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Case Reports
Dental Implants

Clinical evidence of bone apposition and potential osseointegration in additively manufactured subperiosteal implants: a report of three cases

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Abstract. Subperiosteal implants were historically conceived as fixation-based devices rather than osseointegrated implants and were progressively abandoned due to unfavorable long-term outcomes. Recent advances in digital planning and additive manufacturing have led to the reintroduction of custom-made titanium subperiosteal implants; however, direct clinical evidence of osteointegration in humans has not been reported. This case series presents three patients rehabilitated with additively manufactured titanium subperiosteal implants who underwent surgical re-entry for the removal of loosened osteosynthesis screws associated with recurrent, non-infective inflammatory episodes. In all cases, intraoperative exploration revealed partial to complete bone coverage of the subperiosteal implant framework and the associated titanium fixation screws. Two patients showed complete bone coverage of the implant arms anchored to basal bone structures, while early bone apposition was observed in the third case. Removal of the loosened screws resulted in complete resolution of clinical symptoms in all patients. These findings provide direct clinical evidence of bone apposition and ossification and suggest the possibility of osseointegration in modern subperiosteal implants. Further clinical studies with larger cohorts and long-term follow-up are required to determine the impact of bone coverage and potential osteointegration on the long-term survival of contemporary subperiosteal rehabilitations.

Keywords: Subperiosteal implants; Osseointegration; Additive manufacturing; Titanium; Severe jaw atrophy.

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Subperiosteal implants were introduced in the mid-20th century as a rehabilitative option for edentulous patients with severe maxillary or mandibular atrophy, prior to the development of endosseous implantology. Early designs consisted of cast cobalt–chromium frameworks positioned beneath the periosteum and relied on broad surface contact and periosteal fixation rather than on direct bone–implant integration. These first-generation devices lacked osteointegration and generated stress shielding due to material mismatches in Young's modulus, resulting in biological instability and unfavorable long-term outcomes. Consequently, subperiosteal implants were progressively abandoned after the introduction of osseointegrated endosseous implants, which showed superior predictability and long-term survival[1].

In recent years, subperiosteal implants have been reintroduced for the management of severe jaw atrophy owing to advances in digital workflows, computer-aided design/computer-aided manufacturing planning, and additive manufacturing. Patient-specific titanium frameworks produced by laser melting techniques enable improved anatomical adaptation and rigid fixation to basal bone, overcoming many limitations of cast-based implants and allowing single-stage, graftless rehabilitations in selected cases[2,3].

Despite renewed clinical interest, the biological behavior of modern subperiosteal implants remains incompletely understood. Historically, they have been regarded as fixation-based devices rather than osseointegrated implants, distributing occlusal loads over a wide surface area without requiring intimate bone–implant contact[1,4]. However, experimental and preclinical studies have demonstrated that additively manufactured titanium and titanium alloy surfaces support osteoblast adhesion, bone apposition, and osteoconductive behavior, suggesting a potential biological interaction distinct from that of historical designs[5–7]. Moreover, rigidly fixed subperiosteal frameworks share conceptual similarities with titanium osteosynthesis plates used in maxillofacial surgery, which are known to undergo progressive bone apposition at the bone–implant interface[8].

To date, direct clinical evidence of osteointegration of modern subperiosteal implants in humans has not been reported. The purpose of this case report is to present clinical evidence of osteointegration observed in three patients rehabilitated with additively manufactured subperiosteal implants during surgical re-entry performed for the removal of osteosynthesis screws associated with recurrent inflammation.

Patients and methods

All patients were treated using a fully digital workflow[9,10]. A retrospective analysis was conducted on 124 patients who received a total of 211 additively manufactured titanium custom-made subperiosteal implants between 2018 and 2025 at the Maxillofacial Surgery Unit of the University of Sassari, Italy. Loosening of osteosynthesis screws was observed in eight cases. Among these, surgical re-entry was performed in four symptomatic patients. The present report includes three consecutive cases in which intraoperative findings demonstrated bone apposition and ossification over the implant framework and fixation screws (Table S1). One additional case, in which surgical re-entry was performed at an early stage (7 months after implantation), did not show evidence of bone coverage and was not included due to the short follow-up time.

Preoperative cone-beam computed tomography (CBCT) scans and digital impressions were acquired in all cases to allow prosthetically driven planning of custom-made subperiosteal implants. Virtual implant design was performed by merging DICOM and STL data, taking into account the planned prosthetic set-up, anatomical constraints, and established biomechanical principles for maxillary and mandibular applications. Patient-specific subperiosteal frameworks were designed to engage basal bone structures (nasomaxillary and zygomatic buttresses in maxillary cases, lateral cortical plate in mandibular cases) and to incorporate transmucosal abutments aligned with the prosthetic plan. All implants (B&B Dental, Argelato, Bologna, Italy) were manufactured from grade V titanium alloy (Ti6Al4V) using additive manufacturing by laser melting, followed by post-processing heat treatment to stabilize the alloy. All devices were produced as patient-specific custom-made implants in accordance with the European Medical Device Regulation (EU MDR 2017/745). As custom-made devices, they are not CE-marked as standard commercial products but were manufactured under a certified quality management system. Fixation was achieved using grade V titanium osteosynthesis screws with diameters of 2.0 mm (and 2.3 mm safety screws when required). Surgical placement was performed under local anesthesia, with elevation of full-thickness mucoperiosteal flaps, preparation of crestal slots for abutment housing, passive positioning of the framework, and rigid fixation to basal bone using osteosynthesis screws. Tension-free primary closure was obtained in all cases. Immediate or early loading with fixed provisional prostheses was performed in most patients, followed by delivery of definitive restorations after soft tissue maturation.

Case 1

A 54-year-old female smoker underwent a sectional rehabilitation of the posterior maxilla using a custom-made subperiosteal implant (Fig. 1A, B). The postoperative course was uneventful until 10 months after surgery, when the patient began to experience recurrent episodes of edema localized to the right zygomatic eminence. No clinical signs of infection were observed, and the swelling consistently regressed following short courses of corticosteroid therapy.

Over the subsequent four months, the patient experienced four additional episodes of self-limiting edema. Computed tomography (CT) performed during follow-up showed no evidence of infection, implant exposure, peri-implant bone loss, or mechanical complications involving the implant framework or fixation screws.

Following a fifth episode occurring 41 months after the initial surgery, a surgical exploration was performed through a vestibular approach. Intraoperatively, a loosened osteosynthesis screw was identified at the level of the zygomatic eminence and was removed. Intraoperative inspection revealed extensive bone apposition covering the anterior arm, the horizontal arm, and the proximal portion of the posterior arm of the implant. Overall, approximately 75% of the implant framework appeared covered by bone (Fig. 2A, B). After screw removal, the patient experienced complete resolution of symptoms, with no further

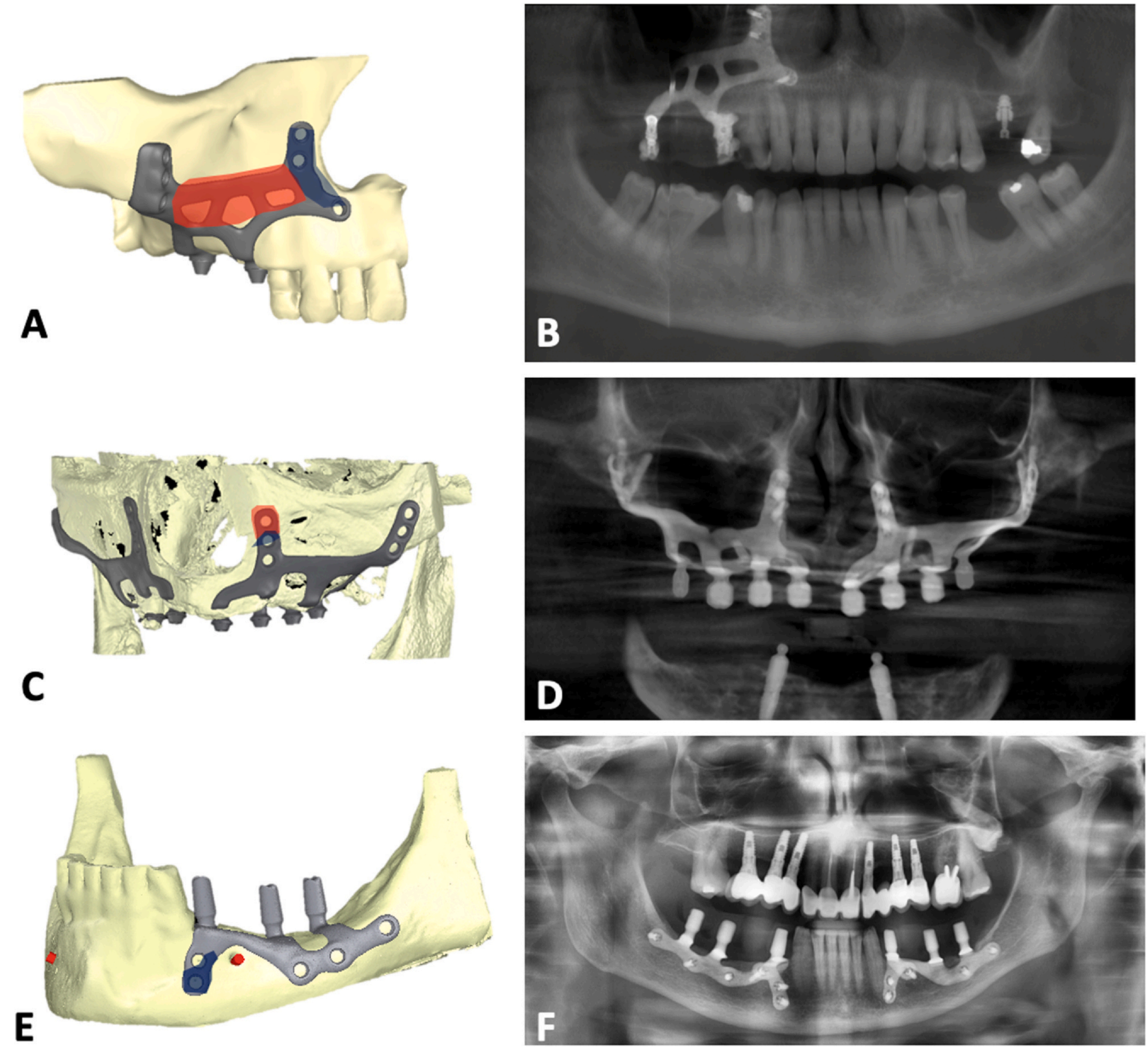

Fig. 1. Digital implant design, areas of bone apposition, and corresponding panoramic imaging. (A, C, E) Graphical representations of the patient-specific subperiosteal implant frameworks. Areas of bone apposition observed during surgical re-entry are highlighted: red indicates regions of complete bone apposition, while blue indicates regions of partial bone apposition. (B, D, F) Corresponding panoramic radiographs showing the subperiosteal implants in situ.

episodes of edema reported during follow-up.

Case 2

A 63-year-old female patient underwent full-arch rehabilitation of the maxilla using a custom-made additively manufactured subperiosteal implant (Fig. 1C, D). Six months after surgery, the patient developed episodic swelling localized to the left zygomatic eminence. The edema resolved within a few days following corticosteroid therapy and was not associated with pain, erythema, or other signs of infection.

Preoperative CT imaging was performed; however, it did not demonstrate any signs of screw loosening or structural implant failure. Given the recurrence of inflammatory episodes despite the absence of radiological findings, surgical re-entry was indicated. Twenty-eight months after the initial procedure, a vestibular approach to the left maxillary region was performed. A loosened osteosynthesis screw located at the most proximal fixation point on the nasomaxillary buttress was identified and removed, and subsequently replaced with a rescue screw. Intraoperative inspection of the corresponding implant arm revealed extensive bone apposition, with approximately 12 mm of the distal portion of the arm completely covered by bone. The bone appeared adherent to the implant surface and required partial removal to allow access to the fixation site (Fig. 2C, D). Postoperatively, the patient reported no further episodes of edema.

Case 3

A 54-year-old female patient underwent a left-sided posterior mandibular rehabilitation using a custom-made

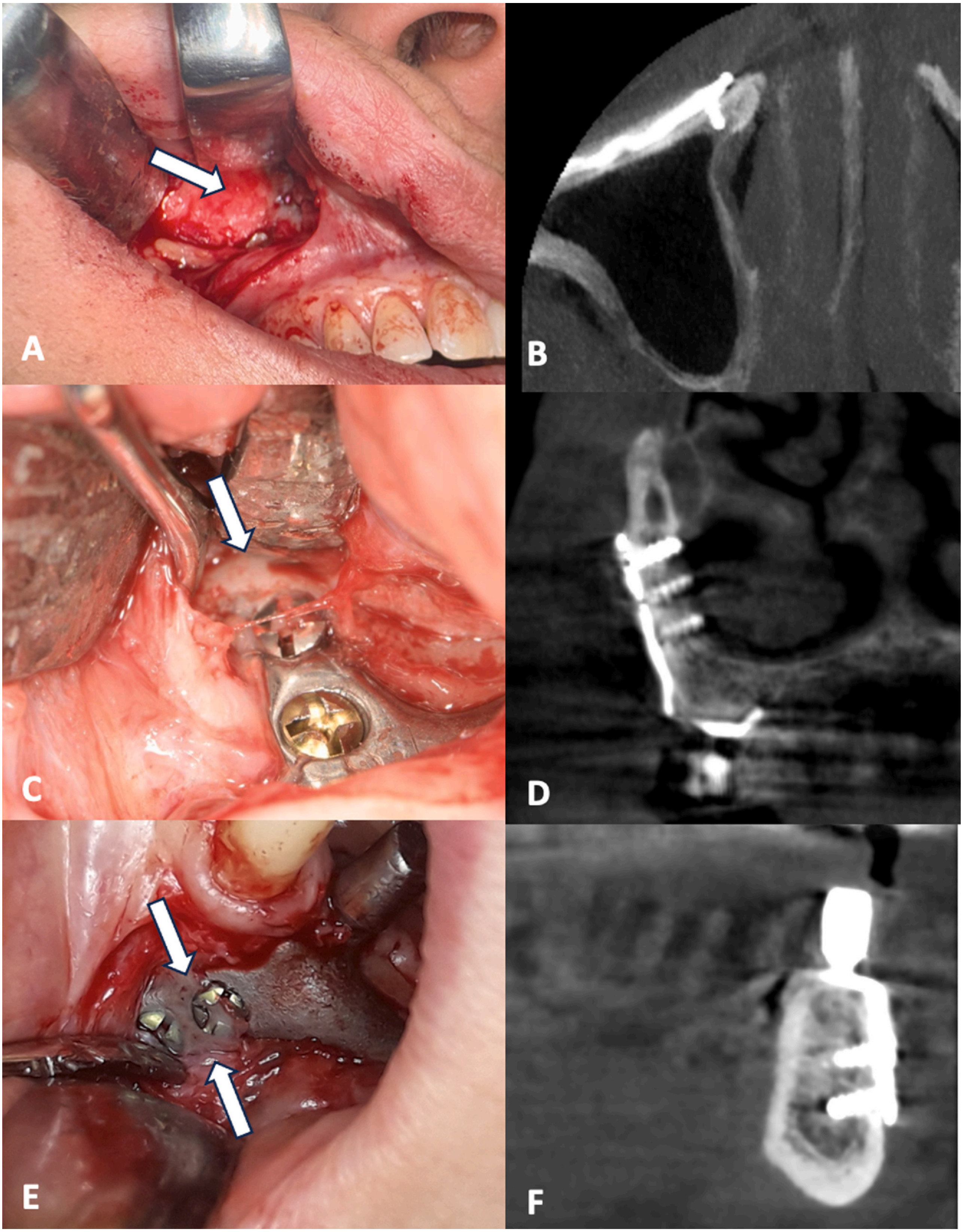

Fig. 2. Intraoperative findings and corresponding pre-re-entry computed tomography (CT) imaging. (A) Case 1: vestibular surgical access at the right nasomaxillary buttress showing extensive bone apposition coverage of the subperiosteal implant arm and fixation screws (arrow). (B) Corresponding pre-re-entry CT image of Case 1, in which no clear radiological signs of bone coverage or ossification are appreciable. (C) Case 2: surgical exploration of the left nasomaxillary buttress demonstrating complete bone apposition coverage of the distal portion of the implant arm (arrow). (D) Corresponding pre-re-entry CT image of Case 2, without evident radiological signs of bone apposition or ossification. (E) Case 3: mandibular re-entry revealing bone apposition involving the implant framework and adjacent fixation screws at the anterior arm (arrows). (F) Corresponding pre-re-entry CT image of Case 3, in which bone coverage is not clearly detectable.

subperiosteal implant (Fig. 1E, F). During follow-up, the patient developed recurrent episodes of localized edema in the treated region. Preoperative CT imaging was obtained but did not reveal evidence of screw loosening or implant-related complications. Due to the persistence and recurrence of non-infective inflammatory episodes, surgical re-entry was therefore performed 34 months after the first surgery.

Through a surgical re-entry approach, one loosened osteosynthesis screw located in the posterior portion of the implant was identified and removed, leading to complete resolution of the clinical symptoms. Intraoperative exploration demonstrated partial bone apposition involving approximately the distal 10 mm of the anterior arm of the implant involving both the implant framework and the associated osteosynthesis screws (Fig. 2E, F).

Discussion

The present case series provides direct intraoperative evidence of bone apposition and progressive bone coverage over additively manufactured titanium subperiosteal implants and their osteosynthesis screws in three patients undergoing surgical re-entry. In all cases, the implants had been originally placed as fixation-based devices, and surgical exploration was indicated for the management of recurrent inflammatory episodes associated with screw loosening rather than suspected implant failure.

From a clinical standpoint, an important consideration emerging from the present cases is the limited sensitivity of radiological imaging in detecting screw loosening in subperiosteal implants. In two of the three cases, preoperative CT imaging did not reveal any signs of mechanical failure or loosening, despite the presence of recurrent symptoms[11]. This suggests that radiological findings alone may underestimate minor mechanical complications, and that clinical symptoms should play a central role in decision-making. In the present series, the indication for surgical re-entry was therefore based primarily on the recurrence of localized inflammatory episodes rather than on radiological evidence. Furthermore, no microbiological sampling or laboratory investigations were performed, as all clinical presentations were consistent with aseptic inflammatory reactions rather than infection. In all cases, the edema was transient, not associated with pain or systemic signs, and responded promptly to corticosteroid therapy, supporting a non-infective etiology.

Nonetheless, intraoperative findings consistently demonstrated partial to complete bone coverage of the implant framework and fixation screws, supporting the occurrence of a biological bone–implant interaction beyond simple mechanical stabilization. These observations challenge the traditional concept that subperiosteal implants function exclusively as non-osseointegrating devices[1,4] and suggest that contemporary designs may undergo progressive bone apposition and potentially osseointegration in vivo, although definitive confirmation would require histological evidence.

From a biological standpoint, the osteointegrative potential observed in these cases is consistent with a growing body of experimental evidence on additively manufactured titanium and titanium alloy surfaces[5–7]. In-vitro studies have demonstrated that laser-melted Ti and Ti6Al4V surfaces promote osteoblast adhesion, proliferation, and osteogenic differentiation, with up-regulation of key markers involved in bone formation and mineralization, including RUNX2, osteocalcin, and osterix[5–7]. These effects are strongly influenced by surface micro- and nano-topography generated by additive manufacturing and post-processing treatments, which enhance osteoconductivity and bone–implant contact[5]. Preclinical models further support this concept, showing direct bone apposition, bone ingrowth, and high bone-to-implant contact values on subperiosteal and onlay titanium constructs manufactured by selective laser melting, even when placed on cortical bone surfaces rather than within endosseous sites.

Importantly, the clinical behavior observed in the present cases mirrors that reported for titanium osteosynthesis plates used in maxillofacial traumatology[8]. Although fixation plates are not classified as dental implants and are traditionally regarded as temporary devices, multiple experimental and clinical studies have demonstrated progressive bone apposition and intimate bone–implant contact at the interface between titanium plates and cortical bone[8]. This phenomenon is facilitated by rigid fixation, mechanical stability, and the intrinsic biocompatibility of titanium alloys. Modern subperiosteal implants share these fundamental characteristics—namely, patient-specific adaptation, rigid fixation to basal bone with titanium screws, and prolonged functional loading—providing a plausible mechanistic explanation for the osteointegration observed in the present cases.

Alternative biological mechanisms should also be considered when interpreting these findings. The observed bone coverage may reflect periosteal bone apposition stimulated by surgical elevation and reattachment of the periosteum, a process well documented in maxillofacial surgery[12]. Additionally, the pattern of bone deposition is reminiscent of plate-like bone overgrowth observed in titanium osteosynthesis systems, where rigid fixation and mechanical stability promote progressive bone formation over the implant surface[8]. The possibility of heterotopic ossification cannot be excluded, particularly in response to local mechanical and biological stimuli[13]. Taken together, these considerations suggest that the intraoperative findings are consistent with bone apposition and ossification at the implant interface; however, in the absence of histological or quantitative analysis, it is not possible to definitively distinguish between these mechanisms or to confirm true osseointegration.

From a clinical perspective, the possibility that contemporary subperiosteal implants may undergo osteointegration has relevant implications for their long-term behavior and stability. Osteointegration could contribute to improved load distribution, reduced micromovement, and enhanced resistance to mechanical fatigue over time, potentially increasing implant survival compared with historical cast-based designs. However, it must be emphasized that long-term survival data for modern additively manufactured subperiosteal implants remain limited, and the relationship between osteointegration and clinical outcomes has yet to be fully elucidated. The absence of bone apposition in an early re-entry case (7 months after implantation) may suggest that bone formation over subperiosteal implants is a time-dependent process.

A key limitation of the present report is the absence of histological or retrieval analysis. Although intraoperative findings demonstrated clear bone apposition and ossification over the implant framework and fixation screws, no biopsies were obtained during surgical re-entry. This was due to the therapeutic nature of the procedure, which was limited to the removal of loosened screws, and the lack of clinical indication for additional bone or implant sampling that could have increased patient morbidity. As a result, the macroscopic intraoperative observations cannot definitively distinguish between true osseointegration, dense fibrous apposition, or reactive periosteal bone formation. Therefore, the present findings should be interpreted as clinical evidence of bone–-implant interaction rather than conclusive proof of osseointegration. Histological or quantitative analyses would be required to confirm the exact nature of the interface.

An additional limitation is related to case selection, as surgical re-entry was performed only in symptomatic patients presenting with screw loosening. This introduces a potential observational bias and raises the possibility that the observed bone apposition may represent a reactive process secondary to local inflammatory stimuli rather than a primary biological response to the implant.

However, in the present cases, no signs of infection were detected clinically or radiologically, and the inflammatory episodes were transient and non-infective. Furthermore, the intraoperative findings showed structured and extensive bone coverage involving both the implant framework and fixation screws, which may suggest a progressive and organized bone formation process. Nevertheless, a multifactorial origin, including mechanical stability, periosteal response, and local inflammatory stimuli, should be considered.

Another limitation of the present study is the absence of quantitative radiological analysis. No measurements of bone-to-implant contact, densitometric changes, or volumetric bone remodeling were performed. This is partly due to the limitations of CT and CBCT imaging in the presence of metallic implants, where artifacts and the extraosseous positioning of subperiosteal frameworks hinder accurate quantitative assessment. Moreover, in none of the pre-re-entry CT scans was it possible to clearly identify signs of bone coverage or ossification of the implant framework. Therefore, the present findings are based on qualitative imaging evaluation and direct intraoperative observations. In this context, the role of aseptic inflammatory mechanisms should also be considered. Mechanical loading, micromotion, or partial loosening of fixation screws may lead to the release of titanium particles at the implant–bone interface. These particles have been shown to induce local inflammatory responses through macrophage activation and cytokine release, even in the absence of bacterial infection[14]. Such aseptic inflammation may contribute to the clinical presentation observed in these cases, characterized by recurrent, non-infective edema responsive to corticosteroids. At the same time, inflammatory mediators are known to interact with bone remodeling pathways, potentially promoting both bone resorption and new bone formation depending on the local microenvironment[14]. Therefore, the observed bone apposition may result from a complex interplay between mechanical stability, periosteal response, and inflammation-related biological processes.

A further limitation is related to sample selection. The cases included in this report were identified based on the occurrence of complications requiring surgical re-entry, and therefore do not represent a random or prospective sample of all treated patients. Consequently, it is not possible to determine whether similar patterns of bone apposition are present in asymptomatic cases that did not undergo re-entry. However, it should be emphasized that surgical re-entry provided a unique opportunity to directly observe the implant–bone interface in vivo, which is not accessible in uneventful cases. Therefore, the present findings should be interpreted as descriptive observations rather than representative outcomes.

Finally, the small sample size and the lack of sex heterogeneity, with all included patients being female, further limit the generalizability of the findings. Larger and more diverse cohorts will be required to validate these observations.

While the findings reported here provide compelling clinical evidence of bone–implant integration, larger clinical series and long-term follow-up studies are required to determine whether this biological behavior translates into improved predictability and longevity of subperiosteal rehabilitations.

Ethical approval

This retrospective study was approved by the Ethics Committee of Sardinia (approval number 22/2025).

Patient consent

Obtained.

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Competing interests

None.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT-5 (OpenAI, San Francisco, CA, USA) for language editing and proofreading purposes only.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ijom.2026.05.026.

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