

Firstly, H₂O₂ assists in breaking the outer "protective shell" of the bacteria—the phospholipid bilayer of the cell membrane, which enters the interior of the bacteria and reacts with the internal biomolecules such as lipid bilayer, proteins and nucleic acids, destroying the structure of the bacteria and thus leading to their death. It is encouraging to note that the modified ZnO composites could generate ROS under the excitation of visible light that was not significantly harmful to humans. (ii) Release of Zn²⁺. As a cofactor for nearly 300 enzymes in living organisms [135], Zn²⁺ has a specificity for sulfur groups and inhibit glycolytic enzymes by oxidizing their thiol groups [136]. However, as the glycolytic reactions occur in the cytoplasm, the ROS produced at this time will open channels for Zn²⁺ to cross the cell membrane of the bacteria, and could denature their internal proteins and disrupt proliferation. Zn²⁺ also breaks electron transport, allowing disruption of cellular respiration. It should not be overlooked that the release of Zn²⁺, despite being synergistically bactericidal, can also lead to increased toxicity to normal cells. (iii) Endocytosis. Bacterial cell walls are negatively charged, and ZnO NPs can attach to the outer surface of bacteria by the electrostatic effect of Zn²⁺ on negatively charged membranes. This phenomenon can change the resting potential of the cell membrane and induce depolarization of the cell membrane by blocking the K⁺ channels [137] presented in the cell membrane, which leads to loss of phospholipid bilayer integrity and leakage of intracellular components such as lipopolysaccharides and ATP from the cell, ultimately leading to cell death (Fig. 13). Interestingly, the researchers found that the loss of cell membrane integrity was the main reason for the antibactericidal effect of ZnO NP on *E. coli* [138]. Padmavathy et al. [139] discovered that the larger the surface area of ZnO, the higher the concentrations of surface oxygen species, and the smaller the particles, the greater the antibacterial activity, thus opening the door to "non-drug" therapy. In addition, Gupta et al. [152] prepared Fe₃O₄@ZnO core-shell nanoparticles (Fe₃O₄@ZnO CSNPs) using a hydrothermal method that combined magnetothermal and bioimaging, and the photoluminescence spectrum showed a UV emission peak at 383 nm. To investigate the imaging properties, green and red fluorescence of human cervical cancer cells (HeLa) were observed by confocal microscopy. Valenzuela et al. [141] reported that the ZnO-rGO photocatalytic coating showed excellent bactericidal ability against Gram-positive bacteria *Staphylococcus aureus* by the reduction of e⁻/h⁺ pairs recombination and the enhancement of [•]OH production by ZnO, which showed excellent bactericidal properties and high stability in preventing bacterial adhesion and transmission, making it a great prospect for surface antimicrobial functionalization. In this regard, Mahmood et al. [158] successfully prepared ZnO/Cu₂O composite films by electrodeposition and constructed composite electrodes, and EIS and IV measurements showed the lowest electron mobility at the electrode/electrolyte interface, high current density of ZnO, and good stability of hydrolysis reaction. Raghupathi and colleagues [134] found that ZnO NPs produced more ROS and exhibited more antimicrobial activity under UV illumination, the reason of which was mainly attributed to that the electron leaps inside the ZnO nanoparticles could generate photogenerated e⁻ and h⁺, further generating ROS through in redox reactions. Biomedical field Zinc is an essential trace metal for normal growth, development and physiological functions of organisms.