**FUNDAMENTALS OF INFECTION PREVENTION AND CONTROL IN THE OPERATING DEPARTMENT**

**INTRODUCTION**

Despite being relatively common and often harmless, infection can have potentially life changing consequences for patients. Infections in surgical wounds are associated with longer stays in hospital, further surgical treatment, admissions to ITU and higher rates of mortality [1]. As a result, the prevention of infections is a paramount aspect of patient care in the perioperative environment [2]. Infections occur when pathogens overcome a patient’s natural defences and colonise their tissue or systems. Pathogenic organisms are made up of five main types: viruses, bacteria, fungi, protozoa, and worms.   
  
A patient’s risk of infection is dependent on several intrinsic and extrinsic factors [3]. Intrinsic factors include—age, birth weight, pre-existing conditions, and the health and nutritional status of the patient. Practitioners often have very little control over these factors, although the patient should be optimised, and care planning should consider any intrinsic factors [4]. Practitioners are more able to control the extrinsic factors that contribute towards infections. These include environmental factors, the cleanliness of the theatre, staff, and equipment—a key part of limiting extrinsic risk is asepsis. This describes the processes aimed at the elimination of pathogenic microorganisms from the environment, personnel, and instruments. Where possible this should also incorporate barriers to transmission—gloves, gowns, and surgical drapes [4].

The link between infections and extrinsic factors was first identified by Ignaz Semmelweis in 1847, who demonstrated that good hand hygiene could prevent the spread of infection. Although his theory was not well received at the time, he was later vindicated by the work of Louis Pasteur and Joseph Lister, who showed that infections were caused by pathogenic microorganisms [5]. The elimination of as many pathogens as possible from the surgical environment is achieved by several methods including cleaning, ventilation, decontamination, and sterilisation.

**CHAIN OF INFECTION**

Health organisations and practitioners alike have a legal and ethical obligation to provide patients with safe care and treatment in an environment and with equipment that are maintained to a high standard of cleanliness [6, 7]. To ensure that these standards are maintained, all health organisations must undertake adequate auditing of their infection and prevention systems on a regular basis, with input from dedicated Infection and Prevention teams [6,8]. To comply with and deliver this essential element of patient care, healthcare practitioners must understand how their daily activities and omissions can aid in the spread of microorganisms. The ‘chain of infection’ outlines a series of links, in which the potential for microorganism growth and transmission can be understood. Knowledge of these links allows for an understanding of how to interrupt the sequence and reduce the spread of infection to the patient, environment, and colleagues.  
  
1. Infectious agent  
2. Reservoir  
3. Portal of exit from the reservoir  
4. Mode of transmission  
5. Portal of entry into the host  
6. Susceptible host  
  
*Infectious agent*  
The infectious agent is any organism that has the potential to cause infection (pathogenicity) and the capability of the agent to infect a host (virulence). The likelihood of pathogenicity is increased in those patients with compromised immunity [3,9,10,].

*Reservoir*  
The reservoir can be defined as an area (human, animal, or environment) where microorganisms can readily reside, offering them moisture, nutrients, and an ability to thrive and multiply [3]. These areas can be further categorised into endogenous and exogenous sources [11]. Endogenous sources are where local resident microbial flora can be found in body sites of patients such as skin, mouth, nose, gastrointestinal tract, and vagina [11]. Exogenous sources can be defined as those areas outside of the patient, such as the environment, equipment, healthcare workers and visitors [3,11,]. In perioperative environment exogenous sources can include the skin crevices and nail beds of a health practitioner’s hands, or a dry environment with little to no moisture such as medical equipment where pathogenic microorganisms are reported to survive for extended periods [9,12, 13].

*Portal of exit from the reservoir*  
The portal of exit describes the route by which a microorganism exits the reservoir [3]. For example, the release of bodily fluids as seen with a cough releasing aerosol from the respiratory tract; others include urine, blood, faeces, vomit, saliva or exudate from an open wound.  
  
*Mode of transmission*  
The mode of transmission refers to the route by which the organism is spread and can be divided into direct and indirect transmission [3, 11]. Direct transmission occurs with exposure and contact with potentially infected body fluids, secretions, and openings in the skin membrane. Indirect transmission within the healthcare environment may be primarily vehicle-borne, or airborne [11]. Vehicle-borne transmission via environmental sources such as contaminated equipment surfaces. Airborne transmission via particulates such as dust, fluid droplets which can be directly inhaled, or transferred through touch on inanimate surfaces [3].

*Portal of entry into the host*  
The portal of entry into the host, would include transmission via breaks in the dermis, surgical wounds, indwelling devices, or entry via mucous membranes such as the mouth, eyes and nostrils [3,11]

*Susceptible host*  
The susceptible host would include those undergoing surgery the elderly or paediatric population any immunocompromised patient, those with comorbidities, or any other individuals with increased susceptibility [3]. The introduction of pathogenic microorganisms via a break (indwelling catheter) in the susceptible host’s natural protective barriers can potentially culminate in an acquired infection.  
  
Insert Chain of infection figure here

Care should also be taken with personal items being brought into clinical areas that could potentially harbour pathogens, most notably staff lanyards, bags and other such personal belongings [14]. This should reinforce to practitioners the need for vigilance in countering the spread of infection not just within the confines of the operating theatre but also by those items unsuspectingly bought in. Prevention and control of cross-contamination entails provision of the correct equipment, appropriate training of staff and patients, and the utilisation of standards in preventative techniques as well as a robust system for auditing and reporting compliance in infection control [15].

**HEALTHCARE ASSOCIATED INFECTION**

Healthcare associated infections (HCAI), otherwise termed ‘nosocomial’ infection is the global term used to define an infection that has been acquired by a patient during a health care intervention [11, 15]. Contracting an infection may be attributed to exposure with surrounding surfaces, and/or interventions of care that compromise the patient's natural protective barriers. Where surgery, or insertion of indwelling devices and suboptimal care may allow for the migration of exogenous (external origin) or endogenous (internal origin) microorganisms [16]. HCAI are defined as any infection contracted 72 hours post admission, and any infection arising within 48 hours post discharge [17]. The most prevalent HCAI are urinary tract infections (UTI), surgical site infection (SSI), hospital acquired pneumonia (HAP), ventilator associated pneumonia (VAP), and health care associated bloodstream infection (BSI) [17]. Any patient is at risk of contracting a HCAI, but there are increased risk factors, for example an age greater than 65 years; admission to an intensive care unit or as an emergency admission; hospital inpatient stays greater than seven days; indwelling devices; surgery; burns; trauma-induced immunosuppression; neutropenia; impaired functional or coma status, and patients with comorbidities [ 17].

Numerous UK and international campaigns have been promoted to improve public and health professionals’ knowledge and practice in reducing the incidence of MRSA bacteraemia and other HCAI over the course of seventeen years. From “Winning Ways” [18] to “Save lives: Clean your hands” [19] as well as ambitious incentives by the Department of Health to halve MRSA rates by 2008. Public Health England [20] reports a general decline in reported cases of MRSA and Clostridioides difficile infection (CDI) rates from when surveillance was initiated in 2011. HCAI such as Klebsiella and Pseudomonas aeruginosa bacteraemia remain a challenge and as of 2018 have been included in Public Health England’s ongoing national point prevalence survey for HCAI’shealth surveillance [20].

SSI are the second highest reported HCAI in Europe and the United States [21] with 50 % of SSI’s being reported as only becoming evident following discharge from care [19]. The overall impact of HCAI to the patient and their family is significant, with infection comes an increased risk of morbidity and suffering causing undue stress, trauma, and financial burden [14,17]. It is estimated that HCAI can increase hospital admissions from 5 to 29.5 days [17], and the overall impact costs the NHS £2.7 billion annually, with an estimated death toll of 28, 500 for 2016/17 [22]. Guidance suggests that to prevent HCAI’s all healthcare workers must comply with and maintain professional development on the appropriate and current ideologies in infection prevention and control (IPC), and includes compliance with local and national guidelines on provision and use of Personal Protective Equipment [15].

**HOW TO PREVENT SURGICAL SITE INFECTIONS**

Acknowledging that we often have little control over the intrinsic infection risks, Perioperative practitioners must focus on the extrinsic factors which contribute to SSI. These can be reduced or eliminated by several different strategies within the operating department. By looking at each of these in turn, we can see that they are related to the personal, the patient, and the theatre environment, including equipment.

**THE PERSONAL**

The most important aspect of personal hygiene related to the prevention of infections is hand washing and surgical scrubbing [23]. These two practices are separate to each other and should not be confused. Good hand washing is described as one of the standard infection control precautions that is vital to reduce the transmission of infectious agents that can cause hospital acquired infections [24]. Hand washing should be carried out before touching a patient, before any clean or aseptic procedure, after any exposure to body fluid, after touching a patient, or their surroundings, these are known as the five moments for hand hygiene [23].These are universal and should be applied in the operating theatre in the same way they are in any other parts of the hospital.

Surgical scrubbing before participating in a sterile surgical procedure is a more thorough process, which the Association for Perioperative Practice (AfPP) describes as an extension of handwashing [25]. Surgical scrubbing uses antibacterial solutions containing chlorhexidine or povidone-iodine rather than simple soap and can involve the use of a brush or pick to clean the nails. The purpose of surgical scrubbing is to remove transient microorganisms and reduce the number of resident microorganisms that make up the body’s natural flora. This is to minimise the risks of patients developing surgical site infections [26].Surgical scrubbing should not be limited to the surgical team at the operating table, anyone undertaking a sterile procedure for example, an anaesthetist when conducting a sterile procedure such as the insertion of an arterial line should also be “scrubbed up”. The WHO has produced clear guidelines on the correct ways to carry out both hand washing and surgical scrubbing [23].

The use of alcohol-based gels for washing visibly clean hands has become common in all healthcare settings, and their use is now starting to move into theatres, as part of surgical hand preparation. Surgical hand rubbing is sanctioned [23], and supported by evidence [27,28]. Despite the importance of hand washing and scrubbing, on their own they are insufficient to protect the patient from infection. Attention should also be paid to the correct theatre dress. In the operating department everyone should be wearing scrubs, which should be clean every shift and changed when contaminated with bodily fluids or contact with a known infectious patient [29]. Scrubs should not be worn outside of the theatre suite, unless responding to an emergency call and theatre shoes should not be worn outdoors outside of the department. Scrub hats should always be worn in theatres, where disposable masks are worn, they should be carefully removed using the tapes and disposed of immediately on leaving theatre. Non-sterile gloves should be worn for anticipated contact with blood or other body fluids, broken skin or mucous membranes, and should be removed immediately following the end of patient care [30].

Insert Glove pyramid figure here

**THE PATIENT**

Although fit and healthy patients are usually well protected from infection by their immune system, surgical patients do not always fall into this category. And, even when they do, additional precautions need to be taken to prevent them from becoming infected by their own naturally occurring skin flora as well any pathogens present in the air or on surfaces in the theatre. Scrubbing up and the wearing of sterile gloves and gowns alone is insufficient to do this, and further precautions also need to be taken.

To ensure that the risk of infection is minimised, patients need to be properly prepared for surgery once they arrive in theatre. This preparation must be based on the best available evidence, for example, despite shaving of the surgical site being common practice for over a hundred years [31] it is no longer recommended unless necessary [32]. When pre-surgical shaving is done, hair should only be removed using electric clippers with a single-use blade. This is to reduce the damage to the skin that can be caused by a razor, and the resulting increase of surgical site infection [32].

Whether a patient has been shaved or not, the usual first step in any surgery is the preparation of the surgical site with an antiseptic solution. These solutions are either chlorhexidine or povidone-iodine based. Povidone-iodine solutions can be either alcohol or aqueous based. As alcohol is itself an antiseptic it is considered preferable except for pre-term infants or when there is contact with mucus membranes, where the alcohol can cause damage [33]. It is usual for skin prep to be applied using a disposable applicator or a swab, gauze or a sponge moving away from the centre of the site of the incision.

Only once the skin prep is dry, can the drapes be placed on the patient. Surgical drapes are sterile sheets of material, used to cover the patient and the operating table completely except for the area of the surgery, which has been prepped with antiseptic solution [34]. Drapes in the past were made from cotton and had to be clipped to each other to hold them in place. But now they are mostly self-adhesive and made from paper, making them disposable. Modern drapes are treated making them impervious to fluids [35], and procedure packs are often assembled and sterilised in advance, containing the correct number and sizes of drapes for a particular surgical procedure. If it becomes necessary to move or replace drapes, they should only be moved away from the surgical field never towards, if a drape becomes contaminated or has a hole, a second clean drape should be placed over it [25].

One of the final key patient related activities that can be undertaken to reduce infections is the use of antibiotic prophylaxis. This is the administration of antibiotics that are specifically recommended against infections at the site of the surgery. Not all surgeries require antibiotics but the insertion of implants and surgery where there is a risk of contamination from the gastrointestinal tract routinely do. The choice of antibiotic, the dose, timing, and duration are governed by local antibiotic formularies which combine the latest evidence and the best clinical judgement of pharmacists [36]. This forms part of the Department of Health's Antimicrobial stewardship program, which aims to reduce antimicrobial resistance by providing a framework to guide prescribers [2].

**THEATRE ENVIRONMENT**

The last extrinsic factor that needs to be considered in relation to reducing SSI, is the theatre environment itself. Key to this is the cleanliness of the theatre, the discipline of the theatre team in maintaining the hygiene and security of the environment and its ventilation [37].

A theatre suite can be divided into two distinct spaces, and access to both should be limited to patients and staff members wearing scrubs and theatre shoes. Firstly, the area around the theatre, the corridors, storage facilities for consumable and instruments and patient reception areas. Secondly, within this the theatres themselves, where there is a higher level of cleanliness, head coverings must be worn and face masks may be required, particularly when trays of instruments are uncovered [38].

Within the theatre environment, cleaning should take place at the start of the day and following the departure of every patient. The level of cleaning required following procedures is dictated by local policy but will include the use of anti-bacterial or sporicidal wipes as well more technological tools such as ultraviolet light or hydrogen peroxide vaporisation. A rolling program of deep cleaning using equipment of this type should also be in place [39].

The movement of staff, patients, and equipment in and out of the theatre, as well as the numbers of staff present, can increase the risk of a patient acquiring a SSI. Research [40,41], shows that there is a link between, door opening and surgical site infections. For this reason, the traffic in and out of the theatre during surgery should be strictly controlled. Related to this, is the movement of patients, instruments, and waste from the surgical environment. The design of operating theatres should incorporate entry and exit routes, that separates soiled or contaminated items from clean or sterile ones preventing cross contamination of patients and equipment from case to case [42].

The ventilation in theatres is the final environmental factor in reducing SSI. Ventilation can be broadly divided into two distinct types, plenum and laminar flow. Both reduce the contamination of wounds and surgical instruments by airborne particles, like skin cells, dust, and fibres from clothing and the moisture from exhaled breath which can normally be found circulating in the air [37]. Plenum ventilation works along a pressure gradient with the highest-pressure air flowing into one part of the operating suite, usually the lay-up room, and from there into the operating theatre, and out through the anaesthetic room and sluice. The airflow is controlled by a series of weighted pressure stabilising vents connecting the rooms, which close automatically if the pressure in one room drops, for example when a door is opened [43].

Laminar ventilation or air flow channels highly filtered air down directly from the centre of the operating theatre at a pressure greater than the air in the rest of the room, preventing airborne contaminants from entering the surgical field [44]. As laminar flow has a greater number of air exchanges in an hour it is generally considered to be superior to plenum ventilation. Maintaining a clean as possible surgical environment is decisive in the fight against SSI. Regular cleaning, good surgical team discipline and modern ventilation will contribute towards minimising the SSI risk to patients. A multifaceted approach that also includes patient optimisation, preparation, cleaning and draping and in some cases the use of antibiotic prophylaxis, is also necessary. Combining this with effective surgical scrubbing and careful gloving and gowning is crucial for the prevention of infection.

**ANTIBIOTIC RESISTANCE**

Medicines such as antibiotics can be used to destroy or inhibit the growth of a range of bacterial microorganisms. Resistance to these antimicrobials occurs as microorganisms evolve and adapt, through processes of genetic mutation and natural selection. This inevitable resistance has been accelerated and attributed to the inappropriate use of antimicrobials, and broad-spectrum antimicrobials in human, animal and environmental industries [45,46]. At present, 700,000 deaths per year are reported to occur globally due to Antimicrobial resistance (AMR) [46,47]. Various organisations have raised [46,47,48] concerns that if professionals do not take AMR seriously, treatment for diseases will become limited, and inevitably result in prolonged illness, and an increase in the psychological and socioeconomic impact on patients, and their families. As well as leading to an increase in the costs of providing healthcare. As AMR increases, routine operations will potentially become far more hazardous options for patients [45,48]. A major factor contributing to this problem is the fact that there have been no new classes of antibiotics discovered since the 1980’s. And as a result, those readily available today could soon be rendered ineffective in the fight against infection [45,46,48]. Prevalent multidrug resistant organisms (MDRO’s) encountered in healthcare organisations today are:

* Methicillin resistant Staphylococcus aureus (MRSA),
* Vancomycin resistant Enterococci spp. (VRE),
* Extended-spectrum beta-lactamase gram-negative organisms (ESBL),
* Carbapenems resistant Enterobacteriaceae (CRE),
* Multi-resistant Acinetobacter baumannii (MRAB) [45,20]

In response to the threat presented by MDRO’s, the UK government [47] has released a national framework outlining initiatives to enhance AMR awareness, including the promotion of responsible prescribing, and the utilisation of effective infection and prevention measures such as those described in this chapter to curtail spread of microorganisms. To further support this, a robust monitoring and reporting system has been put in place to develop a greater understanding of the indications for antibiotic use, dosages, and adherence to guidelines [49]. The aim of this project is to reduce as much as possible the need for antibiotic use.

On a global as well as a national scale, funding has been ring fenced for further research into new pharmaceuticals, diagnostic tools, and vaccines to combat infection [46,49]. Until these are readily available, health care professionals can aid in tackling the AMR burden, by ensuring that their practice is guided by effective infection and prevention measures and antimicrobial stewardship. [46].

**CONCLUSION**

Although practitioners cannot necessarily control the intrinsic patient factors associated with infection, they can influence the management of infection through appropriate supervision of the surgical environment and patient intervention. With continued application of infection and control practice in their daily activities, practitioners can contribute towards the drive to lower the incidence of HCAI today.

**REFERENCES**

1. European centre for disease prevention and control, Healthcare-associated infections: surgical site infections, Annual Epidemiological Report for 2017. Stockholm: European centre for disease prevention and control; 2019. Available from: https://www.ecdc.europa.eu/en/publications-data/healthcare-associated-infections-surgical-site-infections-annual-1#no-link. [Accessed May 14, 2020].

2. Public Health England. Start Smart - Then Focus: antimicrobial stewardship toolkit for English hospitals. London: Public Health England; 2015. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\_data/file/417032/Start\_Smart\_Then\_Focus\_FINAL.PDF [Accessed May 14, 2020].

3. D. Weston. Fundamentals of Infection Prevention and Control: Theory and Practice. (2nd ed.). Chichester: John Wiley and Sons Ltd; 2013

4. C. Thomas. Intrinsic and extrinsic sources and prevention of infection (in surgery). *Surgery*; 2019; 37 (1), pp 26-32.

5. J. Cavaillon, and F. Chrétien. From Septicaemia to Sepsis 3.0 - From Ignaz Semmelweis to Louis Pasteur. *Genes and Immunity*; 2019; 20, pp 371-382.

6. The Care and Quality Commission (CQC) Regulation 12: Safe care and treatment. United Kingdom, CQC, 2014. Available from: https://www.cqc.org.uk/guidance-providers/regulations-enforcement/regulation-12-safe-care-treatment [Accessed February 4, 2020].

7. HCPC. Standards of proficiency: Operating Department Practitioners. London, Health and Care Professions council, 2018. Available from: https://www.hcpc-uk.org/standards/standards-of-proficiency/operating-department-practitioners/ [Accessed May 19, 2020].

8. The Health and social Care Act. Code of practice on the prevention and control of infections.2008 [updated 2015] Available from: https://www.gov.uk/government/publications/the-health-and-social-care-act-2008-code-of-practice-on-the-prevention-and-control-of-infections-and-related-guidance [Accessed February 4, 2020].

9. D. Chowdhury, S. Tahir, M. Legge, T. Hu, T. Pryan, K. Johani, G.S. Whiteley, T.Glasbey, A. Deva, K. Vickery. Transfer of dry surface biofilm in the healthcare environment: the role of healthcare workers’ hands as vehicles. *Journal of Hospital Infection* 2018; 100: 85 – 90.

10. World Health Organisation. Evidence of hand hygiene to reduce transmission and infections by multi-drug resistant organisms in health-care settings. 2013. Available from: https://www.who.int/gpsc/5may/MDRO\_literature-review.pdf [Accessed February 6, 2020].

11. C. G. Mayhall. Hospital Epidemiology and Infection Control. Philadelphia, Wolters Kluwer Health, 2011.

12. K. Ledwoch, S.J. Dancer, et al. Beware biofilm! Dry biofilms containing bacterial pathogens on multiple healthcare surfaces; a multicentre study. *Journal of Hospital Infection* 2018; 100: 47 – 56.

13. F. Parvin, H. Hu, G.S. Whiteley, T. Glasbey, K. Vickery. Difficulty in removing biofilm from dry surfaces. *Journal of Hospital Infection* 2018; 100:3 85 – 90.

14. K. French. Ten unusual sites in healthcare facilities harbouring pathogens that have been reported in the Journal of Hospital Infection. *Journal of infection control* 2018; 100 (3):361-362.

15. National institute for health and care excellence. Healthcare Associated Infections: Prevention and control in primary and community care. London, NICE, 2017. Available from: https://www.nice.org.uk/guidance/cg139/resources/healthcareassociated-infections-prevention-and-control-in-primary-and-community-care-35109518767045 [Accessed February 12, 2020].

16. National institute for health and care excellence. Infection prevention and control Quality standard. London, NICE, 2014. Available from: www.nice.org.uk/guidance/qs61 [Accessed February 12, 2020].

17. World Health Organisation. Report on the burden of endemic health-care-associated infection worldwide. Geneva, WHO, 2011. Available from: http://www.who.int/infection-prevention/publications/burden\_hcai/en/ [Accessed February 13, 2020].

18. Department of Health. Winning ways: Working together to reduce healthcare associated infection in England. London, DOH, 2003. Available from: https://webarchive.nationalarchives.gov.uk/20120510091859/http://www.dh.gov.uk/prod\_consum\_dh/groups/dh\_digitalassets/@dh/@en/documents/digitalasset/dh\_4064689.pdf [Accessed 21 May 2020].

19. World Health Organisation. Save lives: Clean your hands. Geneva, WHO, 2005. Available from: https://www.who.int/gpsc/5may\_advocacy-toolkit.pdf?ua=1 [Accessed February 13, 2020].

20. Public Health England. Annual epidemiological commentary: Gram-negative bacteraemia, MRSA bacteraemia, MSSA bacteraemia and C. difficile infections, up to and including financial year April 2018 to March 2019. London, PHE publications, 2019. Available from: https://www.gov.uk/government/statistics/mrsa-mssa-and-e-coli-bacteraemia-and-c-difficile-infection-annual-epidemiological-commentary [Accessed August 03, 2020].

21. B. Allegranzi, P. Bischoﬀ , S. de Jonge, N. Z. Kubilay, B. Zayed, S. M. Gomes, M. Abbas, J. Atema, S. Gans, M. van Rijen, M. A. Boermeester, M. Egger, J. Kluytmans, D. Pittet, J. S. Solomkin, and the WHO Guidelines Development Group. Surgical site infections 1: New WHO recommendations on preoperative measures for surgical site infection prevention: an evidence-based global perspective. *Lancet Infect Dis* 2016; 16: e276–87.

22. J. Guest; T. Keating; D. Gould; N. Wigglesworth. Modelling the annual NHS costs and outcomes attributable to healthcare-associated infections in England. *BMJ*, 2020; 10:e033367.

23. World Health Organisation (WHO) WHO guidelines on hand hygiene in health care. Geneva: WHO; 2009. Available from: https://apps.who.int/iris/bitstream/handle/10665/44102/9789241597906\_eng.pdf;jsessionid=C1D950BB42FE9CA543C751149797DA77?sequence=1 [Accessed May 15, 2020].

24. National Health Service (NHS) Standard infection control precautions: national hand hygiene and personal protective equipment policy. London: NHS England and NHS Improvement; 2019. Available from: https://improvement.nhs.uk/documents/4957/National\_policy\_on\_hand\_hygiene\_and\_PPE\_2.pdf [Accessed May 15, 2020].

25. Association for Perioperative Practice (AfPP). Standards and Recommendations for Safe Perioperative Practice (4th ed). Harrogate: AfPP; 2016

26. J. Tanner. Surgical Hand Antisepsis: The Evidence. *Journal of Perioperative Practice*; 2008; 18, (8), pp 330-339.

27. G. G. Gaspar, M. G. Menegueti, A. E. R Lopes, et al. Alcohol-based surgical hand preparation: translating scientific evidence into clinical practice. *Antimicrobial Resistance & Infection Control*; 2018; 7, 80.

28. Y. H. Ho, Y. C. Wang, E. W. Loh, and K. W. Tam. Antiseptic efficacies of waterless hand rub, chlorhexidine scrub and povidone-iodine scrub in surgical settings: a meta-analysis of randomized controlled trials. *Journal of Hospital Infection*; 2019; 101, 4, pp 370-379.

29. Department of Health (United Kingdom) Uniforms and workwear: Guidance for NHS employers. London: NHS England and NHS Improvements; 2020. Available from; https://www.england.nhs.uk/wp-content/uploads/2020/04/Uniforms-and-Workwear-Guidance-2-April-2020.pdf [Accessed May 14, 2020].

30. World Health Organisation (WHO). (2009) Glove use information leaflet. Geneva: WHO; 2009. Available from: https://www.who.int/gpsc/5may/Glove\_Use\_Information\_Leaflet.pdf [Accessed May 15, 2020].

31. O. H. Wangensteen, and S. D. Wangensteen. The Rise of Surgery from Empiric Craft to Scientific Discipline. Minneapolis: University of Minnesota Press; 1978

32. National Institute for Health and Care Excellence (NICE). Surgical site infections: prevention and treatment. London: NICE; 2019. Available from: https://www.nice.org.uk/guidance/ng125 [Accessed May 15, 2020].

33. One Together. Surgical skin preparation: quality improvement resource. London: One Together; 2017. Available from: https://www.onetogether.org.uk/downloads/Surgical%20Skin%20Preparation%20Quality%20Improvement%20Guide\_AW.pdf [Accessed May 15, 2020].

34. World Health Organisation (WHO). Global Guidelines for the Prevention of Surgical Site Infection. Geneva: WHO; 2016. Available from: https://apps.who.int/iris/bitstream/handle/10665/250680/9789241549882-eng.pdf?sequence=8 [Accessed May 15, 2020].

35. T. H. A. Arumlampalam. Principles and Techniques of Operative Surgery Including Neurosurgery, in: Quick, C. R. G., Biers, S. and Arumlampalam, T. H. A. (eds.) Essential Surgery. 6th ed. London: Elsevier; 2020. pp 124-151.

36. National Institute for Health and Care Excellence (NICE). Surgical site infection, Quality standard [QS49]. London: NICE; 2013. Available from: https://www.nice.org.uk/guidance/qs49/resources/surgical-site-infection-pdf-2098675107781 [Accessed May 15, 2020].

37. One Together. Surgical environment: quality improvement resource. London: One Together; 2018. Available from: https://www.onetogether.org.uk/downloads/OneTogether%20Surgical%20Environment%20QIR\_2019.pdf [Accessed May 15, 2020].

38. M. C. Roy. The Operating Theatre. In: G. M. L. Bearman, M. Stevens, M. B. Edmond, and R. P. Wenzel (eds.) A Guide to Infection Control in the Hospital. 5th ed. Boston, USA: The International Society for Infectious Diseases (ISID); 2014. pp 137 – 145.

39. Association of Anaesthetists. Guidelines, Infection prevention and control 2020. London: Association of Anaesthetists; 2020.

40. P. Perez,J. Holloway, L. Ehrenfeld, S. Cohen, L. Cunningham, G B. Miley, and B. L. Hollenbeck. Door openings in the operating room are associated with increased environmental contamination. *American Journal of Infection Control*; 2018. 46, 8, pp 954 – 956.

41. C. Wang, S. Holmberg, and S. Sadrizadeh. Impact of door opening on the risk of surgical site infections in an operating room with mixing ventilation. *Indoor and Built Environment*; 2019. DOI: http://doi.org/10.1177/1420326X19888276

42. C. Spry. Infection Prevention and Control, in: J. C. Rothrock. (ed.) Alexander’s Care of the Patient in the Surgical Environment. 15th ed. St Louis: Elsevier. St. Louis; 2015

43. Department of Health (United Kingdom). Heating and ventilation systems: Health Technical Memorandum 03-01: Specialised ventilation for healthcare premises. Norwich: The Stationary Office. 2007. Available from; https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\_data/file/144029/HTM\_03-01\_Part\_A.pdf [Accessed May 14, 2020].

44. M. Kiernan. Infection Prevention, In: K. Woodhead, and L. Fudge. (eds.) Manual of Perioperative Care, An Essential Guide. Oxford: Wiley Blackwell; 2012, pp 43-55.

45. House of Commons Health and Social Care Committee. Antimicrobial resistance: Eleventh Report of Session. House of Commons 2018. Available from: https://publications.parliament.uk/pa/cm201719/cmselect/cmhealth/962/962.pdf [Accessed February 14, 2020].

46. National institute for health and care excellence. NICE impact antimicrobial resistance. London, NICE, 2018. Available from: https://www.nice.org.uk/media/default/about/what-we-do/into-practice/measuring-uptake/niceimpact-antimicrobial-resistance.pdf [Accessed February 16, 2020].

47. HM Government. Tackling antimicrobial resistance 2019–2024: The UK’s five-year national action plan HM Government. 2019. Available from: https://www.gov.uk/government/publications/uk-5-year-action-plan-for-antimicrobial-resistance-2019-to-2024 [Accessed February 14, 2020].

48. World Health Organisation. Global Action Plan on Antimicrobial Resistance. Geneva, WHO Press, 2015. Available from: https://www.who.int/antimicrobial-resistance/publications/global-action-plan/en/ [Accessed February 16, 2020].

49 Public Health England. English Surveillance Programme for Antimicrobial Utilisation and Resistance (ESPAUR): Report 2018-2019. London, PHE publications, 2019. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\_data/file/843129/English\_Surveillance\_Programme\_for\_Antimicrobial\_Utilisation\_and\_Resistance\_2019.pdf [Accessed May 15, 2020].