Advancing biomedical innovation through composite material strategies

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Natural biominerals such as bone and teeth show how composite structures can combine organic and inorganic components to achieve both strong mechanical performance and essential biological functions. Inspired by these systems, composite materials are becoming an increasingly important class of biomaterials capable of meeting the growing complexity of biomedical challenges.[1] By combining polymers, ceramics, metals, and bioactive components in rational ways, composites offer unique opportunities for tuning mechanical behavior, tailoring biological interactions, and designing materials with multifunctional and application-specific properties. Volume 6, Issue 4 brings together original research and comprehensive reviews that highlight recent advances in composite material science and their expanding impact on biomedical innovation.

Progress in composite design is rapidly advancing the development of next-generation medical devices,[2] controlled drug delivery systems,[3] and engineered matrices for tissue repair and regeneration.[4] As clinical needs move toward more precise treatments, adaptable scaffolds, and implants that can respond to changing biological conditions, composite materials have become essential because they offer functions that single materials cannot provide. The articles in this issue reflect this progress, presenting studies on mechanisms, fabrication methods, and translational pathways that highlight how quickly the field is advancing.

Several research articles in this issue demonstrate how composite systems can be engineered to engage with biological microenvironments and enhance therapeutic efficacy. The study on recombinant human bone morphogenetic protein-2 (rhBMP-2)–engineered piezoplatforms shows that piezoelectric stimulation, combined with a scaffold designed for effective immobilization and sustained release of rhBMP-2, amplifies BMP-2 receptor signaling and leads to synergistic improvements in bone regeneration.[5] Another work reveals that PBVHx-based microspheres provide a controlled-release composite platform capable of delivering BMP-2 with enhanced osteoinductive performance, even under the adverse conditions associated with disuse-induced osteoporosis.[6] Broadening the scope beyond bone repair, the article on viscoelastic collagen/polyethylene glycol hydrogels illustrates how tunable mechanical and biophysical features in composite hydrogels regulate neural and tumor cell behavior in 3D settings, underscoring their relevance for mechanobiology and disease modeling.[7]

This special issue also includes three timely review articles. The review on microneedles summarizes state-of-the-art materials, structural designs, and fabrication strategies, and highlights how smart, stimulus-responsive microneedle platforms are transforming drug delivery, vaccination, biosensing, and minimally invasive therapies.[8] Another review focuses on cold-sintered bioceramics, providing an updated overview of low-temperature densification and discussing how cold sintering opens new possibilities for composite architectures, multifunctional bioceramics, and energy-efficient fabrication routes.[9] The review on fracture-healing mechanisms complements these materials-focused perspectives by outlining key biological principles that next-generation bone repair technologies must integrate.[10] In addition, this issue includes two commentary articles that provide forward-looking perspectives. One examines bacterial membrane–derived vesicles as new composite nanoplatforms that can deliver self-assembling prodrugs and, at the same time, activate the host immune system.[11] The other discusses how ideas such as modular design, hierarchical structures, and adaptive functions may guide the future development of biomedical composite materials.[12]

Together, the articles in this special issue demonstrate the expanding scope and significance of composite strategies in biomedicine, covering areas such as controlled growth factor delivery, mechanobiology-informed matrix design, emerging microneedle systems, and advanced ceramic processing. These interdisciplinary

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advances highlight the strong potential of composite materials to address clinical challenges that require the integration of mechanical, chemical, and biological functions. We hope this collection inspires further exploration of composites as adaptable, modular, and clinically meaningful solutions. Future progress in this field is likely to be driven by artificial intelligence-assisted material discovery, dynamic composites responsive to pathological cues, advanced manufacturing for patient-specific constructs, and more integrated approaches uniting fundamental research with translational medicine.

Conflicts of interest statement
All authors declare no conflicts of interest.

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