a result of compromised immune function [48–50].
- Medications: Certain medications, such as corticosteroids or immunosuppressants, have the potential to compromise the immune system, thereby elevating the susceptibility to infections[51].
- Age: The process of aging results in a progressive reduction in the thickness of the basement membrane and dermis of the skin[52]. This reduction is accompanied by a decrease in the abundance of blood vessels and nerves within the skin, there is also a decrease in collagen production, these factors play vital roles in the healing of wounds. As a consequence, the skin's capacity to

effectively heal wounds is compromised as it gradually depletes its reservoir of these essential components [53].

- Chronic illnesses: Patients who suffer from chronic conditions like heart disease, lung disease, or kidney disease face an elevated susceptibility to postoperative infections[54].
- Previous surgeries or infections: Patients with a history of prior surgeries or infections are more susceptible to the occurrence of postoperative infections. Additionally, it has been observed that radiation therapy can cause harm to the neighboring tissues, consequently hindering the inherent mechanism of wound healing [55,56].

b. Surgical procedure-related risk factors

The surgical procedure carries a notable risk of infection due to the disruption of the skin's natural barrier. Postoperative infections are largely impacted by the methods of drug administration and surgical techniques used.

- Blood coagulation and transfusion: The administration of anticoagulants may lead to an uninterrupted release of fluid from the surgical incision, consequently hindering the customary process of wound healing [57,58]. Likewise, blood transfusions can have adverse effects on the functionality of macrophages, which are crucial in the body's immune response to infections [59–61].
- Operation duration: Extended duration of surgery is associated with increased damage to cells in the wound, contamination of the wound, and exposure to the external environment[21]. Reduced levels of oxygen in the tissues result in a decreased ability of neutrophils to eliminate pathogens through oxidative mechanisms [62]. Additionally, it hampers the tissue repair processes such as epithelialization, neovascularization, and collagen synthesis. Inadequate oxygenation settings during surgery have the potential to decrease the effectiveness of antibiotics given before and after the operation[2].
- Surgery techniques: Several factors can hinder the process of wound healing. These include the existence of devitalized tissues, accidental penetration into hollow organs, inadequate maintenance of blood supply, rough handling of tissue, misplaced drains and sutures, and improper postoperative wound care.
- Perioperative hypothermia: The immune system's ability to defend against surgical wound contamination is negatively impacted by the presence of perioperative hypothermia [63,64]. This is mainly caused by vasoconstriction, which leads to compromised tissue perfusion and limited accessibility for essential immune cells[65]. Moreover, the reduced motility of these crucial immune cells further impairs their effectiveness in fighting potential infections. Furthermore, perioperative hypothermia has been linked to reduced scar formation, which can hinder the overall healing process[66].
- Postoperative hyperglycemia: Research indicates that insulin and glycemic control play a crucial role in improving cellular functions like bactericidal activity, leukocyte adherence chemotaxis, and phagocytosis [67,68]. The findings suggest a clear link between high blood glucose levels and impaired cellular function. This association has been noted in individuals with and without diabetes[69].

c. Hospital environment and procedural factors

Airborne pathogens in the operating room are a key concern, with individuals and their movements playing a significant role in their generation [70,71]. Inadequate ventilation systems can fail to effectively remove or filter out harmful bacteria, increasing the risk of infections for surgical patients. Improper ventilation may also lead to the accumulation of dust and debris, serving as a reservoir for pathogens. Airflow patterns within the operating room must be carefully controlled to prevent turbulent airflow from disrupting the sterile field or introducing contaminants to the surgical site [72,73]. Healthcare facilities must prioritize proper ventilation designand maintenance to meet recommended air exchange rates and reduce the risk of postoperative infections.

In addition, the careful attention given to wound contamination and its appropriate management significantly influences the occurrence of postoperative infections [1,2]. Proper skin preparation and antibiotic administration are key components in reducing the risk of surgical site infection. Shaving the skin can create microabrasions that provide a breeding ground for bacteria, while inadequate draping and barrier protection can lead to contamination from deeper layers of the skin[74]. Beyond that, microorganisms from the surgical team's shoes, mouths, or bodies can also pose a risk of contamination [75,76]. In the operating room, health care workers must adhere to strict handwashing and gloving protocols to prevent the transfer of microorganisms to the patient and surgical field. Lastly, sterilization of surgical instruments is crucial to eliminate pathogens and prevent their transmission during surgery.

IV. Prevention of Postoperative Infections

a. Preoperative care

The involvement of the patient in preoperative care should commence as early as possible to mitigate the potential risk of postoperative infections. It is imperative for the patient to promptly inform the healthcare provider about any observed health issues, particularly illnesses, urinary infections, headaches accompanied by vomiting, and any other concerns. The medical history should be thoroughly reviewed, including any previous infections and the administration of antibiotics, as well as the patient's surgical history. Preoperative tests can be conducted to identify potential sources of postoperative infections and initiate early treatment [77–79]. These tests may encompass blood tests to measure glucose levels, white and red blood cell counts, and potassium levels, an electrocardiogram (ECG), urinalysis, or x-rays for respiratory-related diagnoses. Smoking is a well-known risk factor that heightens the likelihood of postoperative infections, particularly impeding the healing process of traumatized bones[45–47]. Therefore, it is advisable for patients to cease smoking for at least one month prior to surgery to enhance the bone-healing pathway's metabolism. Diabetic patients require extra attention, as diabetes is a risk factor for infections [20,36,37]. Consequently, diligent monitoring should be carried out at each stage of the surgical process, including before, during, and after the surgery. Additionally, efforts should be made to minimize the patient's hospital stay, as an extended duration increases the susceptibility to infections caused by antibiotic-resistant bacteria [23,80].

The preparation and sterilization of the body and surgical area must be conducted meticulously and supervised by the healthcare personnel. The patient's personal clothing should be stored separately to prevent any contamination from external sources, while sterile paper garments should be provided to the patient between the preoperative body wash and the actual surgery[1]. To effectively eliminate bacteria on the skin, a disinfecting soap containing chlorhexidine gluconate (CHG) should be used on the day of the operation as well as the day before [81–83]. Special attention should be given to areas with hair, as they provide an optimal environment for the growth of germs. This is particularly crucial for elective surgeries involving prostheses or other medical foreign bodies, as they can serve as vectors for infections. Shaving of the surgical area should only be performed during the operation itself to minimize the risk of skin injuries in a non-sterile environment[74]. The patient's room should be thoroughly cleaned, with extra focus on the bed, bathroom, and door handles and taps – any surface that can be touched by hands. Antimicrobial wipes should be used to disinfect the hands of the patient, healthcare personnel, and visitors upon entering the hospital, in the patient's room, and before leaving. Implementing a decolonization protocol for surgical patients, involving the use of intranasal antistaphylococcal agent and antistaphylococcal skin antiseptic prior to high- risk procedures, can significantly reduce the risk of Staphylococcus aureus infections[84]. The procedure generally involves the administration of an antistaphylococcal agent, such as mupirocin ointment or povidone iodine, through intranasal treatment. Finally, antimicrobial prophylaxis should be administered within 1 hour of incision using weight-based antimicrobial agents tailored to target the most common pathogens associated with the specific procedure[85].

The following inventory encapsulates the crucial points that necessitate regulation prior to the operation to diminish the chances of postoperative infections:

- Careful assessment of patient's recent health history, including recent illnesses, infections, and antibiotic use
- Eradication of any infections, including urinary tract infections and skin infections, prior to surgery
- Testing for exposure to MRSA (methicillin-resistant Staphylococcus aureus) and other resistant bacteria prior to admission
- Short preoperative stay, less than 1-2 days
- Consider reducing bacterial volume in the intestine for intestinal surgeries
- Consider the necessity of hair removal and if needed, perform it close to the operation but not in the operating room
- Monitor glucose levels preoperatively for all patients and maintain target levels less than 200 mg/dl[86]
- Provide written information before admission to ensure patient understanding and preparation for surgery.

b. Intraoperative measures

Surgical techniques

A well-trained surgical team typically experiences fewer postoperative infections compared to newly formed teams in the department. Additionally, this experienced team operates with greater efficiency and speed. It is important to note that while the volume of surgeries performed does have an impact on infection rates, a higher volume does not necessarily result in a lower infection rate [87–89].

Before commencing the operation, it is advisable to create a calm environment in the operating room for a few minutes. This allows any swirled dust or bacteria to settle. It is crucial to keep the doors closed and minimize major movements and the number of people present in the room. These precautions should be maintained throughout the surgery until the wound is sutured and covered with bandages[1].

It is recommended to use the least amount of foreign materials possible[90]. Thin, preferably synthetic, suture thread should be utilized to minimize the risk of adverse reactions. It is essential to ensure that the suture thread is stored in a sterile manner. Using monophilic sutures may reduce the risk of infection compared to twisted wire sutures made from the same material [1,91]. Whenever feasible, synthetic and resorbable suture materials should be chosen, and the number of different suture variants in the standard scheme should be minimized. The application of triclosan-coated sutures has proven to be highly effective in decreasing the occurrence of postoperative infections when compared to non-coated sutures [91–93]. Furthermore, the implementation of wound protectors has been shown to have a protective influence. Specifically, the use of dual-ring constructed wound protectors has exhibited greater efficacy in preventing postoperative infections compared to single-ring devices[94].

To prevent tissue damage, it is important to avoid poor blood supply by using sharp cuts instead of diathermy [95,96]. Additionally, drying, excessive pressure on tissues, and the use of local constringent medications should be avoided[1].

Efforts should be made to prevent the formation of hematomas and seromas (blood fluid) as they create favorable conditions for bacterial growth [97,98]. Instruments and equipment used during the operation must be sterile and should be covered throughout the procedure.

It is advisable to avoid direct contact with gloves on foreign materials like screws, prostheses, and sutures that are intended for long-term insertion into tissues. It is recommended to use sterile forceps or similar instruments instead [1,99].

Contamination of the suction system's tip is a common issue that should be addressed by replacing the system if contamination is suspected. Different suction systems should be used for interventions in various areas during surgery to prevent cross-contamination [100–102]. It is also crucial to avoid sharing equipment between different operating sites within the same procedure. Closed drainage is recommended for collecting pus, while prophylactic drainage should be avoided or sterile-treated closed drainage should be used [103–105]. Regular checks of compressed air and equipment are necessary, with battery-powered equipment being preferred over wall-supplied compressed air to minimize the risk of bacterial contamination [1, 106].

Antibacterial prophylaxis

It is strongly advised to utilize antibiotic prophylaxis, with a general consensus that antibiotics should be given within an hour of the incision to enhance the antibiotic concentration in the tissue [25,107,108]. The administration of prophylactic antibiotics should commence at the onset of anesthesia and only cover the duration of the current surgical procedure. In cases where short half-life preparations like cefalotin are used, a follow-up dose should be administered if the operation extends beyond the expected duration [25,109]. Furthermore, it is imperative that the prophylactic antibiotics achieve sufficiently high tissue concentrations prior to making an incision. Adjusting the antibiotic dosage based on the patient's weight is recommended to ensure adequate levels in the tissue. In instances of lengthy procedures with excessive bleeding, it is advisable to administer supplementary doses of antibiotics [1,25,109].

It is imperative to carefully choose suitable antibacterial agents that are specifically designed for the particular type of surgical procedure. It is of utmost importance to refrain from using antibiotics that contribute to the development of resistance, such as third- generation cephalosporins, quinolones, and clindamycin [26,110,111]. Furthermore, it is crucial to avoid the utilization of commonly prescribed and essential antibiotics, with particular emphasis on the avoidance of vancomycin [112–114]. Below is a summary of the recommended antibiotics for particular surgical procedures[107]:

- Cardiothoracic: Cefazolin, cefuroxime sodium
- Gastrointestinal: Cefoxitin, cefotetan, ampicillin/sulbactam, cefazolin plus metronidazole
- Gynecologic: Cefoxitin, cefotetan, cefazolin, ampicillin/sulbactam
- Orthopedic: Cefazolin, cefuroxime sodium
- Vascular: Cefazolin

Aseptic practices

During the surgical procedure, it is crucial to maintain an aseptic environment to minimize the risk of postoperative infections. Proper hand washing with chlorhexidine gluconate soap combined with alcohol is essential in achieving this goal l[2, 115]. Additionally, the surgical site and all instruments must be kept clean. It is recommended to control the concentration of suspended germs during the operation to less than 100 CFU/m^3 for standard procedures and less than 10 CFU/m^3 for ultraclean surgeries involving prostheses or foreign medical bodies [1,116,117]. The use of an air-filtration system, such as High-Efficiency Particulate Air (HEPA), is highly recommended in the operating room to filter particles down to 300 nm [118–120]. Furthermore, limiting the movement of individuals in the operating room to a minimum and restricting access during the procedure can help reduce the risk of contamination at the surgical site[1].

It is of utmost importance to be mindful of the potential for contamination on sleeves and cuffs when putting on sterile gloves [121–123]. To ensure the safest method of glove application, it is advisable to seek assistance from an assistant. It is recommended to use sterile gloves that are strong and have long cuffs, effectively covering the entire cuff on the gown. After surgical procedures, it is not uncommon to find punctures in the gloves. Therefore, thorough hand disinfection before surgery becomes particularly crucial. If a puncture is detected during the operation, it is essential to immediately divert attention away from the operating table, remove the gloves, disinfect the hands, and then put on new sterile gloves. Ideally, the use of double gloves, possibly equipped with a color indicator for detecting holes, is preferred, especially in situations where there is a risk of puncture, such as in orthopedics and other surgeries susceptible to infection[1]. Double gloves should always be used in procedures where the glove is prone to tearing and in cases involving potential blood- borne infections like hepatitis or HIV [1,123]. Additionally, it is important to change gloves and disinfect hands when transitioning from an unclean operating area to a cleaner one. Furthermore, gloves should be changed and hands disinfected if there is a significant amount of biologic material on the gloves or if contamination is suspected.

Finally, it is important to uphold normothermia during surgical procedures in order to prevent infections, as hypothermia (a body temperature below 36°C) can compromise the immune system's function and elevate the likelihood of surgical site infections [63,124]. Furthermore, hypothermia can hinder the effectiveness of antibiotics, diminish blood circulation to tissues, impede wound healing, and escalate the chances of various complications like cardiac issues and excessive bleeding[125]. Ensuring normothermia throughout surgery aids in bolstering the body's innate defense mechanisms and enhancing patient outcomes.

c. Postoperative care

Following the surgical procedure, it is imperative to ensure that the patient is isolated from individuals who have infections, particularly in areas such as corridors or shared rooms[1]. To cater to the needs of post-operative patients, the hospital should allocate specific rooms for their recovery. It is crucial to educate the patient about refraining from touching the bandages, as the wound requires a sterile environment. However, it is equally important to ensure that the bandage remains dry, as a moist environment can easily become contaminated by bacteria [126,127]. In the event that the bandage needs to be changed or removed, it is essential to thoroughly clean the hands using chlorhexidine gluconate soap and wear sterile gloves. Additionally, any equipment involved in the process must also be sterile.

In order to facilitate the healing process of the wound, incisional negative pressure wound dressings can be employed [128–131]. These dressings create a suction effect over the wound site, which aids in the removal of excess fluid, reduction of swelling, and enhancement of blood circulation in the area. Consequently, the utilization of such dressings can effectively prevent complications like infection and promote a faster healing of the wound. It is crucial to closely monitor the patient's condition throughout the healing period and for up to one month after the surgery. Any abnormalities or pain experienced by the patient should be duly recorded and observed by a physician. Additionally, the patient may be advised to engage in breathing exercises, as they have been observed to have a beneficial impact in reducing postoperative infections [1,132,133].

V. Management Strategies for Postoperative Infections

Diagnostic techniques for postoperative infections typically involve a combination of clinical assessment, laboratory tests, and imaging studies.

One of the primary methods of diagnosing postoperative infections is through clinical assessment, which involves evaluating the patient's symptoms, vital signs, and physical exam findings [1,2]. Common signs of postoperative infections include fever, increased pain or swelling at the surgical site, redness or warmth around the incision, and purulent drainage.

Laboratory tests such as complete blood count (CBC), C-reactive protein (CRP), and erythrocyte sedimentation rate (ESR) are often used to help diagnose postoperative infections [134,135]. An elevated white blood cell count, along with increased levels of CRP and ESR, can indicate the presence of an infection. C-reactive protein is a protein produced by the liver in response to inflammation in the body. When there is an infection, injury, or other inflammatory process occurring, CRP levels increase in the blood. Therefore, measuring CRP levels can indicate the presence and severity of inflammation, which is often seen in infections. Elevated levels of CRP can help healthcare providers identify infections, monitor the progress of treatment, and determine the likelihood of complications. Erythrocyte sedimentation rate (ESR), also known as sed rate, is a test that measures how quickly red blood cells settle at the bottom of a tube in a solution of blood. When there is inflammation in the body, certain proteins cause red blood cells to stick together and settle faster, which results in an elevated ESR. Elevated ESR levels can indicate the presence of an inflammatory condition, including infections. Similar to CRP, ESR is used to help diagnose infections, monitor response to treatment, and assess disease activity [134,135].

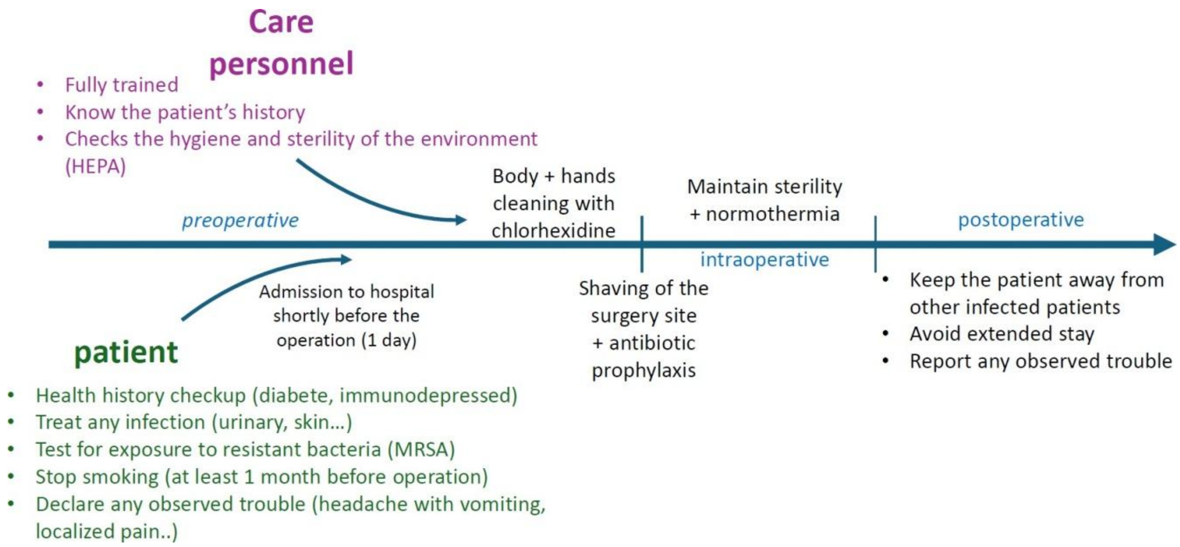
Imaging studies such as ultrasound, CT scan, or MRI may also be used to visualize the surgical site and surrounding tissues to help identify the source of infection [136–138]. These imaging modalities can help identify abscesses, fluid collections, or other abnormalities that may indicate an infection. Ultrasound employs sound waves of high frequency to generate visual representations of the internal structures within the human body. It can be used to detect swelling, fluid accumulation, or abscesses, which are common signs of infection. Ultrasound is particularly useful for detecting infections in superficial tissues and organs such as the skin, soft tissues, and organs in the abdomen[139]. CT scan, or computed tomography, uses X-rays to create detailed cross-sectional images of the body. CT scans can detect abnormalities such as fluid collections, abscesses, or inflammation, which are indicative of infection. CT scans are particularly useful for detecting infections in deeper tissues and organs such as the chest, abdomen, and pelvis, which is complementary to ultrasound imaging[140]. MRI, or magnetic resonance imaging, uses a magnetic field and radio waves to create detailed images of the body's internal structures. MRI can detect soft tissue abnormalities such as swelling, inflammation, or abscesses, which are common signs of infection. MRI is particularly useful for detecting infections in the central nervous system, joints, and soft tissues [140,141].

In some cases, a sample of fluid or tissue from the surgical site may be collected and sent for culture and sensitivity testing to identify the specific pathogen causing the infection and determine the most appropriate treatment[1]. In this case, antibiotic therapy is the primary treatment, and the antibiotics chosen will depend on the specific pathogen causing the infection and the severity of the infection. The choice of antibiotics is guided by the results of culture and sensitivity testing to determine which antibiotics the pathogen is susceptible to. Broad-spectrum antibiotics are often used initially to provide coverage against a wide range of bacteria until more specific information about the pathogen is available; among them, cefazolin, cefotetan or cefoxitin are often recommended (see Table 1)[49,107]. In some cases, combination therapy with multiple antibiotics may be necessary to treat polymicrobial infections. In addition to antibiotic therapy, other treatments such as surgical debridement or drainage of infected areas may be necessary to address the source of the infection and prevent its spread[1]. It is important that antibiotic therapy be administered in the correct dose and for the appropriate duration to ensure the infection is fully eradicated and to reduce the risk of antibiotic resistance developing. Close monitoring of the patient's response to treatment and follow-up care are important aspects of managing postoperative infections.

Along with pharmacological-based therapies, non-pharmacological interventions for treating postoperative infections can help to promote healing, reduce inflammation, and prevent further infections. Some of the common non-pharmacological interventions include:

- Wound care: Proper wound care is essential in preventing and treating postoperative infections. This includes keeping the wound clean and dry, changing dressings regularly, and avoiding any irritants that could cause infection [1,2].
- Use of antimicrobial dressings: Antimicrobial dressings, such as silver dressings, can be used to help prevent infections in postoperative wounds [142,143]. These dressings release antimicrobial agents that help reduce bacterial growth and promote healing.
- Negative pressure wound therapy: Negative pressure wound therapy (NPWT) is a technique that uses negative pressure to help promote wound healing and reduce the risk of infection[128]. This therapy can help remove excess fluid and bacteria from the wound, creating a more optimal environment for healing.
- Wound debridement: Wound debridement is a therapeutic procedure that aims to facilitate the healing process by eliminating necrotic or contaminated tissue from the wound[144]. This can help reduce the risk of infection and improve the body's ability to heal.
- Nutrition and hydration: Proper nutrition and hydration are essential for supporting the body's immune system and promoting healing. A well-balanced diet rich in vitamins and minerals can help the body fight off infections and recover from surgery more effectively [145,146].
- Physical therapy: Physical therapy can help improve circulation, reduce inflammation, and promote healing after surgery. It can also help improve range of motion, strength, and overall function, which can aid in the recovery process [145,146]. To ensure the quality of the treatment, having a multidisciplinary team is important because postoperative infections can be complex and may require a range of expertise to effectively treat: surgeons, infectious disease specialists, nurses, pharmacists, and other healthcare providers [147,148]. It ensures that all aspects of the patient's care are

coordinated and communicated effectively, reducing the risk of errors or gaps in treatment. Collaboration among healthcare professionals from different specialties can lead to innovative treatment approaches and better research outcomes for postoperative infection management. Finally, a multidisciplinary team can provide emotional support and education to patients and their families, helping them navigate the complexities of postoperative infections and promoting better overall outcomes.



VI. Emerging Trends and Innovations

Recent advances in surgical techniques and technologies have greatly reduced infection risks in the operating room.

Technological advances reducing infection risk

Minimally invasive surgical (MIS) methods have transformed the surgical field by enabling procedures with smaller incisions, reduced pain, shorter recovery times, and fewer complications compared to traditional open surgery [149,150]. Laparoscopy is a common minimally invasive technique, involving small incisions in the abdomen or pelvis to insert a laparoscope (a thin tube with a camera and light) and surgical instruments[151]. Surgeons can then perform various procedures, such as gallbladder removal, hernia repair, and gynecological surgeries, with enhanced precision and minimal scarring. Robotic-assisted surgery is another minimally invasive technique, where a surgeon utilizes a robotic system to conduct the procedure with even greater precision and control [152,153]. This allows for the performance of more intricate procedures minimally invasively, such as prostatectomies and hysterectomies. Additional minimally invasive techniques include endoscopic surgery, where a flexible tube with a camera and instruments is inserted through natural openings like the mouth or anus, and interventional radiology, where procedures are carried out using imaging guidance rather than open surgery.

Operating rooms are now equipped with High-efficiency particulate air (HEPA) filtration systems, which are mechanical air filters designed to eliminate airborne particles, including dust, pollen, mold spores, pet dander, and other allergens [118,119,154]. These filtration systems are highly efficient in capturing particles as small as 0.3 microns, making them one of the most effective options available. HEPA filters consist of a tightly woven mat of randomly arranged fibers that form a barrier, effectively trapping particles as air flows through. With a remarkable ability to capture over 99% of airborne particles, HEPA filters are an excellent choice for enhancing indoor air quality and reducing the risk of allergy or asthma symptoms. They play a crucial role in medical facilities, clean rooms, and other environments where maintaining optimal air quality is essential. In addition to their particle-capturing capabilities, HEPA filters also prove effective in trapping bacteria, viruses, and other harmful contaminants, making them a valuable asset in ensuring a clean and healthy indoor environment [120,155].

Ultraviolet (UV) light sterilization is a highly efficient technique employed to disinfect surfaces and eliminate bacteria, viruses, and other pathogens by utilizing UV light [156,157]. Among the various types of UV light, UV-C light with a wavelength of 222 nm stands out as the most effective in eradicating bacteria, viruses, and other pathogens due to its ability to disrupt the DNA and RNA of these microorganisms, thereby hindering their reproduction[158]. Additionally, UV-C light possesses the capability to break chemical bonds, rendering it a potent disinfectant. This method of sterilization finds widespread application in healthcare settings, the food and beverage industry, laboratories, and water treatment facilities. Notably, UV light sterilization is favored in medical applications as it is a rapid and efficient sterilization method that does not rely on the use of harsh chemicals.

Surgical instruments and implants are currently being enhanced with antibacterial materials in order to hinder the growth of bacteria and minimize the likelihood of infections [159,160]. Antibacterial coatings are substances that are applied onto surfaces to impede the proliferation of bacteria and other microorganisms. Various types of antibacterial coatings exist, including silver-based coatings, copper-based coatings, and coatings that contain quaternary ammonium compounds. These coatings function by releasing ions or chemicals that are detrimental to bacteria, thereby preventing their reproduction and dissemination[161]. The utilization of antibacterial coatings offers several advantages, such as reducing the risk of infections, enhancing hygiene, and extending the durability of products and surfaces. Additionally, these coatings contribute to the reduction of harsh chemicals and disinfectants, which can pose risks to human health and the environment.

New pharmacological agents

Pexiganan, a novel peptide-based antibiotic, has emerged as one of the most recent topical antimicrobial agents utilized in clinical research [162–164]. This synthetic peptide effectively imitates the antimicrobial properties of natural peptides present in the human body. Encouraging outcomes have been observed in the treatment of bacterial skin infections, including those caused by methicillin-resistant Staphylococcus aureus (MRSA)[164,165]. Another topical antimicrobial agent currently undergoing clinical trials is a gel known as nitric oxide- releasing hydrogel, which releases nitric oxide [166,167]. Nitric oxide exhibits potent antimicrobial properties, effectively eradicating a broad spectrum of bacteria, fungi, and viruses. This hydrogel has demonstrated efficacy in the treatment of diabetic foot ulcers and other persistent wounds. Furthermore, scientists are actively exploring the potential of utilizing antimicrobial peptides derived from plants and animals to combat various skin infections. These peptides have exhibited promising results in preclinical studies and hold the potential to establish a new category of topical antimicrobial agents [168,169].

Immuno modulators, a significant category of pharmacological agents employed in the treatment of postoperative infections, encompass drugs that aid in the restoration or alteration of the immune system. This modification aims to enhance the immune system's capacity to combat infections or diseases. Among the more recent immune modulators utilized

for infection treatment is Dupilumab, which belongs to the monoclonal antibody class and targets specific proteins implicated in the immune response [170–172]. Dupilumab is administered to address infections such as atopic dermatitis, asthma, and chronic rhinosinusitis with nasal polyps. Its mechanism of action involves reducing inflammation and regulating the immune response.

Guidelines and Protocols to reduce postoperative infection

The Centers for Disease Control and Prevention (CDC) has formulated comprehensive guidelines to address the prevention of postoperative infection[86]. These guidelines encompass recommendations for preoperative, intraoperative, and postoperative care, all aimed at mitigating the risk of postoperative infections. The CDC emphasizes several key strategies, including the appropriate utilization of antimicrobial prophylaxis, adherence to surgical hand hygiene practices, maintenance of aseptic technique during surgery, and proper wound care following the procedure. Similarly, various other organizations such as the National Institute for Health and Care Excellence (NICE)[173], Surgical Care Improvement Project (SCIP)[174], World Health Organization (WHO)[175,176], American College of Surgeons[39], Surgical Infection Society[39,177], Society for Healthcare Epidemiology of America (SHEA)[89,178], Association of periOperative Registered Nurses (AORN)[179], American Society of Anesthesiologists[180], and Society of Critical Care Medicine[181] have also published guidelines in a similar vein. These guidelines are regularly updated based on the latest clinical data and serve as a comprehensive framework for implementing sound clinical practices to minimize the occurrence of postoperative infections.

VII. Conclusion

Adequate hand hygiene is essential for healthcare workers to prevent the spread of infections. It is recommended that they wash their hands regularly with soap and water or use alcohol-based hand sanitizer. Administering preoperative antibiotics can help reduce the risk of infection, and healthcare professionals should adhere to strict sterile techniques during surgical procedures to prevent contamination. Proper wound care, including keeping surgical wounds clean and covered, is crucial in reducing the risk of infection. Healthcare providers should also monitor patients closely for signs of infection, such as fever, redness, swelling, or pus at the surgical site. Hospitals must maintain a clean environment by following strict protocols for cleaning and disinfecting surgical equipment and operating rooms. Additionally, healthcare workers should receive adequate education and training on infection control practices to prevent postoperative infections.

In order to shape the future of this field, it is imperative to prioritize personalized approaches that incorporate advancements in diagnostics and leverage innovative strategies such as immunomodulation to effectively prevent postoperative infections. Given the escalating challenge of antibiotic resistance, striking the right balance between efficacious prophylaxis and judicious antibiotic usage is of utmost importance. One promising avenue for tailoring treatments to individual patients is the utilization of artificial intelligence (AI)[182,183]. AI possesses the potential to furnish treatment plans that are not only more precise but also more personalized. By scrutinizing vast quantities of data, AI can discern patterns that may elude human physicians, thereby enabling more accurate diagnoses of infections and the selection of appropriate treatments. Moreover, AI can expedite the diagnostic process by analyzing symptoms, medical history, and other pertinent information to swiftly provide precise recommendations for treatment. This expeditiousness is particularly critical when dealing with potentially life-threatening infections. Lastly, the advent of telemedicine opens up avenues for a more systematic postoperative patient follow-up, thereby mitigating the risk of infections associated with patients returning to the hospital [184,185].

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