J Stomatol Oral Maxillofac Surg 000 (2024) 102206

Available online at ScienceDirect www.sciencedirect.com

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Original Article

Management of adverse effects following additively manufactured subperiosteal jaw implantation in the maxilla

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ARTICLE INFO

Article History:
Received 16 November 2024
Accepted 18 December 2024
Available online xxx

Keywords:
Dental implantation
Subperiosteal
Maxilla
Postoperative complications
Therapeutics

ABSTRACT

Objective: This expert opinion presents provisional guidelines for addressing complications associated with Additively Manufactured Subperiosteal Jaw Implants (AMSJI®) in patients with severe maxillary atrophy. AMSJI®'s custom design, supported by finite element analysis (FEA), allows precise placement that avoids critical anatomical structures and minimizes complications relative to alternative solutions.
Materials and Methods: Data were gathered through firsthand experiences, direct communications, two structured surveys and insights from international workgroup meetings.
Results: Minor complications, such as soft tissue recession with inflammation, can be managed through thorough patient selection and early intervention. Severe complications, such as ascending infections and mechanical issues (e.g., fractures of implant components), have been rare. Compared to zygomatic implants and bone grafting, AMSJI® demonstrates a favorable safety profile. Zygomatic implants may lead to severe issues like orbital cellulitis and diplopia, while bone grafting risks include graft resorption, loss, and donor site complications. To mitigate risks, selecting patients carefully and ensuring diligent follow-up are critical, especially in those with risk factors like smoking or bruxism. Improved imaging, planning, and FEA have further contributed to minimizing complications, reinforcing AMSJI®'s role in complex maxillary reconstructions and implant-supported prosthetics.
Conclusions: AMSJI® demonstrates high success rates but requires meticulous risk management. Key strategies involve carefully candidates by excluding those who are smokers, immunocompromised, or non-compliant, or diabetics with a history of infectious complications. Additionally, strict adherence to oral hygiene protocols is essential to optimize outcomes and minimize risks.Proactive management in these areas is crucial to optimize outcomes, ensure implant longevity, and support successful prosthetic rehabilitation.
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1. Introduction

The first additively manufactured subperiosteal jaw implant, known as AMSJI® (CADskills BV, Ghent, Belgium), was successfully implanted in 2011 to reconstruct a three-quarters maxillary defect in a four-year-old patient [1]. Notably, the two segments have remained stable and free from long-term complications for over 13 years. Since its introduction, AMSJI® has gained considerable traction, particularly for its capacity to provide a custom-made solution specifically designed for patients with severe residual alveolar crest atrophy in the maxilla and mandible (over 500 cases – company information). Despite their advantages, AMSJI placement carries inherent risks, as is typical of all reconstructive procedures, particularly those involving alloplastic materials and complex anatomical conditions. Adverse effects can manifest as minor complications or develop into more serious issues that can affect patient satisfaction and overall functionality. This manuscript aims to offer expert insights into the management of these adverse effects, focusing on strategies for prevention, early detection, and effective intervention for AMSJI in the maxilla.

2. Materials and methods

Clavien et al. proposed a new classification system for assessing negative outcomes in surgery, focusing on standardizing the evaluation of postoperative complications [2]. The study emphasized the need for a uniform, objective, and practical method to categorize surgical complications, enabling better comparison across studies and improving clinical decision-making. The classification ranked complications by severity, ranging from minor deviations in the postoperative course to life-threatening events or death. The system aimed to improve transparency in reporting surgical outcomes, foster clearer communication among healthcare professionals, and ultimately enhance patient safety and care quality. It defined *complications* as

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https://doi.org/10.1016/j.jormas.2024.102206
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Please cite this article as: M.Y. Mommaerts, Management of adverse effects following additively manufactured subperiosteal jaw implantation in the maxilla, Journal of Stomatology oral and Maxillofacial Surgery (2024), https://doi.org/10.1016/j.jormas.2024.102206

Table 1
Clavien-Dindo classification of surgical complications [2].

Grade I	Any deviation of the normal postoperative course without the need for pharmacological treatment or surgical, endoscopic and radiological intervention. Allowed therapeutic regimens are drugs as antiemetics, antypyretics, analgesics, diuretics, electrolytes and physiotherapy.
Grade II	Requiring pharmacological treatment with drugs other than allowed for grade 1 complications. Blood transfusion and total parenteral nutrition are also included.
Grade III	Requiring surgical, radiological, endoscopic intervention
IIIa	Intervention not under general anesthesia
IIIb	Intervention under general anesthesia

any deviation from the expected postoperative course, including asymptomatic issues. A *sequela* was described as an inherent "after-effect" of surgery, such as the inability to walk following a leg amputation. Additionally, the system acknowledged that surgery can be technically successful without complications but still result in failure. Dindo et al. refined the classification, and for the analysis in this article, Grade IV (life-threatening complications) and Grade V (death) were excluded (Table 1) [3]. The classification was then further adapted to address complications specific to ASMJI surgery (Tables 2 and 3).

Over an eight-year period, the author has systematically gathered information on complications reported by AMSJI practitioners. This includes insights from five international working group meetings, where complications, prevention strategies, and treatment protocols were discussed in detail. Risk factors for mucosal recession and mucositis have been retrospectively identified [4] and integrated into the evaluation process. In November and December 2024, surveys were conducted among 132 surgeons who collectively implanted AMSJI devices in 552 patients, with follow-up durations ranging from 3 months to 6 years. To ensure consistency and reflect the matured application of the technique, cases treated prior to 2018, when the concept was refined, were excluded from the survey analysis. As this study is not longitudinal but rather based on an expert opinion derived from communications, clinical observations, and survey data, it does not permit the assessment of complication evolution over time. However, the clinical management of complications was monitored until their resolution within the necessary observation period.

This article aims to address the majority of identified complications, though it does not claim to provide an exhaustive account or to offer definitive, evidence-based solutions. However, as the AMSJI inventor with access to extensive, current data, the author offers an expert perspective that may be of considerable value for AMSJI surgeons.

Table 2
Clavien-Dindo classification [3] adapted to AMSJI complications.

Grade 1		Recession around on a post, lack of osteointegration
Grade 2		Inflammation around a post, recession with inflammation
Grade 3		Ascending cheek infection (early)
	Grade 3a (not under general anesthesia)	Cellulitis/abscess, skin fistula, arm fracture, oroantral fistula
	Grade 3b (under general anesthesia - sometimes possible under local anesthesia)	Loop fracture, sinusitis caused by a screw penetrating the sinus, non-osteointegration

Table 3
Survey results.

Type of complication	
Lack of osteointegration	1
Inflammation around a post	2
Recession with inflammation	2
Ascending cheek infection	3
Cheek cellulitis	2
Skin fistula	1
Arm fracture	1
Oroantral fistula	
Loop fracture	
Sinusitis caused by screw penetrating the sinus	
Other	7

Out of 132 recipients, 9 responded following two email reminders. These 9 respondents collectively reported on 92 cases they had treated. Among the responses under "other," the following complications were reported: screw fracture, allergic reaction to titanium, loss of osseointegration due to uncontrolled diabetes and non-compliance (2), and four instances of buccal or palatal recessions without accompanying inflammation.

3. Results

The survey results are summarized in Table 1.

3.1. Grade 1 complications

Recession around a post, on its own, is not considered a complication. Action is only required if the recession becomes progressive, to prevent a Grade 2 complication, such as inflammation around the post. The condition of the buccal mucosa plays a crucial role in this phenomenon, with a thin gingival biotype being particularly susceptible. Vestibular fornix depth does not appear to be a factor [5,6], and mucogingival height is also unlikely to be involved [7] (Fig. 4). Non-progressive recession requires only monitoring. Monitoring is conducted through intraoral photo-documentation and measurements taken with a periodontal probe. To prevent progressive recession, a bioengineered acellular dermal matrix (BADM) graft, such as Geistlich Mucograft (Geistlich Pharma AG, Wolhusen, Switzerland), may be utilized. The authors' preferred techniques to increase buccal gum thickness include an apically repositioned flap with a beveled incision 2 mm palatal to the crestal height or a palatal connective tissue flap tucked under the buccal gingiva (Fig. 5). Each time, high horizontal periosteal relaxation incisions, performed at the end of flap elevation (to prevent late bleeding and cheek hematomas), ensure tension-free closure with precise epithelial approximation.

It is essential to monitor brushing habits, as excessive force can exacerbate the condition. For the first three weeks post-surgery, brushing around the wound area is prohibited. During the initial two postoperative weeks, a periodontal dressing (such as Coepack from GC Company, Alsip, USA, or Elemental Periodontal Dressing from Ora-Pharma, Horsham, USA) can help protect the site. Disinfection of the area is achieved using chlorhexidine 0.12% (e.g., PerioAid Intensive Care, Dentaid, Cerdanyola del Vallès, Spain) in a waterpik device.

Smoking cessation and controlled diabetes (HbA1c < 7.0%) can only be monitored. Recession in unreliable patients can be mitigated by avoiding their selection for treatment. Alternatively, with a properly signed informed consent, the associated risks may be accepted.

Micro-mobility due to a non-compliant diet or bruxism should be monitored over time in the absence of complaints. To prevent osteointegration failure, the number of osteosynthesis screws may be increased, provided there is sufficient bone stock. The shape of the AMJSI in the upper and lower jaw was modified in 2024 to direct forces to areas of increased bone density and thickness. Additionally, dietary restrictions should be enforced during the first three months, with clear communication to the patient that the temporary prosthesis is 3D printed from a weak polymer (NexDent, 3D Systems, Rock Hill, USA).

3.2. Grade 2 complications

Inflammation around a post can occur in immunologically susceptible patients and those with poor oral hygiene. Patients are often unaware of this condition. Treatment involves pocket lavage with a 0.12% chlorhexidine solution, followed by ultrasonic cleaning using Teflon-coated sonic and ultrasonic scaler tips performed by an oral hygienist.

Prevention strategies include using lozenges with probiotics, such as Lactobacillus reuteri (e.g., GUM PerioBalance, Sunstar, Chicago, USA), and a 0.05% chlorhexidine solution (e.g., PerioAid Active Control, Dentaid, Cerdanyola del Vallès, Spain) for six months. Alternatively, active oxygen gel (e.g., BlueM Oral Gel, Bluem Europe, Zwolle, The Netherlands) can be applied three times daily after tooth brushing.

Regular check-ups with an oral hygienist every three months are essential for patients with recurring inflammation to ensure proper management and prevention.

The same regimes are installed for patients with inflammation and progressive recessions. However, a palatal or tuberosity connective tissue graft with partial thickness flap tunneling may be considered in resistant cases [8].

3.3. Grade 3a complications

Insufficient follow-up is particularly concerning in smokers and diabetic patients. As early as the author's third case in 2016, it became evident that a carefully placed incision extending over the maxillary tuberosity—or a sufficiently posterior, cephalically oriented release incision—was essential. This approach allows a rotational cheek flap to cover the distal mucosal defect that arises when the flap is draped around the posts, starting from the anterior. In this particular case, failing to cover the distal aspect of the loop led to an ascending cheek infection. To address this, incision guides were developed and have proven invaluable in guiding the operator to extend the incision adequately posteriorly.

In addition to the previously mentioned pocket lavage, antibiotic treatment may become necessary. Key etiological agents of chronic periodontitis, including Porphyromonas gingivalis, Aggregatibacter actinomycetemcomitans, Prevotella intermedia, and Treponema denticola, are highly susceptible to a combination of amoxicillin and metronidazole [9–11]. While no studies have specifically addressed the rare instances of ascending cheek infections in terms of bacterial characterization, the author has observed positive outcomes using a combination of ciprofloxacin for three weeks alongside metronidazole during the first week perorally. Preventive measures before the event primarily focus on careful patient selection. To prevent recurrence, options such as a palatal or tuberosity connective tissue graft or a buccal fat pad flap may be considered.

In cases of cellulitis or abscess formation, the treatment follows a similar approach as previously described but includes flap surgery with debridement. If the infection drains spontaneously through a skin perforation, percutaneous removal of any loose osteosynthesis screws, along with fistula excision and aesthetic closure of the skin, is necessary.

Fractures of an AMSJI arm were a significant concern in the past, occurring in less than 0,08% of the arms, when the quality of cone-beam computed tomography (CBCT) could not be assured. These fractures can still arise, especially in patients with undiagnosed bruxism. Bruxers experience a significantly higher incidence of mechanical complications compared to non-bruxers when it comes to immediately loaded fixed complete dentures supported by implants in patients with a history of periodontitis [12]. Treatment involves removing the affected arm under local anesthesia, utilizing either a tungsten-carbide fissure drill or a narrow-diameter diamond disk, cutting through the branches connecting the arm to the looped frame (Fig. 1). The stability of the prosthetic solution may be jeopardized if this procedure must be performed more than once, as it depends on at least four of the six posts being appropriately distributed. Prevention mainly depends on eliminating non-resilient forces, such as those from porcelain bridgework or bruxism, and ensuring precise radiological imaging. Semi-automated and manual segmentation processes generate STL files that accurately depict bony morphology, scan prostheses, and double-scan markers. However, the quality of the original DICOM files significantly influences the fidelity of the rendered bone surface. In private practice, CBCT devices typically do not achieve the same resolution or produce artifact-free images as multidetector computed tomography devices found in hospitals. This

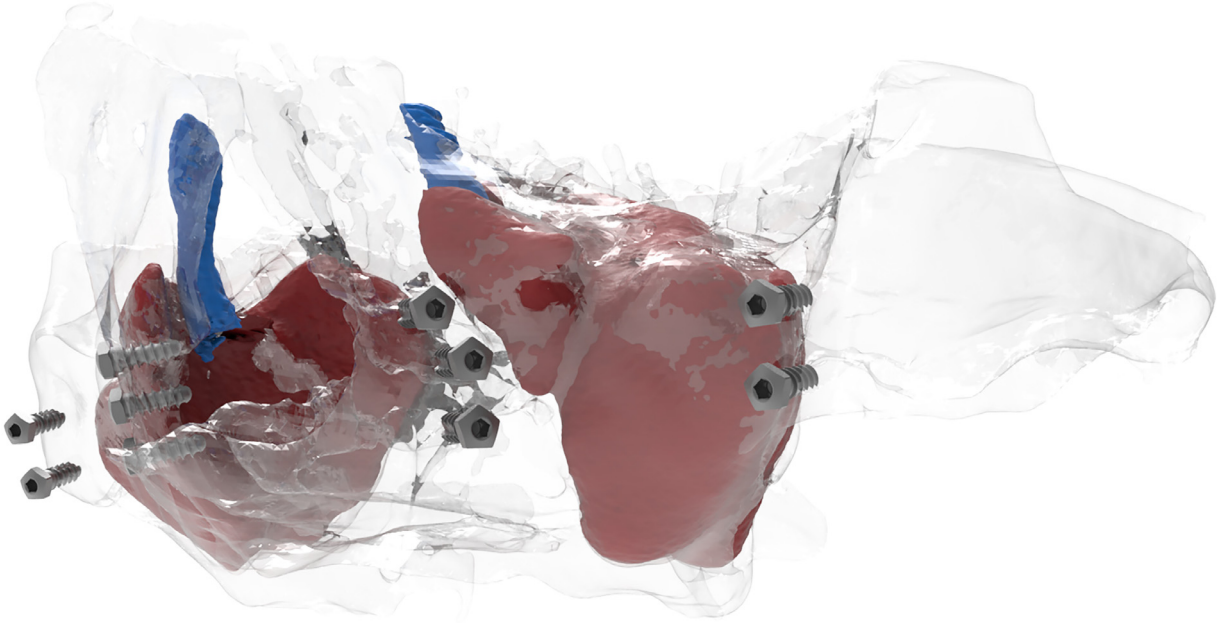

Fig. 1. Fixation screws avoid the maxillary sinus and the nasolacrimal duct by using Mimics Medical (Materialise, Heverlee, Belgium).

discrepancy is largely due to the rigorous daily calibration and the availability of Metal Artifact Reduction Software in hospital settings. FEA is now utilized at CADskills BV to rigorously evaluate the design's performance under both static and dynamic stress conditions. This analytical approach allows for a comprehensive assessment of stress distribution, strain, and potential fracture points, even in regions that lack bone support. Given that bone resorption may occur due to infection, FEA helps identify critical areas that may be vulnerable to failure, enabling the optimization of design parameters to enhance structural integrity and longevity.

The author observed two cases of oroantral communication. The first incident occurred inadvertently due to penetration through extremely thin bone during periosteal elevation. The second case involved a patient requiring simultaneous removal of a residual endosseous implant during AMSJI implantation. In both instances, localized wound dehiscence developed over an AMSJI arm, with patients reporting air escape when exhaling with the nose closed. Treatment involved mobilizing local flaps, interposing a collagen membrane (Evolution Fine, OsteoBiol, Biofixt) between the AMSJI arm and the bony roof, securing it with fibrin glue (Artiss, Baxter), and meticulous suturing.

3.4. Grade 3b complications

While some of the following adverse effects can be managed under local anesthesia, most typically require intubation anesthesia. In the early years, few fractures of the loop occurred because the finite element analysis (FEA) assumed that the AMSJI segments would always be supported by bone [13]. However, improper segmentation due to artifacts or possible bone resorption caused by infection led to two known fractures of the looped frame. While the loop structure ensures sturdiness, the arms are attached to the frame but are not crucial to the implant's overall stability. Modern FEA should prevent such incidents. When fractures did occur in the past, the solution involved removing the affected AMSJI segment and reinstalling a new segment with relocated osteosynthesis screws but maintaining the same connection points. This procedure was performed under general anesthesia.

Lack of osseointegration, along with inflammation and ascending cheek infections, can result from bruxism or non-compliance with dietary restrictions. The author encountered this complication in a patient who had undergone simultaneous mandibular repositioning for a deep bite and required postoperative elastic traction to the AMSJI. Both AMSJI segments were successfully replaced under local anesthesia, and full osseointegration was achieved. Patient selection (excluding bruxers) and enforcing dietary restrictions (highlighting the fragility of the temporary prosthesis) are now considered critical in preventing this complication.

Two cases of sinusitis have been reported, both linked to screws penetrating the maxillary sinus, smoking, and patients missing follow-up appointments. In one case, removing the problematic screw resolved the issue, while in the other, removal of the AMSJI segments was necessary.

The design engineer determines the placement, length, and direction of the osteosynthesis screws. Limited mouth opening, both vertically and horizontally, can lead to improper drill direction, but this can be mitigated by requesting precision tools, such as drill guides (Fig. 2).

4. Discussion

The reported survival rate of screwtype, endosseous implants placed in the maxilla using onlay bone grafts from both intraoral and extraoral sources is generally favorable [14]. Numerous studies have confirmed the effectiveness of bone grafting in improving the volume and quality of maxillary bone for successful implant placement, with reported survival rates of implants in grafted bone comparable to those in native bone [15,16]. Onlay bone grafts, especially from intraoral donor sites such as the mandibular symphysis or ramus, or extraoral sources such as the iliac crest, have been widely used to

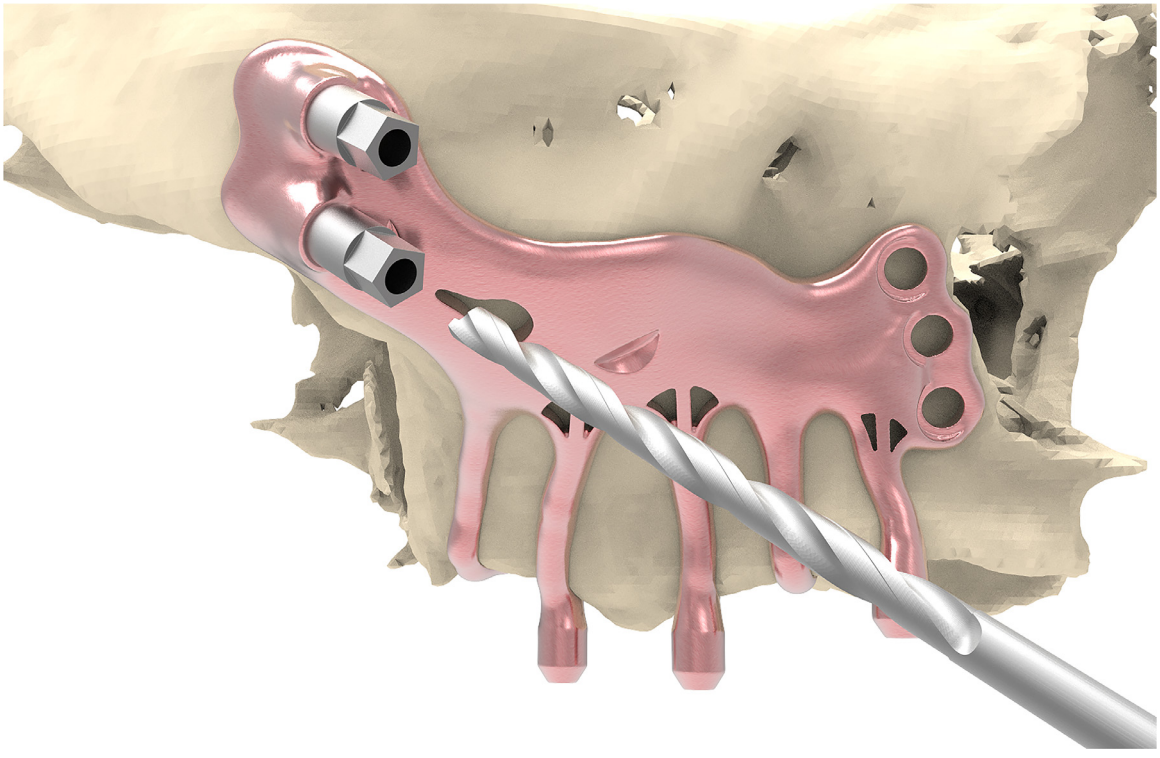

Fig. 2. Precision tools, such as drill guides, can be helpful in ensuring the surgeon maintains the correct drill direction.

augment bone in the atrophic maxilla and support implant-based reconstructions.

However, the procedure does come with some notable drawbacks. Donor site morbidity is a primary concern, particularly in extraoral grafting where complications such as postoperative pain, hematoma formation, and sensory disturbances can occur. Intraoral grafts, while involving less invasive harvesting techniques, can still result in localized complications such as temporary numbness or paresthesia.

Another critical issue is the risk of early wound dehiscence, which, though underreported in literature, is well-known to clinicians involved in the field of implantology. Early dehiscence may compromise graft healing, leading to partial or complete graft exposure and potential graft failure. This complication is particularly relevant in grafts placed in areas with thin mucosal coverage or high tension, where maintaining primary closure is challenging [8]. While published studies on bone grafting tend to focus on graft survival and implant success, they may overlook these early-stage soft tissue complications that can significantly affect long-term outcomes. A significant drawback in clinical practice is patients' general aversion to bone grafting and general anesthesia, especially for a condition that, while socially isolating, is not life-threatening. It is unsurprising that endosseous implant solutions, such as zygomatic implants, have emerged to avoid the need for bone grafting, though they still typically require general anesthesia.

However, zygomatic implants can also be associated with significant adverse effects, including the potential for deep cheek infections and sinusitis [17]. There have also been rare reports of more severe complications, such as orbital cellulitis, diplopia, and amaurosis [18,19]. Additionally, in uncommon instances, zygomatic implants may fracture or become displaced, particularly when subjected to excessive occlusal forces. Removing the cranial portion of a fractured or segmented zygomatic implant can be particularly challenging. The systematic review published in 2023 [17] does not address the incidence of severe complications or the technical challenges involved in removing residual fragments of fractured zygomatic implants. A direct comparison between AMSJI and zygomatic implants is currently impractical due to the extensive number of cases required to mitigate statistical bias. Furthermore, variables such as surgical expertise and patient adherence to postoperative protocols introduce additional complexity, making consistent monitoring, evaluation and comparison challenging.

AMSJI is designed to encompass the maxillary sinus, with small osteosynthesis screws strategically placed using design software to optimally engage high-quality and ample bone [20]. This careful positioning helps to avoid critical anatomical structures, such as the maxillary sinus and nasolacrimal duct (Fig. 1). Drilling guides can be utilized to assist the surgeon in determining the precise direction for drill and screw insertion (Fig. 2). Additionally, finite element analysis (FEA) provides a visual representation of stress distribution, highlighting areas that may require redesign to enhance implant stability and performance (Fig. 3). The guiding principle of AMSJI is "primum non nocere," meaning "first, do no harm." In the rare event of complications, the most severe outcome would be the removal of all AMSJI segments, which would simply return the patient to their original condition without causing further deterioration, unlike the potential risks associated with zygomatic implant removal. When patient selection is carefully performed and patients maintain healthy habits, such as avoiding smoking and practicing good oral hygiene, while adhering to monitoring protocols, this complication has not yet been observed.

Additively Manufactured Subperiosteal Jaw Implants (AMSJI) represent a transformative innovation in the rehabilitation of patients suffering from significant resection defects and severe jaw atrophy. These implants offer a tailored approach, addressing unique anatomical challenges and restoring function and aesthetics effectively [21,22]. The process of additive manufacturing titanium allows for the creation of patient-specific implants that conform closely to individual anatomical features, thereby improving osseointegration and overall success rates.

However, the integration of AMSJI into clinical practice brings with it a series of potential adverse effects that must be meticulously managed. The potential for complications, such as inflammation, progressive recession around posts, and mechanical failures, necessitates a proactive approach to patient selection and postoperative care [23–25]. Studies have consistently demonstrated that careful patient

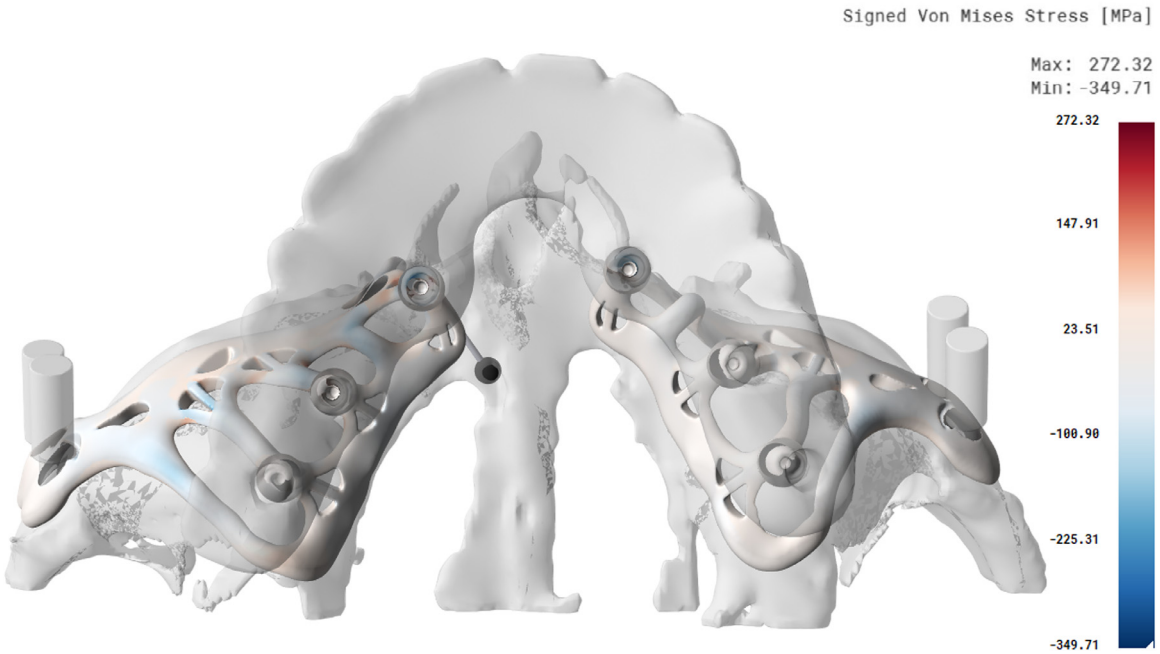

Fig. 3. Finite element analysis (FEA) was performed on a case with a large anterior cantilever, with color codes highlighting the stress-prone areas.

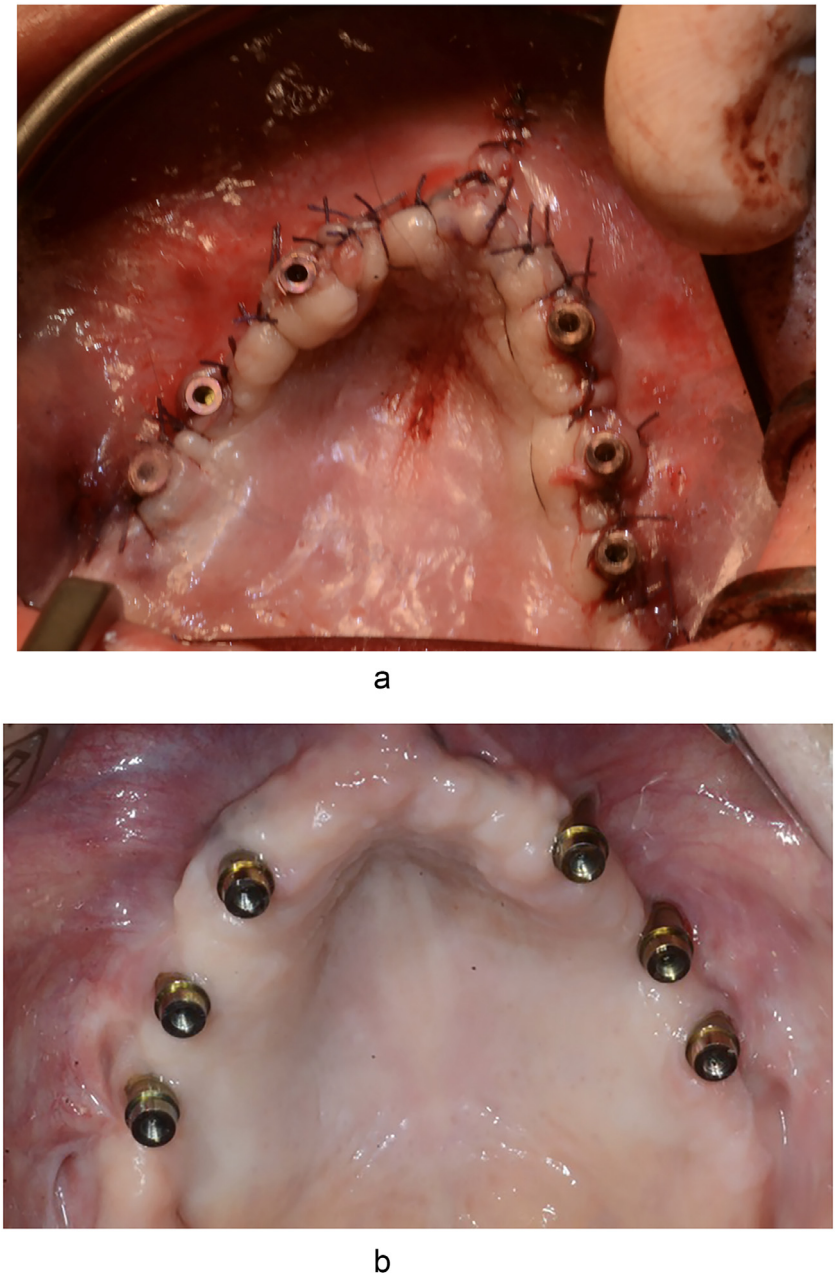

Fig. 4. 5-year result indicating healthy conditions without keratinized mucosa buccally to some of the posts. In 2018, flap design encompassed a minimal strip of keratinized mucosa on the buccal side.Courtesy Dr. Marco Rinaldi, A. Palatal view, immediately after wound closure, B. Palatal view, 5-years postoperatively

selection is pivotal; patients with a history of bruxism [12] and smoking are particularly at risk for complications, leading to poorer outcomes.

Oral hygiene maintenance is another crucial factor that directly impacts the success of AMSJI. Regular follow-ups, including professional cleanings and patient education on effective oral hygiene practices, can significantly mitigate the risks of peri-implant diseases [9]. Additionally, the use of adjunctive therapies, such as probiotics and chlorhexidine rinses, has shown promise in reducing inflammation and improving overall oral health [10].

Patients with controlled diabetes face an elevated risk of infections due to the hyperglycemic environment, which disrupts immune function, particularly neutrophil activity and macrophage response. Studies have identified that complications such as vascular conditions, retinopathy, osteomyelitis, nephropathy, and recurrent ulcers significantly heighten infection susceptibility ($p < 0.05$). Lifestyle factors including smoking, physical inactivity, obesity, inadequate hygiene, and poor glycemic control exacerbate these risks. Diabetic individuals generally have a 1.5- to 4-fold higher likelihood of infections, including peri-implantitis. However, despite a higher rate of infectious complications, current evidence indicates that diabetes does not markedly influence the overall failure rates of dental implants [26–31].

Understanding the complexities of AMSJI requires a comprehensive approach that integrates clinical expertise with advancements in imaging technologies. This combination allows for improved surgical planning and the identification of potential complications before they become critical. The application of finite element analysis (FEA) in evaluating implant designs under varying stress conditions further enhances the predictability of outcomes and minimizes the risk of mechanical failure [13].

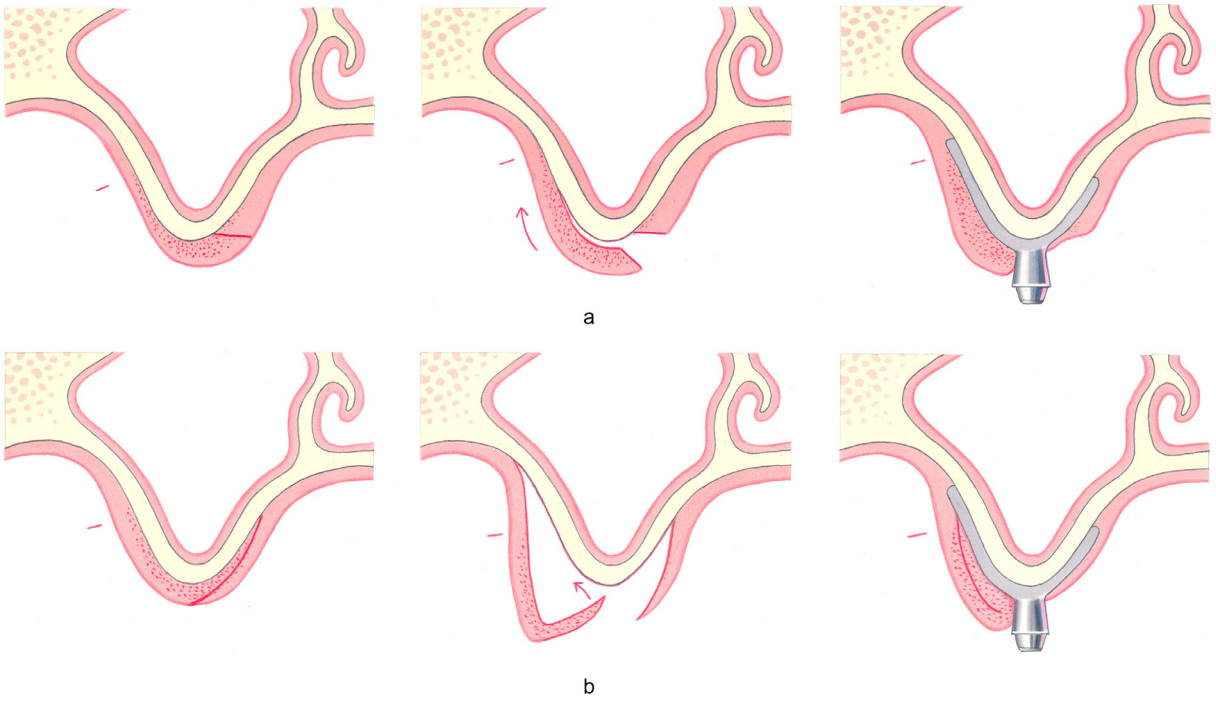

Fig. 5. Gingivaplasty types to thicken the buccal gum biotype. The small red line marks the mucogingival junction.A. Apically repositioned flap, B. Palatal connective tissue flap

Total knee arthroplasty (TKA) stands as one of the most effective and economically viable procedures in modern healthcare [32]. Although TKA offers significant functional improvements, it is not without risks, especially among older patients who often have multiple comorbidities [33]. Like TKA, AMSJI-based dentures can dramatically improve quality of life by restoring function and social interaction for the end-stage diseased. However, in both cases, patient selection, surgical planning, and risk management are critical due to age-related factors and pre-existing health conditions.

5. Conclusion

In conclusion, while AMSJI represents a significant advancement in the rehabilitation of patients with jaw atrophy, the potential for adverse effects necessitates rigorous management protocols. By prioritizing careful patient selection and maintaining stringent oral hygiene practices, clinicians can significantly enhance the success rates of these innovative implants. The continuous evolution of clinical practices and technological advancements will undoubtedly pave the way for even greater success in the future.

Disclosure

The expert opinion conforms to the Declaration of Helsinki from 1964 and its later amendments or comparable ethical standards. Informed consent was obtained from all patients whose data are presented in the figures.

Funding

None

Declaration of competing interest

Pr. Maurice Yves Mommaerts MD, DMD, PhD, FEBOMFS, FICS, FAACS is innovation manager and clinical lead at CADskills BV.

CRediT authorship contribution statement

Maurice Y. Mommaerts: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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