International Journal of Modern Achievement in Science, Engineering and Technology (IJSET)
ISSN 3023-459X
DOI: 10.63053/ijset.108

A Review of Novel Biomaterials in Maxillofacial and Dental Orthopedics

Fatemeh Farahmandi Moghaddam[1]
1. DDS, Alumnus of I.M. Sechenov First Moscow State Medical University, Moscow, Russia.

ARTICLE INFO

Keywords:
Novel biomaterials,
Orthopedics,
Maxillofacial,
Dentistry

ABSTRACT

Maxillofacial and dental orthopedics is a critical field within dentistry and oral and maxillofacial surgery, aiming to restore normal function and improve patients' aesthetics. The selection of appropriate biomaterials plays a pivotal role in this domain, as any biological incompatibility or mechanical weakness may lead to serious consequences. Traditional materials such as metals, ceramics, and pure polymers, despite their widespread use, have shown limitations including brittleness, biological incompatibility, and induction of inflammatory responses, highlighting the urgent need for novel biomaterials. These new biomaterials have been developed with the goals of enhancing biocompatibility, increasing bioactivity, and stimulating natural tissue regeneration. Representative examples include modified metals and alloys, bioceramics, biodegradable polymers, and nanocomposites. In particular, nanotechnology has played a crucial role in improving the surface properties of implants, enhancing mechanical strength, and accelerating the process of osseointegration. The clinical applications of these biomaterials range from dental implants and maxillofacial fracture repair to the reconstruction of defects caused by trauma or tumor resection, as well as three-dimensional scaffolds in tissue engineering. Findings from this review indicate that novel biomaterials have successfully addressed many of the shortcomings of traditional materials and have opened new horizons for regenerative treatments in maxillofacial and dental practice. Nevertheless, challenges such as high production costs and the necessity of comprehensive clinical evaluations remain significant obstacles. Overall, this study concludes that the advancement and application of novel biomaterials hold great promise for the future of maxillofacial and dental orthopedics, with the potential to improve treatment outcomes and enhance patients' quality of life.

Introduction

Maxillofacial and dental orthopedics represent a key field in dentistry and oral and maxillofacial surgery, directly concerned with restoring the natural function and aesthetic appearance of patients (Germaini et al., 2022). In this domain, the selection of biomaterials plays a crucial role, as the hard and soft maxillofacial tissues possess a complex and delicate structure. Even minor disruptions in the reconstruction or replacement of these tissues can result in significant functional and psychological consequences for the patient (Huang et al., 2023). Over the past decades, a variety of materials such as metals, ceramics, and polymers have been employed in maxillofacial orthopedic treatments (Hakim et al., 2024). Although these materials have achieved partial success in some cases, limitations such as poor biocompatibility, brittleness, or induction of inflammatory responses have increasingly highlighted the need for the development of novel biomaterials (Chan et al., 2025).

Novel biomaterials are specifically designed to overcome these limitations. They are required not only to demonstrate sufficient mechanical strength but also to be biocompatible and capable of establishing positive interactions with cells and tissues. In fact, the new approach extends beyond mere physical replacement of damaged tissues, aiming instead to stimulate natural processes of healing and tissue regeneration (Kumar et al., 2020). A notable advance in this regard is the application of nanotechnology. Nanostructures, with their large specific surface area, can promote enhanced cell adhesion, accelerate osteogenesis, and improve the mechanical strength of materials. Accordingly, nanocomposites and nanoscale coatings are currently at the forefront of both research and clinical applications in maxillofacial orthopedics (Arias-Betancur et al., 2022). Alongside nanotechnology, the use of bioceramics—particularly hydroxyapatite and tricalcium phosphate—has gained prominence due to their chemical similarity to natural bone. These materials not only provide an excellent scaffold for osteoblast adhesion but also gradually resorb and are replaced by new tissue, thereby enabling progressive and coordinated tissue regeneration (Liu et al., 2021). Biodegradable polymers constitute another group of novel biomaterials, offering the advantage of controlled degradation rates that allow them to serve as temporary scaffolds for tissue growth. When combined with nanoparticles or bioceramics, these polymers achieve improved mechanical and biological properties, making them suitable for maxillofacial implants and bone regeneration applications (Matichescu et al., 2020). Furthermore, metallic alloys such as titanium and shape-memory alloys continue to be widely utilized in maxillofacial orthopedics (Liu et al., 2021). Their high strength and corrosion resistance make them suitable implant candidates; however, recent research has increasingly focused on surface modifications to enhance bioactivity and promote stronger osseointegration between bone and implant (Germaini et al., 2022).

Recent studies have demonstrated that combining different materials can yield superior clinical outcomes. For instance, biopolymers reinforced with bioceramics or nanoparticles offer the advantage of simultaneously harnessing favorable mechanical and biological properties. This multifunctional approach has led to composite biomaterials being identified as preferred candidates in many investigations (Tsouknidas, 2024). Beyond mechanical and biological characteristics, bioactivity has emerged as a critical factor. Bioactive materials can provide biochemical signals that stimulate cells and induce osteogenic differentiation, thereby supporting natural and higher-quality tissue regeneration (Kouhi & Khodaei, 2023). Clinically, novel biomaterials have been applied in a broad range of treatments, including fracture repair, reconstruction of defects caused by trauma or tumor resection, and replacement of missing teeth with advanced implants. The success of such treatments depends on careful material selection, optimal design, and alignment with patient-specific conditions (Huang et al., 2023). Moreover, novel biomaterials are increasingly being incorporated into advanced fields such as tissue engineering and regenerative medicine. The development of three-dimensional scaffolds capable of loading cells and growth factors has opened new avenues for complete maxillofacial tissue regeneration, offering promising prospects for future dental and maxillofacial surgical treatments (Ievina & Dubnika, 2024).

One of the major challenges in the application of novel biomaterials is the evaluation of their safety and efficacy under clinical conditions. While many of these materials have shown encouraging results in laboratory studies, their use in humans requires extensive clinical trials and strict compliance with safety standards, which makes the transition from research to clinical application both cautious and time-consuming (Chan et al., 2025). From an economic perspective, the development and implementation of novel biomaterials also present challenges. The production of advanced materials is often costly, which may limit their accessibility to patients (Germaini et al., 2022). Therefore, future research must not only aim to improve the quality of biomaterials but also address economic feasibility and scalable production (Huang et al., 2023).

Despite these challenges, the growing body of research and successful experimental and clinical applications suggest a promising future for novel biomaterials in maxillofacial orthopedics. These materials can simultaneously meet the mechanical, biological, and aesthetic requirements of patients, ultimately improving their quality of life. Accordingly, the present review aims to provide a comprehensive overview of novel biomaterials in maxillofacial and dental orthopedics, introducing their types, properties, advantages, and limitations, while also analyzing current research trajectories and clinical applications. This review may serve as a valuable guide for clinicians and researchers in selecting and advancing innovative approaches within this field.

Literature Review

Biomaterials in Maxillofacial and Dental Orthopedics

Biomaterials in maxillofacial and dental orthopedics play a fundamental role in restoring natural function, aesthetics, and patients' quality of life. The complex and delicate structure of the maxillofacial region, which not only enables chewing and speech but also contributes significantly to facial appearance, requires materials that combine sufficient mechanical strength with excellent biocompatibility (Tsouknidas, 2024). Over the years, numerous efforts have been made to identify materials capable of replacing or regenerating maxillofacial tissues, marking a remarkable progression from traditional metals and ceramics to advanced and intelligent biomaterials (Hakim et al., 2024). Metals, particularly titanium and its alloys, remain among the most widely used biomaterials in dental implants and maxillofacial orthopedics. Their corrosion resistance, high strength, and ability to achieve osseointegration—direct and stable bonding with bone—are the primary reasons for their popularity (Matichescu et al., 2020). Nevertheless, recent studies have increasingly focused on surface modifications to enhance bioactivity and ensure faster, safer integration with bone. In addition to metals, bioceramics such as hydroxyapatite and tricalcium phosphate, due to their chemical similarity to natural bone, are widely used in bone defect reconstruction and as implant coatings (Liu et al., 2021).

Biodegradable polymers also occupy a distinctive position as temporary scaffolds in tissue regeneration. These materials degrade gradually in the body in parallel with new tissue growth, thereby reducing the need for secondary surgeries. When combined with bioceramics or nanoparticles, their mechanical and biological properties are significantly improved (Ievina & Dubnika, 2024). This advancement has led to the development of polymer composites and nanocomposites as the new generation of biomaterials in maxillofacial orthopedics. Nanotechnology plays a particularly important role in this progress. Nanoscale coatings on implant surfaces enhance cell adhesion and accelerate bone tissue formation. Moreover, nanostructured scaffolds, by mimicking the extracellular matrix, provide a more natural environment for cell proliferation and differentiation (Szczesny et al., 2022). This technology also enables the incorporation of drugs and growth factors into scaffolds, thereby facilitating faster and more efficient tissue repair (Kouhi & Khodaei, 2023). Despite these advances, challenges remain, including high production costs, concerns about biosafety, and mechanical limitations of certain materials. Nevertheless, ongoing research and promising clinical outcomes indicate that the future of maxillofacial orthopedics will be strongly driven by the development of novel biomaterials. By combining mechanical strength, biological compatibility, and smart functions, these materials are poised to deliver safer, more effective, and more durable treatments for patients, opening new horizons in dental and surgical care (Tsouknidas, 2024).

Metals and Advanced Alloys

Metals have long been one of the primary choices in maxillofacial and dental orthopedics. Titanium and its alloys are currently regarded as the gold standard in dental implant fabrication, primarily due to their superior strength, corrosion resistance, and ability to achieve stable osseointegration with bone. However, challenges such as immune responses and the potential for corrosion in the oral environment remain (Szczesny et al., 2022). Recent research has therefore focused on modifying titanium surfaces using nanoscale coatings, surface oxidation, and the addition of bioactive agents. These strategies enhance osteoblast adhesion, accelerate bone formation, and reduce the risk of implant failure (Ievina & Dubnika, 2024).

Shape-memory alloys such as nickel–titanium (NiTi) have also introduced significant innovations in orthodontics and maxillofacial surgery. Their unique ability to return to their original shape after deformation makes them highly useful in orthodontic devices and fixation systems. Additionally, their flexibility and fatigue resistance provide further clinical advantages (Hakim et al., 2024). Nonetheless, concerns about the release of metal ions and the relatively high cost of production remain important challenges. Consequently, future research should aim at minimizing these drawbacks while enhancing surface properties and biocompatibility, thereby ensuring greater clinical safety and effectiveness (Arias-Betancur et al., 2022).

Bioceramics and Their Applications in Bone Tissue Regeneration

Bioceramics are a class of bioactive materials that have found widespread application in maxillofacial and dental orthopedics due to their chemical and structural similarity to the mineral phase of bone. Hydroxyapatite (HA) and tricalcium phosphate (TCP) are among the most widely studied examples. These materials provide a favorable scaffold for osteoblast adhesion and can accelerate the process of bone formation (Heboyan & Bennardo, 2023). A major advantage of bioceramics is their gradual biodegradability (Kouhi & Khodaei, 2023). Over time, they are resorbed in the body and replaced by natural bone, thus reducing the need for secondary surgical interventions. Furthermore, combining bioceramics with polymers or metals enhances their mechanical properties and broadens their clinical applicability (Chan et al., 2025).

The clinical applications of bioceramics include their use as bone fillers in maxillofacial surgeries, replacement of areas lost due to trauma or tumor resection, and as surface coatings for titanium implants. Ceramic coatings on metals improve biocompatibility and accelerate the osseointegration process (Heboyan & Bennardo, 2023). However, bioceramics are inherently brittle and have limited capacity to withstand mechanical loads (Szczesny et al., 2022). For this reason, current research focuses on the development of ceramic composites or their integration with other materials to compensate for mechanical shortcomings (Matichescu et al., 2020).

Biodegradable Polymers and Polymeric Composites

Biodegradable polymers such as polylactic acid (PLA), polyglycolic acid (PGA), and their copolymers hold a prominent place in maxillofacial and dental orthopedics because they degrade within the body without producing toxic byproducts. These polymers can act as temporary scaffolds for the growth of new tissue. One of their most valuable features is the ability to control their degradation rate (Heboyan & Bennardo, 2023), allowing the scaffold to degrade in synchrony with new bone formation. Furthermore, the incorporation of nanoparticles or bioceramics significantly enhances both the mechanical strength and biocompatibility of these polymers (Arias-Betancur et al., 2022).

In addition to their role in bone scaffolding, modern biodegradable polymers have been employed in the design of targeted drug delivery systems. Such systems enable the controlled release of antibacterial agents or growth factors, thereby accelerating tissue repair (Wei et al., 2024). Despite these advantages, pure polymers face certain limitations, including insufficient mechanical strength and the potential for inflammatory responses due to their degradation byproducts (Liu et al., 2021).

Nanocomposites and the Role of Nanotechnology in Enhancing Material Performance
Over the past decades, nanotechnology has introduced a fundamental transformation in the field of biomaterials. Nanocomposites, owing to their nanoscale structures, provide a larger surface area for cellular interactions, which enhances cell adhesion and accelerates osteogenesis. Moreover, nanoparticles can actively influence cellular behavior by creating a microenvironment similar to the natural extracellular matrix (Van Erk et al., 2023). The incorporation of bioactive nanoparticles into polymers or metals has resulted in simultaneous improvements in both mechanical and biological properties. For instance, the addition of hydroxyapatite nanoparticles to polymeric scaffolds increases compressive strength while improving biocompatibility. Similarly, nanoscale coatings on titanium implants accelerate the osseointegration process and reduce the likelihood of implant failure (Kumar et al., 2020).

Another advantage of nanotechnology lies in its ability to facilitate drug and growth factor loading onto nanoparticles or nanofibers. This functionality has enabled the development of smart drug delivery systems integrated with bone scaffolds, thereby enhancing tissue regeneration (Wei et al., 2024). Despite these promising attributes, concerns remain regarding nanoparticle cytotoxicity and potential long-term effects within the human body (Tsouknidas, 2024).

Clinical Applications of Novel Biomaterials in Implants and Maxillofacial Fracture Repair

Novel biomaterials have demonstrated a broad spectrum of clinical applications in maxillofacial and dental orthopedics. One of the most significant applications is their use in the fabrication of dental implants. These implants must not only replace missing tooth roots but also withstand the functional forces of mastication (Van Erk et al., 2023). Modified titanium with ceramic or nanoscale coatings has significantly improved implant success rates. Beyond implants, novel biomaterials are also used in reconstructing maxillofacial fractures and repairing defects caused by trauma or tumor resections. Polymeric and ceramic scaffolds serve as effective bone fillers, promoting new tissue growth (Wei et al., 2024). In this regard, composites combining bioceramics with biodegradable polymers have shown particularly promising clinical outcomes.

Another important clinical domain involves orthognathic surgery and the correction of maxillofacial deformities. In these procedures, fixation devices such as plates and screws made from shape-memory alloys have been employed, providing enhanced stability and reducing postoperative complications (Kouhi & Khodaei, 2023). Furthermore, in the field of tissue engineering, three-dimensional bioactive scaffolds have recently been introduced. When loaded with stem cells and growth factors, these scaffolds enable full and natural regeneration of maxillofacial tissues. This technology represents a highly promising future for the treatment of patients with complex bone defects (Matichescu et al., 2020).

Challenges and Biological–Mechanical Limitations of Biomaterials

Despite remarkable progress, the use of novel biomaterials still faces significant challenges. One of the most critical concerns is biosafety and the potential immune or inflammatory responses of the body to new materials. Although many biomaterials are engineered for biocompatibility, unpredictable immune reactions may compromise treatment outcomes (Van Erk et al., 2023). From a mechanical perspective, certain materials such as bioceramics suffer from brittleness and limited capacity to withstand high mechanical loads. Conversely, polymers, while more flexible, often lack sufficient strength to endure long-term stress. Therefore, achieving a balanced combination of biological compatibility and mechanical performance remains a major challenge (Arias-Betancur et al., 2022).

Another limitation lies in the high production costs of advanced biomaterials. Cutting-edge technologies such as nanotechnology and tissue engineering typically require sophisticated equipment and expensive raw materials. This economic burden can restrict patient accessibility and hinder widespread clinical application. Moreover, extensive and long-term clinical trials are essential to validate the safety and efficacy of these materials (Ievina & Dubnika, 2024). The lengthy process of clinical evaluation often delays the translation of innovative biomaterials from research laboratories to therapeutic markets. Consequently, close collaboration among researchers, manufacturers, and regulatory authorities is essential to accelerate approval processes and clinical adoption (Wei et al., 2024).

Future Perspectives and Research Directions in Maxillofacial Biomaterials

The future of novel biomaterials in maxillofacial orthopedics is closely tied to multidisciplinary and innovative approaches. One key trajectory involves the development of smart biomaterials—materials capable of responding to biological or environmental stimuli (such as changes in pH or temperature) and adjusting their functionality in a self-regulating manner. Tissue engineering and three-dimensional printing represent other crucial directions (Kouhi & Khodaei, 2023). 3D printing enables the production of patient-specific scaffolds tailored to individual anatomical structures, thereby improving precision and treatment outcomes (Van Erk et al., 2023). Integrating this technology with stem cells and growth factors holds the potential to achieve complete and natural regeneration of maxillofacial tissues (Tsouknidas, 2024).

Furthermore, future technologies are expected to emphasize cost reduction and expanded patient access. Advances in large-scale manufacturing and streamlined fabrication processes could lower production costs, thus making these treatments more widely available at the community level (Liu et al., 2021). Collaboration among engineering sciences, biomedical research, nanotechnology, and clinical disciplines will be pivotal in shaping a clear and promising outlook for this field (Matichescu et al., 2020). Ultimately, novel biomaterials will not only improve the quality of patient care but also serve as a crucial step toward enhancing public health and overall quality of life (Liu et al., 2021).

Research Methodology

The present study is a review research focusing on the investigation of novel biomaterials in maxillofacial orthopedics. A review study is considered one of the fundamental approaches in scientific research, particularly in the fields of medical and social sciences, aiming to collect, examine, and analyze existing information and findings within a specific domain (Daldrup-Link, 2018). The main purpose of such studies is to provide a comprehensive overview of the subject under investigation, identify gaps and limitations in current knowledge, and establish a suitable foundation for future research. By nature, review studies are often designed in a descriptive–analytical manner. This means that the researcher initially describes and summarizes previous studies and findings and then analyzes these data to draw general and meaningful conclusions (Bahl, 2023). The analytical process typically involves comparison, critique, and detailed evaluation of various sources in order to present a clearer and more coherent perspective on the research topic. Review research is primarily conducted as documentary research, in which the researcher collects the required data by studying a wide range of sources such as scientific articles, books, research reports, dissertations, and other reliable references (Chatterjee et al., 2025). Documentary research is recognized as one of the key methods in scientific inquiry, as it enables the researcher to interpret and analyze complex issues without the need for fieldwork or experimental studies. In this approach, the accuracy and reliability of data collection are of utmost importance; therefore, the use of up-to-date and credible sources, alongside rigorous analysis, is essential to ensure the scientific validity and reliability of the outcomes (Dhillon, 2022).

In general, review research not only contributes to the enrichment of existing knowledge but also highlights the strengths and weaknesses of previous studies, thereby suggesting new directions for future investigations. With its focus on comprehensive analysis, this method assists in identifying and prioritizing novel research areas (Paul & Criado, 2020). Systematic review and evaluation of previous studies allow the researcher to detect existing research gaps and propose targeted future research pathways. Thus, review studies not only collect and synthesize existing knowledge but also contribute to its organization and development. Through the analysis of diverse findings, researchers are able to provide a holistic and integrated perspective on the status of the subject across temporal and spatial dimensions. Such a broad viewpoint is particularly valuable for decision-making, policy formulation, and scientific advancement. By offering a wider perspective, review studies facilitate deeper and more precise analyses and, through the integration of existing information, not only enhance the coherence of scientific knowledge but also open up new pathways for future research (Paul et al., 2021).

Discussion

Novel biomaterials in maxillofacial orthopedics have fundamentally transformed therapeutic approaches. Whereas in the past the primary focus was on the use of metals and ceramics as replacement materials, the current emphasis is on developing materials that not only provide structural support but also stimulate natural tissue regeneration. This shift has marked the transition from passive substitution to active regeneration, leading to improved functional and aesthetic outcomes for patients. Metals, particularly titanium, have retained their central role in the fabrication of dental implants. Their unique mechanical properties have yielded stable and reliable clinical outcomes. However, challenges such as surface corrosion and potential inflammatory reactions necessitate surface modification and enhanced bioactivity. Consequently, research has increasingly focused on nanoscale coatings, surface treatments, and the incorporation of bioactive compounds to achieve faster and more stable integration between implant and bone.

Bioceramics, due to their structural and chemical resemblance to natural bone, represent an ideal option for the reconstruction of bone defects. Materials such as hydroxyapatite and tricalcium phosphate have proven effective as scaffolds for osteoblast adhesion and bone formation. Their primary advantage lies in their biodegradability and gradual replacement by natural bone. Nevertheless, their intrinsic brittleness and limited mechanical strength restrict their broader use. As a result, combining bioceramics with polymers and metals has gained increasing importance in recent years to achieve improved mechanical properties. Similarly, biodegradable polymers have demonstrated high potential as temporary scaffolds. Their ability to adjust degradation rates makes them compatible with tissue regeneration, while reducing the need for secondary surgeries. However, limitations such as mechanical weakness and potential inflammatory responses to degradation products remain. The integration of polymers with nanoparticles and bioceramics has successfully mitigated many of these drawbacks, giving rise to a new generation of polymer composites.

Nanocomposites and nanotechnology have introduced remarkable advances in this field. Nanoscale structures improve cell–material interactions, accelerate osteogenesis, and enable the delivery of drugs and growth factors. Despite these advantages, concerns remain regarding the potential cytotoxicity of nanoparticles and their long-term effects on the human body, highlighting the need for further clinical research. Nonetheless, the potential of nanotechnology suggests that the future of regenerative maxillofacial treatments is closely tied to its continued development. Clinically, the applications of novel biomaterials have expanded beyond dental implants to include maxillofacial fracture repair, filling of bone defects caused by trauma or tumor surgery, and even orthognathic surgery. The use of three-dimensional bioactive scaffolds combined with stem cells and growth factors has paved the way for personalized regenerative therapies. These advancements not only enhance treatment outcomes but also shorten patients’ recovery periods.

Despite these achievements, challenges such as high production costs, lengthy regulatory approval processes, and the need for long-term safety evaluations persist. While many novel biomaterials have demonstrated success in laboratory and preclinical studies, their clinical translation requires robust research and healthcare infrastructures. This underscores the necessity for interdisciplinary collaboration among materials scientists, biomedical engineers, dental specialists, and regulatory bodies. The future of this field is undeniably linked with the advancement of smart biomaterials and innovative technologies such as three-dimensional printing. Patient-specific 3D-printed scaffolds are expected to provide highly accurate and personalized reconstruction. Moreover, the development of cost-effective, large-scale manufacturing methods will increase accessibility to these treatments for broader patient populations. Overall, the research trajectory of novel biomaterials in maxillofacial orthopedics presents a promising future that not only enhances patients' quality of life but also establishes new standards in maxillofacial surgery and dental treatments.

Conclusion

The review of novel biomaterials in maxillofacial orthopedics demonstrates that this field has undergone remarkable transformations in recent years. The shift from traditional materials such as pure metals and classical ceramics toward composite biomaterials, nanocomposites, and smart scaffolds reflects a fundamental change in therapeutic approaches. This transition not only enhances mechanical strength but also emphasizes biocompatibility, bioactivity, and the facilitation of natural tissue regeneration. Metals, particularly titanium, continue to play a vital role in the fabrication of dental implants; however, nanoscale coatings and surface modifications have significantly reduced their limitations. Similarly, bioceramics such as hydroxyapatite and tricalcium phosphate remain central to bone regeneration due to their chemical similarity to bone minerals, though their brittleness poses a persistent challenge. Combining bioceramics with polymers and metals has proven an effective strategy to overcome these shortcomings and achieve optimized performance.

Biodegradable polymers emerged in this review as one of the most innovative options. Their controlled degradation reduces the need for secondary surgeries and aligns well with the natural process of tissue healing. Nevertheless, their mechanical weakness, particularly in long-term applications, remains a significant limitation. Future research must therefore focus on developing polymeric composites with improved mechanical properties alongside high biocompatibility. Nanocomposites, as an advanced generation of biomaterials, have shown unprecedented potential to improve treatment outcomes. With their large surface area and ability to deliver drugs and growth factors, they enable targeted and efficient tissue regeneration. However, concerns regarding nanoparticle toxicity and their long-term biological effects require thorough investigation in future studies. The clinical applications of novel biomaterials are broad, encompassing dental implants, maxillofacial fracture repair, filling of defects resulting from trauma or tumor resection, and even tissue engineering for three-dimensional reconstruction. This wide scope highlights their potential not only to improve existing therapies but also to open new avenues for personalized treatments and complete regeneration of maxillofacial tissues.

Despite these significant achievements, challenges such as high production costs, regulatory complexities, and the need for long-term clinical studies remain major barriers to commercialization and widespread clinical adoption. The future of this field will therefore depend on interdisciplinary collaboration among materials scientists, dentists, maxillofacial surgeons, and healthcare policymakers. The findings of this review indicate that the future of maxillofacial orthopedics is closely tied to the development of smart biomaterials and technologies such as three-dimensional printing. The production of patient-specific scaffolds tailored to anatomical structures, combined with stem cells and bioactive factors, holds the promise of achieving full and natural tissue regeneration. This approach can improve treatment quality while minimizing the need for invasive procedures. Novel biomaterials represent a comprehensive response to the limitations of traditional approaches and have the potential to usher maxillofacial orthopedics into a new era. The full realization of their potential will require continuous fundamental research, the development of cost-effective technologies, and rigorous clinical validation. Under these conditions, such materials may become the future gold standard of maxillofacial therapies and play a pivotal role in advancing oral health and enhancing patients' quality of life.

References

- Arias-Betancur, A., Badilla-Wenzel, N., Astete-Sanhueza, Á., Farfán-Beltrán, N., & Dias, F. (2022). Carrier systems for bone morphogenetic proteins: An overview of biomaterials used for dentoalveolar and maxillofacial bone regeneration. *The Japanese Dental Science Review*, 58, 316 - 327. https://doi.org/10.1016/j.jdsr.2022.10.001.

- Bahl, M. (2023). A Step-by-Step Guide to Writing a Scientific Review Article.. *Journal of breast imaging*, 5 4, 480-485 . https://doi.org/10.1093/jbi/wbad028.
- Chan, R., Lee, S., Wang, F., Zhou, T., Kishan, R., Shum, H., Yang, W., Su, Y., Tsoi, J., Diwan, A., Prusty, B., & Cho, K. (2025). Engineered 3D-Printable Nanohydroxyapatite Biocomposites with Cold Plasma-Tailored Surface Features to Boost Osseointegration. *ACS Applied Materials & Interfaces*, 17, 23522 - 23535. https://doi.org/10.1021/acsami.4c22032.
- Chatterjee, K., Davies, G., Engqvist, H., & Winter, J. (2025). Writing an impactful Review: top tips from the Editors.. *Journal of materials chemistry. B*. https://doi.org/10.1039/d5tb90038g.
- Daldrup-Link, H. (2018). Writing a review article - Are you making these mistakes?. *Nanotheranostics*, 2, 197 - 200. https://doi.org/10.7150/ntno.24793.
- Dhillon, P. (2022). How to write a good scientific review article. *The FEBS Journal*, 289. https://doi.org/10.1111/febs.16565.
- Germaini, M., Belhabib, S., Guessasma, S., Deterre, R., Corre, P., & Weiss, P. (2022). Additive manufacturing of biomaterials for bone tissue engineering – A critical review of the state of the art and new concepts. *Progress in Materials Science*. https://doi.org/10.1016/j.pmatsci.2022.100963.
- Hakim, L., Yari, A., Nikparto, N., Mehraban, S., Cheperli, S., Asadi, A., Darehdor, A., Nezaminia, S., Dortaj, D., Nazari, Y., Dehghan, M., Hojjat, P., Mohajeri, M., & Jebelli, M. (2024). The current applications of nano and biomaterials in drug delivery of dental implant. *BMC Oral Health*, 24. https://doi.org/10.1186/s12903-024-03911-9.
- Heboyan, A., & Bennardo, F. (2023). New biomaterials for modern dentistry. *BMC Oral Health*, 23. https://doi.org/10.1186/s12903-023-03531-9.
- Huang, X., Lou, Y., Duan, Y., Liu, H., Tian, J., Shen, Y., & Wei, X. (2023). Biomaterial scaffolds in maxillofacial bone tissue engineering: A review of recent advances. *Bioactive Materials*, 33, 129 - 156. https://doi.org/10.1016/j.bioactmat.2023.10.031.
- Ievina, L., & Dubnika, A. (2024). Navigating the combinations of platelet-rich fibrin with biomaterials used in maxillofacial surgery. *Frontiers in Bioengineering and Biotechnology*, 12. https://doi.org/10.3389/fbioe.2024.1465019.
- Kouhi, M., & Khodaei, M. (2023). Editorial: Additive manufacturing and biomaterials in regenerative dentistry. *Frontiers in Bioengineering and Biotechnology*, 11. https://doi.org/10.3389/fbioe.2023.1211009.
- Kumar, S., Nehra, M., Kedia, D., Dilbaghi, N., Tankeshwar, K., & Kim, K. (2020). Nanotechnology-based biomaterials for orthopaedic applications: Recent advances and future prospects.. *Materials science & engineering. C, Materials for biological applications*, 106, 110154 . https://doi.org/10.1016/j.msec.2019.110154.
- Liu, T., Xu, J., Pan, X., Ding, Z., Xie, H., Wang, X., & Xie, H. (2021). Advances of adipose-derived mesenchymal stem cells-based biomaterial scaffolds for oral and maxillofacial tissue engineering. *Bioactive Materials*, 6, 2467 - 2478. https://doi.org/10.1016/j.bioactmat.2021.01.015.
- Liu, Z., Liu, X., & Ramakrishna, S. (2021). Surface engineering of biomaterials in orthopedic and dental implants: Strategies to improve osteointegration, bacteriostatic and bactericidal activities. *Biotechnology Journal*, 16. https://doi.org/10.1002/biot.202000116.
- Matichescu, A., Ardelean, L., Rusu, L., Craciun, D., Bratu, E., Babucea, M., & Leretter, M. (2020). Advanced Biomaterials and Techniques for Oral Tissue Engineering and Regeneration—A Review. *Materials*, 13. https://doi.org/10.3390/ma13225303.
- Paul, J., & Criado, A. (2020). The art of writing literature review: What do we know and what do we need to know?. *International Business Review*, 29, 101717. https://doi.org/10.1016/j.ibusrev.2020.101717.
- Paul, J., Merchant, A., Dwivedi, Y., & Rose, G. (2021). Writing an impactful review article: What do we know and what do we need to know?. *Journal of Business Research*, 133, 337-340. https://doi.org/10.1016/J.JBUSRES.2021.05.005.
- Salgado, C., Cochis, A., Varoni, E., & Mendes, R. (2025). Editorial: The expanding Frontiers of stem cells therapy in oral maxillo-facial engineering and regenerative medicine. *Frontiers in Bioengineering and Biotechnology*, 13. https://doi.org/10.3389/fbioe.2025.1548950.
- Szczesny, G., Kopeć, M., Politis, D., Kowalewski, Z., Łazarski, A., & Szolc, T. (2022). A Review on Biomaterials for Orthopaedic Surgery and Traumatology: From Past to Present. *Materials*, 15. https://doi.org/10.3390/ma15103622.
- Tsouknidas, A. (2024). Advancements in Biomaterials for Bioengineering and Biotechnology. *International Journal of Molecular Sciences*, 25. https://doi.org/10.3390/ijms25147840.
- Van Erk, M., Lomme, R., Roozen, E., Van Oirschot, B., & Van Goor, H. (2023). A novel ex vivo perfusion-

based mandibular pig model for dental product testing and training. *BMC Oral Health*, 23. https://doi.org/10.1186/s12903-023-02794-6.

- Wei, X., Lei, L., Luo, L., Zhou, Y., Zheng, Z., & Chen, W. (2024). Advances in osteoimmunomodulation of biomaterials after intrabone implantation: focus on surface hydrophilicity.. *Journal of materials chemistry. B*. https://doi.org/10.1039/d4tb01907e.