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Clinical Effectiveness and Outcomes of Customized Subperiosteal Implants: A Systematic Literature Review

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ABSTRACT Severe alveolar bone atrophy remains a major challenge in implant dentistry because conventional endosseous implants often require sufficient bone volume or invasive augmentation procedures, limiting treatment options for patients with advanced bone loss. Recent advances in digital imaging and computer-aided manufacturing have renewed interest in customized subperiosteal implants (CSIs) as a less invasive alternative; however, their clinical effectiveness and long-term outcomes have not been comprehensively synthesized. This systematic review aimed to evaluate the clinical effectiveness, implant stability, functional outcomes, and complications associated with modern digitally fabricated customized subperiosteal implants in patients with severe alveolar bone deficiencies. The review was conducted in accordance with the PRISMA 2020 guidelines through systematic searches of PubMed and Google Scholar. Study quality and risk of bias were assessed using the Joanna Briggs Institute (JBI) critical appraisal checklist. From 6,101 initially identified records, 11 studies met the eligibility criteria and were included in the qualitative synthesis, comprising five retrospective cohort studies and six case series. The findings demonstrate that contemporary CSIs, designed using Cone Beam Computed Tomography (CBCT), Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM), and three-dimensional printing technologies, achieve excellent anatomical adaptation, high primary stability, and predictable functional rehabilitation in patients with severe jaw atrophy. Reported implant survival rates ranged from 93.75% to 100% during the first year of follow-up and remained between 95.8% and 97.1% in studies with follow-up periods extending up to six years. Most complications were minor soft-tissue events, including swelling, bleeding, implant exposure, and peri-implant inflammation, whereas late failures were predominantly associated with infection and prosthetic misfit. Overall, customized subperiosteal implants represent a reliable and minimally invasive treatment option for complex alveolar bone deficiencies when integrated with digital workflows. Nevertheless, the current evidence is primarily derived from retrospective studies and case series, emphasizing the need for well-designed multicenter randomized controlled trials with long-term follow-up to establish standardized treatment protocols and confirm long-term clinical effectiveness.

INDEX TERMS Customized Subperiosteal Implants, Severe Alveolar Bone Atrophy, CAD/CAM, Three-Dimensional Printing, Systematic Review

I. INTRODUCTION

The rehabilitation of patients with severe alveolar bone atrophy remains one of the most challenging issues in contemporary implant dentistry. Conventional endosseous dental implants are considered the gold standard for replacing missing teeth; however, their successful placement requires adequate bone volume and density, which are frequently compromised in patients with advanced maxillary or mandibular resorption [1], [2]. To overcome insufficient bone support, clinicians commonly perform bone augmentation procedures such as guided bone regeneration, sinus floor elevation, and autogenous bone grafting. Although these techniques have demonstrated favorable clinical outcomes, they are associated with increased surgical complexity, prolonged treatment duration, higher financial costs, donor-site morbidity, and a greater risk of postoperative complications [3]–[6]. Consequently, there is an increasing demand for minimally invasive treatment approaches that can provide predictable implant rehabilitation while reducing surgical burden and improving patient quality of life.

Recent technological advances have substantially transformed the development and clinical application of customized subperiosteal implants (CSIs). Unlike conventional subperiosteal implants introduced several decades ago, modern CSIs integrate Cone Beam Computed Tomography (CBCT), Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM), and additive manufacturing technologies to fabricate patient-specific

implants that accurately conform to the underlying bone anatomy [7]–[10]. These digital workflows have significantly improved implant adaptation, primary stability, prosthetic accuracy, and surgical predictability while reducing complications previously associated with traditional subperiosteal implant systems [11], [12]. Furthermore, three-dimensional (3D) printing and Direct Metal Laser Sintering (DMLS) technologies enable the fabrication of customized titanium frameworks with superior mechanical properties, excellent biocompatibility, and enhanced osseointegration potential, thereby expanding treatment opportunities for patients who are unsuitable candidates for conventional implant placement [13]–[15]. Recent clinical applications have also demonstrated the successful use of customized subperiosteal implants for reconstructing complex maxillofacial defects following oncological resection, highlighting their versatility beyond conventional rehabilitation of severely atrophic jaws and supporting their broader clinical applicability in challenging anatomical conditions [16].

Despite these technological advancements, the current evidence regarding the long-term clinical effectiveness of customized subperiosteal implants remains limited. Most available studies consist of retrospective cohort studies, pilot investigations, and case series with relatively small sample sizes, heterogeneous patient populations, variable follow-up durations, and inconsistent outcome measurements [9], [14], [17]. Although many investigations have reported implant survival rates exceeding 90% together with favorable functional rehabilitation and patient satisfaction, considerable heterogeneity remains regarding surgical protocols, implant materials, prosthetic loading strategies, complication reporting, and patient selection criteria [18]–[20]. Furthermore, direct comparisons between customized subperiosteal implants and alternative treatment modalities, including zygomatic implants and advanced bone augmentation procedures, remain scarce. These methodological limitations hinder the generalizability of current findings and prevent the establishment of standardized evidence-based clinical protocols for widespread implementation of digitally manufactured customized subperiosteal implants.

Therefore, a comprehensive synthesis of the most recent evidence is essential to critically evaluate the clinical performance of customized subperiosteal implants developed using contemporary digital technologies. This systematic review aims to evaluate the clinical effectiveness, implant stability, functional rehabilitation, postoperative complications, and survival outcomes of digitally fabricated customized subperiosteal implants for patients with severe alveolar bone deficiencies through a systematic analysis of recent clinical studies.

This study offers several important contributions to the existing body of knowledge. First, it synthesizes the latest clinical evidence published between 2020 and 2025 concerning digitally fabricated customized subperiosteal implants utilizing advanced CBCT, CAD/CAM, and additive manufacturing technologies. Second, it critically evaluates implant survival, functional outcomes, prosthetic performance, postoperative complications, and methodological quality using the Joanna Briggs Institute (JBI) critical appraisal framework, thereby providing a comprehensive assessment of the current level of evidence. Third, it identifies existing knowledge gaps and proposes future research directions to support the development of standardized clinical protocols, improve evidence-based decision-making, and facilitate broader clinical adoption of customized subperiosteal implants in implant dentistry.

The remainder of this article is organized as follows. Section II describes the systematic review methodology, including the search strategy, eligibility criteria, study selection process, data extraction, and quality assessment procedures. Section III presents the findings synthesized from the included studies. Section IV discusses the clinical implications of the findings, compares them with previous literature, and addresses the strengths and limitations of the available evidence. Finally, Section V summarizes the principal conclusions and provides recommendations for future research.

II. METHOD

A. STUDY DESIGN AND REPORTING GUIDELINES

This study employed a systematic literature review to evaluate the clinical effectiveness and outcomes of customized subperiosteal implants (CSIs) in patients with severe alveolar bone atrophy. A systematic review design was selected because it enables the comprehensive identification, critical appraisal, and synthesis of evidence from multiple clinical studies while minimizing selection bias and improving the transparency and reproducibility of the review process. The review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines, which provide standardized recommendations for literature identification, screening, eligibility assessment, and evidence synthesis. Furthermore, methodological quality assessment followed the recommendations of the Joanna Briggs Institute (JBI) for evidence synthesis to ensure rigorous evaluation of the included studies.

B. RESEARCH QUESTION

The review question was formulated using the Population, Intervention, Comparison, and Outcome (PICO) framework to ensure a structured and reproducible search strategy.

1. Population (P): Adult patients presenting with severe maxillary or mandibular alveolar bone atrophy that precluded placement of conventional endosseous dental implants.
2. Intervention (I): Rehabilitation using customized subperiosteal implants designed through digital workflows incorporating Cone Beam Computed Tomography (CBCT), Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM), and additive manufacturing technologies.
3. Comparison (C): Conventional endosseous implants, zygomatic implants, or alternative reconstructive procedures, where applicable.

4. Outcome (O): Implant survival, implant stability, prosthetic function, postoperative complications, patient satisfaction, and functional rehabilitation.

Based on this framework, the primary research question was: "What are the clinical effectiveness, implant survival, functional outcomes, and postoperative complications associated with digitally fabricated customized subperiosteal implants in patients with severe alveolar bone atrophy?"

C. ELIGIBILITY CRITERIA

Eligibility criteria were established before literature screening to reduce selection bias and ensure consistency throughout the review process. Eligible studies included original clinical investigations published between January 2020 and August 2025, including prospective studies, retrospective cohort studies, comparative clinical studies, case-control studies, and case series involving at least four patients. Studies were required to evaluate customized subperiosteal implants manufactured using contemporary digital technologies and report at least one relevant clinical outcome, including implant survival, osseointegration, functional rehabilitation, prosthetic performance, or postoperative complications.

Studies were excluded if they were review articles, editorials, conference abstracts, letters to the editor, technical notes without clinical outcomes, animal or in-vitro experiments, duplicate publications, or studies lacking full-text availability. Reports describing conventional non-customized subperiosteal implants without digital design or additive manufacturing techniques were also excluded.

D. INFORMATION SOURCES AND SEARCH STRATEGY

A comprehensive literature search was conducted using PubMed (MEDLINE) and Google Scholar, which were selected because they provide broad coverage of biomedical, dental, and surgical literature. The search was initially performed on 15 February 2025 and updated until 30 August 2025 to ensure inclusion of the most recent eligible publications.

Search terms were developed from the PICO framework and combined using Boolean operators. The primary search strategy included combinations of the following keywords: ("subperiosteal implant" OR "customized subperiosteal implant" OR "atrophic maxilla" OR "atrophic mandible") AND ("CAD/CAM" OR "3D printing" OR "additive manufacturing") AND ("implant survival" OR "oral rehabilitation" OR "osseointegration").

Additional manual screening of reference lists from eligible articles was performed to identify potentially relevant studies not captured through the electronic database search. Literature searching and reporting procedures followed the recommendations of PRISMA 2020 and PRISMA-S to maximize search transparency, reproducibility, and methodological rigor.

E. STUDY SELECTION AND DATA EXTRACTION

All retrieved records were exported to a reference management spreadsheet, and duplicate publications were removed before the screening process. Two reviewers independently screened article titles and abstracts according to the predefined eligibility criteria. Studies considered potentially relevant were retrieved in full text and independently assessed for inclusion. Any disagreement regarding study eligibility was resolved through discussion until consensus was achieved. When consensus could not be reached, a third senior reviewer was consulted to make the final decision. This independent screening process was implemented to minimize selection bias and enhance the reliability of study inclusion.

The study selection process followed the PRISMA 2020 flow diagram, comprising four sequential stages: identification, screening, eligibility assessment, and final inclusion [21]. Data extraction was subsequently conducted independently by the two reviewers using a standardized extraction form developed before the review commenced. The extracted variables included publication characteristics (author, year, and country), study design, participant demographics, number of patients and implants, implant material, digital workflow technology (CBCT, CAD/CAM, and additive manufacturing), surgical procedures, follow-up duration, prosthetic loading protocol, implant survival rate, postoperative complications, functional outcomes, and patient-reported outcomes. The extracted data were cross-checked to ensure consistency and completeness before synthesis.

F. QUALITY ASSESMENT AND RISK OF BIAS

The methodological quality of all included studies was evaluated using the Joanna Briggs Institute (JBI) Critical Appraisal Checklists, which provide validated tools for assessing observational studies and case series [22]. Different JBI appraisal instruments were applied according to the study design. Each checklist evaluates methodological domains including participant selection, measurement validity, confounding factors, follow-up adequacy, statistical analysis, and outcome reporting.

Each assessment item was rated as "Yes," "No," "Unclear," or "Not Applicable." Studies demonstrating predominantly affirmative responses were categorized as having a low risk of bias, whereas studies with several methodological limitations were classified as having a moderate or high risk of bias. Quality assessment was independently performed by two reviewers, and discrepancies were resolved through discussion to achieve consensus. The resulting quality assessment informed the interpretation of evidence but was not used as a criterion for excluding eligible studies.

G. DATA SYNTHESIS

Because substantial heterogeneity was observed among the included studies regarding study design, patient characteristics, implant systems, follow-up periods, outcome definitions, and reported clinical parameters, quantitative meta-analysis was considered inappropriate. Instead, a qualitative narrative synthesis was performed in accordance with current recommendations for systematic reviews involving heterogeneous clinical evidence [23].

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The synthesized evidence was organized into several thematic categories, including patient characteristics, implant design and manufacturing technology, surgical procedures, prosthetic rehabilitation, implant survival, postoperative complications, functional outcomes, and overall clinical effectiveness. Whenever available, quantitative outcomes such as implant survival rates, follow-up duration, and complication frequencies were summarized descriptively to facilitate comparison across studies. Particular attention was given to identifying consistent clinical trends, technological advancements, and methodological limitations that may influence interpretation of the current evidence.

H. ETHICAL CONSIDERATIONS

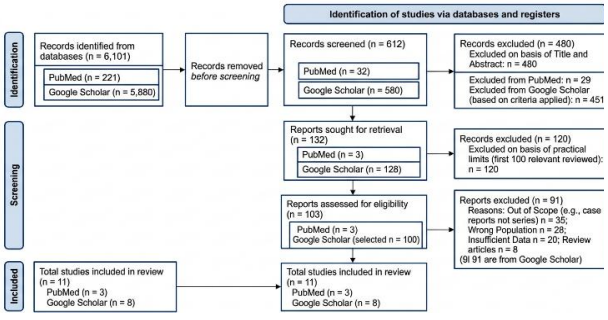
This study analyzed data exclusively from previously published scientific literature and did not involve the recruitment of human participants, collection of identifiable patient information, or experimental intervention. Consequently, institutional ethical approval and informed consent were not required, consistent with international ethical recommendations for systematic reviews [24].

The review was conducted in accordance with internationally accepted standards for responsible research, including transparent reporting, objective study selection, accurate data extraction, and appropriate citation of all original sources. Every effort was made to minimize bias throughout the review process by implementing predefined eligibility criteria, independent screening, standardized quality assessment, and transparent reporting procedures. These methodological safeguards enhance the credibility, reproducibility, and scientific rigor of the present systematic review [25].

III. RESULTS

The flow of studies through the selection process is summarized in FIGURE 1, in accordance with the PRISMA guidelines.

Figure 1
Selection Diagram of Articles



The initial electronic database search yielded a total of 6,101 records (221 from PubMed and 5,880 from Google Scholar). Following the application of automated filters ("published within the last 5 years," "English or French," and "Humans"), 32 records remained in PubMed. For Google Scholar, the first 100 most relevant records were retained for screening, aligning with practical feasibility and relevance.

A total of 132 unique titles and abstracts were screened. Based on the predefined inclusion and exclusion criteria, 121 records were excluded (29 from PubMed and 92 from Google Scholar) because they did not meet the criteria (e.g., incorrect study type, wrong population, insufficient data).

11 full-text articles were sought for retrieval and assessed for eligibility. All 11 articles (3 from PubMed and 8 from Google Scholar) met all criteria and were included in the final qualitative synthesis for data extraction and analysis. The 11 included studies consisted of 5 retrospective cohort studies and 6 case series.

TABLES 1 and TABLE 2 show basic information about the articles selected: The majority of the selected patients presented with severe bone atrophy, classified as Cawood and Howell Class V or higher; in good general health status; maintained oral hygiene; and refused bone augmentation. The majority included older adults, but a number of younger patients were also included due to trauma or anatomical limitations. Exclusion criteria included systemic diseases, immunosuppressive therapy, smoking, and poor oral hygiene. (8,13,16,20,21,23,25,10,9,17)

Procedures usually took 1.5 to 2 hours and were generally performed by maxillofacial surgeons under local anesthesia, although sedation or general anesthesia could be used, depending on the complexity of the case. The surgical procedure included incision, flap elevation, bone preparation, and fixation of the implant with titanium screws. In many cases, temporary prostheses were loaded within 24 hours. Antibiotics, pain management, and oral hygiene were part of the postoperative measures. The final restorations were placed after 5–12 months, when the soft tissues had healed.

Immediate or early loading was the norm, using temporary prostheses after 24 hours to 2 weeks of the surgical appointment, while final prostheses were delivered from 5-6 months, even up to 12 months. A variety of materials were used, including CAD/CAM PMMA, zirconia-ceramic, composite resin, and metal-ceramic. Early impression and digital workflows provided improved efficiencies and increased patient satisfaction.

Implant survival rates were reported as 94% to 100% for the first year and remained relatively stable throughout follow-ups up to 6 years. Complications occurred such as implant failures between 3–6 years primarily from infection or poorly fitted prosthesis. Overall, long-term treatment success was often high, but continuous follow-up of patients remains critical.

Episodes of early complications were described as implant malposition, nerve injury, hemorrhage, and swelling. Short-term complications (0–6 months) were described as abutment exposure, bleeding on probing, and temporary hypoesthesia. Long-term complications (6 months–4 years) were reported as peri-implantitis, bone resorption, and implant mobility. Each of the early complications were oftentimes soft-tissue based complications that were successfully treated with minimal intervention. Timely follow ups, especially within the first 8 months, is important for patients so potential problems can be managed as needed.

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Of the articles, 75% (N=9) presented a low risk of bias, showing that studies were well-designed and, for the most part, adhered to methodologies that reduce bias. While there were some minor flaws, the high percentage of affirmative ("YES") responses supports the overall validity of these studies. On the contrary, 16.6% (N=2) presented a moderate risk of bias, with an average of 71.36%, reflecting generally sound design but with notable limitations that may impact

TABLE 1
Characteristics of the Included Studies and Patient Demographics

Article N°	N° of patients	N° of implants	Type of edentulism	Material of the implant	Imaging techniques	General or local anesthesia	Inclusion and exclusion criteria
1	36 patients: average age 61.1 years.	72 implants	Complete Edentulism	titanium	CBCT, Digital impressions. DICOM and STL files	Local anesthesia, complemented by intravenous sedation with diazepam	Inclusion: -Cawood and Howell class V and VI atrophy of the maxilla. - Presence of peri-implantitis.
2	17 patients: Average age: 60.4	30 implants	Partial Edentulism	grade V porous titanium	CBCT, Digital scanning DICOM and STL files	Local anesthesia	Inclusion: -Cawood and Howell class V and VI atrophy of the maxilla.
3	4 Patients: Age range: 65-75 years	4 implants	Completely Edentulism	Frameworks made of milled Polyether Ether Ketone (PEEK)	CBCT, CT scans STL files	local anesthesia.	Inclusion: Patients with significant ridge resorption and no systemic illnesses. Exclusion: Patients with absolute and relative contraindications.
4	18 patients: Age: 40-80 years (62.39 years)	No relevant information	Complete Edentulism	Titanium	OPT and CBCT Intraoral scans saved as STL files	Local anesthesia	Exclusion: patients with contraindications like uncontrolled diabetes or previous radiation.
5	150 patients Age : 35 and-80 years	No relevant information	Complete Edentulism	No relevant information	CBCT Digital imaging	Subperiosteal implant: local or general anesthesia Zygomatic implant: general anesthesia	Inclusion: -Class V and VI atrophy of the maxilla. Exclusion: - smoking, uncontrolled diabetes or other systematic diseases.
6	15 patients: Age range: 63.70 years.	30 implants	Complete Edentulism	titanium	CBCT	No relevant information	Inclusion: - Cawood and Howell class V or higher atrophy of maxilla. Exclusion: - patients who refused to get a CBCT after one year of the surgery for follow up.
7	40 patients: Mean age: 65.24 years	No relevant information	Bilateral Maxillary	No relevant information	CBCT	Local anesthesia	Inclusion: - had bilateral maxillary AMSJI placements at least a year prior - Class V and higher Exclusion: - Maxillary defect reconstructions
8	16 patients: mean age of 61.5 years	No relevant information	Completely Edentulous	Titanium	OPT and CBCT 3Dimaging and printing (Direct Metal Laser Sintering DMLS)	No relevant information	Inclusion: -patients aged over 55 and are in overall good health. -no desire to go through bone augmentation procedures. Exclusion: -patients who are immunocompromised, suffer from pathologies and have inadequate oral hygiene. -smoking
9	36 patients	61 subperiosteal implants	Complete Or Partial Edentulism	titanium alloy powder	DICOM data from the CBCT scans STL file	local anesthesia and sedation	Inclusion: Age: Over 60 or younger with significant bone loss Health: Good dental hygiene, stable general and oral health. Exclusion: Age: Under 6, Health issues Inadequate dental care. Bruxism, tobacco use.
10	4 patients: Age: 59-72 years	20 implants	Complete Edentulism	Titanium	DICOM data from the CBCT scans, STL and titanium meshes (CAD/CAM)	General anesthesia	inclusion: patients with segmental maxillary oncological defects due to maxillary squamous cell carcinoma.
11	10 patients: Age range: 69.6 years	No relevant information	Partial Edentulism	titanium grade 5 micro-powders using, Direct Metal Laser Sintering technology	OPT and CBCT (DICOM data) Intraoral scans Data saved as STL files	Local anesthesia	Inclusion: Patients over 65, in good health, with proper hygiene; and with certain oral health issues. Exclusion: Patients with insufficient bone height, smokers, systematic pathologies or heavy therapies.

result validity. This finding points to the need for careful interpretation and further review for possible bias in certain studies.

IV. DISCUSSION

A. INTERPRETATION OF FINDINGS AND COMPARISON WITH PREVIOUS STUDIES

The present systematic review synthesized evidence from 11 clinical studies to evaluate the effectiveness and clinical outcomes of customized subperiosteal implants (CSIs) for the rehabilitation of patients with severe alveolar bone atrophy. Overall, the findings indicate that contemporary CSIs, developed using digital workflows integrating Cone Beam Computed Tomography (CBCT), Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM), and additive manufacturing technologies, represent a promising treatment alternative for patients who are unsuitable candidates for conventional endosseous implants. Across the included studies, implant survival rates ranged from 93.75% to 100% during the first year of follow-up and remained consistently high in studies reporting medium-term follow-up periods of up to six years. These findings suggest that advances in digital implant design have substantially improved the predictability, stability, and functional performance of subperiosteal implant therapy compared with earlier implant designs.

The favorable clinical outcomes observed in this review are largely attributable to improvements in digital planning and patient-specific implant fabrication. The integration of CBCT imaging with CAD/CAM software enables accurate three-dimensional reconstruction of the patient's maxillofacial anatomy, facilitating the production of implants that closely match individual bone morphology. Consequently, customized implants demonstrate superior anatomical adaptation, enhanced primary stability, and reduced intraoperative adjustments, thereby minimizing surgical trauma and shortening operative time. Similar observations have been reported in recent clinical investigations, which demonstrated that digitally fabricated subperiosteal implants improve prosthetic accuracy while reducing mechanical complications associated with poor implant adaptation [26], [27].

The present findings are also consistent with previous systematic reviews indicating that modern customized subperiosteal implants have overcome many of the limitations associated with conventional subperiosteal implant systems introduced during the twentieth century. Earlier implant designs were frequently associated with inaccurate adaptation, peri-implant infection, implant mobility, and high failure rates because manufacturing techniques relied primarily on conventional impression methods and manual fabrication processes. In contrast, current digital manufacturing technologies have significantly improved implant precision, resulting in higher survival rates and improved patient satisfaction [28], [29]. These technological advances have renewed clinical interest in customized subperiosteal implants, particularly for patients presenting with severe jaw atrophy who wish to avoid extensive bone grafting procedures.

Although the overall outcomes were encouraging, considerable variability was observed among the included studies regarding implant design, surgical protocols, prosthetic loading strategies, follow-up duration, and outcome reporting. Such heterogeneity limits direct comparison between studies and complicates the interpretation of pooled evidence. For example, several investigations adopted immediate loading protocols using provisional prostheses within 24 hours, whereas others delayed prosthetic rehabilitation for several weeks or months. Similarly, reported follow-up periods ranged from one year to six years, making long-term comparisons difficult. These methodological differences may partly explain the variation in reported complication rates and implant survival across studies.

Another important finding of this review is that postoperative complications were generally limited to mild soft-tissue events, including transient swelling, edema, bleeding, temporary hypoesthesia, and localized implant exposure. Most complications were successfully managed through conservative postoperative care without compromising implant survival. Nevertheless, late complications including peri-implantitis, chronic infection, prosthetic failure, screw loosening, and progressive bone resorption were occasionally reported during extended follow-up. Similar patterns have been described by recent longitudinal studies, which concluded that long-term success depends not only on implant design but also on meticulous surgical technique, prosthetic accuracy, patient compliance with oral hygiene, and regular maintenance therapy [30]. Therefore, despite the encouraging clinical performance demonstrated by customized subperiosteal implants, continuous postoperative monitoring remains essential to preserve implant stability and maximize long-term treatment success.

B. CLINICAL IMPLICATIONS AND COMPARISON WITH RECENT EVIDENCE

The findings of this systematic review have important implications for clinical decision-making in implant dentistry, particularly in the management of patients with severe alveolar bone atrophy who are unsuitable candidates for conventional endosseous implant placement. Traditionally, rehabilitation of severely resorbed jaws has relied on complex augmentation procedures, including autogenous bone grafting, sinus floor elevation, distraction osteogenesis, or zygomatic implants. Although these approaches have demonstrated acceptable long-term outcomes, they often involve multiple surgical interventions, prolonged healing periods, increased treatment costs, and greater postoperative morbidity. In contrast, the reviewed studies consistently demonstrate that customized subperiosteal implants provide a less invasive alternative capable of restoring oral function while avoiding extensive reconstructive surgery. This advantage is particularly relevant for elderly individuals and medically compromised patients who may not tolerate multiple surgical procedures [31], [32].

Another important observation concerns the substantial contribution of digital technologies to the clinical success of customized subperiosteal implants. The integration of CBCT imaging, virtual surgical planning, CAD/CAM software, and additive manufacturing enables clinicians to produce patient-

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specific implants with excellent anatomical adaptation.

TABLE 2
Surgical Details and Postoperative Outcomes of The Selected Articles

Article N°	Performed by	Duration of the surgry	Surgical procedure	Complications	follow-up
1.	Maxillofacial Surgery Operative Unit and the Department of Prosthodontics and Gerostomatology	64 -122 minutes	**Incision** : full-thickness **Flap creation** **Dissection** **Implant placement** : with titanium screws. **Covering** Immediate loading Post-surgery : antibiotics and pain relief. Definitive prosthesis : after 6 months	Surgical complications may include bleeding, nerve injury, malposition, and infection. In the first 6 months, risks include bleeding on probing and bone loss >0.2 mm/year. Long-term issues (up to 4 years) include persistent bleeding on probing, implant mobility, bone resorption, and chronic inflammation like peri-implantitis or sinusitis.	no implants lost during follow-up (range 12–64 months) Implants showed stability with minimal evidence of screw loosening. 100% implant survival rate and 90.3% success rate observed.
2.	Maxillofacial Surgery Operative Unit	No relevant information	**Full-thickness incision** **Dissection** **Bone Preparation** **Insertion of the Implant** : Osteosynthesis screws (2 mm) for fixation. **After Surgery :** Amoxicillin plus clavulanic acid for six days as antibiotics. temporary prosthesis is placed ten days later.	**During surgery:** inaccurate fitting of ridge preparation template. **Short term:** postoperative oedema, temporary hypoesthesia,bleeding on probing. **Long term:** At 1 year, 5.8% of abutments continued to present bleeding on probing. At 2 years, 10% of abutments presented bleeding on probing.	Absence of infections or implant loss during the follow-up, averaging 22.5 months.
3.	prosthodontics department of the Faculty of Dentistry	No relevant information	oblique release incisions at the distal ends and crestal incisions from the left to right second molar. Implant placement : Ø2mm titanium screws Resorbable sutures used for flap closure. Postoperative Care : Hyaluronic acid mouthwash, diclofenac, and amoxicillin. definitive prosthetics with veneers made of composite resin.	**- Immediate postoperative complications (1 month)**: partial exposure of the framework of one participant's right maxillary canine abutment. **- long term (12-24 months):** No complications, implants stable, healthy soft tissues, no fractures, infections, or radiolucency.	12 to 24 months No implants were lost during this period of time
4.	the department of Oral and Maxillofacial Surgery	No relevant information	mucosal incision and subperiosteal flap Bone reduction The implant placed and secured with screws. Temporary abutments are attached for a provisional prosthesis. Postoperative care : prescription for antibiotics and chlorhexidine mouthwash.	**3 intraoperative complications**: issues with implant fitting. **1 postoperative complication**: minimal mucosal exposure without infection.	After 1 year follow up: the implant success rate was 94.44%.
5.	Dental clinic	**SI:** 174 minutes **ZI:** 120 minutes	**SI protocol:** Crestal incision and raised palatal flap Implant placement Fixation : with titanium screws After surgery : permanent prosthesis is inserted five months after temporary bridges. **ZI protocol:** Surgical access : a lateral sinus window, raising the palatal flap, making a crestal incision. Implant Placement : into the zygomatic bone. Postoperative Care : Permanent restorations at 5 months, temporary bridges within 24 hours.	**-ZI** presented a Higher rate incidence of sinus-related complications and orbital damage (12.4%) compared to **SI** that showed lower incidence of soft tissue complications (5.6%). - **ZI** presented lower Soft Tissue Stability compared to **SI**.	5 years follow up: Both **zygomatic implants** (96.3% survival rate) and **subperiosteal implants** (97.1% survival rate) demonstrated high survival rates
6.	Maxillo-facial surgeons	No relevant information	No relevant information can be provided based on the available text.	-no infections were recorded. -there was a small amount of bone loss.	After 1 year: Implant survival rates were from 73.3% to 100%.
7.	No relevant information	No relevant information	No relevant information	**short term:** Inflammation and soft Tissue Infections **Long-term:** removal of a screw, partial exposure of implant components, slight implant movement	2.5 years: high percentage of survival, with only one implant showing any symptoms of malfunction.
8.	Oral and Maxillofacial Surgery Center	86.18 min	Incision and Flap Elevation Bone Reduction & Implant Testing Implant Fixation Abutment Placement & Closure Prosthetic Impressions & Temporary Final Restoration : placed 6 months post-surgery.	**Short term complications:** -pain and inflammation, bleeding. **long term complications:** - exposed implants, a fracture in the temporary prosthesis occurring in one of the implants, no pain, swelling, suppuration, or movement.	6 months Due to repeated, incurable infections and inadequate fit, one implant was removed during the process. Survival rate**:** 93.75%**.**
9.	private Oral and Maxillofacial Surgery Center	No relevant information	Incision and Flap Reflection : A crestal incision Bone Preparation : using a bone-cutting guide Screw Insertion : Self-drilling screws (2 mm) resorbing membrane Closure : Resorbable sutures prescription : antibiotics, anti-inflammatory drugs, and chlorhexidine mouthwash. Prosthetic rehabilitation : taking impressions two to seven days after surgery and having final restorations done 6 to 12 months later.	**Short term (within 2weeks):** Biological problems include pain, bleeding, edema, and swelling and Early Issues: minor exposure, mobilization, and infection. **long term:** -Biological problems: severe recurrent infections, pain, edema, pus, bone loss, and mobilization brought on by loosening screws following infections.	After 6 years, fifteen implants had to be removed because of problems. Nine of the twelve patients who are still being monitored have shown no problems. 62.3% was noted as success percentage for implants in the first 3 years, with a 45.9% failure rate after 6-years.
10.	Oral and Maxillofacial Surgery Department	No relevant information	* Crestal incisions * Dissection & Implant * Suturing *****Postoperative Care: Antibiotics, anti-inflammatory drugs, and chlorhexidine mouthwash * Provisional Prosthesis: 2 weeks after surgery. * Fixed Prosthesis	no signs of infections, or problems with the bone graft, no visible titanium mesh exposure. Every patient recovered without developing mucosal recessions or ulcers.	3 years The implant survival rate was reported at 95.8%.
11.	Maxillofacial surgeon	44.3 min	A crestal incision The implant replica was used to prepare the flap DMLS implants were fixed with mini-screws Suturing ensured no tension prescription Initial Restoration : PMMA restoration. Final Delivery : The zirconia-ceramic bridge	**immediate postoperative issue:** -swelling, oedema and bleeding **late complications:** Bone loss, aching, swelling, pus, severe infections, Chipping or cracking of temporary or permanent prostheses.	1 year None of the implants were lost at the one-year follow-up, showing a 100% survival percentage.

Accurate digital planning not only improves implant fit but also reduces intraoperative adjustments, shortens surgical duration, and facilitates immediate or early prosthetic loading. Several recent investigations have similarly reported that digital workflows improve prosthetic precision, reduce technical complications, and enhance patient satisfaction compared with conventional manufacturing techniques [26], [33]. These findings suggest that technological innovation has fundamentally transformed subperiosteal implant therapy from a historically unpredictable procedure into a more reliable and reproducible treatment modality.

The present review also demonstrates that implant survival should not be interpreted as the sole indicator of clinical success. Although most included studies reported survival rates exceeding 90%, successful rehabilitation also depends on prosthetic stability, preservation of peri-implant soft tissues, patient comfort, masticatory efficiency, speech function, and oral health-related quality of life. Several investigations included in this review reported high levels of patient satisfaction despite the occurrence of minor postoperative complications, indicating that functional improvement and quality-of-life outcomes are equally important when evaluating treatment effectiveness. This observation is consistent with contemporary patient-centered approaches in implant dentistry, which emphasize functional rehabilitation and long-term quality of life rather than implant survival alone [34].

Nevertheless, comparison among the included studies reveals substantial methodological heterogeneity that should be considered when interpreting the available evidence. Differences were observed in patient selection criteria, implant design, manufacturing techniques, fixation methods, surgical protocols, prosthetic rehabilitation strategies, and duration of follow-up. Furthermore, outcome measures were inconsistently reported across studies, with some investigations emphasizing implant survival while others focused on patient satisfaction or radiographic stability. Such heterogeneity limits direct comparison and prevents the establishment of definitive conclusions regarding the superiority of one surgical protocol over another. Similar concerns have been highlighted in recent evidence syntheses evaluating digital implant rehabilitation, where variability in study methodology was identified as one of the principal barriers to high-quality evidence synthesis [35].

Another noteworthy finding is the limited availability of comparative clinical studies evaluating customized subperiosteal implants against alternative treatment modalities. Only a small number of studies directly compared customized subperiosteal implants with zygomatic implants or extensive bone augmentation procedures. Existing comparative evidence suggests that customized subperiosteal implants may reduce sinus-related complications, minimize donor-site morbidity, and shorten rehabilitation time while maintaining comparable implant survival. However, because these conclusions are primarily derived from retrospective observational studies, they should be interpreted cautiously. Well-designed prospective comparative studies and randomized controlled trials remain necessary to determine the relative effectiveness, safety, cost-effectiveness, and long-term clinical performance of customized subperiosteal implants compared with other advanced reconstructive approaches.

Overall, the accumulated evidence indicates that customized subperiosteal implants represent an increasingly valuable treatment option within modern implant dentistry. Their combination of digital planning, patient-specific manufacturing, and favorable short- to medium-term clinical outcomes provides a strong foundation for broader clinical implementation. Nevertheless, standardized treatment protocols, consistent outcome reporting, and high-quality comparative research remain essential to strengthen the evidence base and facilitate widespread evidence-based adoption in routine clinical practice.

C. STUDY LIMITATIONS, FUTURE PERSPECTIVE, AND PRACTICAL IMPLICATIONS

Although the findings of this systematic review support the clinical potential of customized subperiosteal implants (CSIs) for the rehabilitation of severe alveolar bone atrophy, several methodological limitations should be considered when interpreting the available evidence. First, the overall quality of evidence remains limited because the majority of the included studies consisted of retrospective cohort studies and case series, while high-level evidence such as randomized controlled trials and prospective multicenter studies was absent. Observational study designs are inherently susceptible to selection bias, information bias, and uncontrolled confounding variables, thereby limiting the strength of causal inferences that can be drawn from the reported outcomes [36]. Consequently, although the reported implant survival rates and functional outcomes are encouraging, they should be interpreted with appropriate caution until validated by more robust clinical investigations.

Second, considerable heterogeneity was identified across the included studies. Variations were observed in participant characteristics, severity of alveolar bone atrophy, implant design, manufacturing technology, surgical technique, fixation protocols, prosthetic loading strategies, follow-up duration, and outcome assessment methods. Such heterogeneity reduced the comparability of individual studies and precluded quantitative meta-analysis. Furthermore, differences in clinical reporting made it difficult to identify which specific components of the digital workflow contributed most significantly to favorable clinical outcomes. Similar methodological challenges have been recognized in recent systematic reviews evaluating digitally assisted implant rehabilitation, emphasizing the need for standardized reporting guidelines and harmonized clinical outcome measures [37].

Another limitation relates to the relatively short follow-up periods reported in most studies. Although implant survival rates remained high during the first year and were generally maintained throughout medium-term follow-up, only a limited number of investigations evaluated outcomes beyond five years. Consequently, evidence regarding the long-term biomechanical stability, prosthetic durability, marginal bone remodeling, and biological complications associated with customized subperiosteal implants remains insufficient. Longitudinal investigations with extended observation periods are required to determine whether the promising short-term outcomes observed in current studies

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can be sustained over longer periods of functional loading [38].

The present review is also subject to several limitations associated with the review methodology itself. Literature retrieval was restricted to PubMed (MEDLINE) and Google Scholar, which may have resulted in the omission of relevant studies indexed in other databases such as Scopus, Embase, Web of Science, or the Cochrane Library. Furthermore, only articles published in English or French between 2020 and 2025 were considered eligible. Although this approach was intended to focus on contemporary digitally manufactured customized subperiosteal implants, language restrictions and publication date limitations may have introduced publication bias and reduced the comprehensiveness of the evidence base. In addition, practical constraints limited Google Scholar screening to the first 100 relevant records, which may have excluded potentially eligible studies appearing beyond the initial search results [39].

Despite these limitations, the findings of this review provide several important clinical implications. The available evidence suggests that customized subperiosteal implants represent a viable treatment option for patients with severe alveolar bone deficiencies who are unsuitable for conventional implant placement or who wish to avoid extensive bone augmentation procedures. The integration of CBCT imaging, CAD/CAM technology, and additive manufacturing has substantially improved implant adaptation, primary stability, and prosthetic rehabilitation while reducing surgical invasiveness. These technological developments have renewed clinical interest in customized subperiosteal implants and support their increasing incorporation into contemporary digital implant dentistry.

Future research should prioritize well-designed multicenter prospective cohort studies and randomized controlled trials involving larger patient populations and standardized clinical protocols. Future investigations should incorporate uniform outcome measures, including implant survival, prosthetic success, peri-implant tissue health, patient-reported outcome measures (PROMs), oral health-related quality of life, and cost-effectiveness analyses. Comparative studies evaluating customized subperiosteal implants against zygomatic implants, short implants, and advanced bone augmentation techniques would provide valuable evidence to guide treatment selection under different clinical conditions. Furthermore, future developments in artificial intelligence, automated implant design, finite element analysis, and patient-specific biomechanical simulation may further optimize implant planning, reduce manufacturing variability, and improve long-term treatment predictability [40].

Overall, the evidence synthesized in this review indicates that customized subperiosteal implants have evolved into a clinically promising rehabilitation strategy supported by modern digital technologies. Nevertheless, broader clinical adoption should be accompanied by rigorous scientific validation through high-quality clinical research to establish standardized treatment guidelines and strengthen evidence-based practice in implant dentistry.

V. CONCLUSION

This systematic review aimed to comprehensively evaluate the clinical effectiveness, implant survival, functional rehabilitation, and postoperative outcomes of digitally fabricated customized subperiosteal implants (CSIs) for the treatment of patients with severe alveolar bone atrophy who are unsuitable for conventional endosseous implant placement. Based on the synthesis of 11 eligible clinical studies identified from an initial 6,101 records, the findings demonstrate that contemporary CSIs designed using digital workflows integrating Cone Beam Computed Tomography (CBCT), Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM), and additive manufacturing technologies represent a reliable and minimally invasive treatment alternative for complex implant rehabilitation. Across the included studies, implant survival rates ranged from 93.75% to 100% during the first year of follow-up and remained between 95.8% and 97.1% in studies reporting medium- to long-term follow-up of up to six years, indicating favorable clinical stability and predictable treatment performance. Furthermore, most postoperative complications were limited to manageable soft-tissue events, including transient swelling, localized bleeding, temporary implant exposure, and peri-implant inflammation, while serious biological or mechanical failures were relatively uncommon. These findings suggest that advances in digital planning and patient-specific manufacturing have substantially improved implant adaptation, prosthetic accuracy, and functional rehabilitation compared with conventional subperiosteal implant techniques. Nevertheless, the current evidence remains constrained by the predominance of retrospective cohort studies and case series, heterogeneous surgical protocols, relatively small sample sizes, and inconsistent outcome reporting, thereby limiting the overall strength and generalizability of the available evidence. Therefore, although customized subperiosteal implants demonstrate considerable promise as an alternative treatment for patients with severe jaw atrophy, broader clinical implementation should be supported by stronger scientific evidence. Future research should prioritize well-designed multicenter prospective cohort studies and randomized controlled trials with larger study populations, standardized surgical and prosthetic protocols, longer follow-up periods, and comprehensive evaluation of implant survival, peri-implant tissue health, patient-reported outcome measures, oral health-related quality of life, and cost-effectiveness. Such investigations will be essential for establishing evidence-based clinical guidelines and optimizing the long-term application of customized subperiosteal implants in contemporary digital implant dentistry.

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DATA AVAILABILITY

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No datasets were generated or analyzed during the current study.

AUTHOR CONTRIBUTION

Imen Raâdani conceptualized and designed the study, conducted data collection, and participated in data analysis and interpretation. Yasmine Ayedi participated in the literature review, data collection and contributed to manuscript writing and revisions. Hend Ouertani assisted with data analysis and interpretation and provided critical feedback on the manuscript. All authors reviewed and approved the final version of the manuscript, and agreed to be responsible for all aspects of the work ensuring integrity and accuracy.

DECLARATIONS

ETHICAL APPROVAL

Not applicable.

CONSENT FOR PUBLICATION PARTICIPANTS

Consent for publication was given by all participants.

COMPETING INTERESTS

The authors declare no competing interests.

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