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Brief Review Paper : Policy Research – Survey Paper

Study on Antibacterial Properties of Metal Matrix Composites for Medical Scaffolds

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Abstract: Metal composites' antibacterial properties have piqued the interest of numerous sectors, including industry, healthcare, and environmental applications. One important advantage of metal composites is their capacity to damage bacterial cell membranes. Magnesium-based nanocomposites have demonstrated significant potential as materials possessing potent antibacterial properties. The addition of nanoparticles like silver, zinc oxide, or copper oxide improves the antibacterial properties of magnesium matrices. Certain metals, such as silver and copper, release ions that interfere with essential bacterial processes. These ions have the power to damage cell membranes, DNA, and proteins, which ultimately causes bacterial death. Copper ions (Cu2+), which are produced when copper is added to composite materials, damage proteins, DNA, and bacterial cell membranes. Moreover, silver nanoparticles emit Ag+, which has a broad spectrum of antibacterial activity. These ions kill bacteria by interfering with their ability to function as proteins and enzymes. Zinc ions interfere with bacteria's metabolism, stopping them from breathing and proliferating. Iron is commonly used as the base material for these composites due to the mechanical strength and biocompatibility. It provides the structural stability needed for the implant while acting as a platform for the addition of antibacterial substances. This study examines the antibacterial properties of different metal composites.

Keywords: Metals, Medicals , Cu2+, Human Trials, DNA.

1. Introduction

Human tissues are highly hierarchical, which leaves them susceptible to trauma, cancer, and degenerative disorders. Therefore, it is crucial to create novel strategies for tissue regeneration and repair. A multitude of structures, mostly scaffolds for tissue engineering and biomaterials, are being developed and optimized. But there's no denying that putting foreign objects or materials within the human body would increase the chance of bacterial infection. For example, even low levels of microorganisms in an operating room might have disastrous consequences.

These bacterial infections may manifest months or years following surgery, causing implant failure and agony for the patient. Thus, it's critical to comprehend the fundamental processes and the antibacterial qualities of the different metal ions and metal nanoparticles that are employed. Because it is of significant importance to produce biomaterials and constructs that might decrease such harmful bacterial infections, our study will largely concentrate on these features. Importantly, the biochemistry and metabolism of the living organisms depend on a range of metals to perform cellular functions Key metal ions required for the synthesis of DNA and the cell membrane include copper (Cu), manganese (Mn), iron (Fe), and zinc (Zn). Furthermore, these ions typically take part in electron transport and catalysis, two crucial cellular functions.

Because metals such as copper, silver, zinc, and others may release ions or nanoparticles that damage proteins, bacterial cell membranes, and vital biological processes, metal composites have strong antibacterial qualities. Examples of composites that release copper ions are those made of copper (Cu2+), while composites made of silver release silver ions that have wide antibacterial activity (Ag+). Zinc composites stop bacteria from breathing and developing by interfering with their metabolism.

One significant limitation with implantation biomaterials is the possibility of bacterial infection. Significantly, because of the bacteria causing them and their deep tissue localization, infection at implantation or its sites are often challenging to treat.

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2. Literature Review

Mg-Nd-Zn-Zr (JDBM), a special magnesium alloy, developed by Hui Qin et al. (2015), to increase resistance to corrosion and antimicrobial actions. Although magnesium's (Mg) antibacterial properties have long been recognized, its therapeutic applications are limited by their rapid corrosion and possible toxicity. Microbiological counts, CLSM, SEM, and culture data show that JDBM effectively enhances Mg's properties through increased cytocompatibility and antibacterial activity.

In their 2018 study, Siba Soren et al. examined the cytotoxic and antioxidant characteristics of Zinc Oxide (ZnO NPs) made using two distinct techniques. Tests conducted throughout the investigation demonstrate that these nanoparticles have a considerable capacity to scavenge free radicals. Significantly, ZnO NPs made by the polyol approach outperformed those made by water precipitation in terms of their antibacterial qualities against both Gm +ve and Gm -ve bacteria. The results validate the potential of ZnO nanoparticles for a variety of antimicrobial applications, especially in the formation of nanodrugs.

With a significant danger of post-operative infections and osteolysis, Bo Jia et al. (2021) investigated the use of Zn–Ag alloy for patients having internal fixation or two-stage joint surgery. By suppressing different staphylococci strains, including antibiotic-resistant ones, and reducing bacterial adherence and biofilm development, the Zn–2Ag alloy showed strong antibacterial characteristics. Additionally, it had an impact on MRSA's expression of genes linked to drug resistance. The alloy demonstrated strong antibacterial action against MRSA in a rat model. Furthermore, in experiments involving mice and rabbits, the Zn–2Ag alloy demonstrated anti-osteolytic characteristics by preventing osteoclastic development and boosting bone volume and density.

The promise of customised ZnO nanoparticles for antibacterial applications was highlighted by Nasrin Talebian et al. (2013). The solvothermal approach was used to generate nanocrystalline ZnO powders; the solvent used affected the formation of the ZnO nucleus as well as the growth of the crystal. There was a correlation observed between the morphology of the product and the dielectric constant of the solvent. Water produced ZnO that looked like flowers, 1-hexanol produced structures that looked like hexagonal rods, and ethylene glycol produced ZnO that was spherical. Among these, ZnO that resembled flowers showed potent antibacterial properties after brief UV exposure. MgO/ZnO nanocomposites were synthesized and characterized by Abhishek Nigam et al. in 2021. Their single-phase, crystalline nature is confirmed by XRD examination, with crystallite diameters ranging from 18 to 53 nm. ZnO and MgO/ZnO together display a hexagonal wurtzite structure, but MgO has a cubic structure. The typical size of the dumbbell-shaped structures shown in FE-SEM images is 450 nm. These nanomaterials are potential for use in biomedical applications since they are compatible with human cells, cytotoxic to cancer cells, and have superior antibacterial action.

Annas Al-Sharabi et al. (2022) concentrated on Mg based nanocomposites , which were made using an economical solvent-deficient method. The samples were primarily monoclinic crystalline α-Bi_2O_3, with no MgO peaks, according to XRD examination at x=0. In MgO– Bi_2O_3, replacing Bi with Cr produced the tetragonal $BiCrO_3$ phase with a smaller crystallite size. Micrometer-sized, evenly distributed, aggregated grains were visible in the SEM pictures. Elemental composition was verified by EDXA. The antibacterial activity of the nanocomposite against different microorganisms was diminished by Cr doping.

Bijan Nasri-Nasrabadi et al. (2018) described the process of creating three-dimensional porous scaffolds with interconnected pores made of MO nanoparticles and sodium alginate through film casting and PVA leaching. The mechanical behaviour , absorption capacity, and in-vitro degradation of these scaffolds were all affected by the nanoparticle integration. The improved antimicrobial properties of the nanocomposites were partly credited to anti-bacterial properties of MO NPs. These nanocomposite scaffolds facilitated cell adhesion, dispersal, and growth, as confirmed by the MTT test and images captured by scanning electron microscopy. This suggests their potential for use in biomedical settings where high mechanical strength and antibacterial properties are needed.

Biodegradable magnesium (Mg) alloys are making promising advances as biological materials, according to research by Junxiu Chen et al. (2021). While hydroxyapatite (HA) coating has been shown to successfully lower corrosion rates in magnesium alloys, enabling tunable deterioration, no single surface protection technique has been established to simultaneously address rapid corrosion, biocompatibility, and bioactivity. Strong biocompatibility of HA- coated surfaces renders them appropriate for use in bone fixation devices, cardiovascular stents, and other implant applications. The performance of implants may be hampered by HA coatings' tendency to be brittle, which results in a poor bond with the metal matrix.

The effects of implanting magnesium (Mg) and titanium (Ti) nails into bone tissue were studied by Yang Li et al. in 2014. They discovered that many

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bacterial clusters enclosed in a biofilm matrix present on the surfaces of Ti nails and surroundings of the bone tissues. On the magnesium nail surfaces and in the bone tissue, few microorganisms were discovered. Furthermore, the investigation showed that magnesium implants have antibacterial qualities that decreased bacterial adhesion and inhibited the formation of biofilms. All things considered, orthopaedic implants may be able to avoid or treat implant-associated infections with use of biodegradable magnesium-based biomaterials, increasing both therapeutic efficacy and patient safety.

Using a developing rat model and ongoing in vivo CT monitoring, Tanja Kraus et al. (2011) reported the degrading performance of two magnesium alloys. While WZ21 degraded more slowly, losing roughly 0.5 percent of its volume per day, one alloy, ZX50, broke down quickly and produced a lot of gas. Magnesium exhibited good osteoconductivity and osteoinductivity around WZ21 implants, which retained their integrity for four weeks and displayed increased bone neoformation surrounding them. The results are significant for the use of magnesium implants in paediatrics, where full bone healing and mechanical integrity for a minimum of four weeks are required.

According to Satish Jaiswal et al. (2017), orthopaedic accessories such as screws and plates can be effectively made from magnesium (Mg) with different percentages of hydroxyapatite (HA) and 3 percent zinc (Zn). The mechanical characteristics and resistance to corrosion of this Mg-Zn matrix were enhanced by the adding HA. Extended immersion experiments revealed that Mg-3Zn-5HA displayed better resistance to corrosion, resistance to pitting, and lower galvanic corrosion rates among the compositions. The appropriate compressive strength and elastic modulus were also shown by this combination. Highly promising for orthopaedic applications, Mg-3Zn-5HA demonstrated enhanced osteogenic cell adhesion and survival.

The integration of Ag NPs into MCMZ composites preserved the pore structure and porosity, as reported by Hamid R.R et al. (2019). It was noteworthy that the Ag-free MCMZ scaffolds were not as strong as the nanostructured MCMZ-Ag scaffolds in terms of final compressive strength. These biomaterials displayed solid bactericidal effects on S.aureus and E.coli, with an increase in antibacterial efficacy increasing Ag content. With their potent antibacterial properties and unique characteristics, the porous scaffolds containing 0.5 weight percent Ag-MCMZ fulfil all requirements for bone tissue engineering needs.

The effects of magnesium on biocomposites and bio-alloys were investigated by Murad Ali et al. in 2019. Magnesium composites provide a remedy to the fast deterioration of magnesium alloys while maintaining mechanical strength, even though magnesium alloys are essential. It is possible to overcome this difficulty by selecting metallic and ceramic reinforcements that are naturally biocompatible and have a consistent grain size. Based on the study, magnesium- based biocomposites' mechanical characteristics and resistance to corrosion can be greatly influenced by different types of reinforcements. Powder metallurgy and fragmented melt deposition are two promising fabrication processes.

In order to improve bone repair, Hang Zhou et al. (2021) looked at the superior biodegradability and biocompatibility of Mg-based biomaterials. Even though every substance is different, they all have similar biological features that support better bone regeneration. The critical role that magnesium plays in both in vitro and in vivo bone repair has been shown by basic investigations. While most magnesium-based materials have issues with mechanical characteristics and corrosion resistance, new technologies provide answers. Preliminary research on large animal models is necessary before evaluating magnesium-based orthopedic implants in human trials, especially for load-bearing applications.

Gr-modified Mg–1Al–Cu materials that are fully biodegradable and mechanically robust were produced by Narges Safari et al. (2020) using a novel and straightforward method. When Gr nanoparticles (0.18% weight percent) were added to the Mg–1Al–Cu matrix, they showed a significant reduction in in vitro corrosion and an enhancement in antimicrobial activity against S.aureus and E.coli. Moreover, Gr-modified Mg–1Al–Cu samples demonstrated cytocompatibility; in the case of osteogenic gene expression levels, the 0.18 weight percent Gr- modified Mg–1Al–Cu sample outperformed the non-Gr-modified sample in terms of cell proliferation and Oste promotive qualities.

The usage of HA/PDA composite coating loaded with pharmaceuticals on a Zn–1Mg porous scaffold was investigated by Zhenbao Zhang et al. (2023) in order to limit biodegradation and distribute antibacterial drugs and osteogenic growth factors locally, leading to increased osteogenic and antibacterial capabilities. Gm +ve and gm -ve bacterias were efficiently killed by the prolonged release of Van from the PDA coating, which demonstrated a strong antibacterial activity. As a result, Zn–1Mg scaffolds exhibited increased antibacterial activity.

Bo Yuan et al. (2022) reported that Mg/HA composite In their study, Chao Xu et al. (2022) examined the production of porous Fe-HA MMCs using DIW. The MMCs were found to have various porosities and HA concentrations .In vitro studies revealed that the addition of HA micropowders greatly accelerated the

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rate of disintegration of these materials. After adjusting the HA content to within 0–2.5 weight percent, the compressive strengths matched those of bones. The Fe-HA scaffolds exhibited no deformation during immersion, indicating that they might be used as transient bone substitutes. Further in-vitro and in-vivo research is necessary in light of these promising results for the clinical use of porous Fe-based implants.

The zinc oxide nanoparticles (ZnO NPs) studied by Pawan K. Mishra et al. (2017) have the properties so that it can be used for biological applications because they can trigger apoptosis and the creation of reactive oxygen species, which makes them useful for antifungal, anticancer, and antibacterial applications. Combining them with other drugs can also improve their therapeutic benefits. Because of their high surface area and metallic characteristics, ZnO NPs are still thought to be generally harmless, but concerns regarding their toxicity remain. More investigation is required to completely comprehend their toxicity profile and optimise their advantages, despite their encouraging biomedical potential.

Adel M. El Sayed and associates (2022) discussed the addition of magnesium oxide nanoparticles to PVAc/PVC nanocomposites by means of sol-gel and solution casting/evaporation processes. Based on MgO nanoparticles in the periclase phase, XRD measurements revealed that the nanocomposite maintained an amorphous structure. SEM scans, which revealed a smooth surface, verified the blend's homogeneity. MgO nanoparticle doping improved the material's mechanical properties and UV-blocking capability, leading to an improvement in toughness and strength. The enhanced antimicrobial activity of the nanocomposites also raised the possibility of applications in food packaging, transportation, and optical components.

Because metal-based materials are selectively toxic to bacteria while sparing host cells, Maria Godoy-Gallardo coated on a ZQ71 alloy surface using a blend of hydrothermal treatment, electrophoretic deposition, and electrochemical deposition. Moreover, ZQ71-HEP showed enhanced antibacterial activity against gm-ve and gm+ve bacteria, like S. aureus (E. coli). ZQ71-HEP demonstrated superior pro-osteogenic and bactericidal effects in vivo under both normal and infectious conditions, suggesting that they could be used in biomedical applications as multifunctional magnesium-based implants..

In their study from 2022, Ning Wang et al. noted that alloys based on magnesium (Mg), zinc (Zn), and iron (Fe) had a lot of potential for creating biodegradable materials with antibacterial qualities for orthopedic implants. Now, in vitro antimicrobial assays are the main method used for the incomplete assessment of alloy performance. To progress these materials toward therapeutic usage, additional tinkering and in vivo tests are required. Likewise, there is a dearth of research and development of Iron-based alloy with antimicrobial capabilities for orthopedic grafts.

Powder metallurgy and spark plasma sintering were used for creating Fe-Ag and Fe-Au alloy with different Ag or Au concentrations, as Tao Huang et al. (2015) reported. Grain diameters in these composites were lesser than in pure iron as-cast. The mechanical properties of the Fe- 5 weight percent Ag, Fe-2 weight percent Au, and Fe-10 weight percent Au composites were notably better than those of as-sintered pure iron. Additionally, there was little hemolysis and platelet adhesion in them. Overall, these Fe-based composites with 5 weight percent Ag or Au exhibit promising characteristics for biodegradable materials, including appropriate degradation rates and favorable mechanical and biocompatible qualities. And discussed the importance of metal-based materials in the fight against antibiotic-resistant bacteria. Reactive oxygen species (ROS) production, membrane disruption, and interactions with biomolecules are the methods by which metals, including Au, Zn, Fe, Cu, and Ag ions and nanoparticles, exhibit antibacterial properties. In light of the dearth of novel antibiotics, metal-based materials present a promising avenue for combating antibiotic-resistant microorganisms.

Copper and titanium were added to poly(lactide-co-glycolide) scaffolds by magnetron co- sputtering in a pulsed direct current mode, as reported by Arsalan D. Badaraev et al. in 2023. While titanium increased biocompatibility without changing its antibacterial qualities, an increase in copper content increased antimicrobial activity and toxicity. Scaffold shape, mechanical characteristics, and wettability were all maintained during the alteration procedure. Tissue engineering could benefit from scaffolds with a modest copper content because they demonstrated antibacterial qualities without being harmful to cells.

Yangmin Wu and colleagues (2018) reported on the process of chemical etching and in-situ self-assembly treatment to produce Cu surfaces with multiple hydrophobic morphologies, such as , nanosheet, and micro flower. A structure-activity relationship was established by four cycles of antibacterial studies, in which hydrophobic copper sheets demonstrated effective antibacterial characteristics by releasing copper ions and reduced bacterial adherence. Superior antibacterial effectiveness was demonstrated by nanowire structures, which were able to lyse bacterial cells. Whereas the quantity of micro flowers in nanosheet/micro flower complexes determined their resistance to bacterial attachment, the composition of bacterial liquid determined the ability of nanowires to withstand it.

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The test known as the Minimum Bactericidal Concentration (MBC): A continuation of the MIC test is this one. To find the lowest dose of MMC that kills bacteria rather than merely inhibits their growth, samples are sub-cultured onto agar plates after the MIC has been determined.

Colony Counting: Using this technique, bacterial cultures are exposed to MMCs, and the number of colonies that survive is then recorded. When colony-forming units (CFUs) are much lower than in the control group, antibacterial activity is present.

3. Result and Discussion

Based on the information gathered from the numerous research, it is challenging to identify a single "optimal" metal or combination for metal alloys because of the variability in reinforcement material effectiveness and its ability to improve antibacterial behaviour. If Metal Matrix Composites (MMCs) have sufficient antibacterial properties, they can be used more successfully in the construction of medical scaffolds. Infection control at the implant site is critical in medicine, especially in orthopaedics and tissue engineering settings. After surgery, infections can lead to serious complications, such as implant failure. Antibacterial MMCs can assist in reducing this danger. Antibiotic resistance may arise from both the negative effects of antibiotic use and their use for sickness prevention or treatment.

Antibacterial MMCs are a supplemental or alternative method of infection prevention that can be employed in place of antibiotics alone. Scaffolds made of antibacterial MMCs have the potential to present improved biocompatibility. For the surrounding cells and tissues, an environment that is less inflammatory and more suited to integration is produced by blocking bacterial colonisation and the formation of biofilms on the scaffold surface. Antibacterial MMC scaffolds have a longer shelf life because to their resistance to bacterial colonisation and degradation. Thus, there may be a reduction in the number of scaffold replacement operations needed, which would ease patient discomfort and save costs. Through the prevention of infections and maintenance of a neutral environment, antibacterial MMC scaffolds may facilitate natural tissue regeneration more effectively. Particularly important for applications involving.

Because of this, fewer scaffold replacement operations might be needed, which would ease patient discomfort and save costs. By preventing infections and maintaining a neutral environment, antibacterial MMC scaffolds may facilitate spontaneous tissue regeneration. Given that the scaffold performs as a template for creation of new tissues, this is particularly important for applications involving tissue engineering. Due to their ability to be engineered to possess additional desirable properties including osteoconductive properties, antibacterial MMCs are appropriate for application in bone tissue engineering

4. Conclusion

Finally, the utilization of antimicrobial MMCs in medical scaffolds represents a potential advancement in the medical field. By reducing the risk of problems and infections following surgery in addition to offering structural support, these cutting-edge materials present a comprehensive solution. These MMCs' antimicrobial qualities support efficient tissue regeneration and patient safety, especially in wound care, dentistry, and orthopedic applications. Antibiotic resistance endures, and with the growing demands on healthcare, MMCs have the potential to improve the efficacy and safety of medical interventions. Owing to their numerous uses and capacity to enhance patient outcomes, they are an essential part of contemporary healthcare systems.

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