

The history of oro-maxillofacial implantology: from ancient attempts to modern clinical applications

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Abstract

Oro-maxillofacial implantology has evolved from empirical attempts to replace missing teeth in ancient civilizations to a mature, evidence-based discipline that supports dental rehabilitation and complex craniofacial reconstruction. This narrative review retraces the field's historical trajectory and highlights the scientific milestones that enabled the achievement of predictable outcomes. Early archaeological findings suggest that pre-Columbian populations experimented with shell or stone substitutes placed into extraction sockets. Still, long-term stability was generally limited by infection and lack of biological fixation. During the nineteenth and early twentieth centuries, clinicians explored metals and designs such as cages, posts, and subperiosteal frameworks; however, fibrous encapsulation and mechanical failure were standard. The discovery of osseointegration and its clinical translation to titanium endosseous implants constituted a paradigm shift, providing reproducible bone anchorage and establishing modern success criteria. Subsequent advances in biomaterials, surface engineering, imaging, guided surgery, and additive manufacturing expanded indications to oncology, trauma, and congenital defects, while also increasing demands for maintenance and prevention of peri-implant disease. Emerging directions include patient-specific implants, bioactive and drug-eluting surfaces, sensor-enabled "smart" systems, and artificial intelligence-supported planning and monitoring. Understanding the historical drivers of progress helps contextualize current practice and identify the most plausible pathways for future innovation.



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Introduction

Oro-maxillofacial implantology represents one of the most remarkable success stories in modern dentistry and reconstructive surgery. While the replacement of missing teeth and craniofacial structures has been attempted since antiquity, it was not until the late twentieth century that the field achieved predictable and reproducible outcomes. Early archaeological evidence, such as the Mayan use of shell fragments and the Egyptian practice of gold and ivory prostheses, underscores humanity's long-standing pursuit of functional and aesthetic rehabilitation (1,2). However, these efforts lacked a biological foundation and were plagued by failures stemming from infections, poor integration, and instability. The scientific advances of the nineteenth and early twentieth centuries, including the introduction of novel metals and implant designs, represented essential milestones. Still, it was the mid-twentieth-century discovery of osseointegration by Per-Ingvar Brånemark that transformed implantology into a reliable clinical discipline (3,4). Today, oro-maxillofacial implantology extends far beyond dental prosthetics, encompassing applications in oncological reconstruction, the treatment of congenital deformities, and trauma rehabilitation. Its success rests on an interdisciplinary foundation that brings together oral and maxillofacial surgery, prosthodontics, plastic surgery, materials science, and biomedical engineering. The evolution of the field reflects broader scientific progress

in metallurgy, surface modification, imaging, and regenerative medicine, each of which has contributed to expanding the scope and predictability of implant-based treatments (5,6). At the same time, implantology is a discipline in continuous transformation, now being reshaped by digital workflows, additive manufacturing, and biologically active materials. This work aims to provide a comprehensive overview of the historical development of oro-maxillofacial implantology, tracing its trajectory from primitive ancient attempts to the modern integration of digital and regenerative approaches (Figure 1).

Particular attention is given to the pivotal discovery of osseointegration, the expansion of implantology into craniofacial reconstruction, and the emerging innovations that promise to enhance functional outcomes and quality of life further. In doing so, this article seeks not only to recount the evolution of a clinical practice but also to illustrate how scientific discovery and technological innovation can converge to reshape patient care.

Evidence acquisition and approach

This work is structured as a narrative historical review. Source material was identified through targeted searches of PubMed/Medline and major reference texts, combining keywords related to dental implants, craniofacial osseointegration, biomaterials, guided surgery, additive manufacturing, and peri-implant diseases, with additional hand-searching of seminal historical contributions. Priority was given to primary reports describing major technical or conceptual advances, consensus documents and systematic reviews that clarified clinical indications, outcomes or complications.

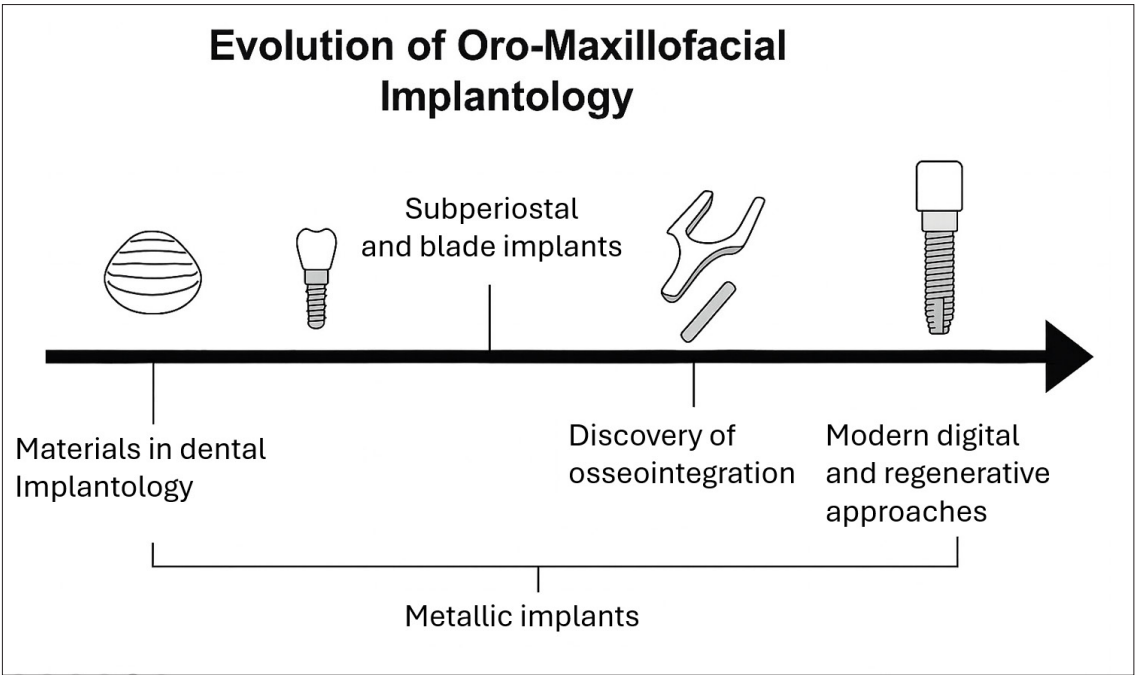


Figure 1. Timeline of the evolution of oro-maxillofacial implantology, illustrating the transition from early ancient attempts (e.g., shell substitutes) to 19th-century metallic implants, the introduction of subperiosteal and blade implants, the revolutionary discovery of osseointegration, and contemporary digital and regenerative approaches.

Early Historical Evidence

Prehistoric and Ancient Civilizations

Archaeological findings reveal that the quest to replace missing teeth and craniofacial structures is as old as human civilization. The Mayans (600 AD) are the most frequently cited example, with skeletal remains showing the placement of seashells and carved stones in alveolar bone sockets. Interestingly, radiographic analyses demonstrated evidence of partial bone adaptation to these implants, suggesting primitive biocompatibility (1). In Egypt (2000 BC), gold wires and ivory pegs were used to stabilize teeth, while Phoenician remains document early forms of dental bridges employing metallic cables (2).

Middle Ages and Renaissance

Throughout the Middle Ages, little progress was made due to limited surgical knowledge and a lack of sterilization methods. Ivory, bone, and animal teeth were the most common substitutes. The Renaissance, however, rekindled scientific interest in anatomy and surgery, paving the way for early experimentation with metals such as gold and silver. While failures were the norm, these attempts set the stage for the emergence of scientifically informed implantology.

The 19th and Early 20th Century: The Age of Metals

The nineteenth century marked a significant shift in the history of implantology, as scientific curiosity and advances in surgical techniques encouraged systematic experimentation with metallic implants. In 1809, Maggiolo reported the use of a gold implant placed directly into a fresh extraction socket, representing one of the earliest documented attempts to anchor an artificial structure into living bone. Throughout the century, other clinicians experimented with materials such as lead, platinum, and iridium, yet these early efforts were plagued by high rates of infection, poor integration, and implant mobility. Despite their lack of predictability, these interventions reflected an emerging recognition of the potential for intraosseous anchorage. Progress continued into the early twentieth century, when improvements in metallurgy and surgical methodology introduced new possibilities. The orthopedic work of Venable and colleagues in the 1930s demonstrated that stainless steel, cobalt-chromium, and tantalum exhibited relatively favorable tissue tolerance compared to earlier metals, findings that quickly influenced dental and craniofacial applications. During this period, novel implant designs such as subperiosteal frameworks and blade implants began to gain traction, offering alternatives to endosseous placement and achieving partial success in clinical practice. Nevertheless, the absence of a biologically sound interface between bone and implant limited long-term survival, with failures often attributed to fibrous encapsulation, infection, or mechanical instability. This era, while marked by frequent disappointments, was crucial in establishing the foundational understanding that biomaterial properties and host responses are central to the success of implant-based rehabilitation,

thereby setting the stage for the revolutionary discovery of osseointegration in the mid-twentieth century as reported in Table 1 (7).

The Discovery of Osseointegration

The breakthrough came with Per-Ingvar Brånemark's serendipitous discovery of osseointegration in the 1950s. Initially investigating microcirculation in rabbit bone with titanium chambers, he observed that titanium fused with bone tissue in a stable and durable manner (4). By the 1960s and 1970s, Brånemark and colleagues translated this finding into clinical practice, introducing endosseous titanium implants that demonstrated long-term predictability and reliability (3).

Osseointegration not only transformed dental implantology but also paved the way for craniofacial rehabilitation. Tjellström and Albrektsson (8) extended its application to facial prosthetics, allowing patients with auricular, orbital, or nasal defects to benefit from stable, prosthetically retained reconstructions.

Expansion into Oro-Maxillofacial Surgery

The application of osseointegrated implants rapidly extended beyond the confines of the oral cavity, opening new avenues for comprehensive craniofacial rehabilitation. In particular, the development of implant-retained craniofacial prosthetics represented a major advance, enabling the stable restoration of auricular, orbital, and nasal defects in patients for whom conventional reconstructive methods were limited or unsuitable. Similarly, in the field of oncological reconstruction, osseointegrated implants provided an effective means of rehabilitating post-resection defects, significantly improving both functional outcomes and aesthetic appearance, thereby enhancing overall quality of life for cancer survivors. The technology also transformed the management of trauma and congenital anomalies, allowing patients with severe craniofacial injuries or developmental malformations such as microtia and cleft-related deformities to benefit from predictable, prosthetically retained reconstructions. This expansion underscored the inherently multidisciplinary nature of implantology, which brought together prosthodontists, oral and maxillofacial surgeons, and plastic and reconstructive specialists within a collaborative framework that continues to define the practice today (9-15).

Contemporary advances shaping predictability

Biomaterials and surface engineering

Beyond bulk material selection, implant surfaces have been engineered to influence protein adsorption, cell adhesion and early bone formation. Sandblasted/acid-etched microtopographies and chemically modified, high-wettability surfaces were associated with accelerated early bone apposition in preclinical models and informed clinical protocols. At the same time, zirconia implants have gained interest as metal-free alternatives, particularly in aesthetic zones, and recent systematic reviews have reported high survival in

Table 1. Selected chronological milestones in oro-maxillofacial implantology.

Period	Representative milestones	Materials/technologies	Persistent limitations
<i>Antiquity (≥2000 BC–600 AD)</i>	Prosthetic stabilization with gold bands; “implant-like” socket inserts in pre-Columbian remains	Gold, bone/ivory, shell/stone	No asepsis; limited fixation; infection and mobility
<i>17th–18th centuries</i>	Tooth transplantation/replantation practices; advances in anatomy	Natural teeth, early prosthetic materials	High infection rates; poor long-term retention
<i>19th century</i>	Early endosseous intent (e.g., gold devices in extraction sockets)	Gold alloys, platinum/iridium	Inflammation; lack of integration; limited surgical control
<i>Early 20th century (1900–1940s)</i>	Greenfield cage implant; Vitallium screw experiments; post/spiral designs	Cobalt–chromium alloys; stainless steel	Fibrous encapsulation; fracture; peri-implant infection
<i>Mid-20th century (1940s–1960s)</i>	Subperiosteal/transosteal frameworks; blade implants	Co–Cr frameworks; early titanium use; improved imaging	Technique sensitivity; soft-tissue complications
<i>1950s–1970s</i>	Discovery and clinical translation of osseointegration	Commercially pure titanium; two-stage protocols	Learning curve; need for maintenance
<i>1980s–2000s</i>	Expansion to craniofacial prosthetics and oncologic reconstruction; emergence of GBR and sinus augmentation	Titanium implants and abutments; barrier membranes; early CAD/CAM	Cost; morbidity of augmentation; complications
<i>2000s–present</i>	CBCT-based planning, static/dynamic guidance; 3D printing; patient-specific implants; alternative ceramics	Digital workflows; additive manufacturing; zirconia; surface nano-engineering	Peri-implant disease burden; need for long-term evidence

selected indications while highlighting fracture risk in narrow designs (16–20).

Imaging, navigation, and digital workflows

Cone-beam computed tomography, virtual planning and computer-aided design/manufacturing have fundamentally changed diagnostic accuracy and surgical execution. Static computer-aided implant surgery (template-guided placement) improves positional control but retains measurable deviations; meta-analyses suggest that clinically meaningful safety margins remain necessary, particularly near critical anatomy. Dynamic navigation and robotic assistance represent the next step toward real-time error compensation, with ongoing evaluation of cost-effectiveness and learning curves (21–25).

Additive manufacturing and patient-specific reconstruction

Additive manufacturing enables patient-specific implants (PSIs), cutting guides and customized meshes that match complex craniofacial anatomy. Recent systematic reviews in maxillofacial reconstruction have reported improved fit and workflow efficiency in many settings, although heterogeneity of outcome reporting and limited long-term data remain challenges. Material choices include titanium alloys, high-performance polymers (e.g., PEEK), and resorbable composites,

selected according to defect size, load demands and infection risk (25,26).

Regenerative and reconstructive integration

Regenerative strategies—guided bone regeneration, sinus augmentation and the use of autologous or biomaterial grafts—expanded implant therapy to previously “unfavorable” sites. These approaches remain essential in staged reconstruction but also introduce unique complication profiles, reinforcing the need for patient-specific risk assessment and maintenance planning (22).

Complications and the rise of peri-implant disease as a public health challenge

As implant therapy became widespread, biologic complications such as peri-implant mucositis and peri-implantitis emerged as significant determinants of long-term success. International consensus reports have refined case definitions and emphasized that peri-implant health can exist even in the presence of reduced bone support. In contrast, inflammatory changes and progressive bone loss characterize peri-implantitis. Risk mitigation includes smoking cessation, control of diabetes, optimized prosthetic cleansability, regular maintenance, and early intervention when inflammation is detected (22–26).

Future Directions

The future of oro-maxillofacial implantology is likely to be shaped by the convergence of advanced technologies, biologics, and personalized medicine. One of the most promising developments is the advent of smart implants equipped with biosensors that monitor peri-implant health parameters, such as pH, bacterial load, and early signs of peri-implantitis, thereby enabling real-time clinical feedback and preventive interventions. In parallel, nanotechnology is expected to further refine the surface characteristics of implants at the molecular level, optimizing protein adsorption, osteoblast adhesion, and long-term stability. Another transformative frontier is bioprinting, which combines additive manufacturing with tissue engineering to create patient-specific scaffolds that support bone and soft tissue regeneration directly at the defect site. Furthermore, the integration of artificial intelligence and robotics into clinical workflows promises unprecedented precision in surgical planning, implant positioning, and long-term monitoring, reducing variability between operators and enhancing predictability. Artificial intelligence is increasingly explored for image interpretation, risk prediction and workflow automation, but will require transparent validation and robust governance to ensure clinical safety (27). Together, these innovations not only hold the potential to improve functional and aesthetic outcomes but also to usher in an era of individualized, patient-centered implantology, where rehabilitation strategies are tailored to the unique biological, anatomical, and lifestyle needs of each patient, according to the modern era as well as evidence based-dentistry (28-30).

Conclusion

The historical trajectory of oro-maxillofacial implantology demonstrates humanity's persistent effort to restore lost structures and functions. From rudimentary ancient attempts with shells and gold wires to the revolutionary discovery of osseointegration and today's era of digital and regenerative innovations, the field exemplifies the synergy between science, technology, and clinical practice. Future directions, rooted in biotechnology and personalized medicine, hold the potential to redefine standards of care further and improve patients quality of life.

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