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Comprehensive Guidance for the Prevention of Periprosthetic Joint Infection After Total Joint Arthroplasty and Pitfalls in the Prevention

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ABSTRACT

Total joint arthroplasty (TJA) is a surgical procedure, in which parts of damaged joints are removed and replaced with a prosthesis. The main indication of TJA is osteoarthritis, and the volume of TJA is rising annually along with the increase of aged population. Hip and knee are the most common joints, in which TJAs are performed. The TJA prosthesis is composed of metal, plastic, or ceramic device. Even though TJA is the most successful treatment for end-stage osteoarthritis, it is associated with various complications, and periprosthetic joint infection (PJI) is the most serious complication after TJA. With the increasing volume of TJAs, there is a simultaneous rise in the incidence of PJI. Contamination of the surgical wound and the adherence of bacteria to the surface of prosthetic component represent the initial step in the pathogenesis of PJI. The main sources of the contamination are 1) patient's own flora, 2) droplets in the operation room air, and 3) surgical gloves and instruments. Even though modern techniques have markedly reduced the degree of contamination, TJAs cannot be done in completely germ-free conditions and some degree of contamination is inevitable in all surgical procedures. However, not all contamination leads to PJI. It develops when the burden of contamination exceeds the immune threshold or the colony forming units (CFUs) and various factors contribute to a decrease in the CFU level. Surgeons should be aware of the germ burden/CFU concept and should monitor sources of contamination to maintain the germ burden below the CFU to prevent PJI.

Keywords: Total Joint Arthroplasty; Periprosthetic Joint Infection; Contamination; Germ Burden; Prevention

INTRODUCTION

Total joint arthroplasty (TJA) is the most reliable and successful treatment for advanced osteoarthritis.[1] This procedure not only reduces joint pain but also improves the quality of life.[2,3] Both the number and the rate of TJAs (particularly knee and hip arthroplasties)

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increased steadily during last 3 decades. Approximately 790,000 total knee arthroplasties and over 450,000 total hip arthroplasties are performed annually in the United States, and the number of TJAs continues to increase in accordance of the increase of elderly (older than 65 years) population.[1,4]

Although the 10-year survival rate of TJA exceeds 95%,[1] and this surgery offers favorable clinical outcomes in most patients, TJAs are associated with complications, which necessitates additional surgeries.[3] Among the various complications, periprosthetic joint infection (PJI) is a devastating and costly complication following TJAs. Functional recovery and pain improvement of PJI patients may not be satisfactory, and prolonged use of antibiotics and repeated surgeries increase the patient morbidity and mortality.[5]

The overall incidence of PJI following hip and knee arthroplasty reported in the nationwide inpatient sample data of the USA ranges from approximately 2% to 2.7%. In Canada, the reported incidence of PJI following hip and knee arthroplasty is 1.6%.[6-8] The PJI incidence based on medical claim data from the Korean Health Insurance and Review and Assessment from 2010 to 2018 was similar with that of the United States, ranging between 2.3% and 2.8%.[5] PJI accounts for 14.8% and 25.2% of revision surgeries following hip and knee arthroplasty, respectively.[9,10] The prevention of PJI remains a crucial challenge and a comprehensive strategy for PJI prevention has been sought.

In this review, we implemented germ burden/colony forming unit (CFU) concept, classified the contamination process of surgical site into three categories, and noted key points of contamination in each category.

GERM-BURDEN/CFU CONCEPT

PJI occurs not only when there is exposure to microorganisms capable of inducing infection but also when these microorganisms are present in quantities sufficient to evade the host's immune system. In this context, the level of germ-burden at which PJI can occur is referred to as the level of CFU. The weakening of the host's immune system can decrease the level of the CFU, while substantial exposure to microorganisms capable of inducing PJI can increase the germ-burden beyond the CFU threshold (**Fig. 1**).

The infection typically occurs through either an exogenous route, primarily acquired during the perioperative period, or a hematogenous route originating from a distant source.[11] Despite numerous sources of bacteria, including the patient's endogenous flora and/or exogenous bacteria from the environment reaching the implant surface, contamination of the surgical wound and bacterial adherence represent the initial steps in the pathogenesis of PJI.[11,12] Even though modern techniques have reduced the degree of contamination, TJAs cannot be done in completely germ-free conditions. Thus, some degree of contamination is inevitable in all surgical procedures. The basic concept is that if the degree of contamination and bioburden in the surgical site exceed the immune threshold or CFU threshold, infection develops.

Although intraoperative inoculation of microorganisms is the major source of surgical site contamination, other sources of contamination also exist.[11] Thus, comprehensive understanding of contamination source and mechanism is necessary to prevent PJI.

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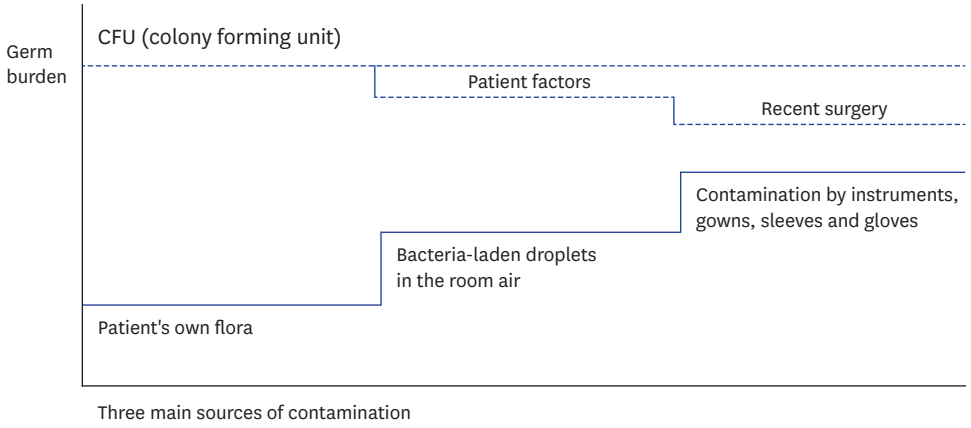

Fig. 1. CFU and germ burden. In uneventful total joint arthroplasties, the germ burden on the surface of implant is below CFU, and PJI does not occur. However, when germ burden is higher than CFU, PJI occurs. The weakening of the host's immune system can decrease the level of the CFU, while substantial exposure to microorganisms capable of causing PJI can increase the germ-burden beyond the CFU threshold.
CFU = colony forming unit, PJI = periprosthetic joint infection.

Whether through direct seeding or hematogenous spread, microorganisms capable of causing contamination during the perioperative period can be present in the patient, healthcare personnel or surgical devices, and the operating environment.[13] Therefore, we believe that the microorganisms find their way into the surgical site through sources of contamination: 1) patient's own flora, 2) droplets in the room air, and 3) contamination of the surgical site by gloves, instruments, implants.[2] These three sources are inevitably associated with some degree of contamination.

THREE MAIN SOURCES OF SURGICAL SITE CONTAMINATION

Patient's own flora

It is well recognized that patient's own flora in the skin, hair, mucous membranes, and hollow viscera can act as microorganism reservoir for surgical site infections (SSIs).[14] A systematic review reported antibiotic prophylaxis reduces the risk of SSI by 81% in patients undergoing TJA.[6] Even though our accumulated knowledge on how to do antibiotic prophylaxis, skin preparation and draping has markedly reduced PJI associated with the endogenous flora, our understanding of these kinds of PJI is still evolving (**Table 1**).[7]

Bacteria-laden droplets in the room air

Each personnel in operation room shed around 10,000 bacteria per every minute during walking.[8] These airborne bacteria originate from the skin of individuals, comprising both aerobes and anaerobes. For instance, individuals with discharge due to *Staphylococcus aureus* infection can release *S. aureus* into the air. Thus, aseptic attire policy, optimal humidity and temperature of the operation room are important to reduce the number of droplets.

The purpose of ventilation in the operating room is to prevent airborne bacteria from outdoor air, other areas of the hospital, and adjacent rooms.[8] Additionally, the ventilation system should effectively eliminate any airborne contamination generated within the operation room. Laminar air systems are thought to reduce airborne contamination. Sterile

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Table 1. Preoperative and intraoperative variables to be checked, along with solutions for prevention of PJI

Time	Variables to be checked for prevention of PJI
Preoperative period	Obesity, malnutrition, uncontrolled diabetes mellitus, rheumatoid arthritis, anemia, chronic renal failure, smoking, use of steroids, alcohol abuse et al. - Control for medical risk factors of host Prior intra- or peri-articular injection Prior various procedures and surgeries - Check for history of injections or surgeries and delay TJA
Intraoperative period	Patient's own flora - Antibiotic prophylaxis use, careful skin preparation and draping Bacteria-laden droplets in the room air - Optimal humidity and temperature of the operation room - Laminar air systems with HEPA filter Contamination by instruments, gowns, sleeves, and gloves - Careful sterilization, additional extra-gown and additional non-woven helmet cap use, additional non-fabric sleeve use

PJI = periprosthetic joint infection, TJA = total joint arthroplasty, HEPA = high efficiency particulates air.

air filtered by high efficiency particulates air at the ceiling flows into the operation field and then passes out through air suction at the wall. All objects along the steam of air flow can shed particulates. The astral lamp, its lever and handle should be kept clean (**Fig. 2**). Charnley[15] recognized the potential of droplet-related PJI during TJA and thus, mandated the use of sterile hood, body exhaust suit, and ultra-clean air-flow system of the operating room. His concept reduced exposure time to contaminated air by 81% and the incidence of PJI within the first six months after the operation. Earlier studies reported the use of exhaust suit reduced particulate exposure compared to conventional gown-and-mask clothing.[16] However, the use of the positive-pressure exhaust suit remains controversial because recent studies suggested that it might be associated with air contamination and increased incidence of PJI.[17] In a recent study comparing particle and microbiological emission rates (PER and MER) between exhaust suits and conventional surgical clothing, exhaust suits had increased PER and MER.[18] While the study is confined to laboratory research, there is a potential risk of contamination to the surgical field due to air emanating from the joints of the suit or turbulence caused by the air expelled from the suit. Additionally, the reduced spatial awareness experienced by surgeons when wearing the suit may lead to inadvertent contamination, emphasizing the need for careful consideration in the use of exhaust suits.

Contamination by instruments, gowns, sleeves, and gloves

In steam or ethylene oxide sterilization, there should be no over-stacking of items inside the sterilizer. Condensation without an appropriate space between packs leads to incomplete sterilization. The volume of instruments put into the sterilizer should be less than 70% of total capacity of the sterilizer. After sterilization, items should be dried completely to prevent wet packs.[19]

Surgical gown can be contaminated during skin preparation and draping. Thus, we recommend wearing additional extra-gown after draping (**Fig. 3A**). During surgery, surgical staffs' heads are located at the stream of laminar air flow. It is necessary to completely seal off hairs and ears of surgical staffs. We recommend wearing additional non-woven helmet cap (**Fig. 3B**).

Blom et al.[20] highlighted the superiority of disposable non-woven drapes over reusable woven cotton/linen drapes in resisting bacterial penetration, allowing passage of fewer than 100 CFU within 90 minutes. However, cuff of surgical gown is made of cloth, which becomes soaked with sweat in prolonged surgery. The soaked sweat spreads inside the surgical globe and then

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Fig. 2. All objects along the steam of air flow can shed particulates. The astral lamp, its lever and handle should be kept clean.

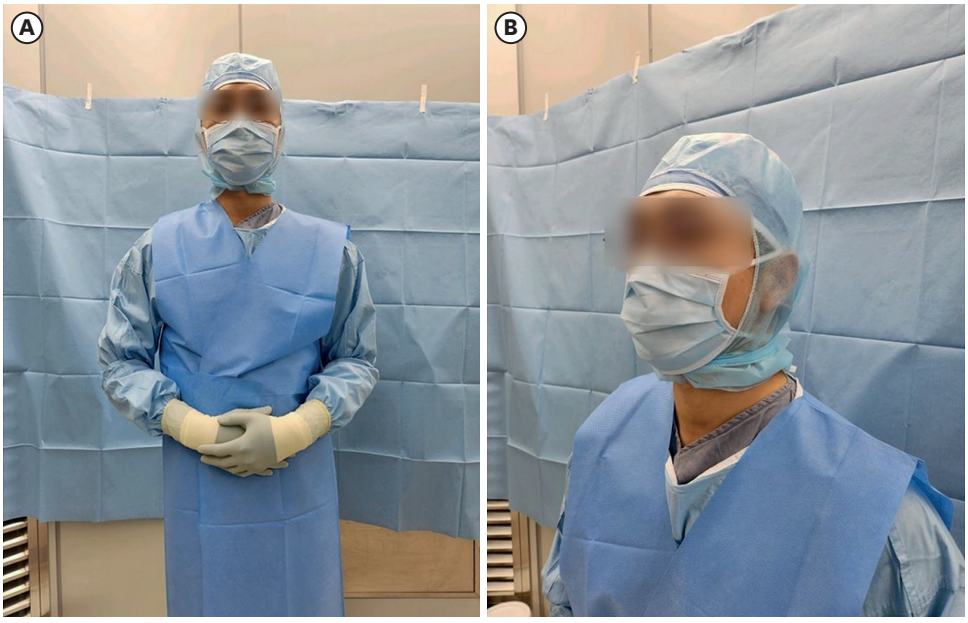

Fig. 3. Additional scrub vest with head sealing. (**A**) Surgical gown can be contaminated during skin preparation and draping. Thus, it is recommended to wear additional extra-gown after draping. (**B**) During surgery, surgical staffs' heads are located at the steam of laminar air flow. Thus, it is necessary to completely seal off hairs and ears of surgical staffs. We recommend wearing additional non-woven helmet cap. The individual depicted has granted consent for their inclusion in this paper's figure.

leaks out to the surface of surgical gown. Moreover, surgical gown is made of non-woven fabric, which is not completely waterproof. Actually, it is water-resistant for a while. It becomes soaked in prolonged wet and high-pressure condition (**Fig. 4A**). We recommend the use of additional non-fabric sleeve (**Fig. 4B**).

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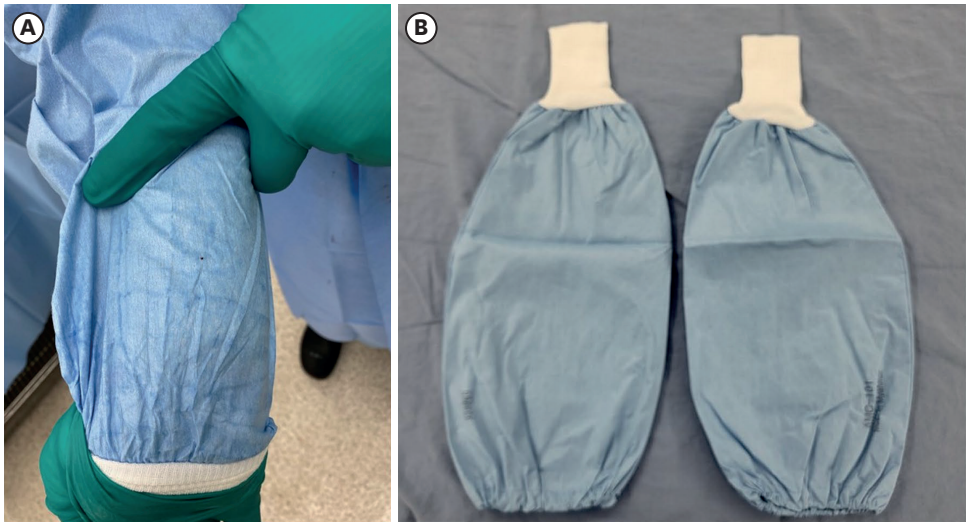

Fig. 4. Surgical gown and sleeve. (**A**) Surgical gown is made of non-woven fabric, which is not completely waterproof. It is simply water-resistant for a while. It becomes soaked in prolonged wet and high-pressure condition (dark lines). (**B**) We recommend the use of additional non-fabric sleeve.

RISK FACTORS FOR PJI OTHER THAN CONTAMINATION

Host factors

Medical risk factors for PJI: obesity, malnutrition, uncontrolled diabetes mellitus, rheumatoid arthritis, anemia, chronic renal failure, smoking, use of steroids and alcohol abuse, decrease the level of CFU (**Fig. 1**, **Table 1**).[21,22]

Prior injections and surgeries

Prior surgeries and intra- or peri-articular injections are risk factors for PJI and decrease the level of CFU. A systematic review and meta-analysis showed that patients with a history of steroid injection had an increased risk of PJI (relative risks [RRs], 1.26; 95% confidence interval [95% CIs], 1.26–2.25) compared without history of steroid injection, and patients with previous joint surgery had an increased risk of PJI (RRs, 1.49; 95% CIs, 1.49–5.93) compared without previous joint surgery.[21]

Studies about the risk of PJI after intra- or peri-articular injection showed that there are time- and dose-dependent relationships between the injections and the risk of postoperative PJI. Injections administered closer in the time to TJA and multiple injections are associated with a higher rate of postoperative PJI.[23,24]

Although there is no universal agreement in terms of the clearance period after various procedures ranging from steroid injection to major surgeries, at least 3 to 4 months of clearance period prior to TJA is considered advisable to prevent PJI.[23,24]

TREATMENT OF PJI

Most PJIs necessitate further surgical interventions (debridement, one- or two-stage revision surgery), which are associated with further risk of re-infection and repeated revisions.[2,25-29]

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1) Debridement, Antibiotics and Implant Retention is indicated in patients, who have a brief symptom duration without any sinus tracts.[11,25] The success rate of this procedure ranged from 14% to 90% and highly influenced by the stability of the implant, the type of microorganism, and the interval between the onset of symptoms and treatment with debridement and antimicrobial therapy.[11,30]
2) One stage prosthesis exchange is indicated when pathogen and effective antibiotics are identified.[2]
3) Two stage prosthesis exchange stands as the standard protocol for eradicating infection and maintaining joint function in most PJIs.[27,28] During the initial procedure, infected tissue and components are removed and an antibiotics-impregnated cement spacer is implanted. Intravenous pathogen-directed antibiotics are administered for 4 to 6 weeks after the first stage. Subsequently, a 2- to 6-week antibiotic-free period follows, during which ongoing infection signs are evaluated using inflammatory markers and synovial fluid aspiration. If ongoing infection is detected, additional debridement may be conducted, followed by extended antimicrobial therapy. When biomarkers are normalized and there is no symptom of infection, a new prosthesis is implanted.[27,28]
4) Resection arthroplasty or joint fusion is done when above procedures are not effective.[2,29]

SUMMARY

Actually, all TJAs are exposed to some degree of contamination. When the sum burden of contamination from the 3 sources is higher than the level of CFU, and various factors contribute to a decrease in the CFU level, PJI occurs. Surgeons should be aware of the germ burden/CFU concept and should monitor sources of contamination to maintain the germ burden below the CFU to prevent PJI. Arthroplasty surgeons could benefit from the germ-burden/CFU concept and enhanced preventive methods.

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