

AVIDICARE

References to literature

The following references are divided into categories based on their content and represent a selection of articles, conference papers and reports from organizations that are related to infection control and prevention. Table 1 lists abbreviations used in this document.

Table 1: A list of abbreviations used and their meaning.

Abbreviation	Meaning
SSI	Surgical site infection
CFU	Colony forming unit
TAF	Temperature controlled airflow
LAF	Laminar airflow
TMA	Turbulent mixed airflow
CFD	Computational fluid dynamics

1. *"Surgical site infections are correlated with airborne bacteria levels"*

- (a) Charnley, J. (1972). Postoperative Infection after Total Hip Replacement with Special Reference to Air Contamination in the Operating Room. *Clinical Orthopaedics and Related Research*, 87, 167-187.

Sir John Charnley, recognized as one of the main contributors to the surgical method for hip replacement also contributed to decreasing the rate of postoperative infections. In 1972 Charnley summarized the results from 5800 total hip replacements and found that the infection rate fell from about 7-9% in 1960 to below 1% in 1970. The reduction was a result of taking measures to reduce sources of exogenous infection in the operating room, i.e. the usage of clean air technology and body exhaust suits. The use of prophylactic antibiotics was in this study purposely avoided.

- (b) Lidwell, O. M. (1988). Air, antibiotics and sepsis in replacement joints. *Journal of Hospital Infection*, 11, 18-40.

In 1973 the Medical Research Council together with the Department of Health and Social Security in the United Kingdom carried out an

investigation on the relationship between the reduction of air contamination and the incidence rate of joint sepsis. 19 hospitals in Europe took part in the multicenter investigation and more than 8 000 operations were performed. The results strongly suggest that sepsis in the joint is the result of bacteria introduced into the wound at the time of surgery although an infection might not occur instantly. The study attributes the observed reduction of joint sepsis to ultra clean air ventilation systems, occlusive clothing and the use of antibiotics.

2. "Particles carrying bacteria are continuously spread to the air from people in the operating room or from adjacent rooms in the case of door opening"

- (a) Noble, W.C. (1975). Dispersal of skin microorganisms. *British Journal of Dermatology*, 93(4), 477-485.

Noble summarizes in his review article that each person sheds around 10 000 skin particles per minute into the air when he or she walks. Approximately 10% of these are estimated to carry bacteria. Moreover, a person is estimated to release more than 10^7 skin particles each day.

- (b) Benediktsdóttir, E. & Kolstad, K. (1984). Non-sporeforming anaerobic bacteria in clean surgical wounds —air and skin contamination. *Journal of Hospital Infection*, 5(1), 38-49.

Bacteria found on skin scales are either anaerobic, meaning that they do not require oxygen to survive and grow, or aerobic which in contrast implies that they require an oxygenated environment. The contamination of clean surgical wounds with anaerobic and aerobic bacteria was studied in 52 hip operations by Benediktsdóttir and Kolstad. Anaerobic bacteria was found account for about 30% of the total number of bacteria present in the air inside an operating room on average. Those have the ability to survive long enough in the air to be viable once they reach the surgical wound.

- (c) Andersson, A.E., Bergh, I., Karlsson, J., Eriksson, B.I., & Nilsson, K. (2012). Traffic flow in the operating room: An explorative and descriptive study on air quality during orthopedic trauma implant surgery. *American journal of infection control*, 40(8), 750-755.

The study by Andersson et al including 30 orthopedic procedures investigated the air quality in terms of cfu/m³ during orthopedic trauma surgery in a conventionally ventilated operating room. The effect of traffic flow and number of surgical staff present in the operating room on the air contamination rate was evaluated in the vicinity of the surgical wound. The study concludes that traffic flow has a strong negative impact on the operating room environment and reducing traffic flow is an important measure to prevent surgical site infections. A weaker yet still positive correlation between the number

of people present and airborne bacterial count was also found.

3. "The majority of the bacteria contaminating the surgical wound are likely to have reached it by the airborne route"

- (a) Lidwell, O.M., Lowbury, E.J.L., Whyte, W., Blowers, R., Stanley, S.J. & Lowe, D. (1983). Airborne contamination of wounds in joint replacement operations: the relationship to sepsis rates. *Journal of hospital Infection*, 4(2), 111-131.

A correlation between the mean values of air contamination and the number of bacteria isolated from wound wash-out samples as found by Lidwell et al. as well as a correlation between mean airborne contamination and joint sepsis rate. The results indicate that the majority of the bacteria found after insertion of the prosthesis reached the wound by the airborne route. The study concludes that this was especially clear for operations performed in operating rooms with conventional ventilation.

- (b) Whyte, W., Hodgson, R. & Tinkler, J. (1982). The importance of airborne bacterial contamination of wounds. *Journal of Hospital Infection*, 3(2), 123-135.

A study of potential sources of bacterial contamination of the surgical wound during hip and knee replacement operations performed in conventionally and laminar airflow ventilated operating rooms was conducted by Whyte et al. From the results it was estimated that 98% of the bacteria in the patients' wounds came directly or indirectly from the air in conventionally ventilated operating rooms.

4. "Indirect contamination of the surgical wound via medical devices occurs as well as direct airborne contamination"

- (a) Edmiston, C.E., Seabrook, G.R., Cambria, R.A., Brown, K.R., Lewis, B.D., Sommers, J.R., Krepel, C.J., Wilson, P.J., Sinski, S. & Towne, J.B. (2005). Molecular epidemiology of microbial contamination in the operating room environment: Is there a risk for infection?. *Surgery*, 138(4), 573-582.

Via air currents bacteria can be deposited in the surgical wound or onto a surface that might come in contact with the wound. To investigate the potential sources of contamination during operation, air sampling was performed ranging from 0.5 to 4 m from the surgical wound during 70 vascular surgical procedures. This study documents that during operations and under optimal environment conditions, microbial populations were frequently recovered from the sampling points. This is believed to be the result of failure of the traditional surgical mask to prevent microbial shedding which is likely to be associated with an increased risk of perioperative contamination. For

example, *Staphylococcus aureus* was recovered from 64% of air samples, 39% from within 0.5 m from the wound.

- (b) Whyte, W., Hodgson, R. & Tinkler, J. (1982). The importance of airborne bacterial contamination of wounds. *Journal of Hospital Infection*, 3(2), 123-135.

An investigation regarding bacterial wound contamination during hip and knee replacement surgery was conducted in an operating suite using either laminar flow or conventional ventilation. It was found that the bacterial count in the air was substantially lowered, representing a 97-fold reduction, when laminar flow ventilation was used. The average number of bacteria that was washed out after surgery was 35 times lower compared to when conventional ventilation was applied. Therefore, a minority of the bacteria that contaminated the wound are estimated to have fallen directly from the air. The rest is assumed to have been transferred to the wound indirectly by depositing on the surgeon's hands, drapes and instruments.

- (c) Benen, T., Wille, F. & Clausdorff, L. (2013). Influence on different ventilations systems upon the contamination of medical devices. *Hyg Med*, 38(4), 142-146.

One main aspect of avoiding surgical site infections is to ensure the sterility of the medical devices and instruments in the operating room and their location in the operating room is important. In this study, laminar airflow ventilation manages to maintain ultraclean air within the surgical protection zone but a 55-fold increase of the mean value of airborne colony forming units was observed outside the protected area compared to the value inside.

- 5. "Microbiological air sampling is a suitable method for investigating operating room air quality"

Cristina, M. L., Spagnolo, A. M., Sartini, M., Panatto, D., Gasparini, R., Orlando, P., Ottria, G. & Perdelli, F. (2012). Can particulate air sampling predict microbial load in operating theatres for arthroplasty? *PLOS One*, 7(12)

Measuring airborne particle counts as an indirect indicator of the microbiological air quality in operating rooms is derived from cleanroom technology standards but has seldom been subjected to evaluation. In this study by Cristina et al. including 95 surgical arthroplasty procedures (59 hip replacements and 36 knee replacements), the aim was to determine whether particle counting could predict microbiological air contamination in an operating theatre.

The results did not indicate any statistical correlation between microbial air contamination in terms of CFU/m³ and airborne particle counts for either of the particle diameters considered ($\geq 0.5\mu\text{m}$ and

$\geq 5\mu\text{m}$) and the study concludes that microbiological air sampling remains the most suitable method for investigating the quality of air in operating theatres.

6. "The size of airborne particles carrying microorganisms are in the order of a few micrometers"

Noble, W. C., Lidwell, O. M. & Kingston, D. (1963). The size distribution of airborne particles carrying micro-organisms. *The Journal of Hygiene*, 61(4), 385-391.

This article by Noble et al investigated the size distribution of particles carrying different species of bacteria and fungi. Particles were collected with an air sampler which divided the collected particles into four size ranges and deposits the airborne particles onto a Petri dish containing the agar medium. The article summarizes that organisms associated with human disease or carriage are usually found on particles in the range 4-20 μm equivalent diameter. The equivalent particle diameter is here referred to the diameter of a sphere of unit density which has a settling rate in air equal to that of the particle in question.

7. "The main measures to prevent SSI are antibiotics, the use of suitable ventilation, surgical clothing, staff number and behaviour"

- (a) Lidwell, O. M., Lowbury, E. J., Whyte, W., Blowers, R., Stanley, S. J. & Lowe, D. (1982). Effect of ultraclean air in operating rooms on deep sepsis in the joint after total hip or knee replacement: a randomised study. *British Medical Journal (Clin Res Ed)*, 285(6334), 10-14.

Lidwell's previously mentioned randomized study, see 1b, involved 8,000 patients undergoing knee or hip replacement surgery. All patients were then followed up for 2 to 3 years for evidence of post-operative wound sepsis. The reduction of joint sepsis rates was attributed to air cleanliness, special operating suits and the use of antibiotic prophylaxis which reduced the sepsis rate independently. More specifically, the use of antibiotics resulted in a four fold reduction of the incidence rate. The use of occlusive clothing halved the rate further and so did the use of ultra clean air.

- (b) Burman, L. G. (2006). *Att förebygga vårdrelaterade Infektioner—ett kunskapsunderlag*. Stockholm: Swedish National Board of Health and Welfare., ISBN 91-85482-14-5

The report from Swedish National Board of Health and Welfare informs that deep postoperative infection is a consequence of bacterial contamination during surgery. This is believed to apply for other postoperative wound infections as well. The number of bacteria carrying particles in the operating room air depends on the number

of people, their activity and routines, clothing and the type of ventilation used. To limit the rate of postoperative infections actions regarding these are important apart from the use of prophylactic antibiotics, good hygiene, and a suitable design of the operating room that minimizes unnecessary traffic and allows for proper transportation of the patient, staff and goods in and out of the operating room.

- (c) Sadrizadeh, S., Tammelin, A., Ekolind, P. & Holmberg, S. (2014). Influence of staff number and internal constellation on surgical site infection in an operating room. *Particuology*, 13, 42-51.

The number of surgical personnel and their positions influence the ventilation airflow and thereby the concentration and distribution of colony forming units in an operating room. The influence on airborne bacteria distribution within the critical surgical zone was investigated using a numerical model and the results imply increasing concentrations of colony forming units when the number of staff was increased. From the results it can also be concluded that the number of staff located in the critical surgical zone should be kept to a minimum since the concentration increase with decreasing distance.

- (d) Buhl, S., Eschenbecher, N., Hentschel, S. & Bulitta, C.(2016) Multiple factors influencing OR ventilation system effectiveness In: *Current Directions in Biomedical Engineering*, 2(1), 333-335. DOI: <https://doi.org/10.1515/cdbme-2016-0074>

In this study clothing and three types of ventilation systems have been investigated and their ability to reduce airborne bacterial counts in the operating room was assessed. The clothing evaluated were German and Swedish operating gowns. The main difference was that the Swedish clothing had tightened cuffs and a closed neck region to avoid unintentional spreading of particles. The results in the study favored the Swedish clothing regarding cfu-levels. The ventilation systems tested were temperature controlled ventilation, laminar airflow and turbulent mixed ventilation. The temperature controlled system provided the lowest overall mean value for the three different measurement sites.

8. "Postoperative infections not only cause suffering -they are also costly"

- (a) Leaper, D. J., Van Goor, H., Reilly, J., Petrosillo, N., Geiss, H. K., Torres, A. J. & Berger, A. (2004). Surgical site infection –a European perspective of incidence and economic burden. *International wound journal*, 1(4), 247-273.

This study reviewed data from 48 studies and estimated the economic costs of surgical site infections in Europe to range between € 1.47–19.1 billion. Furthermore, the review suggests that the economic burden is likely to have been underestimated since the infection rate

reported is believed to represent an underestimation.

- (b) Burman, L. G. (2006). *Att förebygga vårdrelaterade Infektioner—ett kunskapsunderlag*. Stockholm: Swedish National Board of Health and Welfare., ISBN 91-85482-14-5

The previously mention report from the Swedish National Board of Health and Welfare, see 7b, states that the cost of care is increased by nosocomial infections. Patients that are victims to nosocomial infections, which lead to an extended length of stay, spend 500 000 days extra in hospital each year. This consequently leads to increased costs of 3700 million SEK corresponding to € 388 million annually, according to an estimation by the authors.

- (c) American College of Surgeons and Surgical Infection Society (2016). *Surgical Site Infection Guidelines, 2016 Update*. [http://www.journalacs.org/article/S1072-7515\(16\)31563-0/pdf](http://www.journalacs.org/article/S1072-7515(16)31563-0/pdf)

SSIs accounts for 20% all hospital-acquired infections in the US and are reported as the most common and costly of all hospital-acquired infections. The incidence of SSI is 2% to 5% in patients undergoing inpatient surgery. The estimated annual incidence varies widely and ranges from 160,000 to 300,000 in the US although this is likely to represent an underestimation due to the surveillance challenges after discharge. The cost for surgical site infections are mainly associated with extended length of stay, emergency department visits and readmissions. The annual cost of SSI in the US is estimated at \$3.5 to \$10 billion in this report.

9. "Antimicrobial and antibiotic resistance is an increasing threat"

- (a) World Health Organization (2014). *Antimicrobial resistance: Global report on surveillance*. http://apps.who.int/iris/bitstream/10665/112642/1/9789241564748_eng.pdf?ua=1

Antimicrobial resistance threatens the effective prevention and treatment of an increasing range of infections caused by bacteria, parasites, viruses and fungi. WHO establishes that this is an increasingly serious threat to global public health, development and food security that requires action across all government sectors and society. Furthermore, antimicrobial resistance leads to higher medical costs, longer hospital stays as well as increased mortality. The report states that measures can be taken at all levels in society to limit the impact and spread of antimicrobial resistance and that global surveillance generating reliable data is urgently needed. In all WHO regions very high resistance rates have been observed for common bacteria, such as *Escherichia coli* and *Staphylococcus aureus*, that cause common nosocomial and community-acquired infections.

- (b) World Health Organization. (2016). *Antibiotic Resistance*. <http://ww>

w.who.int/mediacentre/factsheets/antibiotic-resistance/en/ [2017-08-21]

WHO informs in their fact sheet from 2016 that antibiotic resistance is rising to dangerously high levels in all parts of the world. New resistance mechanisms are emerging and spreading globally which threaten the ability to treat common infectious diseases. Resistance is enhanced by poor infection prevention and control, misuse and overuse of antibiotics. WHO points out that without urgent action, we are heading for a post-antibiotic era in which common infections and minor injuries can pose a deadly threat. Organ transplantation, chemotherapy and major surgical procedures such as caesarean sections or hip replacement will become much more dangerous without effective antibiotics for the prevention and treatment of infections.

- (c) U.S. Centers for Disease Control and Prevention. (2013). *Antibiotic resistance threats in the United States*. <https://www.cdc.gov/drugresistance/threat-report-2013/pdf/ar-threats-2013-508.pdf> [2017-08-22]

The U.S. Centers for Disease Control and Prevention estimates in their report from 2013 that there are about 2 million people who become infected by bacteria or fungus that are resistant to antibiotics and 23000 deaths resulting from these infections each year in the United States. The estimation is reported to represent a minimum. When antibiotic resistance grows, the ability to fight routine infectious diseases is weakened and it will also impair treatment of infections complications in patients with other diseases. Many of the modern advances in medicine are dependent on the effectiveness of antibiotics to fight infections. For example, patients that undergo complex surgery such as cardiac bypass or joint replacement are subjected to the risk of SSIs. Prophylactic antibiotics is often used to prevent such infections but if the effectiveness of antibiotics is lost, so is the advantage of these modern medical advances.

- 10. "Downward airflow is effective regarding reduction of airborne bacterial counts and velocities of at least 0.3 m/s are needed to break body convection"

- (a) Whyte, W., Shaw, B. H. & Barnes, R. (1973). A bacteriological evaluation of laminar-flow systems for orthopaedic surgery. *Epidemiology & Infection*, 71(3), 559-564.

In 1973 Whyte et al investigated the efficiency of unidirectional airflow in operating theaters where both horizontal and vertical flow were evaluated. Conventional surgical clothing was used and the investigation concluded that vertical airflow velocities in the region 0.3-0.4 m/s is enough to keep the mean value of airborne bacterial counts measured at the wound site below the limit for ultraclean surgery. Furthermore, it was concluded that the vertical airflow was

about 11 times more efficient regarding airborne bacteria count than horizontal.

- (b) Nielsen, P. V. (2009). Control of airborne infectious diseases in ventilated spaces. *Journal of the Royal Society Interface*, 6(6), 747-755.

Experiments with heated manikins indicate that downward air velocities up to 0.25 m/s preserves isothermal smoke released from above the standing manikin at head height. The thermal plume above a person has an upward velocity of approximately 0.25 m/s and downward air velocities of at least 0.30 m/s are needed to break the body convection.

11. “TAF ventilation keeps the whole operating room ultraclean”

Alsved, M., Civilis, A., Ekolind, P., Tammelin, Erichsen-Andersson A., Jakobsson, J., Svensson, T.; Ramstorp, M.; Sadrizadeh, S., Larsson, P.-A., Bohgard, M. Šantl-Temkiv, T. & Löndahl, J. (2017) Temperature controlled airflow ventilation in operating rooms compared with laminar airflow and turbulent mixed airflow. *Journal of Hospital Infection*, DOI: <http://dx.doi.org/10.1016/j.jhin.2017.10.013>

CFU concentrations were measured at three locations in an operating room during 45 orthopaedic surgeries close to the wound (<40 cm), at the instrument table, and in the periphery. 15 of these operations corresponding to 250 samples, were performed in operating rooms equipped with TAF-ventilation. The study resulted in a median value of 1 CFU/m³ in the vicinity of the wound for the TAF system. Median values at the instrument table and in the periphery were also well below the limit required for infection-prone surgery 10 CFU/m³.

12. “TAF ventilation is energy efficient and provides a comfortable working environment”

- (a) Löndahl, J., Ekolind, P., Tammelin, A., Ramstorp, M., Civilis, A. & Larsson, P.-A. (2017). *Energieffektiv ventilation för sjukhus och renrumsmiljöer inom industrin*. (E2B2 – ett samverkansprogram mellan Energimyndigheten och IQ Samhällsbyggnad Rapport 2017:04) http://www.e2b2.se/library/3117/slutrapport_energieffektiv_ventilation_for_sjukhus.pdf

TAF ventilation is in this study observed to consume 28% less energy than LAF, related to the almost double airflow volume in LAF. TAF requires lower airspeed than LAF, since the air supplied above the surgical zone has a slightly lower temperature, i.e. higher density than the rest of the room. The higher density of the cooled air causes it to fall at a speed dictated by this temperature difference and lower airspeed is required. The same report also states that the impact of the TAF system on the staff work environment from draught and

noise levels also were significantly lower compared to laminar airflow which is primarily due to reduced airspeed.

- (b) Alsved, M., Civilis, A., Ekolind, P., Tammelin, A., Erichsen Andersson, A., Jakobsson, J., Svensson, T., Ramstorp, M., Santl-Tenkiv, T., Larsson, P.-A., Bohgard, M. & Löndahl, J. (2017). Airborne bacteria in hospital operating theatres during surgery. In: *12. Ulmer Symposium Krankenhausinfektionen, Epidemiologie Hygienemassnahmen Antibiotikaprophylaxe*. Ulm, Germany, March 15-17 2017, 50-51.

The results from the study above, see 11, were also presented on the conference Ulmer Symposium Krankenhausinfektionen, Epidemiologie Hygienemassnahmen Antibiotikaprophylaxe in March 2017 by M. Alsved from Lund University.

13. "TAF ventilation has been evaluated using CFD"

- (a) Sadrizadeh, S. & Ekolind, P. (2016). A new ventilation system principle for operating rooms: Temperature-Controlled Air Flow. In: *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 5*. Aalborg, Denmark, May 22-25 2017.

The performance of a TAF ventilation system was evaluated using CFD. The temperature difference between the air supplied from the central and external air showers subdivided a fully equipped operating room into two distinct zones; one in the critical surgical zone that showed a strong unidirectional downward airflow with air velocities high enough to wash of all released bacteria carrying particles above the operating table, and another in the periphery where the external air showers diluted periphery-emitted particles via a mixed airflow. The system proved robust to heat loads as well. A recovery test based on ISO 14644-3:2005 showed that the recovery time for the TAF ventilation system is well below the limit proposed by the standard.

- (b) Sadrizadeh, S. & Holmberg, S. (2014). Comparison of different ventilation principles in an operating suite. In: *Proceedings of 13th SCANVAC International Conference on Air Distribution in Rooms*, São Paulo, Brazil Oct 19-22.

By using computational fluid dynamics the performance of three different ventilation systems for operating rooms was investigated. The examined ventilation principles were turbulent mixed airflow, laminar airflow and temperature controlled airflow and each system was evaluated in the same operating suite. Using LAF ventilation, a strong reverse flow pattern was observed in the outer edges of the operating room. The TAF ventilation system managed to damp the reverse flow well with the external air showers. Regarding the TMA ventilation, reverse flows occurred in most parts of the operating room as

well as airflow stagnation in the corners of the room.

- (c) Bulitta, C., Magerl, F., Hartwich, R. & Russwurm, B. (2015) CFD analysis of a high-tech operating room using Star-CCM+. In: *Magazine DYNAMICS from CD-adapco*, (38), 70-73. <https://mdx2.plm.automation.siemens.com/magazine/dynamics-38>

The Technical University of Applied Sciences Amberg-Weiden in Germany is equipped with a fully functioning high-tech operating room. A TAF ventilation system installed in the operating room was subjected to CFD analysis and the temperature and airflow behaviour was examined and compared with experimental data. The results showed good agreement between simulation and measured air velocities as well as temperature distribution which supports the notion of CFD analysis being a good tool to investigate such properties.

- (d) Buhl, S., Eschenbecher, N. & Bulitta, C. (2016). Erste Ergebnisse und Erfahrungen mit einem neuartigen OP-Lüftungssystem auf Basis einer temperaturkontrollierten Luftströmung. *Krankenhaus-Hygiene + Infektionsverhütung*, 38(2), 67-73.

A TAF ventilation system installed in the research operating room of the Ostbayerische-Technische Hochschule Amberg-Weiden in Germany was evaluated using CFD analysis. It was proven to be less influenced by obstacles in the operating room such as operating lamps. According to Swedish standard for microbiological purity in the operating room SIS-TS 39: 2012 active air sampling was performed under real operating conditions and verified that the TAF ventilation system is efficient regarding reduction of airborne bacterial contamination.