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Review Article

Surface modification of SiO_2 nanoparticles for bacterial decontaminations of blood products

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ABSTRACT

Bacterial infections can be caused by contamination of labile blood products with specific bacteria, such as *Staphylococcus aureus* and *Staphylococcus epidermidis*. Hospital equipment, bio-protective equipment, delivery systems, and medical devices can be easily contaminated by microorganisms. Multidrug-resistant bacteria can survive on various organic or inorganic polymeric materials for more than 90 days. Inhibiting the growth and eradicating these microorganisms is vital in blood transfusion processes. Blood bags and other related medical devices can be improved by the incorporation of organic or inorganic nanomaterials, particularly silicon dioxide (SiO_2) nanoparticles. The addition of solid organic or inorganic nanoparticles to synthetic polymers or biopolymers can provide new properties in addition to antimicrobial activity. Among these NPs, formulations composed of SiO_2 nanoparticles and polymers have been shown to improve the mechanical and antimicrobial properties of catheters, prosthetic inserts, blood bags, and other medical devices SiO_2 nanoparticles possess several advantages, including large-scale synthetic availability, simple one-pot synthesis methods, porous structure for loading antibacterial agents, good biocompatibility, and thermal stability. Plasticized polyvinyl chloride is the main polymer, which has been functionalized by these nanoparticles. In this review, we discuss the recent advances and challenges regarding the functionalization of polyvinyl chloride by SiO_2 nanoparticles to hinder bacterial contaminations in blood products.

1. Introduction

Blood banks are responsible for ensuring the safe supply of blood products to hospitals to meet the needs of transfusion medicine. The need for blood transfusions and the selection of blood products are governed by the treatment priority, as well as the age and sex of the patient [1]. The main constraint during transfusion is the availability of donations, where any ABO blood group incompatibility that may cause transfusion reactions should be avoided [2]. Plasma,

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platelet concentrates (PC), and red blood cells (RBCs) are obtained by centrifugation and filtration of whole blood and represent the products most frequently used in transfusion [3]. Plasma is mainly administered in cases of trauma [4], RBCs are one of the only treatments to restore tissue oxygenation [5], while PCs are mainly used to prevent or treat bleeding in patients with thrombocytopenia [6].

The volume of a whole blood donation is usually 450 mL ±10%, and samples undergo leucodepletion, (often by filtration) for removing the immune cells from the blood [7]. In some cases, whole blood donations have the leukocytes removed (below the limit of 5 million per unit) followed by mixing the RBCs with an additive solution and are stored in a blood bag composed of di(2-ethylhexyl) phthalate and polyvinyl chloride (PVC) [8]. The type of treatment process favored by each blood bank is chosen based on several factors, each with advantages and disadvantages [9]. Generally, donors must wait for a minimum of 56 days between donations, except for certain circumstances, which can have a negative impact on supply capacity [10]. For example, women are sometimes called upon to prolong their inter-donation time interval in response to abnormally low iron stores caused by menstruation [11]. In addition, blood donations can be collected using apheresis (a medical technology for separating the soluble and cellular components of blood) [12]. The advantage of this procedure comes from the fact that it is possible to return unwanted blood components to the donor. Moreover, apheresis allows the collection of several blood products simultaneously. In this way, the apheresis process can allow higher donation frequencies closely spaced together [13].

2. Bacterial contaminations of blood products

Hospital equipment, bio-protective equipment, delivery systems, and medical devices may be easily contaminated by microorganisms. Microorganisms such as multidrug-resistant bacteria can survive on various organic or inorganic polymeric materials for more than 90 days and can lead to the transmission of infectious diseases [14]. Blood banks have invested considerable time and effort in the adoption as well as the optimization of the efficiency of various contaminant detection methods. An analytical test for the detection of bacteria must not only be generic, in order to detect all possible strains but also highly sensitive to detect the presence of bacteria at very low numbers [15-18]. Recently, the standard techniques for automated bacterial detection are based on the growth of bacteria such as *Staphylococcus epidermis* and *Staphylococcus aureus* in a non-specific medium both in aerobic and anaerobic conditions. This allows the detection of bacteria at concentrations as low as 1 to 10 colony forming units (CFU) per milliliter [19-21]. Additional analytical techniques such as Real-Time Polymerase Chain Reaction (RT-PCR) for the detection of bacterial contaminants in blood products in a blood bank can be highly sensitive [22, 23]. Because it is not possible to analyze the entire volume of the labile blood product (LBP) in blood storage bags, bacterial testing can be rapidly carried out using the Matrix-Assisted Laser Desorption Ionization–Time Of Flight Mass Spectrometry (MALDI-TOF MS) technique on a small sample [24, 25].

Sending blood products to hospitals before obtaining the results of microbiological testing entails a potential risk involving the transfusion of contaminated or toxic blood products. Since the analytical process is lengthy, PCs with a short shelf life can actually be sent to hospitals before obtaining the final results to limit product losses [26, 27]. On the other hand, an analysis of risks is required and all contaminated products must be traced and removed from inventories. If any contaminated product has been transfused, medical steps must be taken to ensure patient safety [28, 29].

3. Antibacterial and antiadhesive coatings

Materials that make up medical devices, such as blood storage bags and catheters have gradually evolved along with the development of plastic tubes [30, 31]. Different materials or biomaterials such as thermoplastics (PVC and polyethylene), thermosetting polymers (cross-linked polyurethane, PUR), flexible elastomers (silicones and linear PUR), or cellulose can be used to fabricate catheters

[32-34]. Polyethylenes and PVC can be functionalized with various materials, such as polyglycidyl methacrylate allowing biodegradation in physiological conditions [35]. Urinary catheters are mainly based on PUR, and their properties vary depending on the nature of the additives and plasticizers used in their manufacture [36]. Moreover, silicone, polysiloxane, or polydimethylsiloxane [$(CH_3)_2$-SiO] polymer chains (Figure 1) with different lengths and molecular weights are attractive synthetic polymers, with suitable thermal stability, resistance to physical aging, flexibility, biocompatibility, and hydrophobic properties [37-40].

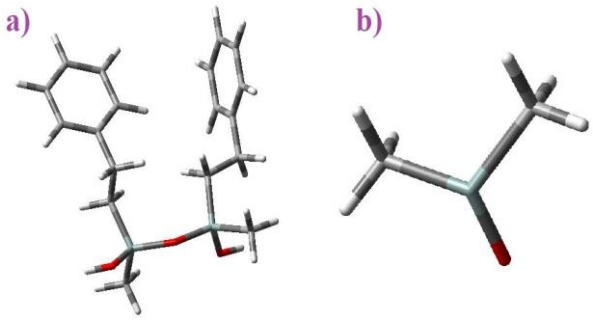

Fig. 1. Polysiloxane (a) or polydimethylsiloxane monomers(b)(https://pubchem.ncbi.nlm.nih.gov).

Many approaches are available for the modification and functionalization of the surface of organic or inorganic polymers, such as cold plasma surface treatment, which has been tested to prevent the colonization of bacteria [41, 42]. The coating of hydrophobic polymers with polyethylene glycol (PEG) chains using physical or chemical bonding to form the shape of a brush or a mushroom, has been tested in recent investigations to produce or modify polymers for different medical applications [43-45]. The goal is to generate a biocompatible interface, where this inert layer acts as a barrier to prevent non-specific biological interactions [46, 47]. For instance, adding a brush-like polymer appears to minimize the adsorption of proteins or cells onto the PVC surface [48]. However, few investigations have been carried out on the effects of PVC coated with brush-like polymers when in contact with blood or blood products [46, 49]. Moreover, other polymers, such as poly(butylene adipate-co-terephthalate) prepared as a thin film filled by SiO_2NPs via a solvent casting method were used for inactivation of *E. coli* and *S. aureus* bacteria [50]. Some research has been done on surface modification with antimicrobial peptides (AMP) as amphiphilic cationic structures, which can bind to anionic bacterial membranes by electrostatic attraction leading to bacterial death [51]. The mechanism of action of AMPs remains complex and poorly studied, and the main problem associated with the clinical use of AMPs is their possible cytotoxicity [52].

4. Surface modification by SiO_2 NPs

The addition of solid organic or inorganic nanoparticles (NPs) to synthetic polymers or biopolymers can provide new properties in addition to antimicrobial activity [53-56]. Among these NPs, formulations composed of silica NPs (SiO_2) and polymers have been shown to improve the mechanical and antimicrobial properties of catheters, prosthetic inserts, blood bags, and other medical devices [57]. SiO_2 NPs can be prepared by three main methods, the Stober process (using a precursor of tetraethyl orthosilicate), green synthesis, and microemulsion based on water-in-oil (W/O) reverse micelles or oil-in-water micelles [58, 59]. The antimicrobial properties of SiO_2NPs are most often associated with their surface functionalization, and any process that leads to their agglomeration can present a major disadvantage [60].

Recently, several studies have described smart antibacterial biomaterials, thin films, hydrogels, and nanoparticles, which can respond to pH changes, magnetic fields, electric currents, temperature, light, as well as hydrophobic properties to be used as a medical antibacterial and antiadhesive coatings (MAAC) [61-64]. More specifically, functionalized SiO_2 NPs can be incorporated into the PU matrix used during its synthesis to provide multifunctional capabilities [65]. The coating should have repellent properties so that bacteria cannot attach to the surface of materials coated by MAACs, and it can exhibit antimicrobial activity by binding to proteins associated with bacterial adhesion [66]. In the light of current knowledge on the mechanisms of action of MAACs, SiO_2 NPs can bind specifically to saccharides contained in the peptidoglycan layer of bacteria, thus

inducing an osmotic change leading to cell death [67]. It is expected that the activity of MAACs is more important for Gram-positive bacteria owing to their thicker cell wall and an accessible layer of peptidoglycan. In fact, the main structural element of Gram-positive bacteria is the peptidoglycan layer, essential for their viability, metabolism, and influx and efflux of molecules, including antibiotics [68]. The peptidoglycan layer provides rigidity to the cell, with a thickness varying between 30-100 nm. In contrast, the peptidoglycan layer of Gram-negative bacteria is only ~3 nm thick and its structure is more complex since it is located between the cytoplasmic and outer membranes [69]. As shown in Figure 2, other components of the bacterial envelope, including capsule, fimbriae, pilus, flagellum, teichoic acid and lipoteichoic acid of Gram-positive bacteria, and lipopolysaccharide of Gram-negative bacteria could be targeted by functionalized SiO_2NPs [68]. In order to achieve synergistic antimicrobial activity against bacteria or viruses, antibacterial or antiviral agents such as metals, metal oxide NPs or antibiotics can be employed to functionalize SiO_2NPs to produce reactive oxygen species (ROS) that can then damage biological macromolecules (Figure 3e) [70-72]. The use of organosilane-based coupling agents is the main way to prepare different derivatives of SiO_2NPs (Figure 3a-3d) [58, 73].

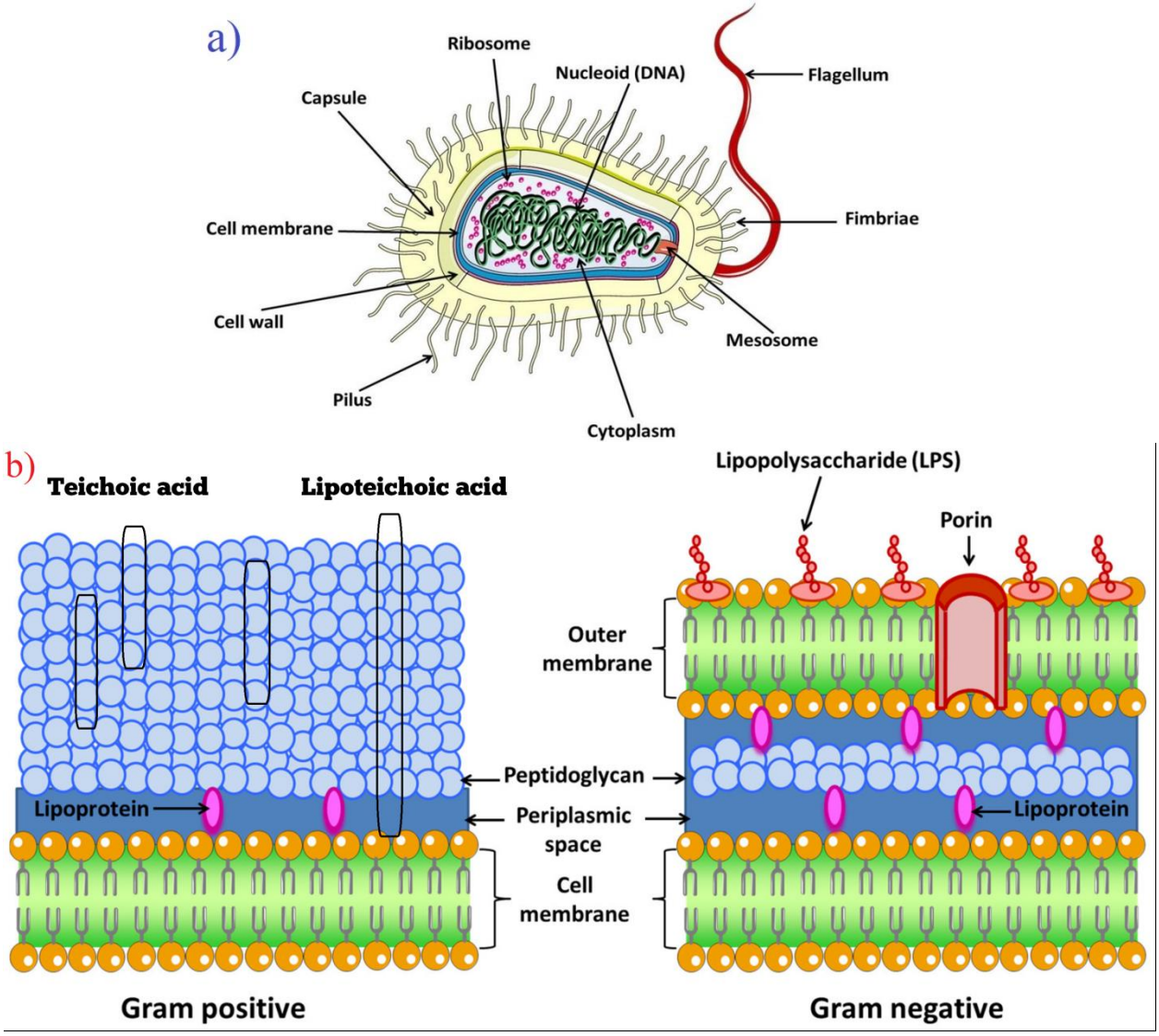

Fig. 2. a) Structure of bacterial cells; b) Structural difference between Gram-positive and Gram-negative bacteria (copyright under license https://creativecommons.org/licenses/by/4.0/) [68].

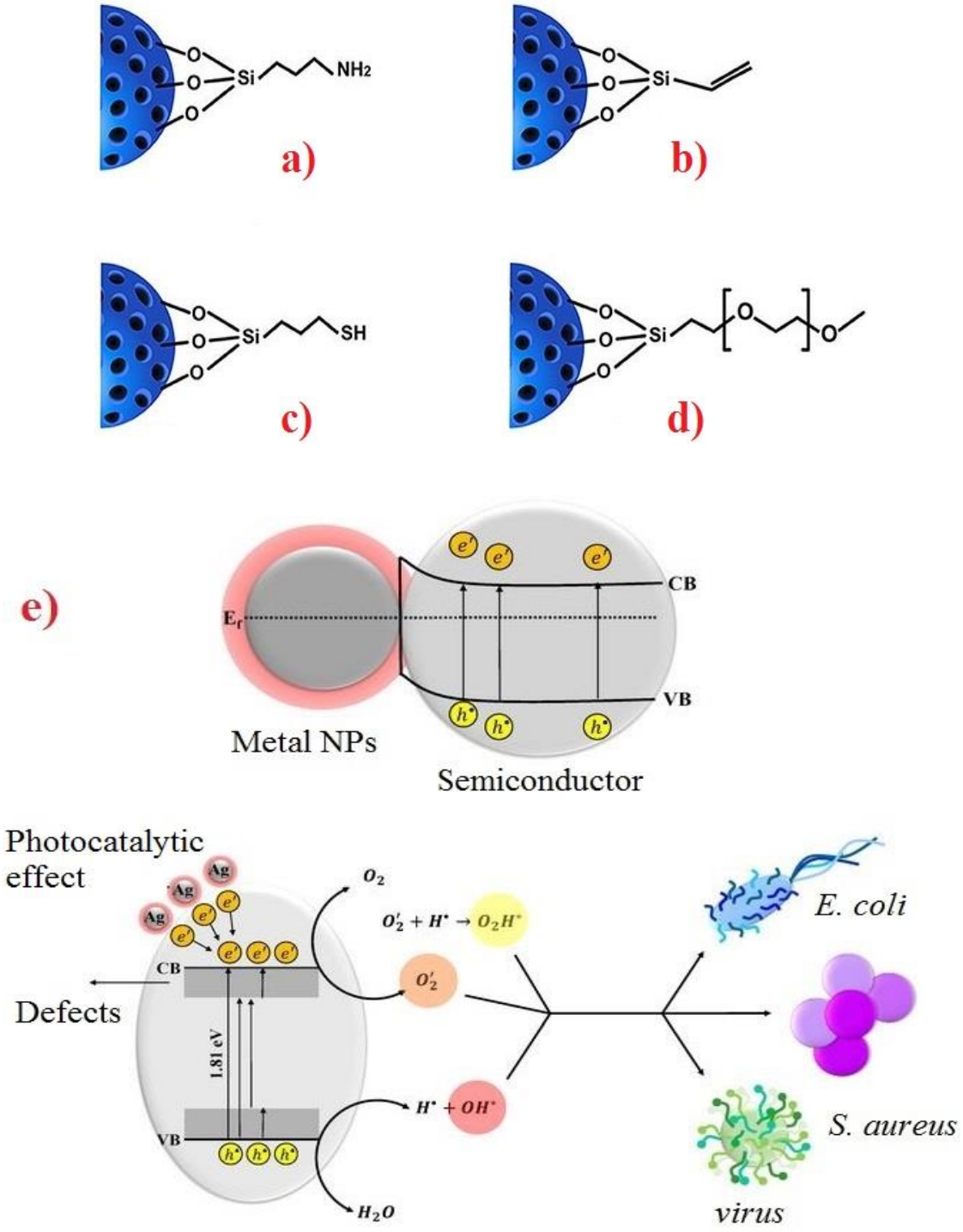

Fig. 3. Common organisilane coupling agents: (a) 3-aminopropyl-triethoxysilane; (b) vinyltriethoxysilane; (c) 3-Mercaptopropyl-trimethoxysilane; (d) methoxy-PEG-silane: (e) production of ROS upon photocatalytic activity of SiO_2-Ag nanocomposites. VB and CB are the valence band and conduction band, respectively. All images have been distributed under the terms of the Creative Commons Attribution License (CC BY) [58, 73].

5. Conclusions

Plasticized polyvinyl chloride is the main polymer used to produce blood bags, which can be functionalized by SiO_2NPs. These NPs can specifically bind to the saccharide residues of the peptidoglycan layer of the bacteria, thus inducing an osmotic change leading to cell death. Both bare and modified SiO_2NPs have advantages, including large-scale synthetic availability, simple one-pot synthesis method, thermal stability, good biocompatibility, and a porous structure for loading with antibacterial agents. Several components of the bacterial envelope include the capsule, fimbriae, pilus, flagellum, teichoic acid, and lipoteichoic acid of Gram-positive bacteria, as well as the lipopolysaccharide of Gram-negative bacteria, can be targeted by functionalized SiO_2NPs. To provide synergistic antibacterial activity and decrease cytotoxicity, both antibacterial agents and biocompatible materials have been employed to functionalize SiO_2NPs. The application of organosilane-based coupling agents is the main route to preparing nanocomposites based on SiO_2NPs combined with PVC. However, the antimicrobial properties of SiO_2NPs are mostly associated with their surface functionalization, but their agglomeration in contact with blood products is an undesirable effect. Therefore, more investigations are needed to overcome these hindrances to obtain more effective antiplanktonic and antibiofilm materials composed of SiO_2NPs combined polymers (specifically PVC) in medical devices suitable for blood transfusion medicine.

Conflict of Interests

All authors declare no conflict of interest.

Ethics approval and consent to participate

No human or animals were used in the present research.

Consent for publications

All authors read and approved the final manuscript for publication.

Availability of data and material

All the data are embedded in the manuscript.

Authors' Contribution

Main draft of the manuscript was written by M.A. and revised by all authors..

Informed Consent

The authors declare not to use any patients in this research.

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References

1. Lin CK, Leung JNS, So BKL, Lee CK (2014) Donor selection for blood safety: is it still necessary? ISBT Science Series 9(1):26-29. doi:https://doi.org/10.1111/voxs.12056
2. Murphy MF, Stanworth SJ, Yazer M (2011) Transfusion practice and safety: current status and possibilities for improvement. Vox Sanguinis 100(1):46-59. doi:https://doi.org/10.1111/j.1423-0410.2010.01366.x
3. Basu D, Kulkarni R (2014) Overview of blood components and their preparation. Indian J Anaesth 58(5):529-537. doi:https://doi.org/10.4103/0019-5049.144647
4. Innerhofer P, Fries D, Mittermayr M, Innerhofer N, von Langen D, Hell T, Gruber G, Schmid S, Friesenecker B, Lorenz IH, Ströhle M, Rastner V, Trübsbach S, Raab H, Treml B, Wally D, Treichl B, Mayr A, Kranewitter C, Oswald E (2017) Reversal of trauma-induced coagulopathy using first-line coagulation factor concentrates or fresh frozen plasma (RETIC): a single-centre, parallel-group, open-label, randomised trial. The Lancet Haematology 4(6):e258-e271. doi:https://doi.org/10.1016/S2352-3026(17)30077-7
5. Bresnick EH, Hewitt KJ, Mehta C, Keles S, Paulson RF, Johnson KD (2018) Mechanisms of erythrocyte development and regeneration: implications for regenerative medicine and beyond. Development 145(1):dev151423. doi:https://doi.org/10.1242/dev.151423
6. EASL Clinical Practice Guidelines on prevention and management of bleeding and thrombosis in patients with cirrhosis (2022). Journal of Hepatology).

doi:https://doi.org/10.1016/j.jhep.2021.09.003
7. Kumar H, Gupta PK, Mishra DK, Sarkar RS, Jaiprakash M (2006) Leucodepletion and Blood Products. Med J Armed Forces India 62(2):174-177. doi:https://doi.org/10.1016/S0377-1237(06)80064-X
8. Hadjesfandiari N, Khorshidfar M, Devine DV (2021) Current Understanding of the Relationship between Blood Donor Variability and Blood Component Quality. International journal of molecular sciences 22(8):3943. doi:https://doi.org/10.3390/ijms22083943
9. Beliën J, Forcé H (2012) Supply chain management of blood products: A literature review. European Journal of Operational Research 217(1):1-16. doi:https://doi.org/10.1016/j.ejor.2011.05.026
10. Lacetera N, Macis M, Slonim R (2012) Will There Be Blood? Incentives and Displacement Effects in Pro-social Behavior. American Economic Journal: Economic Policy 4(1):186-223. doi:https://doi.org/10.1257/pol.4.1.186
11. Kiss JE, Vassallo RR (2018) How do we manage iron deficiency after blood donation? British Journal of Haematology 181(5):590-603. doi:https://doi.org/10.1111/bjh.15136
12. Gifford SC, Strachan BC, Xia H, Vörös E, Torabian K, Tomasino TA, Griffin GD, Lichtiger B, Aung FM, Shevkoplyas SS (2018) A portable system for processing donated whole blood into high quality components without centrifugation. PLoS One 13(1):e0190827. doi:https://doi.org/10.1371/journal.pone.0190827
13. Chell K, Davison TE, Masser B, Jensen K (2018) A systematic review of incentives in blood donation. Transfusion 58(1):242-254. doi:https://doi.org/10.1111/trf.14387
14. Chen Z, Sun Y (2006) N-Halamine-Based Antimicrobial Additives for Polymers: Preparation, Characterization and Antimicrobial Activity. Ind Eng Chem Res 45(8):2634-2640. doi:https://doi.org/10.1021/ie060088a
15. Dietvorst J, Vilaplana L, Uria N, Marco M-P, Muñoz-Berbel X (2020) Current and near-future technologies for antibiotic susceptibility testing and resistant bacteria detection. TrAC Trends in Analytical Chemistry 127:115891. doi:https://doi.org/10.1016/j.trac.2020.115891
16. Rajapaksha P, Elbourne A, Gangadoo S, Brown R, Cozzolino D, Chapman J (2019) A review of methods for the detection of pathogenic microorganisms. Analyst 144(2):396-411. doi:https://doi.org/10.1039/C8AN01488D
17. Abbas-Al-Khafaji ZK, Aubais-aljelehawy Qh (2021) Evaluation of antibiotic resistance and prevalence of multi-antibiotic resistant genes among Acinetobacter baumannii strains isolated from patients admitted to al-yarmouk hospital. Cellular, Molecular and Biomedical Reports 1(2):60-68. doi:https://doi.org/10.55705/cmbr.2021.142761.1015
18. Almasian-Tehrani N, Alebouyeh M, Armin S, Soleimani N, Azimi L, Shaker-Darabad R (2021) Overview of typing techniques as molecular epidemiology tools for bacterial characterization. Cellular, Molecular and Biomedical Reports 1(2):69-77. doi:https://doi.org/10.55705/cmbr.2021.143413.1016
19. Franza T, Rogstam A, Thiyagarajan S, Sullivan MJ, Derré-Bobillot A, Bauer MC, Goh KGK, Da Cunha V, Glaser P, Logan DT, Ulett GC, von Wachenfeldt C, Gaudu P (2021) NAD+ pool depletion as a signal for the Rex regulon involved in Streptococcus agalactiae virulence. PLOS Pathogens 17(8):e1009791. doi:https://doi.org/10.1371/journal.ppat.1009791
20. Liang H, Mao Y, Sun Y, Gao H (2019) Transcriptional regulator ArcA mediates expression of oligopeptide transport systems both directly and indirectly in Shewanella oneidensis. Scientific Reports 9(1):13839. doi:https://doi.org/10.1038/s41598-019-50201-4
21. Aubais aljelehawy Qh, Hadi Alshaibah LH, Abbas Al- Khafaji ZK (2021) Evaluation of virulence factors among Staphylococcus aureus strains isolated from patients with urinary tract infection in Al-Najaf Al-Ashraf

teaching hospital. Cellular, Molecular and Biomedical Reports 1(2):78-87. doi:https://doi.org/10.55705/cmbr.2021.144995.1017
22. Brecher Mark E, Hay Shauna N (2005) Bacterial Contamination of Blood Components. Clinical Microbiology Reviews 18(1):195-204. doi:https://doi.org/10.1128/CMR.18.1.195-204.2005
23. Dreier J, Störmer M, Kleesiek K (2007) Real-Time Polymerase Chain Reaction in Transfusion Medicine: Applications for Detection of Bacterial Contamination in Blood Products. Transfusion Medicine Reviews 21(3):237-254. doi:https://doi.org/10.1016/j.tmrv.2007.03.006
24. Levy JH, Neal MD, Herman JH (2018) Bacterial contamination of platelets for transfusion: strategies for prevention. Critical Care 22(1):271. doi:https://doi.org/10.1186/s13054-018-2212-9
25. Di Gaudio F, Indelicato S, Indelicato S, Tricoli MR, Stampone G, Bongiorno D (2018) Improvement of a rapid direct blood culture microbial identification protocol using MALDI-TOF MS and performance comparison with SepsiTyper kit. Journal of Microbiological Methods 155:1-7. doi:https://doi.org/10.1016/j.mimet.2018.10.015
26. Godbey EA, Thibodeaux SR (2019) Ensuring safety of the blood supply in the United States: Donor screening, testing, emerging pathogens, and pathogen inactivation. Seminars in Hematology 56(4):229-235. doi:https://doi.org/10.1053/j.seminhematol.2019.11.004
27. Saravani K, Afshari M, Aminisefat A, Bameri O (2021) Blood Sugar Changes in Patients with Acute Drug Poisoning. Cell Mol Biomed Rep 1(2):91-97. doi:http://dx.doi.org/10.55705/cmbr.2021.146061.1022
28. Crawford E, Kamm J, Miller S, Li LM, Caldera S, Lyden A, Yokoe D, Nichols A, Tran NK, Barnard SE, Conner PM, Nambiar A, Zinter MS, Moayeri M, Serpa PH, Prince BC, Quan J, Sit R, Tan M, Phelps M, Derisi JL, Tato CM, Langelier C (2020) Investigating Transfusion-related Sepsis Using Culture-Independent Metagenomic Sequencing. Clinical Infectious Diseases 71(5):1179-1185. doi:https://doi.org/10.1093/cid/ciz960
29. Panch SR, Bikkani T, Vargas V, Procter J, Atkins JW, Guptill V, Frank KM, Lau AF, Stroncek DF (2019) Prospective Evaluation of a Practical Guideline for Managing Positive Sterility Test Results in Cell Therapy Products. Biology of Blood and Marrow Transplantation 25(1):172-178. doi:https://doi.org/10.1016/j.bbmt.2018.08.003
30. Zhu Z, Wang Z, Li S, Yuan X (2019) Antimicrobial strategies for urinary catheters. Journal of Biomedical Materials Research Part A 107(2):445-467. doi:https://doi.org/10.1002/jbm.a.36561
31. Erythropel HC, Maric M, Nicell JA, Leask RL, Yargeau V (2014) Leaching of the plasticizer di(2-ethylhexyl)phthalate (DEHP) from plastic containers and the question of human exposure. Applied Microbiology and Biotechnology 98(24):9967-9981. doi:https://doi.org/10.1007/s00253-014-6183-8
32. Hasirci V, Hasirci N (2018) Polymers as Biomaterials. In: Hasirci V, Hasirci N (eds) Fundamentals of Biomaterials. Springer New York, New York, NY, pp 65-82. doi:https://doi.org/10.1007/978-1-4939-8856-3_5
33. Madhumanchi S, Srichana T, Domb AJ (2021) Polymeric Biomaterials. In: Narayan R (ed) Biomedical Materials. Springer International Publishing, Cham, pp 49-100. doi:https://doi.org/10.1007/978-3-030-49206-9_2
34. Tokhadzé N, Chennell P, Pereira B, Mailhot-Jensen B, Sautou V (2021) Critical Drug Loss Induced by Silicone and Polyurethane Implantable Catheters in a Simulated Infusion Setup with Three Model Drugs. Pharmaceutics 13(10). doi:https://doi.org/10.3390/pharmaceutics13101709
35. Costoya A, Velázquez Becerra LE, Meléndez-Ortiz HI, Díaz-Gómez L, Mayer C, Otero A, Concheiro A, Bucio E, Alvarez-Lorenzo C (2019) Immobilization of antimicrobial and anti-quorum sensing

enzymes onto GMA-grafted poly(vinyl chloride) catheters. Int J Pharm 558:72-81. doi:https://doi.org/10.1016/j.ijpharm.2018.12.075
36. Zaokari Y, Persaud A, Ibrahim A (2020) Biomaterials for Adhesion in Orthopedic Applications: A Review. Engineered Regeneration 1:51-63. doi:https://doi.org/10.1016/j.engreg.2020.07.002
37. Zare M, Ghomi ER, Venkatraman PD, Ramakrishna S (2021) Silicone-based biomaterials for biomedical applications: Antimicrobial strategies and 3D printing technologies. Journal of Applied Polymer Science 138(38):50969. doi:https://doi.org/10.1002/app.50969
38. Xu C-a, Chen G, Tan Z, Hu Z, Qu Z, Zhang Q, Lu M, Wu K, Lu M, Liang L (2020) Evaluation of cytotoxicity in vitro and properties of polysiloxane-based polyurethane/lignin elastomers. Reactive and Functional Polymers 149:104514. doi:https://doi.org/10.1016/j.reactfunctpolym.2020.104514
39. Xu C-A, Nan B, Lu M, Qu Z, Tan Z, Wu K, Shi J (2020) Effects of polysiloxanes with different molecular weights on in vitro cytotoxicity and properties of polyurethane/cotton–cellulose nanofiber nanocomposite films. Polymer Chemistry 11(32):5225-5237. doi:https://doi.org/10.1039/D0PY00809E
40. Aymes-Chodur C, Salmi-Mani H, Dragoe D, Aubry-Barroca N, Buchotte M, Roger P (2021) Optimization of microwave plasma treatment conditions on polydimethylsiloxane films for further surface functionalization. European Polymer Journal 150:110416. doi:https://doi.org/10.1016/j.eurpolymj.2021.110416
41. Chouirfa H, Bouloussa H, Migonney V, Falentin-Daudré C (2019) Review of titanium surface modification techniques and coatings for antibacterial applications. Acta Biomaterialia 83:37-54. doi:https://doi.org/10.1016/j.actbio.2018.10.036
42. Hage M, Khelissa S, Akoum H, Chihib N-E, Jama C (2022) Cold plasma surface treatments to prevent biofilm formation in food industries and medical sectors. Applied Microbiology and Biotechnology 106(1):81-100. doi:https://doi.org/10.1007/s00253-021-11715-y
43. Alavi M, Webster TJ (2021) Recent progress and challenges for polymeric microsphere compared to nanosphere drug release systems: Is there a real difference? Bioorg Med Chem 33:116028. doi:https://doi.org/10.1016/j.bmc.2021.116028
44. Alavi M, Rai M (2020) Topical delivery of growth factors and metal/metal oxide nanoparticles to infected wounds by polymeric nanoparticles: an overview. Expert Rev Anti-Infect Ther 18(10):1021-1032. doi:https://doi.org/10.1080/14787210.2020.1782740
45. Alavi M, Nokhodchi A (2022) Micro- and nanoformulations of paclitaxel based on micelles, liposomes, cubosomes, and lipid nanoparticles: Recent advances and challenges. Drug Discovery Today 27(2):576-584. doi:https://doi.org/10.1016/j.drudis.2021.10.007
46. Sun W, Liu W, Wu Z, Chen H (2020) Chemical Surface Modification of Polymeric Biomaterials for Biomedical Applications. Macromolecular Rapid Communications 41(8):1900430. doi:https://doi.org/10.1002/marc.201900430
47. Yin L, Liu L, Zhang N (2021) Brush-like polymers: design, synthesis and applications. Chemical Communications 57(81):10484-10499. doi:https://doi.org/10.1039/D1CC03940G
48. Liu M, Li S, Wang H, Jiang R, Zhou X (2021) Research progress of environmentally friendly marine antifouling coatings. Polymer Chemistry 12(26):3702-3720. doi:https://doi.org/10.1039/D1PY00512J
49. Altinkok C, Karabulut HRF, Tasdelen MA, Acik G (2020) Bile acid bearing poly (vinyl chloride) nanofibers by combination of CuAAC click chemistry and electrospinning process. Materials Today Communications 25:101425. doi:https://doi.org/10.1016/j.mtcomm.2020.101425
50. Venkatesan R, Rajeswari N (2019) Preparation, Mechanical and Antimicrobial Properties of SiO2/ Poly(butylene adipate-

co-terephthalate) Films for Active Food Packaging. Silicon 11(5):2233-2239. doi:https://doi.org/10.1007/s12633-015-9402-8
51. Shen W, He P, Xiao C, Chen X (2018) From Antimicrobial Peptides to Antimicrobial Poly(α-amino acid)s. Adv Healthc Mater 7(20):1800354. doi:https://doi.org/10.1002/adhm.201800354
52. Yu L, Li K, Zhang J, Jin H, Saleem A, Song Q, Jia Q, Li P (2022) Antimicrobial Peptides and Macromolecules for Combating Microbial Infections: From Agents to Interfaces. ACS Applied Bio Materials 5(2):366-393. doi:https://doi.org/10.1021/acsabm.1c01132
53. Alavi M, Nokhodchi A (2022) Antimicrobial and wound healing activities of electrospun nanofibers based on functionalized carbohydrates and proteins. Cellulose 29(3):1331-1347. doi:10.1007/s10570-021-04412-6
54. Alavi M (2022) Bacteria and fungi as major bio-sources to fabricate silver nanoparticles with antibacterial activities. Expert Rev Anti-Infect Ther):1-10. doi:10.1080/14787210.2022.2045194
55. Alavi M, Karimi N (2022) Antibacterial, hemoglobin/albumin-interaction, and molecular docking properties of phytogenic AgNPs functionalized by three antibiotics of penicillin, amoxicillin, and tetracycline. Microbial Pathogenesis 164:105427. doi:https://doi.org/10.1016/j.micpath.2022.105427
56. Alavi M, Varma RS (2021) Antibacterial and wound healing activities of silver nanoparticles embedded in cellulose compared to other polysaccharides and protein polymers. Cellulose 28(13):8295-8311. doi:10.1007/s10570-021-04067-3
57. Colino CI, Lanao JM, Gutierrez-Millan C (2021) Recent advances in functionalized nanomaterials for the diagnosis and treatment of bacterial infections. Materials Science and Engineering: C 121:111843. doi:https://doi.org/10.1016/j.msec.2020.111843
58. Selvarajan V, Obuobi S, Ee PLR (2020) Silica Nanoparticles—A Versatile Tool for the Treatment of Bacterial Infections. Frontiers in Chemistry 8. doi:https://doi.org/10.3389/fchem.2020.00602
59. Adinarayana TVS, Mishra A, Singhal I, Koti Reddy DVR (2020) Facile green synthesis of silicon nanoparticles from Equisetum arvense for fluorescence based detection of Fe(iii) ions. Nanoscale Advances 2(9):4125-4132. doi:https://doi.org/10.1039/D0NA00307G
60. Fonseca S, Cayer M-P, Ahmmed KMT, Khadem-Mohtaram N, Charette SJ, Brouard D (2022) Characterization of the Antibacterial Activity of an SiO(2) Nanoparticular Coating to Prevent Bacterial Contamination in Blood Products. Antibiotics (Basel) 11(1):107. doi:https://doi.org/10.3390/antibiotics11010107
61. Tallet L, Gribova V, Ploux L, Vrana NE, Lavalle P (2021) New Smart Antimicrobial Hydrogels, Nanomaterials, and Coatings: Earlier Action, More Specific, Better Dosing? Adv Healthc Mater 10(1):2001199. doi:https://doi.org/10.1002/adhm.202001199
62. Liu K, Zhang F, Wei Y, Hu Q, Luo Q, Chen C, Wang J, Yang L, Luo R, Wang Y (2021) Dressing Blood-Contacting Materials by a Stable Hydrogel Coating with Embedded Antimicrobial Peptides for Robust Antibacterial and Antithrombus Properties. ACS Applied Materials & Interfaces 13(33):38947-38958. doi:https://doi.org/10.1021/acsami.1c05167
63. Sheridan M, Winters C, Zamboni F, Collins MN (2022) Biomaterials: Antimicrobial surfaces in biomedical engineering and healthcare. Current Opinion in Biomedical Engineering 22:100373. doi:https://doi.org/10.1016/j.cobme.2022.100373
64. Vladkova TG, Staneva AD, Gospodinova DN (2020) Surface engineered biomaterials and ureteral stents inhibiting biofilm formation and encrustation. Surface and Coatings Technology 404:126424. doi:https://doi.org/10.1016/j.surfcoat.2020.126424
65. Moustafa H, Darwish NA, Youssef AM (2022) Rational formulations of sustainable polyurethane/chitin/rosin composites reinforced with ZnO-doped-

SiO2 nanoparticles for green packaging applications. Food Chemistry 371:131193. doi:https://doi.org/10.1016/j.foodchem.2021.131193

66. Sánchez SV, Navarro N, Catalán-Figueroa J, Morales JO (2021) Nanoparticles as Potential Novel Therapies for Urinary Tract Infections. Frontiers in cellular and infection microbiology 11:656496-656496. doi:https://doi.org/10.3389/fcimb.2021.656496
67. Allafchian A, Hosseini SS (2019) Antibacterial magnetic nanoparticles for therapeutics: a review. IET nanobiotechnology 13(8):786-799. doi:https://doi.org/10.1049/iet-nbt.2019.0146
68. Jiménez-Jiménez C, Moreno VM, Vallet-Regí M (2022) Bacteria-Assisted Transport of Nanomaterials to Improve Drug Delivery in Cancer Therapy. Nanomaterials 12(2). doi:https://doi.org/10.3390/nano12020288
69. Silhavy TJ, Kahne D, Walker S (2010) The bacterial cell envelope. Cold Spring Harb Perspect Biol 2(5):a000414-a000414. doi:https://doi.org/10.1101/cshperspect.a000414
70. Alavi M, Rai M, Martinez F, Kahrizi D, Khan H, Rose Alencar de Menezes I, Douglas Melo Coutinho H, Costa JGM (2022) The efficiency of metal, metal oxide, and metalloid nanoparticles against cancer cells and bacterial pathogens: different mechanisms of action. Cellular, Molecular and Biomedical Reports 2(1):10-21. doi:10.55705/cmbr.2022.147090.1023
71. Alavi M, Rai M (2021) Antisense RNA, the modified CRISPR-Cas9, and metal/metal oxide nanoparticles to inactivate pathogenic bacteria. Cellular, Molecular and Biomedical Reports 1(2):52-59. doi:https://doi.org/10.55705/cmbr.2021.142436.1014
72. Alavi M, Karimi N (2020) Hemoglobin self-assembly and antibacterial activities of bio-modified Ag-MgO nanocomposites by different concentrations of Artemisia haussknechtii and Protoparmeliopsis muralis extracts. Int J Biol Macromol 152:1174-1185. doi:https://doi.org/10.1016/j.ijbiomac.2019.10.207
73. Assis M, Simoes LGP, Tremiliosi GC, Coelho D, Minozzi DT, Santos RI, Vilela DCB, Santos JRd, Ribeiro LK, Rosa ILV, Mascaro LH, Andrés J, Longo E (2021) SiO2-Ag Composite as a Highly Virucidal Material: A Roadmap that Rapidly Eliminates SARS-CoV-2. Nanomaterials 11(3):638. doi:https://doi.org/doi:10.3390/nano11030638

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