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Hybrid implant-supported rehabilitation of severely atrophic jaws using custom-made subperiosteal and conventional endosseous implants: A retrospective case series

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ABSTRACT

Severe alveolar bone atrophy represents a major challenge for implant-supported rehabilitation of the maxilla and mandible. While custom-made subperiosteal implants and conventional endosseous implants have each been proposed as graftless solutions in selected clinical scenarios, the outcomes of hybrid rehabilitations combining both implant systems within the same jaw have not yet been investigated. The aim of this retrospective study was to evaluate the clinical and radiological outcomes of hybrid implant-supported rehabilitations using custom-made subperiosteal implants in combination with conventional endosseous implants in patients with severe maxillary and/or mandibular atrophy.

Fourteen consecutive patients affected by advanced jaw atrophy and heterogeneous residual bone availability were included. A total of 20 custom-made subperiosteal implants and 48 conventional endosseous implants were placed to support fixed full-arch or segmental prosthetic rehabilitations. Implant survival, success, biological and mechanical complications, and peri-implant soft tissue conditions were assessed over a mean follow-up of 22.1 months.

At the last follow-up, survival of both subperiosteal and endosseous implants was 100%, with all rehabilitations remaining functional. All endosseous implants fulfilled established success criteria, while all subperiosteal implants met a composite functional success endpoint. Peri-implant soft tissue conditions remained stable, and no prosthetic complications were observed. However, these findings should be interpreted in light of the retrospective design, limited sample size, and relatively short follow-up.

Within the limitations of this retrospective case series, hybrid rehabilitations combining custom-made subperiosteal and conventional endosseous implants may represent a promising and flexible graftless treatment option for severely atrophic jaws with heterogeneous bone availability.

1. Introduction

Severe alveolar bone atrophy remains a major challenge in implant-supported rehabilitation of the maxilla and mandible. In advanced Cawood and Howell class V–VI atrophies, the placement of conventional endosseous implants may be precluded by insufficient bone volume and unfavorable anatomical conditions, particularly in posterior regions but also in selected anterior or interforaminal segments. Traditionally, these clinical scenarios have been managed through extensive bone augmentation procedures, including sinus floor elevation, guided bone regeneration, onlay grafts, distraction techniques, or segmental osteotomies (Chiapasco et al., 2009; Schlund et al., 2016; Varol et al., 2016).

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Although effective, such approaches are associated with increased surgical morbidity, prolonged treatment times, higher costs, and a non-negligible risk of complications or graft failure (Laventure et al., 2022), leading many patients to refuse or discontinue these treatment pathways.

In recent years, graftless rehabilitation strategies have gained increasing attention as alternatives to reconstructive surgery in severely atrophic jaws. Various techniques have been proposed depending on the anatomical district involved, including the use of zygomatic, pterygoid and short and ultra-short implants (Aparicio et al., 2000; Candel et al., 2012; Rosenstein and Dym, 2020; Xu et al., 2020). Although these approaches may provide satisfactory outcomes in selected cases, they are often technically demanding, associated with a steep learning curve, and may expose patients to procedure-specific complications (D'Agostino et al., 2021; Gabriele et al., 2023). Moreover, their indications are frequently limited by patient-related anatomical constraints, and the resulting implant trajectory and prosthetic emergence may not always be optimal from a functional, hygienic, or biomechanical standpoint.

The renewed interest in subperiosteal implants represents a further development in graftless rehabilitation strategies applicable to both the maxilla and the mandible. Unlike historical subperiosteal frameworks, which were burdened by high complication rates and unpredictable long-term outcomes, the contemporary generation of custom-made subperiosteal implants benefits from advances in cone beam computed tomography, digital planning, CAD/CAM technologies, and additive manufacturing (Mommaerts, 2017; Gellrich et al., 2017). These innovations enable the fabrication of patient-specific titanium frameworks with accurate adaptation to the residual basal bone and rigid fixation to stable anatomical structures of the jaws (Mommaerts, 2017, 2019; De Moor et al., 2022). Recent clinical studies have reported encouraging survival rates and acceptable complication profiles for custom-made subperiosteal implants in both full-arch and segmental rehabilitations of severely atrophic maxillary and mandibular jaws (Cerea and Dolcini, 2018; Van den Borre et al., 2021; Van den Borre et al., 2022; Nemtoi et al., 2022; Dimitroulis et al., 2023; Herce-López et al., 2024; Vaira et al., 2024a; Vaira et al., 2024b; Roy et al., 2025; Vaira et al., 2025; Van den Borre et al., 2025).

To date, however, the available literature has focused exclusively on "pure" rehabilitations, either entirely supported by subperiosteal implants or exclusively by endosseous implants. This dichotomous approach does not fully reflect the clinical scenarios encountered in daily practice. In many patients, severe jaw atrophy is not uniformly distributed: areas of extreme bone deficiency may coexist with segments where residual bone volume is still sufficient to allow the placement of conventional endosseous implants. In such cases, pursuing a purely subperiosteal or purely endosseous strategy may result in overtreatment, unnecessary invasiveness, or suboptimal prosthetic design.

From a biological and biomechanical standpoint, a hybrid approach combining custom-made subperiosteal implants with conventional endosseous implants within the same rehabilitation may offer specific advantages. While subperiosteal implants rely on rigid fixation and load distribution rather than on osseointegration, the addition of osteointegrated supports may contribute to long-term prosthetic stability by providing a well-established bone–implant interface in segments where adequate bone is available. This concept may be particularly relevant in extensive rehabilitations where long-term maintenance of passivity, load control, and soft-tissue health is essential.

Furthermore, the surgical protocol required for custom-made subperiosteal implants typically involves a crestal preparation (Vaira et al., 2024a, 2024b, 2024c) to house the transmucosal abutments on basal bone, with the purpose of minimizing progressive bone remodeling beneath the abutment (Van den Borre et al., 2021; Vaira et al., 2024a). While effective in severely resorbed areas, this preparation necessarily implies the removal of residual crestal bone. When such an approach is adopted in sites where adequate bone volume is still present, it may compromise the possibility of placing a conventional endosseous implant at a later stage. In the event of biological or mechanical complications at the abutment level, the altered crestal anatomy may therefore limit or preclude predictable salvage with an osteointegrated implant.

From an evidence-based and medico-legal standpoint, this aspect is particularly relevant. Conventional endosseous implants are supported by several decades of robust clinical evidence, well-established success criteria, and widely accepted long-term outcomes (Albrektsson et al., 1986; Goker et al., 2025). In contrast, although the contemporary generation of custom-made subperiosteal implants has shown promising short- and mid-term results, the available evidence is inevitably more limited in volume and follow-up duration (Herce-López et al., 2024; Gellrich et al., 2025; Ruiz-Rincón et al., 2025). Choosing a less consolidated solution in an anatomical site where a well-documented alternative is feasible may expose both the patient and the clinician to avoidable biological, functional, and medico-legal risks.

Despite these considerations, the clinical outcomes of hybrid rehabilitations combining custom-made subperiosteal implants and conventional endosseous implants have not yet been investigated. As a result, the potential benefits and risks of this approach remain speculative, and no data are available to guide clinical decision-making when residual bone availability differs within the same jaw.

Therefore, the aim of the present retrospective study was to evaluate the clinical and radiological outcomes of hybrid implant-supported rehabilitations combining custom-made subperiosteal implants and conventional endosseous implants in severely atrophic maxillary and mandibular jaws. Implant survival, rehabilitation success, biological and mechanical complications, and peri-implant soft and hard tissue conditions were analyzed to provide the first clinical evidence on this novel and increasingly relevant treatment concept.

2. Materials and methods

2.1. Study design and patient selection

This retrospective observational study was conducted on consecutive patients who underwent hybrid implant-supported rehabilitation combining custom-made subperiosteal implants and conventional endosseous implants between December 2022 and December 2024 at the Maxillofacial Surgery Unit of the University Hospital of Sassari (Sassari, Italy). The study population consisted of partially or completely edentulous patients affected by severe maxillary and/or mandibular atrophy, generally corresponding to Cawood and Howell classes V or VI, in whom residual bone availability was heterogeneous within the same jaw.

Patients were included if they met all of the following criteria: (1) presence of at least one custom-made subperiosteal implant and one or more conventional endosseous implants within the same jaw; (2) fixed implant-supported prosthetic rehabilitation connecting both implant systems or supporting a unified prosthetic reconstruction; (3) availability of complete clinical, radiological, and prosthetic documentation; and (4) a minimum clinical follow-up of 12 months after functional loading. Patients rehabilitated exclusively with subperiosteal implants or exclusively with endosseous implants were excluded, as were cases involving removable prostheses only. The clinical records were also reviewed for major patient-related variables potentially influencing implant outcomes, including smoking habit, systemic conditions relevant to wound healing or osseointegration, and medications potentially affecting bone metabolism. These variables were collected descriptively from the available records.

The study was approved by the institutional Ethics Committee of the University of Sassari (approval number 22/2025). Owing to its retrospective design, no additional interventions were performed for research purposes. Reporting was conducted in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

2.2. Digital planning and treatment rationale

All patients underwent preoperative cone-beam computed tomography (CBCT) of the maxilla and mandible, with slice thickness ranging from 0.1 to 0.3 mm and a field of view adequate to include the entire jaw, relevant buttresses, and adjacent anatomical structures. Digital impressions of both dental arches were obtained, and a diagnostic wax-up was prepared for all cases to define the prosthetic objectives, occlusal scheme, and emergence profile.

Treatment planning was prosthetically driven and based on a site-specific evaluation of bone quantity, bone quality, and anatomical limitations. Conventional endosseous implants were planned in regions where sufficient native bone volume allowed predictable osseointegration without the need for augmentation procedures. Custom-made subperiosteal implants were selectively planned in areas of critical bone deficiency where endosseous implant placement would have required extensive grafting or was deemed unfeasible or excessively invasive.

DICOM data and STL files were imported into proprietary planning software (B&B Dental GS software, B&B Dental, San Pietro in Casale, Bologna, Italy) for three-dimensional reconstruction of the jaws and identification of critical anatomical structures, including the inferior alveolar nerve in mandibular cases and the maxillary sinus in maxillary cases. The STL models of the arches and wax-up were merged with the 3D bone models, and final implant planning was completed using Meshmixer software (Autodesk, San Rafael, CA, USA).

For subperiosteal implants, patient-specific titanium frameworks were designed to achieve intimate adaptation to the basal bone and rigid fixation to stable anatomical regions, while integrated abutments (cementable or multi-unit) were planned to be housed in crestal slots resting on basal bone. For endosseous implants, implant number, diameter, length, and angulation were defined according to standard prosthetic principles, with the aim of harmonizing the emergence and load distribution with the subperiosteal components. Particular attention was paid to the spatial relationship between the two implant systems to ensure prosthetic passivity and biomechanical compatibility.

The planning of conventional endosseous implants was also fully digital and prosthetically driven. Implant position, angulation, diameter, and length were defined within the same virtual workflow used for the subperiosteal implants with the aim of achieving optimal prosthetic emergence, parallelism with the subperiosteal abutments, and favorable load distribution within the hybrid rehabilitation. Surgical templates for guided placement of endosseous implants were designed based on the finalized digital plan.

2.3. Implant manufacturing

Custom-made subperiosteal implants were manufactured from grade V titanium using double laser melting technology (MYSINT100, Sisma, Piovene Rocchette, Italy). After additive manufacturing, the frameworks underwent heat treatment in a sintering furnace to stabilize the alloy and reduce residual porosity without inducing dimensional changes. Abutments were finished using a five-axis milling machine (Datron D5, Datron, Milford, NH, USA), and internal threads for multi-unit abutments were created when required.

All implants were cleaned using an organic solvent (DOWCLENE 1601, Dow Chemical Company, Midland, MI, USA) and sterilized according to the manufacturer's protocol. Dedicated cobalt–chrome surgical guides for crestal slot preparation were milled, and stereolithographic resin models of the jaws and implant frameworks were produced and provided to the surgeons for intraoperative reference.

Conventional endosseous implants were commercially available titanium implants (B&B dental, San Pietro in Casale, Bologna, Italy) with moderately rough surfaces, placed according to the manufacturers' recommendations.

2.4. Surgical protocol

All surgical procedures were performed by experienced maxillofacial surgeons under local anesthesia with articaine containing 1:100,000 epinephrine, with or without conscious intravenous sedation depending on patient preference and anesthesiological assessment. Subperiosteal and endosseous implants were placed either during the same surgical session or in a staged manner, depending on local anatomical conditions and prosthetic planning.

For subperiosteal implant placement, a full-thickness mucoperiosteal flap was raised along the edentulous crest with appropriately positioned releasing incisions to ensure tension-free closure. Crestal slots were prepared using the dedicated surgical guide to house the transmucosal abutments on basal bone. The jaw surface was then skeletonized as required to allow seating of the framework while preserving critical anatomical structures. The implant was inserted, passive fit was verified, and rigid fixation was achieved using grade V titanium osteosynthesis screws (2.0 or 2.3 mm diameter), with screw length determined according to the underlying bone thickness defined during planning.

Endosseous implants were placed following fully guided surgical protocols using tooth- or bone-supported surgical templates derived from the digital planning phase. In cases where subperiosteal and endosseous implants were placed during the same surgical session, particular attention was paid to the spatial coordination between the two implant systems to maintain prosthetic passivity and biomechanical compatibility and to avoid interference between drilling trajectories and subperiosteal fixation screws.

After completion of implant placement, periosteal releasing incisions were performed, and the flaps were advanced and sutured to achieve primary closure around the abutments. All patients received postoperative antibiotic therapy (amoxicillin and clavulanic acid 1 g twice daily for 6 days or equivalent in allergic patients), analgesics, and chlorhexidine mouth rinses.

2.5. Prosthetic protocol

Prosthetic rehabilitation was performed according to a unified protocol aimed at integrating both implant systems into a single functional and biomechanical construct. Immediate or early loading with a screw-retained provisional fixed prosthesis was performed in the majority of cases, either on the day of surgery or within 10–14 days.

The provisional prosthesis was periodically adjusted to optimize occlusion, passivity, and soft tissue conditioning. Definitive prostheses were delivered after a healing period of approximately six months, once peri-implant soft tissues had stabilized. Prosthetic design aimed to minimize cantilevers, ensure even load distribution between endosseous and subperiosteal supports, and facilitate oral hygiene.

2.6. Outcome measures and follow-up

Clinical and radiological follow-up was performed at regular intervals. The primary outcome measure was implant survival, defined as the maintenance of the implant (subperiosteal or endosseous) in situ and in function at the last follow-up. Secondary outcomes included rehabilitation survival, biological and mechanical complications, and peri-implant soft tissue conditions.

Soft tissue health around transmucosal abutments was assessed clinically at each follow-up visit, and peri-implant bleeding on probing (BOP) was recorded at six sites per endosseous implant or subperiosteal abutment using a standardized periodontal probe. BOP was evaluated according to the criteria described by Mombelli (Mombelli, 2005) ranging from 0 (indicating no bleeding) to 3 (denoting severe and extensive bleeding upon probing). An implant or abutment was considered BOP-positive when bleeding was observed at one or more probing sites within 30 s after gentle probing, and BOP-negative when no bleeding was detected. Suppuration, when present, was recorded

separately.

Exposure of the subperiosteal framework was clinically evaluated and classified using a five-stage exposure scale, ranging from absence of exposure (Grade 0) to exposure associated with clinical mobility of the framework (Grade 4). Each level was further divided into two subgroups, A and B, based on the presence or absence of painful or inflammatory symptoms (Vaira et al., 2024a, 2024b).

Radiological examinations, including panoramic radiographs and cone-beam computed tomography when indicated, were used to assess framework stability, integrity of fixation screws, and positional stability of the subperiosteal implants. For endosseous implants, peri-implant bone levels were evaluated to detect marginal bone loss and radiographic signs of peri-implant pathology. Bone remodeling beneath subperiosteal abutments was qualitatively assessed to exclude progressive radiolucencies, displacement of the framework, or loosening of fixation screws over time.

In the absence of universally accepted success criteria for contemporary custom-made subperiosteal implants, a composite functional success endpoint was adopted (Vaira et al., 2024b; Vaira et al., 2025c). Subperiosteal implants were considered successful when all of the following conditions were met: (1) the framework remained in situ and supported a functional fixed prosthetic rehabilitation; (2) no clinical mobility of the framework or abutments was detected; (3) no persistent or recurrent infection requiring major surgical revision or implant removal was observed; (4) peri-abutment soft tissue conditions were considered acceptable, with no exposure beyond the transmucosal abutment and no progressive or symptomatic exposure of the framework; and (5) radiological examinations confirmed stability of the framework and fixation screws without evidence of displacement, fracture, or progressive loosening. Minor, asymptomatic complications that were conservatively managed and did not compromise function or structural stability were not considered success failures.

The clinical success of conventional endosseous implants was evaluated according to the widely accepted criteria proposed by Albrektsson et al. (1986) These criteria included: (1) absence of persistent pain, discomfort, or neuropathies attributable to the implant; (2) absence of clinical implant mobility; (3) absence of continuous peri-implant radiolucency on radiographic examination; and (4) controlled marginal bone loss not exceeding 1.5 mm during the first year after functional loading and not exceeding 0.2 mm annually thereafter. Implants not fulfilling any of these criteria were classified as unsuccessful.

Clinical and radiological evaluations of both endosseous and subperiosteal implants were performed at standardized follow-up timepoints, including baseline assessment at prosthetic loading, 6 months and 12 months after loading, and annually thereafter.

2.7. Statistical analysis

Statistical analysis was performed using open-source software (Jamovi, version 2.717; www.jamovi.org). Descriptive statistics were used to summarize demographic, surgical, and prosthetic variables. Categorical variables were expressed as absolute numbers and percentages, and continuous variables as means ± standard deviations or medians and interquartile ranges, as appropriate. Implant and rehabilitation survival and success rates were calculated.

3. Results

A total of 14 patients (6 males and 8 females) were included in this retrospective study, with a mean age of 65.4 ± 8 years (range: 49–76 years) (Table 1). Hybrid implant-supported rehabilitations were performed in both jaws, involving 7 maxillae and 7 mandibles. Eight rehabilitations (57.1%) consisted of full-arch reconstructions, while six cases (42.9%) involved segmental rehabilitations, predominantly

Table 1
Demographic, surgical, and prosthetic characteristics of the study population.

Case ID	Sex/ Age (yrs)	Jaw	Rehab extent	No. of subperiosteal implants	No. of fixation screws	Subperiosteal implant connection type	No. of endosseous implants	Endosseous implant connection type	Prosthetic loading timing	Complications	Follow-up (months)
01	F/65	Maxilla	Full-arch	1	6	Multi-unit	5	Multi-unit	Immediate	None	36
02	M/ 72	Mandible	Segmental (posterior bilateral)	2	Left 6 Right 6	Multi-unit	2	Multi-unit	Early (14 days)	None	32
03	F/69	Maxilla	Segmental (posterior unilateral)	1	5	Multi-unit	1	Multi-unit	Immediate	Grade 1a exposure	30
04	M/ 75	Mandible	Full-arch	2	Left 7 Right 6	Multi-unit	4	Multi-unit	Immediate	None	28
05	F/63	Maxilla	Full-arch	1	6	Multi-unit	4	Multi-unit	Immediate	Screw loosening	26
06	M/ 49	Mandible	Full-arch	1	5	Multi-unit	6	Multi-unit	Early (15 days)	None	24
07	F/68	Maxilla	Full-arch	1	6	Multi-unit	5	Multi-unit	Immediate	None	24
08	F/54	Mandible	Full-arch	2	Right 6 Left 6	Multi-unit	4	Multi-unit	Early (10 days)	None	21
09	F/66	Maxilla	Segmental (posterior bilateral)	2	Right 6 Left 6	Multi-unit	4	Multi-unit	Early (2 weeks)	None	20
10	F/55	Mandible	Segmental (posterior bilateral)	2	Right 5 Left 5	Multi-unit	2	Multi-unit	Immediate	None	18
11	M/ 64	Maxilla	Full-arch	1	6	Multi-unit	3	Multi-unit	Immediate	None	14
12	M/ 73	Mandible	Segmental (posterior unilateral)	1	5	Multi-unit	2	Multi-unit	Early (14 days)	Episode of inflammation	13
13	F/67	Maxilla	Segmental (posterior unilateral)	1	6	Multi-unit	2	Multi-unit	Immediate	None	12
14	M/ 76	Mandible	Full-arch	2	Left 6 Right 5	Multi-unit	4	Multi-unit	Immediate	None	12

affecting posterior unilateral or bilateral regions (Fig. 1). The mean clinical follow-up was 22.1 ± 7.8 months (range: 12–36 months), and no patients were lost to follow-up during the observation period. Review of the clinical records showed that 2 patients were current smokers and 3 were former smokers. One patient was affected by type 2 diabetes mellitus, and 3 patients had pharmacologically controlled hypertension. No patient was receiving or had previously received antiresorptive therapy. Given the limited sample size and the absence of implant failures, no meaningful subgroup analysis could be performed, and no apparent association emerged between these variables and the reported outcomes.

A total of 20 custom-made subperiosteal implants were placed. Framework fixation was achieved using a total of 115 osteosynthesis screws, corresponding to a mean of 5.75 screws per subperiosteal implant. All subperiosteal implants were restored using multi-unit prosthetic connections. In addition, 48 conventional endosseous implants were placed, with a mean of 3.4 implants per rehabilitation, all featuring multi-unit connections and integrated into the same fixed prosthetic superstructure as the subperiosteal implants. In all cases, subperiosteal implants were positioned during the same surgical session as the endosseous implants, except for one maxillary rehabilitation in which the subperiosteal implant was placed 30 days after the initial endosseous implant surgery. In this case, intraoperative assessment revealed the absence of adequate primary stability for a planned pterygoid implant, leading to the intraoperative decision to plan a secondary rehabilitation with a subperiosteal implant (Fig. 2).

Immediate loading was performed in 9 cases (64.3%), while early loading protocols were adopted in 5 cases (35.7%), with prosthetic delivery occurring between 10 and 15 days after surgery. In all cases, a screw-retained provisional fixed prosthesis was delivered and subsequently replaced by a definitive fixed prosthesis after a standardized healing period of six months. No prosthetic complications were observed during follow-up, either in the provisional or in the definitive prosthetic rehabilitations.

At the last follow-up examination, all subperiosteal implants and all endosseous implants were still in situ and functional, resulting in an overall implant survival rate of 100% for both implant systems. Rehabilitation survival was also 100%, with all fixed prostheses remaining

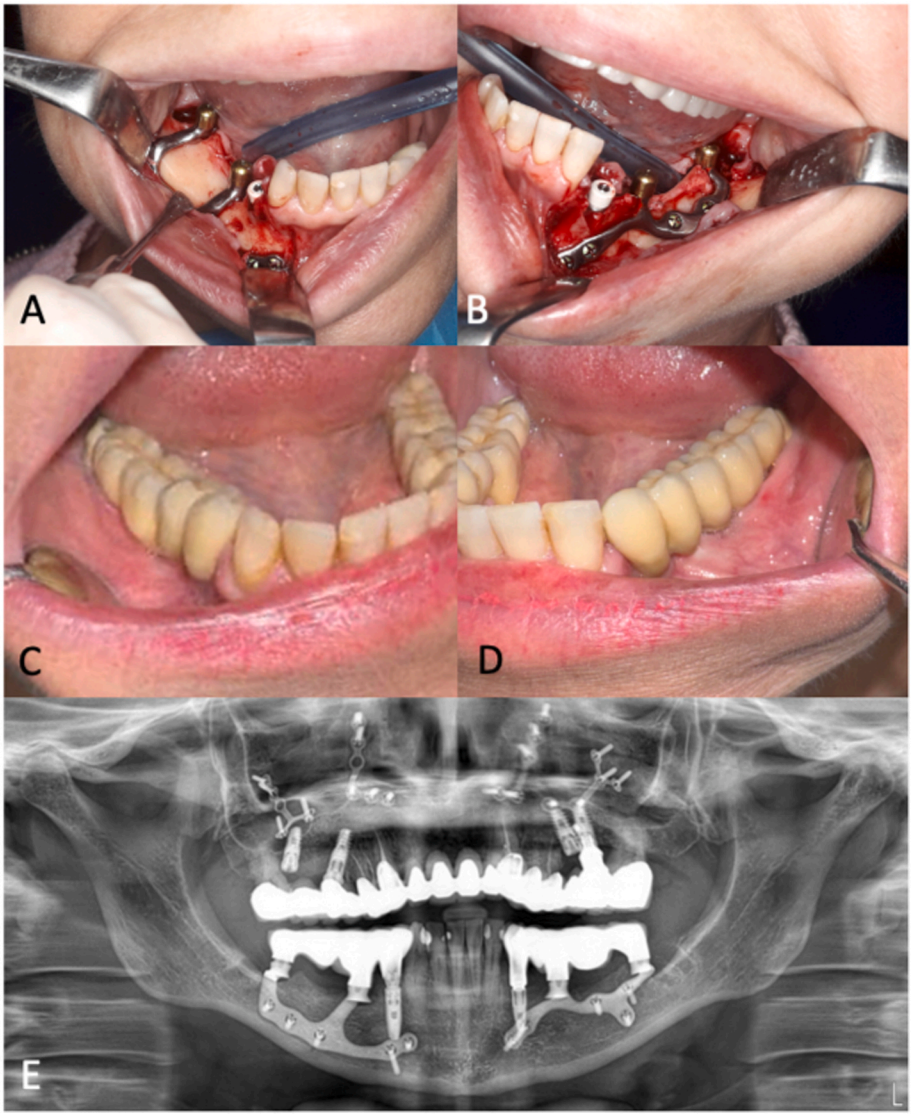

Fig. 1. Clinical and radiological documentation of Case 10/F/55. (A, B) Intraoperative views showing placement and fixation of the custom-made subperiosteal implant in the posterior mandibular region, combined with conventional endosseous implants in sites with adequate residual bone volume. (C, D) Intraoral views after delivery of the definitive fixed prosthetic rehabilitation, demonstrating satisfactory soft tissue healing, prosthetic integration, and functional outcome. (E) Postoperative panoramic radiograph confirming correct positioning and stability of the subperiosteal framework and endosseous implants supporting the hybrid rehabilitation.

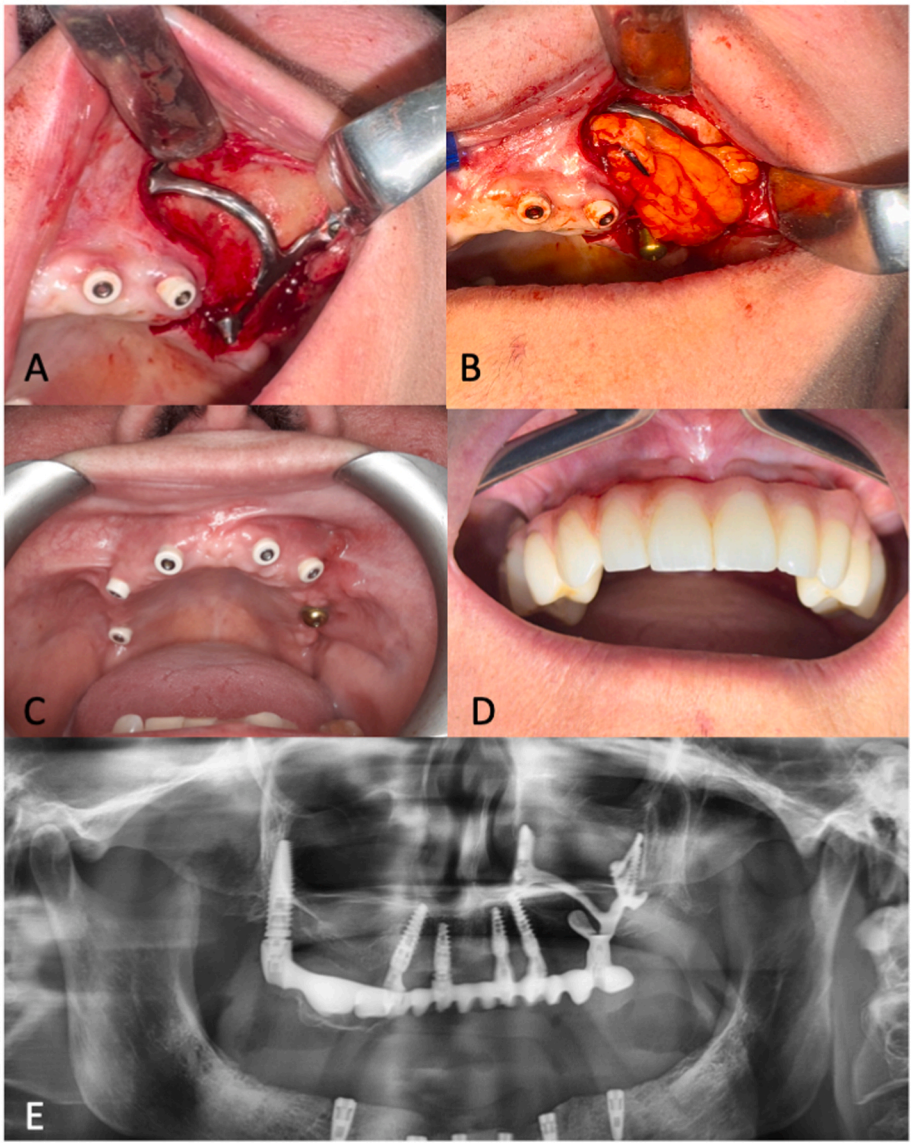

Fig. 2. Clinical and radiological documentation of Case 7/F/68, illustrating the use of a custom-made subperiosteal implant as a secondary graftless solution following intraoperative failure of a planned pterygoid implant due to inadequate primary stability. (A) Intraoperative view showing the custom-made subperiosteal implant positioned and rigidly fixed to the maxillary buttresses. (B) Intraoperative view after coverage of the subperiosteal framework with a pedicled buccal fat pad flap to increase soft tissue thickness and reduce the risk of postoperative exposure. (C) Intraoral view 12 months after the surgery showing the soft tissue healing. (D) Intraoral view after delivery of the definitive fixed prosthetic rehabilitation, showing satisfactory esthetic and functional integration. (E) Postoperative panoramic radiograph confirming correct positioning and stability of the subperiosteal framework and endosseous implants supporting the hybrid rehabilitation.

functional throughout the follow-up period.

The success of conventional endosseous implants was evaluated according to the criteria proposed by Albrektsson et al. (1986). Endosseous implants were assessed at standardized follow-up timepoints every 6 months during the first year after loading and annually thereafter. At 6-month and 1-year follow-up, all 48 endosseous implants met the success criteria, corresponding to a success rate of 100%. At the 24-month follow-up, 27 implants were available for analysis, and all were clinically stable, asymptomatic, and free from radiographic signs of peri-implant pathology. At 36 months, 5 endosseous implants remained under follow-up, all of which continued to meet the Albrektsson success criteria. No endosseous implant failed to meet the predefined success criteria at any evaluation timepoint.

Peri-implant and peri-abutment soft tissue conditions were assessed by recording bleeding on probing (BOP) at six sites per implant or transmucosal abutment according to the criteria described by Mombelli (Mombelli, 2005). The longitudinal distribution of BOP findings is summarized in Fig. 3 (Fig. 3). At the 6-month follow-up, BOP was absent around 43 of 48 endosseous implants (89.6%), while mild bleeding was detected around 5 implants (10.4%) without suppuration or increased probing depth. At the same timepoint, BOP was absent around 90.5% of subperiosteal abutments. At 12 months, 45 of 48 endosseous implants (93.7%) were BOP-negative, while 3 implants (6.2%) showed mild bleeding on probing; among subperiosteal abutments, BOP absence was recorded in 88.9% of sites. At 24 months, 25 of 27 endosseous implants (92.6%) were BOP-negative, while 2 implants (7.4%) showed isolated bleeding; BOP absence was observed in approximately 87% of subperiosteal abutments. At 36 months, 5 of 5 endosseous implants were BOP-negative, and subperiosteal abutments available at this timepoint showed stable peri-abutment soft tissue conditions, with BOP absence in all the cases. No cases of suppuration, progressive soft tissue breakdown, or peri-implant disease were observed at any timepoint.

In addition to survival, a composite functional success endpoint was applied to custom-made subperiosteal implants, based on maintenance

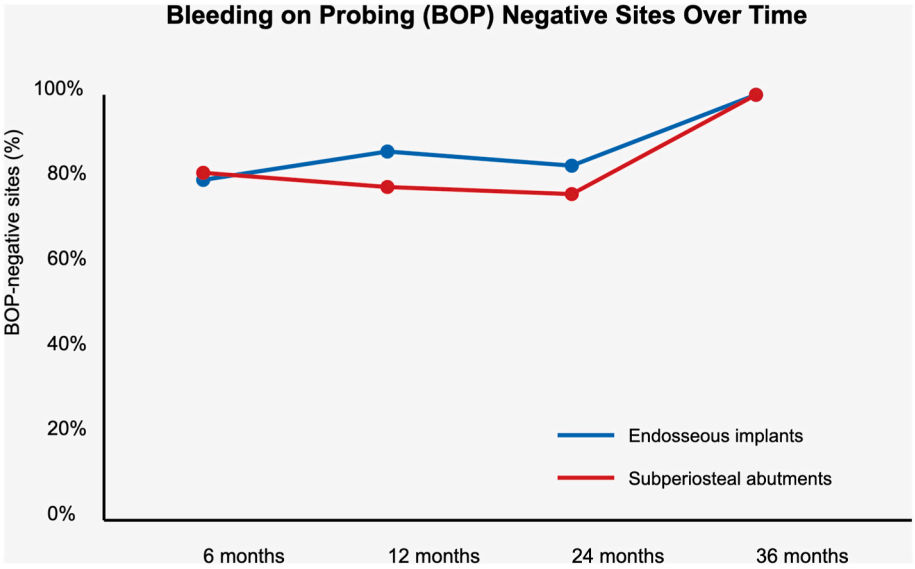

Fig. 3. Longitudinal evaluation of peri-implant soft tissue conditions based on bleeding on probing.

of a functional fixed prosthetic rehabilitation, absence of clinical mobility, absence of persistent or recurrent infection requiring major revision or removal, acceptable peri-abutment soft tissue conditions without clinically relevant exposure, and radiological stability of fixation without evidence of framework displacement or progressive loosening. According to these criteria, all 20 subperiosteal implants met the composite success definition at all available follow-up timepoints, resulting in a success rate of 100%. One minor Grade 1a exposure of a subperiosteal abutment and one episode of soft tissue inflammation were observed during follow-up; both were managed conservatively and did not compromise prosthetic function or framework stability. One case of prosthetic screw loosening was asymptomatic and resolved without inducing framework mobility or loss of function and was therefore not considered a success failure. No subperiosteal implant required partial or total removal.

4. Discussion

The present retrospective study represents, to the best of our knowledge, the first clinical report specifically investigating hybrid implant-supported rehabilitations combining custom-made subperiosteal implants and conventional endosseous implants within the same jaw. The results of this series suggest that this approach may constitute a predictable and clinically sound option for the management of severely atrophic maxillary and mandibular jaws with heterogeneous residual bone availability.

The principal finding of the study is the excellent short-to mid-term performance of hybrid rehabilitations, as demonstrated by 100% survival of both implant systems and 100% rehabilitation survival over a mean follow-up period of more than 22 months. Importantly, survival was paralleled by high success rates when more stringent, biologically meaningful criteria were applied. Conventional endosseous implants fulfilled the well-established Albrektsson success criteria at all evaluation timepoints, while custom-made subperiosteal implants met a composite functional success endpoint specifically tailored to their clinical and mechanical behavior. This distinction between survival and success is particularly relevant when evaluating implant systems characterized by different anchorage mechanisms.

The favorable outcomes observed for endosseous implants are consistent with the extensive literature supporting their long-term predictability even in compromised patients, provided that adequate native bone is available (Howe et al., 2019; Kupka et al., 2024). In the present series, the preservation and exploitation of residual bone for conventional implant placement avoided unnecessary grafting procedures and allowed the use of a highly consolidated treatment modality. From an evidence-based perspective, this strategy appears particularly justified, as endosseous implants remain the reference standard in implant dentistry with regard to documented long-term success and medico-legal defensibility.

The rationale for a hybrid approach is rooted in both biological and biomechanical considerations. Severe jaw atrophy is frequently segmental and non-uniform (Cawood and Howell, 1988; Pietrokovski et al., 2007), and a purely “all-or-nothing” strategy may not reflect the actual clinical needs of individual sites within the same jaw. The selective use of endosseous implants in areas with sufficient bone volume allows preservation of native bone and exploitation of osseointegration, while subperiosteal implants can be reserved for regions where endosseous placement would require extensive augmentation or present an unfavorable risk–benefit ratio.

From a biomechanical and prosthetic perspective, it is also important to contextualize the hybrid approach in relation to widely accepted graftless protocols such as the All-on-Four concept. Full-arch rehabilitation strategies based on implant placement in the premaxilla or interforaminal region, combined with distal angulation of posterior implants, are today well codified and supported by robust clinical evidence, demonstrating high survival rates and predictable outcomes (Sharaf et al., 2024). However, these approaches inherently limit the possibility of posterior prosthetic extension and may not allow adequate reduction of prosthetic cantilever length in patients requiring full molar rehabilitation in the presence of advanced posterior atrophy. In such clinical scenarios, especially when severe bone deficiency precludes the placement of posterior endosseous implants without augmentation, reliance on anterior anchorage alone may result in unfavorable biomechanical conditions with increased cantilever loads. The selective use of custom-made subperiosteal implants in the posterior regions may therefore represent a valuable adjunct, providing additional posterior support and allowing extension of the prosthetic reconstruction while maintaining a graftless approach (Fig. 4). Within this framework, subperiosteal implants should not be regarded as alternatives to established protocols such as All-on-Four, but rather as complementary solutions that expand the therapeutic armamentarium in complex atrophic cases where conventional graftless strategies reach their anatomical or biomechanical limits.

Importantly, when subperiosteal implants are used in combination

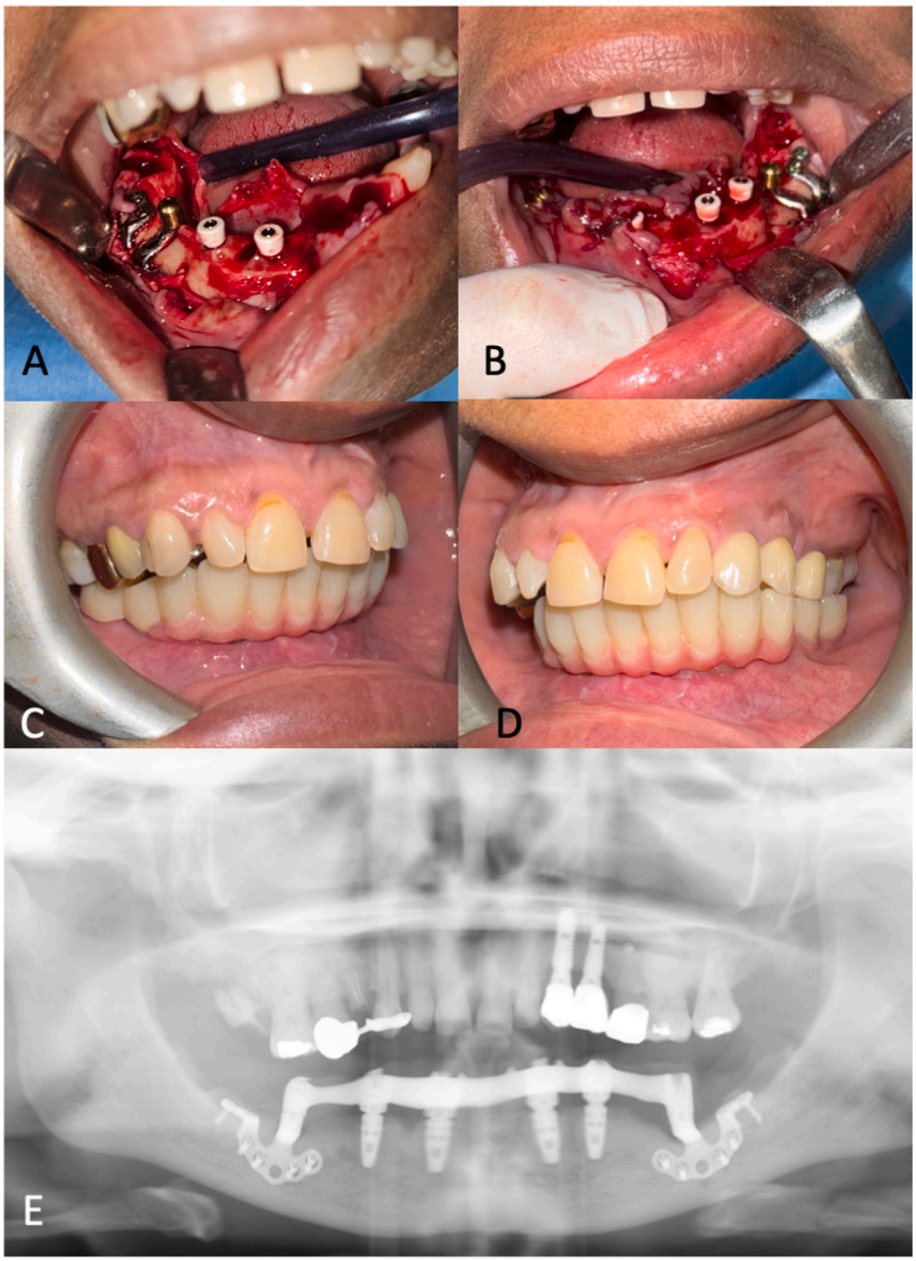

Fig. 4. Clinical and radiological documentation of Case 8/F/54, illustrating a hybrid full-arch mandibular rehabilitation. (A, B) Intraoperative views showing the custom-made subperiosteal implants positioned and rigidly fixed to rehabilitate the severely atrophic posterior sectors, while conventional endosseous implants were placed in the interforaminal region where sufficient native bone volume was available. (C, D) Intraoral views after delivery of the definitive fixed prosthetic rehabilitation, demonstrating stable peri-abutment soft tissues, satisfactory esthetic outcome, and functional occlusal integration. (E) Postoperative panoramic radiograph confirming correct positioning and stability of the subperiosteal framework and endosseous implants supporting the hybrid mandibular rehabilitation.

with endosseous implants, their design principles should not be modified or simplified compared with those adopted for purely subperiosteal rehabilitations. In the present series, subperiosteal frameworks consistently followed established design concepts, with fixation to stable anatomical buttresses rather than relying on adjacent endosseous implants for support. In maxillary rehabilitations, fixation was planned on the naso-maxillary and zygomatic–maxillary buttresses (Zielinski et al., 2023; Ronsivalle et al., 2025), whereas in mandibular cases fixation was achieved along the external oblique ridge and other basal bone areas (Parhiz et al., 2024; Arı et al., 2025). Adhering to these codified fixation principles is considered essential to ensure primary mechanical stability of the framework and to avoid transferring undue functional loads to the endosseous implants. This aspect reinforces the concept that, even within a hybrid rehabilitation, subperiosteal implants should be conceived as structurally autonomous devices rather than as accessory or secondary supports.

Beyond these general principles, the hybrid concept is supported by several procedure-specific surgical considerations. Placement of subperiosteal implants requires a deliberate crestal preparation to remove residual alveolar bone and position the transmucosal abutments directly on basal bone, with the aim of minimizing long-term bone remodeling and reducing the risk of progressive exposure beneath the abutments (Vaira et al., 2024a, 2024b; De Riu et al., 2025). While this approach is effective and justified in severely resorbed areas, it is inherently irreversible and implies the intentional removal of residual crestal bone. Consequently, when performed in anatomical regions where a conventional endosseous implant could have been placed primarily, this preparation may compromise or even preclude the possibility of

secondary endosseous implant placement in the event of future complications or need for revision. From this perspective, reserving subperiosteal abutments for sites of critical bone deficiency while preserving endosseous implant placement in favorable areas appears both biologically conservative and strategically prudent.

These considerations also have important medico-legal implications. Favoring a treatment option that currently relies on a more limited body of long-term evidence in anatomical sites where a well-documented gold standard exists may expose both the patient and the clinician to avoidable risks. Conventional endosseous implants placed in native bone are supported by decades of robust scientific evidence and represent the benchmark against which alternative solutions are evaluated (Howe et al., 2019; Kupka et al., 2024). A hybrid approach allows alignment of clinical decision-making with the hierarchy of available evidence, reducing the likelihood of choosing a less consolidated solution when a proven alternative is feasible.

Additional anatomical advantages of the hybrid approach become particularly evident in posterior mandibular rehabilitations (Fig. 1). When attempting to rehabilitate both mesial and distal sectors relative to the mental foramen using a single subperiosteal framework, the implant design often requires the framework to pass above the emergence of the mental nerve. In cases where the mental nerve presents a high or crestal emergence, this configuration may result in a very superficial positioning of the framework along the alveolar crest, increasing the risk of soft tissue dehiscence and late exposure (Vaira et al., 2024b). By separating the rehabilitation into distinct mesial and distal components—integrating endosseous implants anteriorly and subperiosteal support posteriorly—it is possible to design the subperiosteal framework to course deeper along the basal bone, and thereby reducing the risk of long-term exposure.

An additional, often overlooked advantage of the hybrid strategy lies in its modularity and adaptability over time. The coexistence of two implant systems within the same rehabilitation allows more selective and targeted management of potential future complications. In the event of a localized biological or mechanical issue, revision can often be limited to the affected component without necessitating complete reconstruction of the entire rehabilitative framework. This modular concept may contribute to improved long-term maintainability of complex rehabilitations in severely atrophic jaws.

From a broader clinical perspective, custom-made subperiosteal implants may also represent a valuable secondary or salvage solution in cases where other graftless rehabilitation strategies fail or prove impracticable. Techniques such as pterygoid or zygomatic implant placement, although effective in selected cases, are highly dependent on bone quality and the achievement of adequate primary stability (Lan et al., 2021; Ramezanzade et al., 2021; Brennand Roper et al., 2023). Intraoperative findings may therefore differ from preoperative planning, as observed in one of the cases of the present series, in which a planned pterygoid implant could not be placed due to insufficient bone quality and lack of primary stability. In such scenarios, subperiosteal implants offer a viable alternative that allows completion of the rehabilitation without resorting to extensive grafting procedures or abandoning the graftless treatment concept. This flexibility further supports the role of subperiosteal implants as part of a comprehensive, adaptive graftless rehabilitation strategy rather than as a rigid, stand-alone solution.

Soft tissue health around both implant systems was satisfactory over time, as indicated by consistently low bleeding on probing scores. Although peri-abutment bleeding was slightly more frequent around subperiosteal abutments compared with endosseous implants, no cases of suppuration, progressive tissue breakdown, or peri-implant disease were observed. This finding supports the notion that appropriate prosthetic design, accessibility for hygiene, and structured maintenance protocols are critical determinants of peri-implant tissue stability, regardless of the underlying implant anchorage mechanism.

Several limitations of the present study must be acknowledged. Its retrospective design, limited sample size, and relatively short follow-up preclude definitive conclusions regarding long-term outcomes. Although all patients had at least 12 months of follow-up and the mean observation period exceeded 22 months, this timeframe remains insufficient to draw robust conclusions on the long-term biological and mechanical stability of hybrid rehabilitations, particularly for custom-made subperiosteal implants. Moreover, the absence of a control group treated with purely subperiosteal or purely endosseous rehabilitations limits direct comparative analysis. In addition, although major patient-related variables potentially influencing implant outcomes, such as smoking habit, systemic conditions, and medications affecting bone metabolism, were reviewed descriptively, the limited sample size and absence of failures precluded any meaningful assessment of their potential impact on outcomes. Nevertheless, given the novelty of the treatment concept and the current lack of published data on hybrid rehabilitations, these findings provide meaningful preliminary evidence and a foundation for future prospective studies with larger cohorts, comparative designs, and longer follow-up periods.

5. Conclusions

In conclusion, within the limitations of this retrospective case series, hybrid rehabilitations combining custom-made subperiosteal implants and conventional endosseous implants demonstrated favorable short-to mid-term clinical and radiological outcomes, with high survival and success rates, stable peri-implant soft tissues, and a low incidence of manageable complications. These findings support the potential of this approach as a rational and flexible treatment option for severely atrophic jaws with heterogeneous bone availability, allowing site-specific selection of implant anchorage based on biological, anatomical, biomechanical, and evidence-based considerations. However, longer follow-up, larger patient cohorts, and prospective comparative studies are required before definitive conclusions can be drawn regarding long-term predictability and biological success.

Patient consent

All the patients signed written consent for the use of clinical photographs for scientific purpose.

Ethical approval

Formal ethical approval was obtained from the Institutional Ethics Committee of Sassari University Hospital (approval number 22/2025).

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Competing interests

All authors report no conflict of interest.

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