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Technical Note
Pre-Implant Surgery

# Additively manufactured sub-periosteal jaw implants

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*Abstract.* Severe bone atrophy jeopardizes the success of endosseous implants. This technical note aims to present the innovative concept of additively manufactured sub-periosteal jaw implants (AMSJIs). Digital datasets of the patient's jaws and wax trial in occlusion are used to segment the bone and dental arches, for the design of a sub-periosteal frame and abutments in the optimal location related to the dental arch and for the design of the suprastructure. The implants and suprastructure are three-dimensionally (3D) printed in titanium alloy. The provisional denture is 3D-printed in polymer. AMSJIs offer an alternative approach for patients with extreme jaw bone atrophy. This report refers to the use of this technique for full maxillary rehabilitation, but partial defects in either jaw and extended post-resection defects may also be approached using the same technique. This customized, prosthesis-driven reverse-engineering approach avoids bone grafting and provides immediate functional restoration with one surgical session.

Key words: implantation; sub-periosteal; individualized medicine; printing; three-dimensional; alveolar bone loss.

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Up to 56% of patients with endosseous implant-retained prostheses develop peri-implantitis, leading to eventual fixture loss[1]. Of the many causes of peri-implantitis, most are not clinically controllable[2]. Maxillary bone loss, whether combined with implant loss or arising from disuse atrophy, poses a major challenge. Current solutions include all-on-4, when sufficient bone is present anterior to the maxillary sinuses[3]; 'quad-zygoma' or zygoma implants plus conventional oral implants in the alveolus[4]; and bone grafting with sinus floor augmentation and buccal onlay grafts and subsequent (redo) endosseous implantation[5]. An alternative technique, described below, revisits a 70-year-old concept by applying modern computer-aided design and computer-aided manufacturing (CAD/CAM) technology.

## Materials and methods

The dental practitioner chooses a double structure with overdenture or a screw-fixed hybrid bridge, depending on the inter-crestal space, phonetics, lip contour, and patient preference. A wax trial is fabricated, comprising a base plate with a wax bite rim and teeth of the desired colour, shape, and occlusion.

The patient brings the models of the lower dental arch and wax trial to the surgeon who checks the parameters for adequate positioning of the suprastructure in relation to the crest and the occlusal surfaces. The buccal, lingual, and occlusal surfaces of the wax trial model teeth are brushed with radiopaque silicone varnish (X-resin flow; Bredent GmbH and Co. KG, Senden, Germany). Alternatively, radiopaque artificial teeth are used (SR VivoTac and Posteriors; Ivoclar Vivadent, Schaan, Liechtenstein). Traditional or cone beam computed tomography (CT) of the maxillofacial complex is performed with the wax trial model in centric occlusion (maximum intercuspation). The lower dental arch model is scanned by high-resolution CT or optical scanning in the laboratory.

Bone and radiopaque tooth surfaces are segmented, and a surface tessellation language (STL) file is generated (e.g., with Geomagic Freeform Plus; 3DSystems, Rock Hill, SC, USA). The occluding

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lower dental arch is superimposed. Starting from the upper dental arch (rendered visible by the radiopaquer) that will house the connection screws, the sub-periosteal implant is designed as two segments upon which a customized, screw-retained temporary connecting bar fits. A three-dimensional (3D) print provisional prosthesis is designed. The sub-periosteal implant segment typically has three (sometimes four) abutments fixed to the main frame by four arms (Fig. 1). The main frame generally has two extensions on the midfacial pillars, each of which receives three osteosynthesis screws. The interface between the flanges and the bony surface can be made porous (scaffolding) to encourage osseointegration.

The sub-periosteal implant and temporary bar (Fig. 2) are additively manufactured in titanium grade 23 ELI (extra-low interstitial) (CADskills, Ghent, Belgium). The provisional prosthesis is additively manufactured in C&B MFH (microfilled hybrid) (NextDent, Soesterberg, the Netherlands).

With the patient under general or only local anaesthesia, a crestal incision is made 1 mm caudal to the mucogingival border, with relaxing incisions in the midline and behind the tuberosity (Fig. 3). Sub-periosteal flap dissection is performed in the buccal and palate areas. The AMSJIs are fitted left and right; this may require tapping because of the tight fit.

The temporary bar structure is connected using a 1.26-mm hexagon screwdriver for Straumann CrossFit screws (or other type according to dentist preference). The additively manufactured NextDent prosthesis is positioned on the temporary bar, in proper occlusion with the lower dental arch. The AMSJIs are fixed with osteosynthesis screws of an appropriate length, as indicated by a medical engineer. Adjustments can be performed between the AMSJI and bone surface or between the temporary denture and temporary bar. For the latter, Multilink Hybrid Abutment (Ivoclar Vivadent) forms an ultraviolet-cured hard adhesion, but Coe-Soft pearls (GC Europe, Leuven, Belgium) are preferred. A Coe-Pak (GC Europe) wound dressing is applied. Masticatory load is reduced for 2 months to allow undisturbed osseointegration by progressive loading.

The definitive hybrid bridge (Fig. 4) or double structure is constructed 2 months later, generally based on the original sub-periosteal implant design. Occasionally a new wax trial is used to accommodate the patient's wishes and phonetic results. The base plate of the wax trial is preferably radiopaque (e.g., Henry Schein Dental, Melville, NY, USA) to allow gingival segmentation, which facilitates better cervical contouring of the prosthesis. For double structures, Locator, CM Loc, or Dalbo-X (Cendres + Métaux SA, Biel, Switzerland) connectors are used.

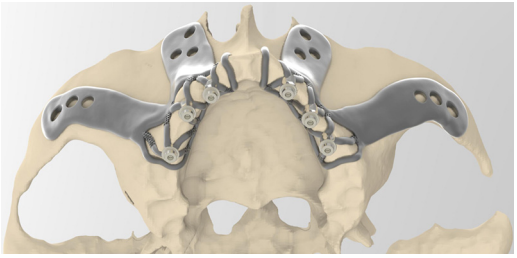

*Fig. 1.* Computer rendering of two additively manufactured sub-periosteal jaw implant (AMSJI) segments positioned on the bone. The arms connecting the main frame are designed in such a way that the incision is not overlying. In the first series of three patients, small dehiscences were observed over the arms when placed on the crest. Note the weakening by scaffolding at the cranial end of the arms connecting the abutments to the main frame. This allows individual dismantling without heating in the case of peri-abutment mucositis, such that the AMJSI segment does not need to be removed. The prosthesis remains functional on four abutments.

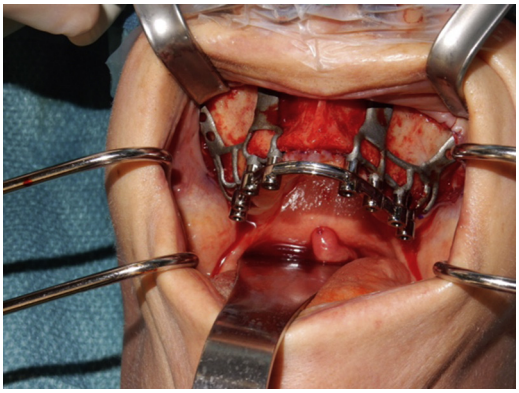

*Fig. 2.* The two additively manufactured sub-periosteal jaw implant (AMSJI) segments have been fitted on the bone and splinted with a temporary suprastructure. Note that some of the connecting arms are on top of the crest, a design that was abandoned after the first three cases.

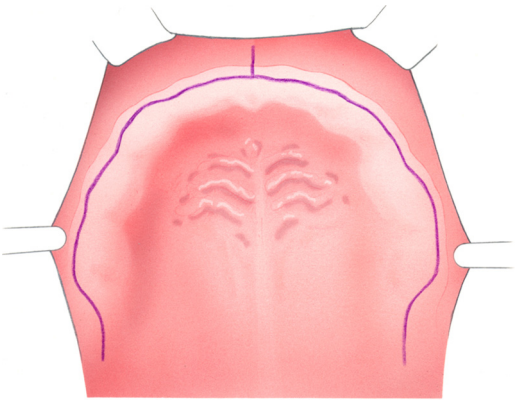

*Fig. 3.* Artist rendering of the horseshoe-shaped incision, with three relaxing incisions oriented sagittally. The main incision is located a few millimetres below the mucogingival margin. The bulk of the frame under the palatal gingiva tends to shift the medial incision line medially. Wound closure around the abutments can be quite challenging when the main incision is placed on top of the crest. Periosteal release should be done at the beginning of the surgery in order to avoid a postoperative haematoma in the cheek.

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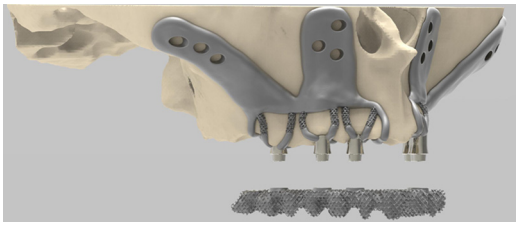

*Fig. 4*. Computer rendering of the additively manufactured sub-periosteal jaw implants (AMSJIs) with definitive titanium suprastructure (with a retentive surface for a polymer or polymethyl methacrylate (PMMA) dental bridge).

## Discussion

Sub-periosteal implants were popular in the 1950s and 1960s[6], before the advent of endosseous titanium implants. They declined in popularity for many reasons. The material used was Vitallium, a cobalt–chromium–molybdenum alloy cast using the lost-wax technique. Mismatch in the elastic modulus between the alloy and bone produced stress shielding and fixation loss. Vitallium has no soft tissue or bone integration properties. For that reason, there was no halt to infection once it was initiated. Massive bone loss with fistula formation to the nose and sinus cavity was a feared complication. Nowadays, these complications also occur when peri-implantitis cannot be controlled in bone grafted maxillae. In fact, a sub-periosteal implant made of 3D-printed titanium has proven to be a solution for these 'lost cases'. In the past, two surgical interventions were required: one to obtain the impression and one for implantation (usually without screw fixation). The discovery of titanium as an outstanding implant material led to the opportunity for the serial production of oral endosseous implants[7,8].

Confronted with extreme atrophy, clinicians focused on implanting in remote bone (e.g. zygoma), local and distant (sinus floor) augmentation with bone transplantation, osseodistraction, or guided bone regeneration. With each, the goal was to connect endosseous fixtures with suprastructures, as this was the 'gold standard', and this was indeed successful using the aforementioned solutions. Zygoma implants may have a clinical survival rate of 96.7% but can cause sinusitis, soft tissue infections, and oronasal fistulas, and are technically challenging for the prosthodontist and laboratory technician[9].

A prosthesis-driven, reverse-engineering approach is described herein, in which CAD-CAM and additive manufacturing are used to restore function and aesthetics in one surgical session, occasionally using only local anaesthesia. Originally, the goal was to restore function in severely resorbed dorsal mandible areas. Partial edentulism and post-resection defects may also benefit from the technique.

Immediate loading may even be considered, with definitive suprastructure and tooth replacement in the first session. However, this may preclude proper AMSJI osseointegration and proper articulation and phonetics testing. Costs may increase when aesthetic requirements are unmet or when the occlusion requires major adjustments. Dental laboratories may require persuasion to proceed without plaster models in an articulator. However, costs and transfer errors increase automatically.

The potential for peri-implantitis remains with the technique presented here. Peri-abutment mucositis can develop, which is addressed by disconnecting the abutment from the main frame by cutting the four arms with rotating instruments. This is performed in areas specifically designed to be weak in order to facilitate cutting and thereby prevent bone and mucosa heating. A number of abutments may be removed before the system fails. With regard to peri-implantitis, a situation will develop similar to that of zygoma implants; fixation at the cranial end of the AMSJI will remain unaffected.

In conclusion, AMSJIs offer an alternative implant approach in the case of extreme bone atrophy. This customized, prosthesis-driven reverse-engineering approach avoids bone grafting and provides immediate functional restoration with one surgical session. Whether the customized screw-retained titanium framework with removable abutments will do better than the Vitallium framework manufactured through the lost-wax technique, remains to be proven clinically.

## Funding

None.

## Competing interests

Dr Mommaerts is innovation manager at CADskills bvba.

## Ethical approval

Not applicable.

## Patient consent

Written consent was obtained.

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