

Editorial

Advances in Functional Bio-Coatings: Progress, Emerging Trends, and Future Perspectives

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Functional bio-coatings have become one of the most dynamic research areas in bio-materials and surface engineering. Rather than serving solely as protective surface layers, modern bio-coatings are increasingly designed to provide multiple functions simultaneously, including corrosion protection, antibacterial activity, enhanced biocompatibility, controlled biodegradation, drug delivery, and tissue integration. As the demand for advanced biomedical devices continues to grow because of population aging and increasing clinical requirements, the development of multifunctional coating systems has become a central research focus. This evolution is further supported by a surge in peer-reviewed research, which highlights the integration of sophisticated surface-engineering techniques to address the complex requirements of modern implantable devices [1–4].

The Special Issue “Advances in Functional Bio-Coatings” was launched to provide an interdisciplinary platform uniting researchers working on innovative coating materials, advanced deposition technologies, and biological surface functionalization. The objective was to highlight recent progress in coating design while encouraging discussion on the challenges that still limit these technologies’ clinical and industrial translation. This Special Issue successfully attracted contributions from researchers working on diverse aspects of functional bio-coatings.

An important theme is development of antimicrobial and infection-resistant surfaces. Preventing bacterial colonization while maintaining excellent biocompatibility remains one of the greatest challenges for implanted medical devices [5]. Several contributions investigated sustainable antimicrobial coating strategies, including lignin-based alkyd coatings containing natural antimicrobial compounds, copper-coated cellulose and cotton nonwovens prepared via magnetron sputtering, and chitosan-based drug-releasing coatings capable of prolonged antibacterial activity. Together, these studies demonstrate the growing shift from conventional antimicrobial approaches to environmentally friendly, multifunctional coating systems that combine long-term protection with reduced environmental impact [6–9]. Another important research direction is the surface modification of biodegradable and polymeric biomaterials. The study on graphene oxide/strontium apatite biocomposite coatings deposited on pure magnesium represents ongoing efforts to control degradation kinetics while simultaneously improving corrosion resistance and biological performance. Likewise, iron-coated poly(lactide) nonwoven fabrics illustrate how metallic surface modification can tailor biological interactions without compromising the desirable properties of biodegradable polymeric substrates. These contributions reflect the increasing interest in designing biodegradable materials whose degradation behavior can be precisely controlled through functional surface engineering [10,11]. The Special Issue also highlights advances in surface biofunctionalization techniques. The contribution



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on metal-free thiol-yne photo-click chemistry demonstrates the growing importance of versatile and highly selective chemical modification routes for immobilizing biomolecules on polymer surfaces. Such approaches provide new opportunities for producing bioactive interfaces capable of directing specific cellular responses while maintaining process simplicity and chemical flexibility [12]. Although these studies investigate different materials, including magnesium, polymers, cellulose, cotton, and lignin-based systems, they collectively emphasize a common concept: modern bio-coatings are no longer passive protective barriers. Instead, they function as intelligent interfaces capable of simultaneously regulating corrosion behavior, antibacterial performance, biological interactions, and material degradation [6–12].

The contributions published in this Special Issue also demonstrate the diversity of deposition and functionalization technologies currently available. Magnetron sputtering, drug-loaded polymer coatings, bio-inspired composite coatings, surface click chemistry, and environmentally sustainable coating formulations illustrate how coating science has evolved into a multidisciplinary field integrating materials science, chemistry, biology, and biomedical engineering. Such integration is essential for developing next-generation biomedical surfaces capable of addressing increasingly complex clinical requirements.

Despite remarkable progress, several scientific and technological challenges remain. Many promising coating systems continue to be evaluated primarily through laboratory-scale *in vitro* investigations. Long-term *in vivo* performance, coating durability under physiological loading, degradation mechanisms, and clinical validation remain insufficiently understood [13]. Furthermore, reproducible large-scale manufacturing, regulatory approval, and cost-effective industrial implementation continue to limit the widespread adoption of many advanced coating technologies [14].

Future research should focus on developing intelligent multifunctional bio-coatings capable of responding to physiological and environmental stimuli such as pH, temperature, mechanical loading, bacterial infection, and inflammatory reactions. The integration of emerging nanomaterials, particularly metal–organic frameworks (MOFs) and MXenes, offers exciting opportunities for controlled drug delivery, enhanced antibacterial activity, corrosion protection, osteogenic stimulation, and stimulus-responsive therapeutic functions [15–18]. Together with advances in artificial-intelligence-assisted material design, additive manufacturing, and sustainable processing technologies, these next-generation hybrid coating systems are expected to accelerate the development and clinical translation of personalized, high-performance biomedical implants.

Another rapidly emerging research direction is the integration of advanced computational tools into coating development. Machine learning, artificial intelligence, computational material design, and digital twins have the potential to accelerate coating optimization by predicting material behavior, corrosion performance, biological response, and long-term durability before experimental validation [19–22]. Such data-driven approaches may significantly reduce development time while improving coating reliability [23,24].

Sustainability will also become increasingly important. The transition toward bio-based raw materials, environmentally friendly deposition technologies, solvent-free processing, recyclable materials, and reduced-energy manufacturing is expected to shape the next generation of functional bio-coatings [25]. The inclusion of sustainable antimicrobial coatings within this Special Issue reflects the growing awareness that environmental considerations should accompany technological innovation. Ultimately, the future of functional bio-coatings lies in interdisciplinary collaboration among materials scientists, chemists, biomedical engineers, clinicians, and industrial partners. Only through such collaborative efforts can laboratory-scale innovations be successfully translated into clinically approved and commercially viable biomedical products.

In conclusion, the papers published in this Special Issue collectively demonstrate the rapid evolution of functional bio-coatings from conventional protective layers into sophisticated multifunctional systems capable of simultaneously improving biological performance, corrosion resistance, antimicrobial activity, and material functionality. This advancement underscores the necessity of continued innovation in surface treatment methodologies to enhance both the longevity of implants and long-term quality of life for patients [26]. We sincerely thank all the authors for their valuable contributions, the reviewers for their constructive evaluations, and the editorial team of *Coatings* for their continuous support throughout the publication process. We hope that the research presented in this Special Issue will stimulate further innovation and encourage new interdisciplinary collaborations that will help further advance functional bio-coatings for biomedical and healthcare applications.

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