REVIEW
DOI:10.5152/EssentDent.2025.25006

ISTANBUL UNIVERSITY CERRAHPASA

From Design to Integration: The Impact of Custom-Made Subperiosteal Implants in Oral Surgery

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Cite this article as: Gedik B, Kundakçıoğlu A. From design to integration: the impact of custom-made subperiosteal implants in oral surgery. *Essent Dent.* 2025; 4, 0006, doi: 10.5152/EssentDent.2025.25006.

Abstract

Subperiosteal implants have been utilized in oral surgery for several decades, with varying degrees of success and clinical outcomes. This review article closely examines the current state of custom-made subperiosteal implants, exploring their advantages, limitations, and the emerging technologies that are actively shaping their future development and clinical application. The use of these specialized implants has evolved over time, incorporating advancements in materials, fabrication techniques, and surgical protocols to address the unique anatomical challenges faced by patients with limited bone volume or quality. Despite the inherent complexities involved in their design and placement, subperiosteal implants have shown promise as an alternative treatment option for individuals with inadequate bone density or volume to support traditional endosseous implants. Through continued research and refinement of the underlying technologies, the future of custom-made subperiosteal implants holds the potential to provide more effective and predictable solutions for patients in need of oral rehabilitation.

Keywords: Dental implantation, digital technology, lasers, oral surgical procedures

What is already known on this topic?

- *Subperiosteal implants are an alternative to traditional endosseous implants, particularly for patients with severe alveolar ridge atrophy or inadequate bone volume.*
- *Advances in computer-aided design (CAD) and computer-aided manufacturing (CAM) have improved the precision and customization of subperiosteal implants, enhancing their stability and long-term success.*
- *Titanium alloys are commonly used for subperiosteal implants due to their biocompatibility, mechanical strength, and ability to support osseointegration.*

What this study adds on this topic?

- *This study highlights the advantages of custom-made subperiosteal implants in overcoming anatomical challenges, providing a personalized fit, and minimizing the need for invasive bone augmentation procedures.*
- *It explores the integration of digital workflows, including cone-beam computed tomography (CBCT) imaging and 3D printing, in the design and manufacturing of patient-specific subperiosteal implants.*
- *The study presents future perspectives on the role of biomaterials, including bioactive coatings and antimicrobial surfaces, in improving the longevity and clinical success of subperiosteal implants.*

INTRODUCTION

Dental implants are one of the cornerstones of modern restorative dentistry, offering an effective solution to replace missing teeth and restore both function and esthetics.[1] Despite their widespread success, the clinical efficacy of traditional endosseous implants is dependent on the presence of adequate bone quality and volume in the implant area, as these factors are critical for achieving and maintaining osseointegration.[2] In cases where patients present with insufficient alveolar bone due to severe atrophy, trauma, periodontal disease, or congenital anomalies, traditional implant protocols often require invasive bone augmentation procedures, which can be costly, time-consuming, and associated with variable outcomes. For such challenging clinical scenarios, custom-made subperiosteal implants have re-emerged as a viable alternative to traditional implants by eliminating the need for extensive bone grafting.[3]

Subperiosteal implants are designed to rest on the surface of the bone beneath the periosteum, rather than being embedded within the bone, making them particularly advantageous for patients with minimal residual bone volume.[4] Unlike traditional implants, their custom fabrication allows precise adaptation to the unique anatomy of the patient's bone, offering a tailored approach that can enhance stability and

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Received: January 9, 2025
Revision Requested: January 24, 2025
Last Revision Received: January 24, 2025
Accepted: February 3, 2025
Publication Date: March 27, 2025

support for dental prosthetics.[5] The resurgence of subperiosteal implants in clinical practice has been accelerated by advances in imaging systems, manufacturing techniques, and surgical protocols aimed at optimizing clinical outcomes while minimizing complications.

A key innovation in custom-designed implants is the integration of digital workflows that leverage advanced imaging techniques, such as cone beam computed tomography (CBCT) and digital intraoral scanning, to create detailed three-dimensional (3D) representations of the patient's anatomy.[6] These 3D models serve as the foundation for computer-aided design/computer-aided manufacturing (CAD/CAM) processes, enabling the production of highly precise and custom-tailored implants. Additionally, stereolithographic 3D printing techniques significantly enhance the accuracy and efficiency of implant production while reducing chairside time for both patients and clinicians.[7]

Recent studies have highlighted the clinical benefits of laser-assisted technologies, such as erbium, chromium-doped yttrium, scandium, gallium, and garnet (Er;Cr:YSGG) lasers, in the treatment of subperiosteal implants.[8] These technologies offer a minimally invasive approach that reduces intraoperative trauma, minimizes postoperative discomfort, and supports faster healing.[6] Moreover, modern implant designs incorporating a variety of endosseous anchorage systems are being developed to increase biomechanical stability and address some of the biological limitations traditionally associated with subperiosteal implants.

The versatility of subperiosteal implants makes them valuable in addressing the needs of patients with difficult-to-treat anatomies. For example, subperiosteal implants have been successfully utilized in cases involving maxillofacial deformities, post-oncological resections, and severe alveolar atrophy.[6] By eliminating the need for invasive bone grafting procedures, subperiosteal implants not only reduce surgical complexity but also enhance patient comfort and acceptance of treatment. Their ability to closely conform to the patient's anatomical contours is also thought to improve the long-term stability and integration of prosthetic rehabilitation.

Although the clinical potential of subperiosteal implants has been extensively discussed in the literature, their adoption in routine practice has been limited due to concerns regarding historical complication rates, such as infections, peri-implantitis, and implant failure.[9] However, the development of modern materials, such as biocompatible titanium alloys and bioactive surface coatings, has significantly reduced many of these concerns and substantially improved the success rates of these implants.

HISTORICAL DEVELOPMENT

The concept of subperiosteal implants dates back to the 1940s and represents a significant milestone in the history of dental implantology.[1] The primary purpose of these implants was to address the challenges faced by edentulous patients with insufficient bone volume for traditional endosseous implants, thereby providing them with fixed prostheses. Early designs relied on metallic alloys such as cobalt-chromium or titanium, which were manually bent and adapted to the contours of the patient's maxilla and mandible through a labor-intensive process.[4] While this was an innovative approach at the time, it often presented several limitations, including difficulties in adapting to the unique anatomical features of patients, leading to clinical challenges with respect to outcomes.[7]

The manual manufacturing process required extensive surgical exposure to obtain measurements of the maxilla and mandible directly, which often led to an increased risk of infections and postoperative complications. Additionally, the lack of advanced imaging and manufacturing technologies limited the precision of these early implants, leading to issues such as soft tissue sensitivity, inadequate stabilization, and eventual implant failure.[10] Despite these challenges, subperiosteal implants were considered a valuable treatment option for patients with severe bone atrophy, providing a new alternative in cases where invasive bone grafting procedures were not preferred.

Significant advancements in material science, surgical techniques, and manufacturing technologies have since revolutionized the design and application of subperiosteal implants. The introduction of biocompatible materials such as titanium alloys has improved the biological integration of these implants, reducing the risk of adverse tissue reactions and increasing their longevity.[11] The lightweight structure, corrosion resistance, and ability to support soft tissue attachment make titanium the preferred material in modern subperiosteal implantology.

One of the most significant developments in the history of subperiosteal implants has been the emergence of digital workflows and computer-aided design/computer-aided manufacturing (CAD/CAM) technologies. High-resolution imaging techniques, such as CBCT, allow for precise visualization of the patient's entire bone anatomy, enabling the creation of highly detailed digital models. These models form the basis for designing custom subperiosteal implants that are specifically tailored to each patient's unique anatomical contours. With the integration of additive manufacturing techniques such as 3D printing, these implants can now be produced with exceptional precision and efficiency.[11]

Modern subperiosteal implants offer numerous advantages over their predecessors. By eliminating the need for manual bending and intraoperative adjustments, digital manufacturing ensures superior fit, minimizing surgical time and postoperative complications. The ability to customize implant design according to the patient's specific anatomical features enhances primary stability and improves integration with

surrounding soft tissues. Moreover, these advancements have expanded the clinical indications for subperiosteal implants, making them a viable option for patients with complex anatomical challenges, such as severe alveolar ridge resorption, congenital deformities, trauma, or a history of oncological resections.

Unlike traditional endosseous implants, which require adequate bone volume for successful osseointegration, subperiosteal implants are designed to rest on the surface of the bone, making them particularly advantageous for patients with significant bone loss. This approach eliminates the need for invasive bone augmentation procedures, such as sinus lifts or ridge grafts, which are associated with increased surgical morbidity and prolonged treatment times.[12] By overcoming the limitations of bone quality and quantity, subperiosteal implants offer an effective alternative for restoring oral function and esthetics in edentulous patients. The evolution of subperiosteal implants reflects a broader trend in dentistry toward patient-centered, technology-driven approaches. The integration of digital workflows and advanced manufacturing techniques has not only improved the precision and predictability of these implants but also enhanced patient satisfaction by reducing surgical trauma and healing time. Today, custom subperiosteal implants provide a highly personalized solution to meet the unique anatomical and functional needs of patients with bone disorders, paving the way for continuous innovation and clinical success in implant dentistry.[13]

DESIGN AND MANUFACTURING PROCESS

Custom-made subperiosteal implants are meticulously designed to fit the anatomical characteristics of patients, ensuring the healthy and long-term use of fixed prostheses. The design process typically includes a specially contoured metal framework that rests on the bone and has extensions penetrating into the surrounding soft tissue to provide additional anchorage and stabilization.[2] This personalized approach ensures that the implant fits precisely with the patient's bone contours, optimizing the integration of the prosthetic restoration. By aligning the implant design closely with the patient's specific anatomy, it provides better stability, enhanced patient comfort, and long-term success compared to standard implant systems.

One of the key factors in the success of subperiosteal implants is the careful selection of materials. The material must possess specific properties to ensure the implant's biocompatibility, longevity, and ability to withstand the stresses of oral function. Titanium and its alloys are preferred materials in this field due to their exceptional properties.[14] Titanium alloys exhibit excellent biocompatibility with human biology, meaning they are well-tolerated by tissues and do not cause significant immune reactions.[12] Their corrosion resistance, particularly in the challenging oral environment where exposure to moisture, temperature fluctuations, and acidic conditions can jeopardize material integrity, is another critical feature. Moreover, titanium alloys are known for their high strength and durability, allowing them to withstand significant forces applied during chewing and other oral functions.[2] These properties ensure that titanium-based subperiosteal implants function effectively for many years, maintaining their structural integrity and supporting prosthetic structures. Furthermore, titanium alloys support osseointegration, providing a long-term solution for the prosthesis.[15] This capacity for osseointegration is particularly important in cases where the amount and quality of bone are insufficient for traditional endosseous implants. The use of titanium alloys has significantly increased the predictability and success rates of subperiosteal implants, making them a reliable alternative for patients with complex anatomical challenges.

The design of custom-made subperiosteal implants requires careful consideration of the patient's bone contours, shape, and the intended position of the prosthesis. The ability to adapt the implant to the patient's individual anatomy is a critical advantage of subperiosteal implants, especially in cases where the patient has experienced extensive bone loss due to periodontal disease, trauma, or congenital anomalies. By designing the implant to follow the patient's anatomy, it becomes possible to improve stability, enhance soft tissue integration, and achieve more predictable and long-term results. For patients with concerns due to complex anatomical tissues, this customized approach ensures the implant fits precisely with the existing bone structure, reducing the risk of complications and improving the success of the restoration.

The production of custom subperiosteal implants involves a multi-step process that integrates advanced technologies such as CAD and CAM. The first step of the manufacturing process typically involves obtaining detailed radiographic imaging using CBCT scans, which provide a high-resolution, 3D view of the patient's bone anatomy.[16] These imaging data serve as the foundation for creating an accurate digital model of the patient's oral structures.

Once the digital model is created, clinicians and technicians collaborate to design the custom implant. The use of CAD allows for precise digital planning and ensures that the implant is adapted to the exact anatomical contours of the patient's bone. This detailed digital design ensures that the implant sits securely and aligns optimally with the surrounding soft tissues, supporting long-term integration and stability.[4]

The final step in the manufacturing process involves using CAM technologies such as 3D printing or other additive manufacturing techniques to create the implant. These advanced manufacturing methods allow for the creation of highly detailed and accurate implant forms that closely match the patient's anatomical features. This manufacturing process

offers various advantages over traditional methods, including the ability to produce complex geometries and details with high precision and reduced production time.[17]

The production of custom subperiosteal implants is a sophisticated and highly personalized process that combines advanced digital technologies with traditional dental expertise. This multi-step approach, involving comprehensive radiographic imaging, precise digital planning, design, and advanced manufacturing techniques, ensures that the final implant is tailored to the patient's specific anatomical needs. This highly customized approach significantly increases the likelihood of successful integration, reduces the risk of complications, and enhances the long-term stability of the restoration.[16,18,19] By using these cutting-edge technologies, clinicians can provide implants that not only meet the functional and esthetic needs of patients but also deliver superior clinical outcomes.

INDICATIONS FOR SUBPERIOSTEAL IMPLANTS

Subperiosteal implants are indicated in cases where there is insufficient bone volume or quality to support traditional endosseous implants, offering an alternative solution for patients with complex anatomical and physiological conditions.[20] Insufficient bone volume can result from various factors such as congenital defects, traumatic injuries, long-term edentulism, or chronic periodontal disease that leads to progressive bone resorption.[3,11]

The most common indication for subperiosteal implants is alveolar ridge atrophy, where significant bone loss occurs due to tooth loss, aging, or other underlying medical conditions.[6] This bone resorption typically results in inadequate volume for supporting traditional endosseous implants, requiring bone augmentation. In contrast, subperiosteal implants are designed to rest on the bone without requiring significant bone volume for osseointegration. This makes them particularly suitable for patients with significant alveolar ridge resorption.[11]

Subperiosteal implants are also indicated in cases where anatomical limitations make the placement of traditional implants challenging. One of these limitations is the relationship between the maxillary sinus and the implant site, as well as the proximity of vital structures such as the mandibular nerve. In these cases, the placement of endosseous implants may not be possible due to the risk of damaging critical anatomical structures and the lack of sufficient bone in the desired position.[21] Subperiosteal implants offer a viable solution in such cases, allowing the implant to rest on the bone surface, minimizing the risk of nerve damage, and eliminating the need for invasive sinus lift procedures and other bone grafting techniques.[1]

For patients with challenging anatomical structures that make bone augmentation and sinus lift surgeries difficult, subperiosteal implants present an alternative treatment option. The ability to design and manufacture custom implants that precisely fit the patient's bone contours provides a tailored solution to address specific anatomical challenges. For example, in patients who have undergone previous surgeries and where traditional implants are not a viable treatment option, subperiosteal implants can be used as a last resort without the need for additional invasive procedures.[3]

SURGICAL STEPS

The placement of custom-made subperiosteal implants is a complex surgical procedure that requires a comprehensive, multi-step approach. It differs in complexity from traditional endosseous implants because it involves significant steps to ensure the implant precisely fits the patient's unique anatomical features. The procedure generally follows a well-defined surgical protocol that includes the following key steps:

1. Comprehensive preoperative planning:

   One of the critical aspects of subperiosteal implant placement is comprehensive preoperative planning. This stage involves detailed radiographic analysis to evaluate the patient's bone anatomy, including any anatomical deviations or abnormalities that could affect implant placement. Cone beam computed tomography imaging is commonly used to obtain high-resolution 3D scans of the bone, providing invaluable information about bone density, volume, and topography.[22] These imaging studies enable the surgical team to meticulously plan the optimum position for the implant and design a custom subperiosteal implant that matches the patient's anatomical contours. The data collected during this planning phase are used not only to design the implant but also to guide the surgical procedure, ensuring the most precise and predictable outcome.
2. Flap elevation:

   After preoperative planning is completed, the surgical procedure proceeds with the elevation of a full-thickness mucoperiosteal flap. The surgeon begins by making a carefully planned incision. The flap is delicately elevated, and the periosteum is separated from the bone. This step is crucial because it provides the necessary access to the bony surface for the precise placement and adaptation of the custom-made implant.[23] Minimizing trauma to the surrounding tissues facilitates optimal healing and reduces the risk of postoperative complications.
3. Implant placement and fixation:

   The next step in the procedure involves the precise placement of the custom subperiosteal implant onto the bony tissue. The implant, which is specially designed based on the patient's anatomical features, is carefully positioned on the bony surface to ensure optimal fit and stability. The surgeon must place the implant in the correct

position according to the shape of the bone, ensuring that it remains secure without applying excessive pressure to the surrounding tissues.[24] The fixation of the implant is typically achieved using screws, pins, or other stabilization methods to ensure it stays in place throughout the healing process. It is essential that the implant is both stable and aligned properly with the intended anatomical position, as this step directly influences the long-term stability and function of the implant.

4. Soft tissue closure:

   After the subperiosteal implant is securely positioned and fixed, the final stage of the surgical procedure involves the closure of the soft tissues. The mucoperiosteal flap is carefully repositioned over the implant and sutured in place to cover the implant site and support optimal healing. Soft tissue closure is essential to protect the implant from infection and ensure that the surrounding tissues can heal and integrate effectively with the implant.[25] Proper closure also helps minimize postoperative discomfort and swelling while ensuring that the implant remains stable during the healing process.

Advantages of Custom-Made Subperiosteal Implants

Custom-made subperiosteal implants offer several significant advantages over conventional endosseous implants, especially in patients with severely atrophic or resorbed bones. These advantages include improved fit and stability, suitability for challenging anatomical conditions, and reduced overall surgical complexity. Each of these benefits contributes to the efficiency and long-term success of the restoration process, providing patients with a reliable solution for dental prosthetics in challenging cases.

One of the main advantages of custom-made subperiosteal implants is the ability to achieve a precise, personalized fit tailored to the unique anatomy of the patient's bone. Unlike standard implants, which may require additional adjustments or modifications to conform to the shape of the jaw, custom-made subperiosteal implants are designed to closely match the contours and characteristics of the patient's bone structure. This customized approach optimizes the integration of the implant with both the surrounding bone and soft tissues, providing a more stable foundation for the prosthesis.[17] The precise fit enhances the long-term stability of the implant and restoration, reducing the risk of complications that could arise from implant failure or poor fit.

In contrast to conventional implants, which often require extensive bone reshaping to ensure proper placement, custom-made subperiosteal implants minimize the need for such procedures. This is particularly advantageous for patients with limited bone volume or poor bone quality, as subperiosteal implants sit directly on the bone surface, preventing further bone loss.[5] By preserving the existing bone structure, subperiosteal implants help maintain the integrity of the jaw, preventing additional atrophy and minimizing the need for complex and potentially unpredictable bone grafting procedures. The preservation of bone resources is especially crucial in patients who have experienced significant bone resorption due to long-term edentulism or other factors. By reducing the need for invasive grafting, subperiosteal implants offer a more conservative approach that helps maintain the patient's natural anatomical features.

Custom-made subperiosteal implants are often considered the last alternative for patients with complex anatomical issues, such as limited bone volume, dense cortical bone, or conditions that preclude the use of conventional endosseous implants. In these cases, conventional implants may not provide the required stability due to existing bone deficiencies, or there may be anatomical restrictions, such as proximity to the maxillary sinus or mandibular nerve, that make the placement of conventional implants difficult. However, subperiosteal implants can be specifically designed to conform to these unique challenges by tailoring the implant to the specific features of the patient's anatomy.[7] The ability to customize the implant design to the patient's individual bone structure offers a viable treatment option where other approaches may not be possible.[26] In cases of severe bone resorption or anatomical constraints, subperiosteal implants offer a practical and effective solution for successful restoration.

Although the surgical procedure for subperiosteal implant placement is more complex compared to conventional implants, the custom-made design can ultimately simplify the overall treatment process. One of the primary advantages is the reduction or elimination of the need for extensive bone augmentation or sinus lift procedures, which are often required when using conventional implants in patients with insufficient bone volume. By avoiding these complex and invasive procedures, subperiosteal implants can expedite the treatment process and reduce the overall treatment time.[5] Additionally, reducing the need for grafting or sinus lifting can result in fewer complications, shorter recovery times, and potentially lower overall costs for the patient. This streamlined approach provides a significant benefit for patients who may not be ideal candidates for more invasive procedures.

Potential Complications

The outcomes of subperiosteal implants have been the subject of various studies, reporting success rates ranging from 80% to 95% over the long term; these rates vary significantly depending on patient-specific factors, the technique used, and the quality of the surrounding bone.[1,2,11,12] The long-term success of subperiosteal implants is largely dependent on several key factors, including biomechanical stability, proper osseointegration, and the precise integration of prosthetic components. Achieving successful osseointegration, which refers to the stable integration of the implant with the surrounding bone, is crucial for ensuring the implant's functionality and durability over time. Similarly, the success of

the prosthetic restoration attached to the implant requires meticulous fabrication and expertise to achieve a satisfactory result.[27]

Despite their potential for successful outcomes, subperiosteal implants are not without risks and possible complications. Clinicians and patients should be aware of the potential adverse events that can arise during the surgical process and with the long-term use of these implants. Some of the most common complications associated with subperiosteal implants include:

1. Infection and inflammation:

   One of the most common complications observed in subperiosteal implants is infection or inflammation of the soft tissues surrounding the implant. If not addressed, these issues can lead to implant failure, as the integrity of the surrounding tissues is critical to the stability of the implant.[28] Early detection and management of infection are vital to ensuring implant success and preventing further complications that could necessitate implant removal or revision surgery.
2. Implant loosening or failure:

   Implant failure may occur due to inadequate osseointegration, which results from improper bonding between the implant and the underlying bone. Excessive loading or stresses placed on the restoration during function can compromise the implant's stability.[29] This can lead to loosening of the implant, which, if not managed promptly, may require implant removal or replacement. In such cases, biomechanical factors such as improper occlusal loading or insufficient bone support should be carefully evaluated to prevent future failures.
3. Esthetic concerns:

   Esthetic issues, particularly those related to visible metal structures or poor gingival contours that may detract from the natural appearance of the prosthesis, are another potential complication associated with subperiosteal implants.[11] The visibility of the metal structure can be a concern, especially in the anterior region where esthetic concerns are most significant. Inadequate soft tissue contouring around the implant site can also jeopardize the visual outcome, leading to unsatisfactory prosthetic results. Proper soft tissue management and careful placement planning can help mitigate these issues.
4. Technical complications:

   Technical complications, such as breakage or failure of the prosthetic components attached to the subperiosteal implant, may require additional interventions or the replacement of both the implant and the restoration. These issues can arise from material fatigue, improper design, or complications during the manufacturing process, and they require expert handling and regular monitoring to ensure the long-term durability of the prosthesis.[30]
5. Mechanical complications:

   Mechanical complications, such as breakage or wear of the components that connect the prosthesis to the subperiosteal implant, may occur due to stresses applied during function. These issues can affect the longevity and functionality of the implant, requiring timely intervention to replace or repair the affected parts. The design of the prosthesis and the materials used in manufacturing play a crucial role in reducing the risk of mechanical failure and ensuring the long-term durability of the implant system.[31]
6. Increased risk in medically compromised patients:

   Patients with underlying medical conditions, heavy smoking habits, or a history of radiation therapy are at higher risk for complications related to subperiosteal implants.[2,11] For example, smoking impairs circulation and healing, while radiation therapy can degrade bone quality and lead to slower osseointegration. These factors can reduce the success rate of the implant and increase the likelihood of complications. Careful patient selection and preoperative evaluation are essential to mitigating these risks and ensuring that subperiosteal implants remain a viable treatment option for such individuals.

Treatment Approaches and Long-Term Success

To ensure long-term success and minimize complications associated with subperiosteal implants, a comprehensive and personalized treatment approach is essential. Clinicians should assess each patient's specific risk factors, including bone quality, medical history, and anatomical considerations, before proceeding with implant placement. Detailed preoperative planning, including advanced radiographic imaging such as CBCT, ensures that the implant is designed and placed precisely according to the patient's unique anatomical features.

Meticulous execution of the surgical procedure, including flap elevation, proper implant placement, and adequate soft tissue closure, is critical to avoiding complications such as infection or poor healing. Regular follow-up visits and imaging, including postoperative monitoring to assess implant stability and osseointegration, are crucial for early detection and management of potential issues.

Additionally, maintaining the health of the soft tissues surrounding the implant and ensuring proper care of the prosthetic components are key to preventing complications such as esthetic concerns or mechanical failure. Patients should be educated on the importance of oral hygiene, lifestyle changes (such as smoking cessation), and regular check-ups to preserve the long-term integrity of the implant and restoration.[11,32-34]

FUTURE PERSPECTIVES AND TRENDS IN SUBPERIOSTEAL IMPLANTS

Oral implantology has made rapid advancements, driven by innovations in digital technology, biomaterials, and

surgical techniques, which have significantly transformed implant treatments. In particular, custom-made subperiosteal implants represent one of the most benefitted areas of personalized medicine from these ongoing developments. As research and technological progress continue to accelerate, it is expected that the precision, stability, and long-term predictability of subperiosteal implants will significantly improve, thereby enhancing their clinical applications and overall success rates.

1. Technological developments in implant design and manufacturing:

   One of the most promising areas for growth in subperiosteal implantology is the integration of digital planning, CAD and CAM. These technologies allow for highly precise and customized implant designs tailored to each patient's unique anatomical features. Digital workflows facilitate more accurate preoperative planning by enabling the creation of patient-specific models, reducing the margin for error during implant placement. As CAD/CAM technologies continue to advance, the design and manufacturing processes of custom-made subperiosteal implants will become more efficient, cost-effective, and accessible.[16]

   Additionally, the integration of 3D printing technologies for the production of subperiosteal implants holds significant promise. Three-dimensional printing enables the fabrication of complex, patient-specific implant designs with high accuracy and reduced delivery times. As these technologies mature, they have the potential to revolutionize the production of custom implants, leading to more reliable outcomes.
2. Advancements in biomaterials:

   Innovative biomaterials are also playing a crucial role in the development of subperiosteal implants. The introduction of biocompatible materials with advanced osseointegration properties, such as titanium alloys, zirconium, and bioactive coatings, has improved the performance and longevity of implants. These materials are designed to enhance the bonding between the implant surface and surrounding bone, increasing implant stability and reducing the risk of complications such as implant failure or loosening.[35] Furthermore, the development of biomaterials with regenerative capabilities may improve the integration of implants with both soft and hard tissues, potentially reducing the need for additional procedures such as bone grafting. As the potential of advanced biomaterials continues to be explored, the future of custom-made subperiosteal implants may involve the production of implants with antimicrobial properties to reduce infection risks, paving the way for more esthetic outcomes, higher patient satisfaction, and improved tissue integration.
3. Integration into comprehensive treatment plans:

   As clinicians gain more experience and expertise with subperiosteal implants, their integration into broader treatment protocols will become more seamless. Increased familiarity with these specialized implant systems, combined with advancements in digital workflows, will allow for the more routine application of subperiosteal implants in complex oral rehabilitation cases. The ability to adapt the implant design and placement to each patient's unique anatomical challenges will make subperiosteal implants an attractive option, especially for patients with severely atrophic or compromised bones where traditional endosseous implants may not be feasible.

   Additionally, as more clinical evidence supporting the success of subperiosteal implants in various clinical scenarios emerges, the decision-making process regarding their use may become more standardized. Comprehensive treatment planning, including subperiosteal implants as a viable option in selected cases, will facilitate their adoption and increase acceptance among clinicians.
4. Patient selection and outcomes:

   Looking to the future, the successful application of custom-made subperiosteal implants will largely depend on improved patient selection criteria. A better understanding of the factors that predict the success of subperiosteal implants (such as bone quality, anatomical considerations, and overall health status) will allow clinicians to make more informed decisions about which patients are most likely to benefit from this treatment modality. With an ideal patient selection system in place, it is likely that the outcomes of subperiosteal implants will improve, complications will decrease, and the longevity of both the implants and associated restorations will increase. Furthermore, the continued development of more sophisticated postoperative monitoring tools, such as digital imaging and intraoral scanning technologies, will enable better tracking of implant integration and long-term performance. These tools will allow clinicians to detect potential issues early, facilitating timely interventions.
5. Expanding the role of subperiosteal implants:

   As advancements continue in materials, digital technologies, and surgical techniques, the role of subperiosteal implants is likely to extend beyond their current applications.[36,37] The ongoing development of minimally invasive surgical techniques, such as robotic-assisted surgery and guided implant placement, may make the subperiosteal implant placement procedure less invasive and more accessible. This could open up new opportunities for their use in a broader range of patients, including those who were previously considered contraindicated for implant surgery.

As demand for esthetic and functional oral rehabilitation continues to grow, the customizable nature of subperiosteal implants will make them increasingly attractive to both clinicians and patients. The ability to design, along with the potential for improved soft tissue integration and overall esthetic outcomes, may position subperiosteal implants as the solution of choice for complex, multidisciplinary oral rehabilitation cases.

CONCLUSION

Custom-made subperiosteal implants offer a valuable treatment option in cases where traditional endosseous implants are not viable due to limited bone volume or quality. The use of subperiosteal implants requires careful planning, design, and surgical execution to ensure long-term success and minimize the risk of complications. As with any surgical procedure, it is essential to thoroughly assess the patient's individual conditions, weigh the benefits and risks, and develop a comprehensive treatment plan in collaboration with the patient.

Availability of Data and Materials: The data that support the findings of this study are available upon request from the corresponding author.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – B.G.; Design – B.G.; Supervision – A.K.; Materials – B.G.; Data Collection – B.G.; Interpretation – B.G.; Literature Search – A.K.; Writing – B.G.; Critical Reviews – A.K.

Declaration of Interests: The authors have no conflict of interest to declare.

Funding: The authors declared that this study has received no financial support.

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