Air Contamination and SSI Risk: Do We Need a New Standard in an Era of Device-Related Procedures?

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“….all surgical wounds are contaminated to some degree at closure – the primary determinant of whether the contamination is established as a clinical infection is host (wound) defense”

Belda et al., JAMA 2005;294:2035-2042
Quantitative Risk of Infection

Microbial Burden
In the Wound ($\sim10^5$) x Microbial Virulence

\[ \text{Host resistance (wound defense)} \]

\[ = \text{Overall risk of SSI} \]

A Foreign Body Trumps This Equation
POSTOPERATIVE INFECTION IN TOTAL PROSTHETIC REPLACEMENT ARTHROPLASTY OF THE HIP-JOINT
WITH SPECIAL REFERENCE TO THE BACTERIAL CONTENT OF THE AIR OF THE OPERATING ROOM

By J. CHARNLEY
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A vast amount of work has been done in the past 50 years in attempts to explain the infection that can follow 'clean' surgical operations performed in modern operating rooms. There is still no completely satisfactory solution forthcoming. It is a paradox that simple adherence to Listerian principles has abolished virulent postoperative infection, but infection by mildly pathogenic staphylococci appears to be increasingly common.

There is still uncertainty as to how often a wound is infected in the operating room and how often at a later date during the healing of the wound. There are those who deny that the air in the operating theatre is an important source of infection, because pathogens form only a minute fraction of the colonies grown from the air in it. This is clearly a matter of extreme importance in planning new hospital buildings if unnecessary expense is to be avoided. The surgical literature is now so immense that no useful purpose is served by attempting a complete review. For a worthy noting are by Tschijian and Compere (1957), Henderson and Kornblum (1961), and Stevens (1964). In 74 consecutive hip operations performed between 1935 and 1938 at Massachusetts General Hospital (Cardenal and Aufranc, 1962) an infection rate of 6.9 per cent was recorded.

BACKGROUND OF THE PRESENT STUDY

This paper is mainly a prospective study of wound sepsis after major hip-joint surgery. It was started in 1961 after encountering an unusually high rate of infection in the preceding years during the development of a new technique of total prosthetic replacement of the hip-joint in 1958. The fact that the infection rate appeared to be much lower after arthrodesis of the hip, a procedure of the same technical magnitude as the arthroplasty, also involving the implantation of a foreign body in the form of a metal screw, and carried out in the same operating-
Protection against airborne contamination and infection requires the development of interdependent practices not only in the operating room but in the hospital as well for (1) the isolation of infected individuals to prevent colonization of patients and personnel, (2) control of dust in the operating room by effective housekeeping and laundering practices, (3) exclusion of bacteria shed by the surgical team by proper garb, (4) ventilation with clean air at a rate sufficient to purge bacteria from the aseptic field or its equivalent in disinfection by ultraviolet radiation, and (5) terminal disinfection of the operating room. Convenience, effectiveness, and economy are the criteria that must be evaluated in the context of each hospital. Emphasis on specific practice will vary in different hospitals. To achieve a low rate of postoperative wound infection in clean cases, the concept of asepsis must be extended and expanded from direct contact alone to include air transport of microorganisms from people as the hazardous perioperative environment.

"You are villains in a plot against your patients. Because of your negligence, 90 percent of the nation's hospitals are a menace to health."

Carl W. Walters, MD

"The airborne component of postoperative wound infection is not a fixed rate but rather varies from hospital to hospital, from OR to OR, and from surgical team to surgical team. The rate is proportional to the number of disseminating carriers in the room - aerosol contamination accounts for 20-24% of postoperative infections."

Wound Contamination and Infection/Walter & Kusdine


The airborne component of postoperative wound infection is not a fixed rate but rather varies from hospital to hospital, from OR to OR, and from surgical team to surgical team. The rate is proportional to the number of disseminating carriers in the room - aerosol contamination accounts for 20-24% of postoperative infections."
### Table 2. — *Staphylococcus aureus Carriers Among Operating Room Personnel*

<table>
<thead>
<tr>
<th>Carriers</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating room nurses</td>
<td>21</td>
</tr>
<tr>
<td>Surgeons</td>
<td>33</td>
</tr>
<tr>
<td>Anesthetists</td>
<td>57</td>
</tr>
<tr>
<td>Orderlies</td>
<td>71</td>
</tr>
</tbody>
</table>

### Table 6. — Chronologic Listing of *S. aureus* Infections Bacteriologically Linked to Four Disseminating Carriers

<table>
<thead>
<tr>
<th>Date</th>
<th>Operation</th>
<th>Infector</th>
<th>Phage†</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/63</td>
<td>Craniotomy</td>
<td>Resident</td>
<td>U</td>
</tr>
<tr>
<td>2/63</td>
<td>Craniotomy</td>
<td>Resident</td>
<td>U</td>
</tr>
<tr>
<td>2/63</td>
<td>Hypophysectomy</td>
<td>Resident</td>
<td>U</td>
</tr>
<tr>
<td>5/63</td>
<td>Craniotomy</td>
<td>Nurse</td>
<td>Y</td>
</tr>
<tr>
<td>6/63</td>
<td>Laminectomy</td>
<td>Intern</td>
<td>Z</td>
</tr>
<tr>
<td>7/63</td>
<td>Cranioplasty</td>
<td>Anesthetist</td>
<td>T</td>
</tr>
<tr>
<td>6/64</td>
<td>Open reduction shoulder</td>
<td>Anesthetist</td>
<td>T</td>
</tr>
<tr>
<td>3/65</td>
<td>Thoracotomy</td>
<td>Anesthetist</td>
<td>T</td>
</tr>
<tr>
<td>6/65</td>
<td>Hiatus herniorrhaphy</td>
<td>Anesthetist</td>
<td>T</td>
</tr>
<tr>
<td>7/65</td>
<td>Hip nailing</td>
<td>Anesthetist</td>
<td>T</td>
</tr>
<tr>
<td>7/65</td>
<td>Mammary artery implant</td>
<td>Anesthetist</td>
<td>T</td>
</tr>
<tr>
<td>7/65</td>
<td>Pyelolithotomy</td>
<td>Anesthetist</td>
<td>T</td>
</tr>
<tr>
<td>8/65</td>
<td>Craniotomy</td>
<td>Resident</td>
<td>V</td>
</tr>
<tr>
<td>11/65</td>
<td>Laminectomy</td>
<td>Resident</td>
<td>V</td>
</tr>
<tr>
<td>11/65</td>
<td>Craniotomy</td>
<td>Resident</td>
<td>V</td>
</tr>
<tr>
<td>12/65</td>
<td>Laminectomy</td>
<td>Anesthetist</td>
<td>T</td>
</tr>
<tr>
<td>7/66</td>
<td>Carotid endarterectomy</td>
<td>Anesthetist</td>
<td>T</td>
</tr>
<tr>
<td>7/66</td>
<td>Hip nailing</td>
<td>Anesthetist</td>
<td>T</td>
</tr>
</tbody>
</table>

* From Walter CW, et al.*
† Phage designation: U, 52/52A/79/7/73/75/80/82; Y, 52A/79; Z, 53/77; T, 83A/6/7/42E/47/54/73/75/42B/83B/UC-18/81/82; V, 52/52A/80/81.
Airborne contamination of wounds in joint replacement operations: the relationship to sepsis rates

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†Formerly of the Medical Research Council’s Burns Unit, Birmingham, ‡Building Services Research Unit, University of Glasgow, Glasgow, §Formerly of the Division of Hospital Infection, The MRC Clinical Research Centre, Harrow, Middlesex, and ‖Medical Research Council Biostatistics Unit, Cambridge

Summary: During operations for total joint replacement done in operating rooms with conventional ventilation the mean air contamination varied considerably among the 15 hospitals studied. The range was from 51 to as many as 539 bacteria-carrying particles per cubic metre. When the data from all the hospitals were grouped according to the mean level of bacterial airborne contamination, including operations done in control and in ultraclean air, there was a good correlation between the air contamination and the joint sepsis rate. There was also a correlation between the mean values of air contamination and the numbers of bacteria isolated from wound wash-out samples; but the apparent efficiency of the sampling method varied a great deal among the hospitals carrying out this procedure. From this data it would seem that by far the largest proportion of bacteria found in the wound after the prosthesis had been inserted reached it by the airborne route. With the mean air contamination found in the control series, 164 bacteria-carrying particles per cubic metre, this proportion was as much as 95 per cent.

The risk of joint sepsis varied widely among the 19 hospitals. The differences between the highest and lowest being probably as much as 20-fold. However, the effect of an ultraclean air environment was similar at all hospitals.
Figure 1. The relationship between mean air contamination and the incidence of joint sepsis. Each point is the mean of the data from between six and nine hospitals (see Table II). The straight line is the regression of sepsis rate on the square root of the air contamination.
Anastomotic femoral pseudoaneurysm: An investigation of occult infection as an etiologic factor

Gary R. Seabrook, MD, David D. Schmitt, MD, Dennis F. Bandyk, MD, Charles E. Edmiston, PhD, Candace J. Krepel, BS, M(ASCP), and Jonathan B. Towne, MD, Milwaukee, Wis.

Molecular epidemiology of microbial contamination in the operating room environment: Is there a risk for infection?

Charles E. Edmiston Jr, PhD, MD, Robert A. Gambria, MD, Kellie R. Brown, MD, Brian D. Lewis, MD, Jay R. Sounness, PhD, Candace J. Krepel, MS, Patti J. Wilson, BSN, Sharon Sink, BSN, and Jonathan B. Towne, MD, Milwaukee, Wis, and Roswell, Ga

Background. Modern operating rooms are considered to be aseptic environments. The use of surgical mask, frequent air exchanges, and architectural barriers are used to reduce airborne microbial populations. Breaks in surgical technique, host contamination, or hematogenous seeding are suggested as causal factors in these infections. This study implicates contamination of the operating room air as an additional etiology of infection.

Methods. To investigate the potential sources of perioperative contamination, an innovative in situ air-sampling analysis was conducted during an 18-month period involving 70 separate vascular surgical procedures. Air-sample cultures were obtained from multiple points within the operating room, ranging from 0.5 to 4 m from the surgical wound. Selected microbial clonality was determined by pulse-field gel electrophoresis. In a separate series of studies microbial nasopharyngeal shedding was evaluated under controlled environmental conditions in the presence and absence of a surgical mask.

Results. Coagulase-negative staphylococci were recovered from 86% of air samples, 51% from within 0.5 m of the surgical wound, whereas Staphylococcus aureus was recovered from 64% of air samples, 39% within 0.5 m from the wound. Anterior nares swabs were obtained from 11 members of the vascular team, clonality was observed between 8 strains of S epidermidis, and 2 strains of S aureus were recovered from selected team members and air-samples collected throughout the operating room environment. Miscellaneous Gram-negative isolates were recovered less frequently (<33%), however, 7 isolates expressed multiple patterns of antimicrobial resistance. The traditional surgical mask demonstrated limited effectiveness at curtailing microbial shedding, especially during symptomatic periods of rhinorrhea.

Conclusions. Gram-positive staphylococcal isolates were frequently isolated from air samples obtained throughout the operating room, including areas adjacent to the operative field. Nasopharyngeal shedding from person participating in the operation was identified as the source of many of these airborne contaminants. Failure of the traditional surgical mask to prevent microbial shedding is likely associated with an increased risk of perioperative contamination of biomedical implants, especially in procedures lasting longer than 90 minutes. (Surgery 2005;138:573-82.)
Intraoperative Measurement of Microbial Populations Within the Operating Room

Cascade Impactor

0.45 μm Filter

Culture Media

Intraoperative Measurement of Microbial Populations Within the Operating Room

Microbial Recovery

Incubate 48 hours 35°C (30°C)

IDENTIFICATION
Vascular Operating Room

- Cascade Impactor
- Personnel

Intake vent

- Colored dots – unique *staphylococcal* strains recovery from anterior nares
Percent Intraoperative Recovery of Airborne Microbial Populations During Vascular Surgery (N=70)

Edmiston et al, Surgery 2005; 138; 573-582
Does operating room traffic influence particulate (viable/nonviable) dispersion?
Typical “Laminar-Flow” Design Used in Most Hospital Operating Rooms

Air Curtain

Multi-Diffuser Array

Single-Large Diffuser

Modified from: Dr. Jenifer Wagner, Air Media Magazine, Summer 2014
Table 1
Reasons operating room doors were opened during procedures

<table>
<thead>
<tr>
<th>Reason</th>
<th>Inner door, n</th>
<th>%</th>
<th>Outer door, n</th>
<th>%</th>
<th>Total, n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment for case</td>
<td>77</td>
<td>35.7</td>
<td>30</td>
<td>20.1</td>
<td>107</td>
<td>30.1</td>
</tr>
<tr>
<td>Status update</td>
<td>22</td>
<td>10.2</td>
<td>20</td>
<td>13.4</td>
<td>42</td>
<td>11.8</td>
</tr>
<tr>
<td>Scrub in or out</td>
<td>2</td>
<td>0.9</td>
<td>35</td>
<td>23.5</td>
<td>37</td>
<td>10.4</td>
</tr>
<tr>
<td>Unknown</td>
<td>18</td>
<td>8.3</td>
<td>20</td>
<td>13.4</td>
<td>38</td>
<td>10.7</td>
</tr>
<tr>
<td>Multiple</td>
<td>26</td>
<td>12.0</td>
<td>10</td>
<td>6.7</td>
<td>36</td>
<td>10.1</td>
</tr>
<tr>
<td>Work conversation</td>
<td>19</td>
<td>8.9</td>
<td>5</td>
<td>3.4</td>
<td>24</td>
<td>6.7</td>
</tr>
<tr>
<td>First entry for case</td>
<td>10</td>
<td>4.6</td>
<td>12</td>
<td>8.1</td>
<td>22</td>
<td>6.2</td>
</tr>
<tr>
<td>Break</td>
<td>19</td>
<td>8.8</td>
<td>2</td>
<td>1.3</td>
<td>21</td>
<td>5.9</td>
</tr>
<tr>
<td>Equipment for other case</td>
<td>11</td>
<td>5.1</td>
<td>3</td>
<td>2.0</td>
<td>14</td>
<td>3.9</td>
</tr>
<tr>
<td>Shift change</td>
<td>5</td>
<td>2.3</td>
<td>4</td>
<td>2.7</td>
<td>9</td>
<td>2.5</td>
</tr>
<tr>
<td>Equipment personnel</td>
<td>1</td>
<td>0.5</td>
<td>4</td>
<td>2.7</td>
<td>5</td>
<td>1.4</td>
</tr>
<tr>
<td>Social conversation</td>
<td>3</td>
<td>1.4</td>
<td>1</td>
<td>0.7</td>
<td>4</td>
<td>1.1</td>
</tr>
<tr>
<td>Instruments for case</td>
<td>2</td>
<td>0.9</td>
<td>1</td>
<td>0.7</td>
<td>3</td>
<td>0.8</td>
</tr>
<tr>
<td>Specimens to laboratory</td>
<td>1</td>
<td>0.5</td>
<td>2</td>
<td>1.3</td>
<td>3</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Table 2
Personnel opening doors during OR procedures

<table>
<thead>
<tr>
<th>Staff</th>
<th>Inner door, n</th>
<th>%</th>
<th>Outer door, n</th>
<th>%</th>
<th>Total, n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circulating RN</td>
<td>96</td>
<td>44.4</td>
<td>24</td>
<td>16.1</td>
<td>120</td>
<td>32.9</td>
</tr>
<tr>
<td>Multiple persons</td>
<td>27</td>
<td>12.5</td>
<td>15</td>
<td>10.1</td>
<td>42</td>
<td>11.5</td>
</tr>
<tr>
<td>Scrub technician</td>
<td>18</td>
<td>8.3</td>
<td>15</td>
<td>10.1</td>
<td>33</td>
<td>9.0</td>
</tr>
<tr>
<td>Resident (surgeon)</td>
<td>14</td>
<td>6.5</td>
<td>15</td>
<td>10.1</td>
<td>29</td>
<td>8.0</td>
</tr>
<tr>
<td>CRNA</td>
<td>6</td>
<td>2.8</td>
<td>19</td>
<td>12.8</td>
<td>25</td>
<td>6.9</td>
</tr>
<tr>
<td>Attending surgeon</td>
<td>5</td>
<td>2.3</td>
<td>16</td>
<td>10.7</td>
<td>21</td>
<td>5.8</td>
</tr>
<tr>
<td>Anesthesiologist</td>
<td>6</td>
<td>2.8</td>
<td>14</td>
<td>9.4</td>
<td>20</td>
<td>5.5</td>
</tr>
<tr>
<td>Nurse (other)</td>
<td>14</td>
<td>6.5</td>
<td>3</td>
<td>2.0</td>
<td>17</td>
<td>4.7</td>
</tr>
<tr>
<td>Researcher</td>
<td>10</td>
<td>4.6</td>
<td>3</td>
<td>2.0</td>
<td>13</td>
<td>3.6</td>
</tr>
<tr>
<td>OR staff</td>
<td>8</td>
<td>3.7</td>
<td>3</td>
<td>2.0</td>
<td>11</td>
<td>3.0</td>
</tr>
<tr>
<td>Unknown or missing</td>
<td>6</td>
<td>2.8</td>
<td>16</td>
<td>10.7</td>
<td>22</td>
<td>6.0</td>
</tr>
<tr>
<td>Medical student</td>
<td>1</td>
<td>0.5</td>
<td>4</td>
<td>2.7</td>
<td>5</td>
<td>1.4</td>
</tr>
<tr>
<td>Vendor</td>
<td>3</td>
<td>1.4</td>
<td>1</td>
<td>0.7</td>
<td>4</td>
<td>1.1</td>
</tr>
<tr>
<td>Equipment staff</td>
<td>2</td>
<td>0.9</td>
<td>1</td>
<td>0.7</td>
<td>3</td>
<td>0.8</td>
</tr>
<tr>
<td>Anesthesiologist (resident)</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

OR, operating room; RN, Registered Nurse.
Major Article

Cost-benefit analysis of different air change rates in an operating room environment

Thomas Gormley PhD 1, 4, Troy A. Markel MD 1, Howard Jones MD 5, Damon Greeley PE 6, John Ostojic IH 1, James H. Clarke PhD 1, Mark Abkowitz PhD, PE 6, Jennifer Wagner PhD, CIC 1

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2 Department of Surgery, Riley Hospital for Children at Indiana University Health, Indianapolis, IN
3 Department of Statistics and Biomathematics, Vanderbilt University, Nashville, TN
4 Global Health Sciences Inc, Fort Myers, FL
5 A2TEC Environmental Monitoring, Indianapolis, IN
6 AHRQ Environmental Health & Safety, Discovery Bay, CA

Key Words:
Air quality in operating rooms
Operating room ventilation rates
Air changes per hour
Surgical site infections
Mechanical procedures
Cost-benefit analysis
Operating cost for HVAC systems in operating rooms
Environmental quality indicators (EQIs)
Cost of ventilation in operating rooms

Background: Hospitals face growing pressure to meet the dual but often competing goals of providing a safe environment while controlling operating costs. Evidence-based data are needed to provide insight for facility management practices to support these goals.

Methods: The quality of the air in 3 operating rooms was measured at different ventilation rates. The energy cost to provide the heating, ventilation, and air conditioning to the rooms was estimated to provide a cost-benefit comparison of the effectiveness of different ventilation rates currently used in the healthcare industry.

Results: Simply increasing air change rates in the operating rooms tested did not necessarily provide an overall cleaner environment, but did substantially increase energy consumption and costs. Additionally, and unexpectedly, significant differences in microbial load and air velocity were detected between the sterile fields and back instrument tables.

Conclusions: Increasing the ventilation rates in operating rooms in an effort to improve clinical outcomes and potentially reduce surgical site infections does not necessarily provide cleaner air, but does typically increase operating costs. Efficient distribution or management of the air can improve quality indicators and potentially reduce the number of air changes required. Measurable environmental quality indicators could be used in lieu of or in addition to air change rate requirements to optimize cost and quality for an operating room and other critical environments.

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Current HVAC systems, including laminar flow and positive pressure systems, do not deactivate microbial aerosols, but displace the microorganisms. Which are continuously being shed within the OR setting, contributing to the airborne (and surface) microbial burden.

TURBULENT ZONES KEEP MICROBIAL PARTICLES IN SUSPENSION
Air Quality in the OR

- The standard (ISO) for airborne contaminants in the “clean room” of a typical semiconductor manufacturer is well defined (ISO Class 1 to Class 4)
- These stringent requirements minimize the fiscal loss that is associated with product failure in a highly sensitive manufacturing environment.
- The difference in the design of HVAC systems in hospital ORs and facilities designed to meet ISO requirements can be radical.
- In the typical OR the arrangement of airflow diffusers over the operating table would not be acceptable to ISO Class 1 to 4.
- ASHRAE Standard 170 and AIA guidelines do not represent an evidence-based aerobiological risk-adjusted standard.
Is it time to propose a standard for microbial airborne burden in the operating room environment?
State of the Science Review

Environment of care: Is it time to reassess microbial contamination of the operating room air as a risk factor for surgical site infection in total joint arthroplasty?

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c Department of Surgery, Medical College of Wisconsin, Milwaukee WI

Key Words:
Operating room
Microbial aerosols
Device-related infection
Intraoperative contamination
Periprosthetic joint infection (PJJ)

In the modern operating room (OR), traditional surgical mask, frequent air exchanges, and architectural barriers are viewed as effective in reducing airborne microbial populations. Intraoperative sampling of airborne particulates is rarely performed in the OR because of technical difficulties associated with sampling methodologies and a common belief that airborne contamination is infrequently associated with surgical site infections (SSIs). Recent studies suggest that viable airborne particulates are readily disseminated throughout the OR, placing patients at risk for postoperative SSI. In 2017, virtually all surgical disciplines are engaged in the implantation of selective biomedical devices, and these implants have been documented to be at high risk for intraoperative contamination. Approximately 1.2 million arthroplasties are performed annually in the United States, and that number is expected to increase to 3.8 million by the year 2030. The incidence of periprosthetic joint infection is perceived to be low (<2.5%); however, the personal and fiscal morbidity is significant. Although the pharmaceutical and computer industries enforce stringent air quality standards on their manufacturing processes, there is currently no U.S. standard for acceptable air quality within the OR environment. This review documents the contribution of air contamination to the etiology of periprosthetic joint infection, and evidence for selective innovative strategies to reduce the risk of intraoperative microbial aerosols.

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Air Quality in the OR

• Current guidelines do not address specific criteria for the quantitative reduction of viable microbial aerosols in the OR environment.

• The EU has proposed the development of new air quality standards for the hospital environment based on patient risk.¹⁻³

• “There is a direct link between the number of particles in the OR and the number of personnel present in the case.”⁴

What is the economic consequences in an era of fiscal liability?
Economic Burden of Periprosthetic Joint Infection in the United States

Steven M. Kurtz, PhD, *† Edmund Lau, MS, ‡ Heather Watson, PhD, ‡ Jordana K. Schmier, MA, § and Javad Parvizi, MD

Abstract: This study characterizes the patient and clinical factors influencing the economic burden of periprosthetic joint infection (PJI) in the United States. The 2001-2009 Nationwide Inpatient Sample was used to identify total hip and knee arthroplasties using International Classification of Diseases, Ninth Revision, procedure codes. The relative incidence of PJI ranged between 2.0% and 2.4% of total hip arthroplasties and total knee arthroplasties and increased over time. The mean cost to treat hip PJIs was $5965 greater than the mean cost for knee PJIs. The annual cost of infected revisions to US hospitals increased from $320 million to $566 million during the study period and was projected to exceed $1.62 billion by 2020. As the demand for joint arthroplasty is expected to increase substantially over the coming decade, so too will the economic burden of prosthetic infections. Keywords: periprosthetic joint infection, total knee arthroplasty, total hip arthroplasty.

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Periprosthetic Joint Infections

- 2.18% of hip and knee implants become infected
- Overall lifetime cost for a single case of a septic THA (age 65) using a one-way sensitivity analysis of $390,806 per patient.
- PJI is associated with a mortality rate of between 2 – 7%
- Experts report that the five-year survival rate of patients with PJI is worse than with most cancers.

Historical and projected number of infected THA, TKA, and total (THA + TKA) procedures in the United States.

Projected Trends and it is not Pretty

US Market, 2016–2026

4 Million TJRs by 2030

$3-5 Billion*

$1.6 Billion*

*Projected Cost of PJI

Tisosky et al. J Am Acad Orthop Surgeons 2017;1:e34
“It is not the air, it is something in the air”

Lister 1861