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Review article

Preventing surgical-site infections: Measures other than antibiotics

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ABSTRACT

Surgical-site infections (SSIs) due to intra-operative contamination are chiefly ascribable to airborne particles carrying microorganisms, mainly *Staphylococcus aureus*, which settle on the surgeon's hands and instruments. SSI prevention therefore rests on minimisation of airborne contaminated particle counts, although these have not been demonstrated to correlate significantly with SSI rates. Maintaining clear air in the operating room classically involves the use of ultra clean ventilation systems combining laminar airflow and high-efficiency particulate air filters to create a physical barrier around the surgical table; in addition to a stringent patient preparation protocol, appropriate equipment, and strict operating room discipline on the part of the surgeon and other staff members. SSI rates in clean surgery, although influenced by the type of procedure and by patient-related factors, are consistently very low, of about 1% to 2%. These low rates, together with the effectiveness of prophylactic antibiotic therapy and the multiplicity of parameters influencing the SSI risk, are major obstacles to the demonstration that a specific measure is effective in decreasing SSIs. As a result, controversy surrounds the usefulness of many measures, including laminar airflow, body exhaust suits, patient preparation techniques, and specific surgical instruments. Impeccable surgical technique and operating room behaviour, in contrast, are clearly essential.

The prevention of surgical-site infections (SSIs) is an integral component of nosocomial infection control and a major priority in orthopaedic surgery. Surgical wound contamination must be prevented to avoid patient colonisation by microorganisms during surgery. In addition to prophylactic antibiotic therapy, SSI prevention involves maintaining an aseptic operating room (OR) environment and impeccable OR discipline on the part of all staff members. The effectiveness of preventive measures is influenced by the quality of the patient's immune defences and type of surgical procedure.

1. Epidemiology of surgical-site infections (SSIs)

The incidence of SSIs in orthopaedic and trauma surgery varies with the level of risk associated with each type of procedure, as assessed using the Altemeier classification (Table 1); general health of the patient (ASA class) (Table 2); and National Nosocomial Infections Surveillance (NNIS) risk index based on the contamination class, ASA class, and operative time (Table 3). SSIs occur in less than 1% of low-risk patients, who account for most scheduled joint replacement procedures. In contrast, SSIs may develop in up to 15% of high-risk patients undergoing contaminated procedures, a situation encountered chiefly in emergency trauma surgery [1–3].

2. Contaminants

2.1. Source of surgical-site infections (SSIs)

The contaminating microorganisms may be endogenous or exogenous. The skin is a source of endogenous microorganisms, and optimal preoperative skin preparation is therefore essential. Exogenous microorganisms are vectored by airborne particles, the staff (hands, other areas of the skin, and mucous membranes) or, more rarely, inanimate objects (instruments, material, furnishing, or irrigation solutions) [4]. The patient's skin is the direct source of contamination in only 2% of cases, leaving 98% of cases related to airborne particles [5]. Surgical-site contamination by airborne particles is ascribable in 30% of cases to direct settling of the particles on the wound and in 70% of cases to settling on the instruments and surgeon's hands followed by transfer to the wound [6]. Thus, surgical-site contamination is chiefly attributable to airborne particles, some of which may carry microorganisms. Given this predominant role for airborne contamination, air quality in the OR deserves close attention.

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Table 1
Contamination classes according to Altemeier et al.

Contamination classes	Classification
Class I, clean surgery (SSI risk < 1%)	The surgical procedure involves a normally sterile area of the body. The skin is initially intact. If drainage is required, a closed system must be used The surgical procedure does not involve opening of the gastro-intestinal, respiratory, genito-urinary, or oro-pharyngeal tract
Class II, clean-contaminated surgery (SSI risk 2–5%)	The procedure involves opening the gastro-intestinal, respiratory, or genito-urinary or oro-pharyngeal tract under tightly controlled technical conditions and in the absence of abnormal contamination (i.e., urine or bile is sterile)
Class III, contaminated surgery (SSI risk 5–10%)	Massive surgical-site soiling by gastro-intestinal lumen contents, opening of the genito-urinary or biliary tract in a patient with urinary or biliary tract infection. Recent open traumatic wounds
Class IV, dirty or infected surgery (SSI risk > 10%)	Surgical procedure involving a body site that contains pus, foreign bodies, or faeces. Traumatic wounds created more than 4 hours earlier This definition suggests the presence of microorganisms responsible for SSI in the surgical-site the before the operation

Altemeier WA, Burke JF, Puitt BA, Sandusky WR. Manual on control of infection in surgical patients. JB Lippincott 2nd Ed, Philadelphia, 1984, p 29.

Table 2
American Society of Anesthesiologists (ASA) preoperative assessment classification.

ASA classification	Preoperative assessement
I	No health condition other than that requiring surgery
II	Mild abnormality in a major function
III	Severe abnormality in a major function
IV	Disease that is a constant threat to life
V	Moribund patient

2.2. Characteristics of airborne particles

Airborne particles come from multiple sources, of which the most relevant is the shedding of squames or skin scales. On average, an individual having a moderate level of physical activity sheds about 10 min^{-1} particles measuring at least 0.5 mm in diameter. Despite their large size, squames circulate via the convection currents created by the temperature gradient between the body and the environment [7]. Other sources of airborne particles include dust and condensation droplets measuring less than 5 μ in diameter and representing the remnants of larger droplets produced during coughing, talking, and suction systems.

Table 3
National Nosocomial Infections Surveillance risk index (NNIS).

Variables	Codification
Contamination class	0, clean or clean-contaminated 1, contaminated or dirty
ASA class	0, patient in normal health or with mild systemic disease 1, patient with severe or incapacitating systemic disease or moribund patient
Operative time	0, time shorter than the T point 1, time equal to or longer than the T point The T point is the time that represents the 75th percentile of similar procedures in the NNIS database The NNIS risk index is computed as the sum of the codes for the three variables and can therefore range from 0 to 3

The NNIS risk index is based on three variables (contamination class, ASA class, and NISS value) scored as described below. Garner JS. CDC guideline for prevention of surgical wound infections. Revised. Infect Control 1985;7:193–200, 1986.

Particle size influences the tendency to settle on surfaces. Particles smaller than 5 μ remain suspended in the air, those larger than 100 μ settle rapidly, and those of intermediate size (5–100 μ) may settle on potentially contaminated surfaces then migrate to another sites. Particles may carry variable bacterial loads, depending on their source.

Particle production and mobilisation vary according to the number of individuals in the OR. Another factor is whether the surgical attire constitutes an effective barrier against the shedding of squames into the OR air: thus, squames may migrate from sites of uncovered skin (e.g., neck and forearms) or through gaps in the material used to make surgical garments (e.g., 80 μ for woven cotton) [8]. Any movement in the OR can mobilise particles. Airborne particle counts are highest at the beginning of the operation because patient installation requires displacements and other movements of the personnel [9]. The many other sources of particles include the use of a cautery, which produces fine and ultrafine particles, and the use of saws or drills [10].

Controlling airborne particle circulation requires careful attention to OR discipline, surgical technique, and operative time. Air can act not only as a reservoir, but also as a vector for the transmission of bacteria via particles (e.g., dust and squames) or condensation droplets smaller than 5 μ.

Contamination by airborne microorganisms plays a central role in the pathogenesis of SSIs. Prevention of contamination by airborne microorganisms requires knowledge of the most commonly encountered microorganisms and of their dissemination characteristics. In addition, familiarity with air quality parameters, air quality measurement tools, and air treatment methods is crucial.

3. Air quality control

3.1. Nature of contaminants

The microorganisms most often responsible for SSIs are *Staphylococcus aureus*, with 40% to 70% of cases [1,11], followed by coagulase-negative staphylococci and Gram-negative bacteria. These bacteria exhibit considerable resistance to exogenous insults (which allows them to survive while airborne) and are consequently associated with a high-risk of transmission (AFNOR classification of the pathogenic potential of microorganisms, from 1 to 4).

Bacteria measure 0.2 to 5 μ. They can adhere to particles, preferably those of greater size, to form larger aggregates known as colony-forming units (CFUs, measured per m^2). Hansen et al. reported a statistically significant correlation between counts of particles larger than 5 μ and counts of bacterial colonies. Thus, all particles measuring 5 to 10 μ can be considered potentially infected [10].

Measures that decrease airborne particle counts are central to diminishing the risk of contamination by airborne microorganisms.

3.2. Air quality parameters

Several parameters are used to assess OR air quality:

- the airborne particle count at rest is used to classify ORs according to an ISO standard. Orthopaedic ORs must meet the ISO 5 criterion, namely, < 3500 particles/m^3 (Table 4). A limitation to this