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Bacterial Biofilms and Its Impact on Device and Non-Device Related Biofilm Infections

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Abstract:

Bacterial biofilms are colonies of aggregated bacterial cells that form extracellular matrix polymeric substances (EPS) that they create on their own. Biofilms are responsible for bacteria developing resistance to antibiotics, resulting in drug resistance in various diseases. This process occurs in a sequence of well-ordered phases. Biofilms are slow to respond to environmental stressors and thus help microorganisms survive in places where they otherwise might not be able to. One of the most serious health problems is the development and spread of antimicrobial resistance among bacteria. One way to combat this is through the production of bacterial biofilms. This review provides the information regarding biofilm formation, composition of microbial biofilm as well as highlights the device and non-device related biofilm infections.

Keywords **—Bacterial biofilms, device related biofilm infections, non-device related biofilm infections**

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I. INTRODUCTION

Biofilms can be formed by multiple microorganisms such as Gram-negative and Gram-positive bacteria (1-4). Biofilms are function to protect microorganism from extreme environment (5). Biofilms are a good example of ,they can occur and grow on minerals, also found underwater ,in food processing, obstruction of pipes, plaque build-up in mouth (6). Additionally, biofilms were the main thing for causing bacteria to become resistant to antibiotics, leading to drug resistance of many pathogens (7). Because biofilms are exceedingly hazardous and have a variety of detrimental consequences on human health and related issues, analysts have concentrated their efforts on biofilm protection and control (8). Biofilms are group of microorganisms that live together (8, 9). They have a complex surface (polymer) (10, 11). Polysaccharides, proteins, and extracellular DNAs make up the majority of them (9, 12, 13). The bacteria to form biofilms has been demonstrated to be a flexible feature of germs (14). The creation of biofilms indicates to be an ancient strategy which gives bacteria more possibilities than planktonic microorganisms, includes improved growth in oligotrophic environments, increased dietary resource availability, better survivability against biocides, increased production and interactions between organisms, also more stable environment (15-19). Biofilms protect microorganisms and make them more adaptable to their surroundings in particular instances (20). Bacterial biofilm formation is largely determined by interactions between bacteria, substrates, and environment (21, 22). This paper will describe about bacterial biofilm formation, identifies the medical issues related with bacterial biofilms. Also, this literature review identified the bacterial infection related to biofilms as well as device and non-devices infection.

II. FORMATION OF BACTERIAL BIOFILMS

Bacterial biofilm formation is a multi-stage procedure that starts with reversible adherence to

surfaces aided by intermolecular force and hydrophobicity, then advances to the development of (EPS) that allow cells to remain permanently adhered to a surface (23-25). Moreover, the biofilm development process is divided into five phases: Dispersal/detachment, reversible and irreversible attachment, EPS synthesis, biofilm maturation (26, 27). In contrast, on different biofilm phases, the expression and regulation mechanisms of different species of bacteria are highly varied (28, 29). Researchers still have a long way to go before fully comprehending the creation mechanism of all bacterial biofilms.

A wide range of strategies have been explored to prevent production of potentially hazardous biofilms, the most popular of which are interference with bacterial adhesion, signal transduction, and disruption of biofilm architecture (6). Manipulation of adhesion surfaces, quorum sensing (QS) signals, and environmental variables can also help in beneficial biofilm formation (30). The examination into the prevention and control of hazardous biofilms which is significantly more extensive than research into the creation of helpful biofilms.

III. COMPOSITION OF MICROBIAL BIOFILMS

Biofilm is a specialized collection of microorganisms that live in an extracellular polymeric matrix and that is irrevocably adhered to the fetish or live surface and will not be removed unless rinsed immediately (31). Extracellular polymeric substance (EPS) are formed during an attachment stage of a biofilm to a surface (32). The creation of matrix, which gives the bacteria in the biofilm more vigor in their contact, determines whether a microbial biofilm will grow on solid surface (33). The thickness of the EPS matrix is typically 0.2–1.0 m, although the biofilm size is typically 10–30 nm (34). Microorganisms typically make up 5–35 per cent of the biofilm volume, with extracellular matrix accounting for the rest. Proteins make up a portion or all of the extracellular matrix (35, 36). The extracellular matrix creates a scavenging system that traps some vital minerals and nutrients derived from the surrounding. Extracellular polymeric compounds have seven different types of components: protein in the majority more than 2%; other constituents, Polysaccharides 1–2%, RNA and DNA molecules 1% per each, ions and water (97%) are among major components. The amount of water in a biofilm affects the movement of critical nutrients (37-39).

Biofilm production, according to genetic studies, is a multi-step process. It necessitates a specific sort of signaling between the microbe cells known as quorum sensing. Furthermore, it needs transcription of a different set of genes than planktonic forms of the same microbial species (40-42). Additionally, the biofilm has canals that divide the microcolonies (41). The viscoelastic properties of the EPS matrix are responsible for the biofilm's mechanical stability (43, 44). Biofilm creation is complicated, but it follows a few common processes, according to different researchers: The phases that follow initial contact/attachment to the surface are microcolony creation, maturation and construction of the biofilm architecture, eventually detachment/dispersion of the biofilm. All the processes will be shown in detail in the following sections (45).

IV. BACTERIAL INFECTION ASSOCIATED WITH BIOFILMS

Bacterial biofilms are thought to be responsible for roughly 65 percent of all bacterial infection (46). Infections caused by devices as well as infections caused by non-devices are included. Device-related infection rates have been calculated for a variety of devices, including Breast implants are 2%, joint prostheses are 2%, mechanical heart valves are 4%, ventricular shunts are 10%, pacemakers and defibrillators are 4%, and ventricular-assist devices are over 40% (47-49). Inflammation caused by bacteria is known as native valve endocarditis (NVE). *Streptococci, Staphylococci, gram-negative bacteria, fungal infections* are the most common causes (50-54). Microbial cells enter the heart and circulatory system via the gastrointestinal tract, urinary tract, and oropharynx during this inflammation. Even when the immune system has removed the bacteria, the undamaged valve endothelium is affected by the microorganisms that cling to it, resulting in non-bacterial thrombotic

endocarditis (NBTE) at a lesion site (55, 56). Thrombus forms as a result, with platelets, red blood cells, and fibrin clumping together (57, 58).

V. DEVICE-RELATED BIOFILM INFECTIONS

Indwelling medical devices where biofilms might grow include contact lenses, prosthetic joints, mechanical heart valves, central venous catheters, urinecatheters, peritoneal dialysis catheters, pacemakers and vocal prosthesis (59-62). A single bacteria species can form a biofilm or a variety of them. This is dependent on the gadgets and how long they are active (63). There are two types of contact lenses, soft and hard. Both types of lenses are susceptible to microorganisms adhering to them. The materials utilized, the frequency with which they are disposed of, the wear schedule, and the design are used to classify them. Microorganisms that adhere to contact lenses include *Pseudomonas aeruginosa, Staphylococcus epidermidis, Candida, Staphylococcus aureus*, *E. coli , Serratia, and Proteus species*(64). The amount of water, the type of substrate, the concentration of electrolytes, and the type of bacterial strain involved, finally lens structure determine a degree of adhesion to the lenses. Biofilm generated by *P. aeruginosa* was discovered on contact lenses of a keratitis patient using scanning electron microscopy (65). On contact lenses placed in cases, biofilms are more prone to form. As a result, the lens storage containers have identified as potentially contaminated lens source.

On central venous catheters, biofilm formation is unavoidable, however an extent together with location of biofilm formation is determined by the length of catheterization. Catheters for a small period of time (10 days), for example, generate the amount of biofilm on exterior surface, but long term (30 days) catheters form more biofilm in the catheter channel (66). The type of the fluid supplied through the central venous catheter may have an impact on microorganism proliferation. Gram-positive bacteria, such as *S. epidermidis* , do not thrive in intravenous fluids, while gram-negative bacteria, such as *P. aeruginosa*, *Enterobacter* species are thrive in fluids (67, 68).

Prosthetic valve endocarditis is caused by microbial cells attaching to biofilm formation on mechanical heart valves and adjacent tissues. *S. aureus, Enterococcus, S. epidermidis, gram-negative Bacillus*, *Streptococcus species and Candida spp.*are bacteria that cause this unpleasant condition. Bacteria could have entered the body through the skin, other indwelling devices, or dental operations (62). At the suture site and on the devices, platelets and fibrin build up and might cause tissue harm during the surgical implantation of prosthetic heart valves. These locations are more likely to be colonized by microbial cells (69).

Urinary catheters are used to monitor urine production and excretion during surgery and are often composed of silicon or rubber. In the urethra and the bladder, urinary catheters are implanted (60). They have the option of having a closed or open system. An open catheter system drains urine through an open collecting center, however there is a larger chance of contamination, which can result in urinary tract infections (UTI) as a few days. Urine is collected in a plastic bag via closed catheter devices, which lowers the risk of urinary tract infections (59). Microorganisms such as *E. coli, Enterococcus faecalis, Streptococcus epidermidis, Pseudomonas aeruginosa, Proteus mirabilis, Klebsiella pneumoniae*, and other gram-negative bacteria constantly contaminate and build biofilms on these devices (59, 68).

VI. NON-DEVICE RELATED BIOFILM INFECTIONS

A gum infection is known as periodontitis. Soft tissues as well as the bones that support teeth are damaged by this illness (70).Typically, It is caused by a lack of dental hygiene (70). Periodontitis is caused by a variety of bacteria, including *Proteus aerobicus* and *Fusobacterium nucleatum(46)*. Although biofilms only occur on the surface of mucosal membranes, these microbes also can form biofilms on numerous other surfaces, including the surface of the oral cavity (71). Invasion of mucosal cells, changes in calcium flow in epithelial cells, and the release of toxins may all be possible when bacteria colonize tooth surfaces and within 2–3 weeks, a plaque can form (72).

Osteomyelitis is a bacterial or fungal infection of the bones. Bacteria can infiltrate the bones via previous infections ,bloodstream, or trauma (73). Microorganisms infect metaphysis of bone when they enter the body through the bloodstream. As a result, WBCs or white blood cells are drawn to infection site, indicating that an infection has occurred. WBCs try to phagocytose infections by secreting enzymes (74, 75). They may lyse the bone, causing pus to collect, and then spread across the blood vessels in the bone, blocking appropriate blood flow to the affected bone sections, resulting in tissue damage and a decline in their capacity to fulfil their tasks (73, 76).

CONCLUSIONS

Bacterial biofilm development takes place in a series of well-ordered steps. In both natural and man-made contexts, it is the most frequent bacterial lifestyle. Bacteria's capacity to colonize surfaces and produce biofilms is a severe issue that has been linked to negative outcomes in a variety of industries, including food, water, pharmaceuticals, and healthcare. Various procedures and approaches have been developed in order to get rid of dangerous biofilms, with the main focus on interfering with QS and bacterial attachment, in addition to destruction of the biofilm matrix. On the other hand, bacterial biofilms have an impact on the environment that goes beyond risk. Bacterial biofilms can be used for a variety of purposes.

REFERENCES

1. Flemming H-C, Wingender J, Szewzyk U, Steinberg P, Rice SA, Kjelleberg S. Biofilms: an emergent form of bacterial life. Nature Reviews Microbiology. 2016;14(9):563-75.
2. Vuotto C, Donelli G, Buckley A, Chilton C. Clostridium difficile biofilm. Updates on Clostridium difficile in Europe. 2018:97-115.
3. Schilcher K, Horswill AR. Staphylococcal biofilm development: structure, regulation, and treatment strategies. Microbiology and Molecular Biology Reviews. 2020;84(3):e00026-19.
4. Babushkina IV, Bondarenko AS, Ulyanov VY, Mamonova IA. Biofilm formation by gram-negative bacteria during implant-associated infection. Bulletin of Experimental Biology and Medicine. 2020;169(3):365-8.
5. Yin W, Wang Y, Liu L, He J. Biofilms: the microbial "protective clothing" in extreme environments. International journal of molecular sciences. 2019;20(14):3423.
6. Galie S, García-Gutiérrez C, Miguélez EM, Villar CJ, Lombó F. Biofilms in the food industry: health aspects and control methods. Frontiers in microbiology. 2018;9:898.
7. Daubenspeck JM, Totten AH, Needham J, Feng M, Balish MF, Atkinson TP, et al. Mycoplasma genitalium biofilms contain poly-GlcNAc and contribute to antibiotic resistance. Frontiers in microbiology. 2020;11:2702.
8. Kranjec C, Morales Angeles D, Torrissen Mårli M, Fernández L, García P, Kjos M, et al. Staphylococcal biofilms: Challenges and novel therapeutic perspectives. Antibiotics. 2021;10(2):131.
9. Maeda K, Okuda Y, Enomoto G, Watanabe S, Ikeuchi M. Biosynthesis of a sulfated exopolysaccharide, synechan, and bloom formation in the model cyanobacterium Synechocystis sp. strain PCC 6803. Elife. 2021;10:e66538.
10. Katuri KP, Kamireddy S, Kavanagh P, Muhammad A, Conghaile PÓ, Kumar A, et al. Electroactive biofilms on surface functionalized anodes: The anode respiring behavior of a novel electroactive bacterium, Desulfuromonas acetexigens. Water Research. 2020;185:116284.
11. Truchado P, Giménez-Bastida J-A, Larrosa M, Castro-Ibáñez I, Espín JC, Tomás-Barberán FA, et al. Inhibition of quorum sensing (QS) in Yersinia enterocolitica by an orange extract rich in glycosylated flavanones. Journal of agricultural and food chemistry. 2012;60(36):8885-94.
12. Schiller H, Schulze S, Mutan Z, de Vaulx C, Runcie C, Schwartz J, et al. Haloferax volcanii immersed liquid biofilms develop independently of known biofilm machineries and exhibit rapid honeycomb pattern formation. Msphere. 2020;5(6):e00976-20.
13. Tremblay YDN, Lévesque C, Segers RPAM, Jacques M. Method to grow Actinobacillus pleuropneumoniae biofilm on a biotic surface. BMC veterinary research. 2013;9(1):1-8.
14. Koczan JM, Lenneman BR, McGrath MJ, Sundin GW. Cell surface attachment structures contribute to biofilm formation and xylem colonization by Erwinia amylovora. Applied and Environmental Microbiology. 2011;77(19):7031-9.
15. Davies D. Understanding biofilm resistance to antibacterial agents. Nature reviews Drug discovery. 2003;2(2):114-22.
16. Dang H, Lovell CR. Microbial surface colonization and biofilm development in marine environments. Microbiology and molecular biology reviews. 2016;80(1):91-138.
17. Escudero C, Vera M, Oggerin M, Amils R. Active microbial biofilms in deep poor porous continental subsurface rocks. Scientific reports. 2018;8(1):1-9.
18. Du B, Gu Y, Chen G, Wang G, Liu L. Flagellar motility mediates early-stage biofilm formation in oligotrophic aquatic environment. Ecotoxicology and environmental safety. 2020;194:110340.
19. Groendahl S, Fink P. High dietary quality of non-toxic cyanobacteria for a benthic grazer and its implications for the control of cyanobacterial biofilms. BMC ecology. 2017;17(1):1-10.
20. Martin M, Hölscher T, Dragoš A, Cooper VS, Kovács ÁT. Laboratory evolution of microbial interactions in bacterial biofilms. Journal of bacteriology. 2016;198(19):2564-71.
21. Cyphert EL, Zuckerman ST, Korley JN, von Recum HA. Affinity interactions drive post-implantation drug filling, even in the presence of bacterial biofilm. Acta biomaterialia. 2017;57:95-102.
22. Yadav N, Dubey A, Shukla S, Saini CP, Gupta G, Priyadarshini R, et al. Graphene oxide-coated surface: inhibition of bacterial biofilm formation due to specific surface–interface interactions. ACS omega. 2017;2(7):3070-82.
23. Caruso C, Rizzo C, Mangano S, Poli A, Di Donato P, Finore I, et al. Production and biotechnological potential of extracellular polymeric substances from sponge-associated Antarctic bacteria. Applied and environmental microbiology. 2018;84(4):e01624-17.
24. Karygianni L, Ren Z, Koo H, Thurnheer T. Biofilm matrixome: extracellular components in structured microbial communities. Trends in Microbiology. 2020;28(8):668-81.
25. Zhang R, Neu TR, Li Q, Blanchard V, Zhang Y, Schippers A, et al. Insight into interactions of thermoacidophilic archaea with elemental sulfur: biofilm dynamics and EPS analysis. Frontiers in microbiology. 2019;10:896.
26. Muhammad MH, Idris AL, Fan X, Guo Y, Yu Y, Jin X, et al. Beyond risk: bacterial biofilms and their regulating approaches. Frontiers in microbiology. 2020;11:928.
27. Toyofuku M, Inaba T, Kiyokawa T, Obana N, Yawata Y, Nomura N. Environmental factors that shape biofilm formation. Bioscience, biotechnology, and biochemistry. 2016;80(1):7-12.
28. Yan J, Nadell CD, Bassler BL. Environmental fluctuation governs selection for plasticity in biofilm production. The ISME journal. 2017;11(7):1569-77.

29. Gonzalez-Machado C, Capita R, Riesco-Pelaez F, Alonso-Calleja C. Visualization and quantification of the cellular and extracellular components of Salmonella Agona biofilms at different stages of development. PLoS One. 2018;13(7):e0200011.
30. Mangwani N, Kumari S, Das S. Involvement of quorum sensing genes in biofilm development and degradation of polycyclic aromatic hydrocarbons by a marine bacterium Pseudomonas aeruginosa N6P6. Applied microbiology and biotechnology. 2015;99(23):10283-97.
31. Hurlow J, Couch K, Laforet K, Bolton L, Metcalf D, Bowler P. Clinical biofilms: a challenging frontier in wound care. Advances in wound care. 2015;4(5):295-301.
32. Di Martino P. Extracellular polymeric substances, a key element in understanding biofilm phenotype. AIMS microbiology. 2018;4(2):274.
33. Høiby N. A short history of microbial biofilms and biofilm infections. Apmis. 2017;125(4):272-5.
34. Sleytr UB. I. Basic and applied S-layer research: an overview. FEMS microbiology reviews. 1997;20(1-2):5-12.
35. Lyu Z, Shang Y, Wang X, Wu Y, Zheng J, Liu H, et al. Monoclonal Antibodies Specific to the Extracellular Domain of Histidine Kinase YycG of Staphylococcus epidermidis Inhibit Biofilm Formation. Frontiers in microbiology. 2020;11:1839.
36. Sun D, Accavitti MA, Bryers JD. Inhibition of biofilm formation by monoclonal antibodies against Staphylococcus epidermidis RP62A accumulation-associated protein. Clinical and Vaccine Immunology. 2005;12(1):93-100.
37. Abedon ST, Danis-Wlodarczyk KM, Wozniak DJ, Sullivan MB. Improving Phage-Biofilm In Vitro Experimentation. Viruses. 2021;13(6):1175.
38. Melo LDR, Pinto G, Oliveira F, Vilas-Boas D, Almeida C, Sillankorva S, et al. The protective effect of Staphylococcus epidermidis biofilm matrix against phage predation. Viruses. 2020;12(10):1076.
39. Abedon ST. Ecology of anti-biofilm agents II: bacteriophage exploitation and biocontrol of biofilm bacteria. Pharmaceuticals. 2015;8(3):559-89.
40. Roszkowiak J, Jajor P, Guła G, Gubernator J, Żak A, Drulis-Kawa Z, et al. Interspecies outer membrane vesicles (OMVs) modulate the sensitivity of pathogenic bacteria and pathogenic yeasts to cationic peptides and serum complement. International journal of molecular sciences. 2019;20(22):5577.
41. Scherlach K, Hertweck C. Chemical mediators at the bacterial-fungal interface. Annual Review of Microbiology. 2020;74:267-90.
42. Marcos-Torres FJ, Volz C, Müller R. An ambruticin-sensing complex modulates Myxococcus xanthus development and mediates myxobacterial interspecies communication. Nature communications. 2020;11(1):1-15.
43. Nguyen H, Ybarra A, Başağaoğlu H, Shindell O. Biofilm viscoelasticity and nutrient source location control biofilm growth rate, migration rate, and morphology in shear flow. Scientific Reports. 2021;11(1):1-17.
44. Shaw T, Winston M, Rupp CJ, Klapper I, Stoodley P. Commonality of elastic relaxation times in biofilms. Physical review letters. 2004;93(9):098102.
45. Wang Q, Chen K, Huang S, Zhu X, Kang F. Spontaneous assembly of microbial extracellular polymeric substances into microcapsules involved in trapping and immobilizing degradation-resistant oxoanions. Science of The Total Environment. 2021;758:143651.
46. Jamal M, Ahmad W, Andleeb S, Jalil F, Imran M, Nawaz MA, et al. Bacterial biofilm and associated infections. Journal of the Chinese Medical Association. 2018;81(1):7-11.
47. Darouiche RO. Treatment of infections associated with surgical implants. New England Journal of Medicine. 2004;350(14):1422-9.
48. Ting M, Wang C-H, Chi N-H, Hsu R-B, Chen Y-S, Yu H-Y. Outcome for surgical treatment of infective endocarditis with periannular abscess. Journal of the Formosan Medical Association. 2020;119(1):113-24.
49. Daye D, Walker TG. Complications of endovascular aneurysm repair of the thoracic and abdominal aorta: evaluation and management. Cardiovascular diagnosis and therapy. 2018;8(Suppl 1):S138.
50. Chamat-Hedemand S, Dahl A, Østergaard L, Arpi M, Fosbøl E, Boel J, et al. Prevalence of infective endocarditis in streptococcal bloodstream infections is dependent on streptococcal species. Circulation. 2020;142(8):720-30.
51. Diaconu R, Golumbeanu E, Constantin A, Donoiu I. Native valve endocarditis with Staphylococcus warneri. BMJ Case Reports CP. 2019;12(6):e229546.
52. Dias MTA, de Almeida J, Santos A, Santos RM, Carvalho A. Enterococcus gallinarum causing native valve endocarditis. European journal of case reports in internal medicine. 2019.
53. Park BS, Lee WY, Ra YJ, Lee HK, Gu BM, Yang JT. Surgical Outcomes for Native Valve Endocarditis. The Korean journal of thoracic and cardiovascular surgery. 2020;53(1):1.
54. Asgeirsson H, Thalme A, Weiland O. Staphylococcus aureus bacteraemia and endocarditis–epidemiology and outcome: a review. Infectious Diseases. 2018;50(3):175-92.
55. Liu J, Frishman WH. Nonbacterial thrombotic endocarditis. Cardiology in review. 2016;24(5):244-7.
56. Sugimoto A, Shiraishi S, Watanabe M, Moon J, Ohashi R, Takahashi M, et al. Non-bacterial thrombotic endocarditis in the right atrium caused by pectus excavatum. Surgical case reports. 2016;2(1):1-3.
57. Ivanova K, Ramon E, Hoyo J, Tzanov T. Innovative approaches for controlling clinically relevant biofilms: current trends and future prospects. Current topics in medicinal chemistry. 2017;17(17):1889-914.
58. Keleştemur S, Çulha M. Understanding and discrimination of biofilms of clinically relevant microorganisms using surface-enhanced Raman scattering. Applied spectroscopy. 2017;71(6):1180-8.
59. Wolcott R. Biofilm and catheter-related bloodstream infections. British Journal of Nursing. 2021;30(8):S4-S9.
60. Bayrak O, Basmaci I, Zer Y, Sen H, Erturhan S, Seckiner I. Colonizations on biofilm layers of DJ catheters under sterile urine conditions. Archivos espanoles de urologia. 2019;72(1):75-9.
61. Pathak R, Bierman SF, d'Arnaud P. Inhibition of bacterial attachment and biofilm formation by a novel intravenous catheter material using an in vitro percutaneous catheter insertion model. Medical Devices (Auckland, NZ). 2018;11:427.
62. Galli J, Calo L, Meucci D, Giuliani M, Lucidi D, Paludetti G, et al. Biofilm in voice prosthesis: A prospective cohort study and laboratory tests using sonication and SEM analysis. Clinical Otolaryngology. 2018;43(5):1260-5.
63. Donlan RM. Biofilms: microbial life on surfaces. Emerging infectious diseases. 2002;8(9):881.
64. Dosler S, Hacioglu M, Yilmaz FN, Oyardi O. Biofilm modelling on the contact lenses and comparison of the in vitro activities of multipurpose lens solutions and antibiotics. PeerJ. 2020;8:e9419.
65. Hilliam Y, Kaye S, Winstanley C. Pseudomonas aeruginosa and microbial keratitis. Journal of medical microbiology. 2020;69(1):3-13.
66. Rosenthal VD, Belkebir S, Zand F, Afeef M, Tanzi VL, Al-Abdely HM, et al. Six-year multicenter study on short-term peripheral venous catheters-related bloodstream infection rates in 246 intensive units of 83 hospitals in 52 cities of 14 countries of Middle East: Bahrain, Egypt, Iran, Jordan, Kingdom of Saudi Arabia, Kuwait, Lebanon, Morocco, Pakistan, Palestine, Sudan, Tunisia, Turkey, and United Arab Emirates—International Nosocomial Infection Control Consortium (INICC) findings. Journal of infection and public health. 2020;13(8):1134-41.
67. Lacostena-Pérez ME, Buesa-Escar AM, Gil-Alós AM. Complications related to the insertion and maintenance of peripheral venous access central venous catheter. Enfermería Intensiva (English ed). 2019;30(3):116-26.
68. Burnham JP, Rojek RP, Kollef MH. Catheter removal and outcomes of multidrug-resistant central-line-associated bloodstream infection. Medicine. 2018;97(42).
69. Suresh MK, Biswas R, Biswas L. An update on recent developments in the prevention and treatment of Staphylococcus aureus biofilms. International Journal of Medical Microbiology. 2019;309(1):1-12.
70. Mosaddad SA, Tahmasebi E, Yazdanian A, Rezvani MB, Seifalian A, Yazdanian M, et al. Oral microbial biofilms: an update. European Journal of Clinical Microbiology & Infectious Diseases. 2019;38(11):2005-19.
71. How KY, Song KP, Chan KG. Porphyromonas gingivalis: an overview of periodontopathic pathogen below the gum line. Frontiers in microbiology. 2016;7:53.

72. Hojo K, Nagaoka S, Ohshima T, Maeda N. Bacterial interactions in dental biofilm development. Journal of dental research. 2009;88(11):982-90.
73. Blyth CC, Gomes L, Sorrell TC, Da Cruz M, Sud A, Chen S-A. Skull-base osteomyelitis: fungal vs. bacterial infection. Clinical Microbiology and Infection. 2011;17(2):306-11.
74. Baumgärtner W, Boyce RW, Alldinger S, Axthelm MK, Weisbrode SE, Krakowka S, et al. Metaphyseal bone lesions in young dogs with systemic canine distemper virus infection. Veterinary microbiology. 1995;44(2-4):201-9.
75. Kahn DS, Pritzker KPH. The pathophysiology of bone infection. Clin Orthop. 1973;96:12-9.
76. Ziran BH. Osteomyelitis. Journal of Trauma and Acute Care Surgery. 2007;62(6):S59-S60.

