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Regenerative horizons: bridging orthopedics and maxillofacial surgery in modern bone healing

Dr. sc. Bruno Nikolovski

Goce Delcev University, Faculty of medical sciences, Stip, North Macedonia

Corresponding Author: Prof. Dr. sc. Bruno Nikolovski, Goce Delcev University, Faculty of medical sciences, Stip, North Macedonia.

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Bone biology stands at the intersection of two rapidly evolving fields—orthopedics and maxillofacial surgery—where the demand for predictable regeneration continues to grow. Although each discipline faces unique anatomical and biomechanical challenges, both share a foundational goal: restoring form and function through biologically sound, minimally invasive, and patient-centered approaches.

The past two decades have witnessed remarkable advancements in bone biology, biomaterials, surgical techniques, and digital planning. Yet, even the most sophisticated tools—piezoelectric surgery, 3D-printed grafts, CAD/CAM prosthetics, or artificial intelligence-driven diagnostics—are ultimately limited by the biological capacity of bone to heal, remodel, and integrate. Therefore, integrating foundational bone biology into everyday clinical decision-making is no longer optional but an essential professional competency.

As biomedical technology accelerates, the integration of tissue engineering, advanced biomaterials, and cellular therapies is shifting the paradigm of bone repair in both the appendicular and craniofacial skeletons (1).

Bone Regeneration: Shared Principles Across Two Fields

Regardless of skeletal location, successful bone healing depends on a synchronized sequence of inflammation, repair, and remodeling. These processes rely on osteogenic cells, molecular signaling pathways, and vascular support (2). In orthopedics, long-bone fractures and segmental defects highlight the importance of stable fixation and controlled mechanical loading. Meanwhile, in maxillofacial surgery, alveolar ridge deficiencies, traumatic defects, and tumor-related resections challenge surgeons to regenerate bone in areas with unique embryological origins and complex soft-tissue conditions (3).

Despite these differences, both fields increasingly adopt the same regenerative toolbox. Autologous bone remains the gold standard due to its osteogenic, osteoinductive, and osteoconductive properties (4). However, morbidity at donor sites has prompted a shift toward alternatives such as allografts, xenografts, and synthetic biomaterials, each with varying degrees of success.

Biomaterials and Scaffolds: Engineering the Future of Bone Repair

Recent advances in scaffold engineering have enhanced the predictability of bone regeneration. Calcium phosphate ceramics, bioactive glass, and collagen-based scaffolds have shown excellent compatibility and integration in both orthopedic reconstructions and maxillofacial bone augmentation (5). The ideal scaffold must support angiogenesis, cellular infiltration, and progressive remodeling while retaining mechanical stability long enough to allow functional bone formation (6).

Three-dimensional (3D) printing has further revolutionized reconstruction by enabling patient-specific scaffolds tailored to defect morphology. In maxillofacial surgery, 3D-printed titanium meshes and biodegradable matrices have improved outcomes in complex mandibular or midface defects (7). In orthopedics, custom implants for segmental bone loss or joint resurfacing demonstrate comparable success, illustrating a convergence between the two specialties.

Biologics: From Platelet Concentrates to Mesenchymal Stem Cells

Biologic enhancement has become central to next-generation bone healing. Platelet-rich fibrin (PRF), platelet-rich plasma (PRP), bone morphogenetic proteins (BMPs), and mesenchymal stem cells (MSCs) are widely used to augment both orthopedic and maxillofacial procedures (8). PRF and PRP improve soft-tissue healing, stimulate angiogenesis, and support early osteogenesis, while BMP-2 remains a powerful—though costly—inductive agent in spinal fusion and craniofacial reconstructions (9).

MSCs have emerged as the most promising cellular therapy, capable of differentiating into osteoblasts, modulating inflammation, and secreting pro-healing cytokines. Their application spans long-bone defects, non-unions, osteonecrosis, and alveolar ridge augmentation (10). Combined with biomaterial scaffolds, MSC-based constructs represent the future of patient-specific regenerative therapy.

Digital Surgery and Robotics: Precision in Bone Reconstruction

Digital planning and robotic assistance are transforming surgical workflows in both fields. Virtual surgical planning (VSP) has become standard for orthognathic surgery, trauma reconstruction, and oncologic defects in the maxillofacial region (11). Similarly, robotic-assisted joint replacement and trauma fixation in orthopedics demonstrate improved accuracy, reduced surgical times, and fewer complications (12).

Artificial intelligence (AI) enhances preoperative prediction models, bone density assessment, and implant selection. As algorithms integrate large datasets from orthopedic and maxillofacial cases, cross-disciplinary insights will become more powerful and clinically relevant.

Clinical Convergence: Shared Challenges and Collaborative Opportunity

Both fields confront challenges such as aging populations, complex comorbidities, and the biological limitations of large bone defects. Importantly, collaborative research between orthopedics and maxillofacial surgery accelerates solutions. Studies on vascularized bone grafts, distraction osteogenesis, and scaffold-based reconstruction have benefited from shared clinical experiences (13).

Large-animal models used in orthopedic research frequently inform craniofacial regenerative strategies, demonstrating the importance of translational work. Meanwhile, innovations originating in maxillofacial surgery—such as minimally invasive sinus lift techniques or microplate fixation—have influenced approaches in small-bone orthopedic trauma.

Conclusion

Bone regeneration constitutes a common biological framework underlying both orthopedic and maxillofacial surgery. Despite anatomical and biomechanical differences between skeletal regions, the fundamental mechanisms of bone healing and remodeling remain consistent and form the basis for successful reconstruction. Recent advances in biomaterials, biologics, and digital surgical technologies have expanded regenerative possibilities across both disciplines, enabling more predictable and personalized treatment approaches. Continued interdisciplinary collaboration and biologically informed clinical strategies are essential for optimizing outcomes and translating emerging innovations into routine practice

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