UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
FACULDADE DE ODONTOLOGIA

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IMPLANTES SUBPERIOSTEAIS PERSONALIZADOS (ISP) COM TECNOLOGIA DIGITAL: UMA REVISÃO DE LITERATURA

Porto Alegre
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Trabalho de Conclusão de Curso apresentado ao Curso de Odontologia da Universidade Federal do Rio Grande do Sul, como requisito parcial para obtenção do título de Cirurgião-Dentista.

Orientador: Prof. Dr. Tiago Fiorini

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RESUMO

Introdução: A reabilitação dentária de pacientes com atrofias maxilares severas é desafiadora. Essa condição é comum em pacientes idosos, vítimas de traumatismos faciais, malformações congênitas ou após tratamento oncológico, exigindo cirurgias reconstrutivas complexas. Diversas terapêuticas têm sido propostas, incluindo enxertos ósseos, regeneração óssea guiada, elevação do seio maxilar, distração osteogênica e implantes zigomáticos. Contudo, tais tratamentos frequentemente implicam em múltiplas etapas cirúrgicas e alta morbidade, além de longos prazos até a entrega da prótese final. Os implantes subperiosteais personalizados (ISP) com tecnologia digital surgem como uma possível solução simplificada. Fixados sobre o osso maxilar/mandibular com parafusos corticais, possibilitam menos etapas cirúrgicas e reabilitação protética imediata. Ademais, através da tecnologia digital, são desenvolvidos de forma personalizada à anatomia do paciente, reduzindo riscos cirúrgicos e simplificando a técnica reabilitadora. **Objetivo**: Analisar a literatura relacionada aos ISP com tecnologia digital, identificando critérios de indicação, resultados clínicos e complicações associadas. **Metodologia**: Foi realizada uma busca eletrônica na base de dados MEDLINE (PUBMED) sem restrições de data. **Resultados**: Foram encontrados 14 artigos, abrangendo 305 pacientes/383 implantes subperiosteais de maxila/mandíbula. A taxa de sobrevivência foi de 93% após um acompanhamento médio de 22,9 meses. A complicação mais comum foi exposição da estrutura metálica do implante. Outras complicações incluem infecções e fratura da prótese. **Conclusão**: Os ISP com tecnologia digital são promissores no curto prazo. Aprimorar design e fixação são pontos críticos para reduzir complicações. Para entender melhor o impacto nos tecidos, é essencial realizar estudos prospectivos de longo prazo com amostras maiores.

Palavras-chave: Implante Subperiostal Personalizado; Impressão em 3D; Engenharia Biomédica; Titânio

ABSTRACT

Introduction: Dental rehabilitation of patients with severe maxillary atrophy is challenging. This condition is common in elderly patients, those with facial trauma, congenital malformations, or following oncological treatment, requiring complex reconstructive surgeries. Various therapies have been proposed, including bone grafts, guided bone regeneration, maxillary sinus elevation, osteogenic distraction, and zygomatic implants. However, these treatments often involve multiple surgical stages and high morbidity, as well as long delays before the final prosthesis is delivered. Customized subperiosteal implants (CSI) with digital technology present a potential simplified solution. Fixed onto the maxillary/mandibular bone with cortical screws, they allow fewer surgical stages and immediate prosthetic rehabilitation. Furthermore, through digital technology, they are customized to the patient's anatomy, reducing surgical risks and simplifying the rehabilitative technique. **Objective**: To review the literature on CSI with digital technology, identifying indications, clinical outcomes, and associated complications. **Methodology**: An electronic search was conducted in the MEDLINE (PUBMED) database with no date restrictions. Results: Fourteen articles were found, covering 305 patients/383 subperiosteal implants in the maxilla/mandible. The survival rate was 93% after a mean follow-up of 22.9 months. The most common complication was exposure of the implant's metal structure, with other complications including infections and prosthesis fractures. **Conclusion**: CSI with digital technology show promise in the short term. Improving design and fixation are critical to reducing complications. To better understand the impact on tissues, long-term prospective studies with larger sample sizes are essential.

Keywords: Customized Subperiosteal Implant; 3D Printing; Biomedical Engineering; Titanium

SUMÁRIO

1 INTRODUÇÃO

O tratamento reabilitador com implantes dentários é amplamente adotado e buscado para pacientes edêntulos parciais e totais, com taxas de sucesso significativas a médio e longo prazo (Esposito; Ardebili; Worthington, 2014). Contudo, a quantidade e a qualidade do osso disponível são características fundamentais para a viabilidade da instalação de implantes osseointegráveis (Rocchietta; Fontana; Simion, 2008). A reabilitação odontológica de pacientes com áreas desdentadas e atróficas na maxila e mandíbula representa um desafio considerável para os profissionais da odontologia. Essas condições são comumente observadas em pacientes idosos com comprometimento de saúde, indivíduos pós-traumáticos e pacientes oncológicos, demandando procedimentos cirúrgicos reconstrutivos (Rocchietta; Fontana; Simion, 2008). Diversas abordagens são empregadas, incluindo enxertos ósseos, regeneração óssea guiada com o uso de membranas absorvíveis ou não, osteotomias mandibulares, levantamento do seio maxilar (Mangano *et al.*, 2015), distração osteogênica (Baas *et al.*, 2015), implantes zigomáticos (Brånemark *et al.*, 2004), protocolos All-on-4 (Maló; Rangert; Nobre, 2005) e fraturas de crista óssea (ridge split) (Anitua; Begoña; Orive, 2013). Tais procedimentos podem ser realizados isoladamente ou em combinação antes da colocação de implantes convencionais endoósseos, com o intuito de aumentar a estrutura óssea (Rocchietta; Fontana; Simion, 2008). Apesar da variedade dos tratamentos para casos de atrofia óssea, esses muitas vezes resultam em uma solução protética limitada, não influenciando positivamente na função mastigatória e a qualidade de vida desses pacientes (Dimitroulis *et al.*, 2023). As principais desvantagens desses tratamentos são as várias etapas cirúrgicas, cirurgias complexas e demoradas, com alta morbidade e prazos prolongados entre o início do tratamento e a entrega da prótese final (Aghaloo; Moy, 2007).

Pacientes com atrofia maxilar ou perda significativa de altura e espessura óssea na mandíbula podem se beneficiar de abordagens de tratamento simplificadas, como o uso de implantes subperiosteais personalizados (ISP) (Dimitroulis *et al.*, 2023). O ISP é um tipo de implante que é colocado sob o periósteo, diretamente sobre o osso maxilar ou mandibular (Linkow; Ghalili, 1998, 1999) e possui componentes transmucosos que servem de conexão entre o implante e a prótese fixa (Linkow, 2000; Linkow; Ghalili, 1999). As principais vantagens desse tipo de implante quando comparado com outros tratamentos é a sua rápida recuperação e os baixos riscos quando comparado a outras alternativas usadas em situações de atrofia maxilar ou mandibular, como o implante

zigomático, que pode resultar em sinusite, parestesia e penetração da cavidade orbital ou região peri-ocular (Chrcanovic; Abreu, 2013). Devido ao desenvolvimento de um dispositivo implantável personalizado construído especialmente sobre a condição óssea disponível, a técnica se torna simplificada e possibilita a reabilitação imediata em casos com áreas extremamente atróficas (Bodine; Yanase; Bodine, 1996).

O uso de implantes subperiosteais foi descrito pela primeira vez por Dahl em 1943, mas ganhou relevância após a publicação de Goldberg & Gerskoff no final da década de 1940 (Linkow; Iyer; Piermatti, 2023). Entretanto, a instalação dos implantes subperiosteais foi abandonada devido a processos rudimentares de fabricação e alto custo, assim como complicações frequentes observadas no longo prazo (Nemtoi *et al.*, 2022). Na década de 1960, com a descoberta da osseointegração, a implantodontia evoluiu de um tratamento experimental para os implantes endoósseos que são utilizados até os dias de hoje. Porém, mesmo os implantes endoósseos não são indicados para todos os tipos de pacientes e apresentam algumas limitações (A El-Sawy; A Hegazy, 2024).

Atualmente, com o avanço tecnológico e ampliação dos recursos digitais (tomografias, aparelhos de escaneamento intra oral, softwares de desenhos, impressão 3D, CAD/CAM), associados a técnicas de fabricação que resultaram em diminuição do seu custo de confecção e maior precisão, fizeram com que esse tipo de implante, agora de forma personalizada, voltasse a ser avaliada com bastante interesse (Colombo *et al.*, 2017; Dumitrescu *et al.*, 2021; Martu *et al.*, 2022; Sonmez *et al.*, 2018; Van Noort, 2012). Dentre as técnicas de manufaturação aditivas, destaca-se a sinterização direta a laser de metal (DMLS), que é uma técnica de fabricação aditiva que utiliza um laser de alta potência para fundir metais em forma de pó, construindo um modelo 3D estratificado, camada por camada, através de um arquivo CAD dividido em camadas finas. Esse processo cria uma série de imagens bidimensionais que, sobrepostas, formam a tridimensionalidade do produto (Mangano *et al.*, 2014) e possibilitam a fabricação de próteses maxilo-faciais feitas sob medida e até implantes perfeitamente adaptados à anatomia específica do paciente com sucesso clínico de 85% em 4 anos (Dimitroulis *et al.*, 2023). Apesar de serem inovadores e promissores, os implantes subperiosteais personalizados são dispositivos relativamente novos e ainda existe certa limitação de publicações científicas relacionadas ao tema (Herce-López *et al.*, 2024). Portanto, faz-se necessário o aprofundamento no tema e a construção de conhecimento que possam contribuir para as novas alternativas de processo de confecção e diminuição de custos

desses dispositivos, para oferecer um tratamento mais simplificado, rápido e com menor morbidade para os pacientes com reabsorção óssea severa de maxila e mandíbula.

Nessa perspectiva, esta revisão de literatura narrativa se propôs a investigar os trabalhos publicados até o presente momento relacionados ao uso de implantes subperiosteais personalizados (ISP) com tecnologia digital.

2 ARTIGO CIENTÍFICO

Customized Subperiosteal Implants (CSI) with Digital Technology: A Literature Review

Isabela Corrêa Dacol, Tiago Fiorini

Abstract

Purpose The aim of the present study was to perform a literature review on customized subperiosteal implants (CSI) to assess implant survival and complications rate of modern subperiosteal implants (CAD designed and additively manufactured).

Methods A manual electronic search was conducted in the MEDLINE (PUBMED) database, without date restrictions.

Results A total of 14 articles included in the review (6 cohort studies and 8 case series) involved a total of 305 patients (165 female / 140 male; weighted mean age 59.9 years) and 383 unilateral/bilateral, maxillary/mandibular implants. After a weighted mean follow-up time of 22.9 months, the survival rate was 93%. Twenty failures reported (5.2%), 66 implants (17.2%) presented partial exposure, 27 patients (8.8%) suffered soft tissue or persistent infection. Fracture of the interim prosthesis was reported in 10 of the 305 patients (3.2%) in which the use of a provisional prosthesis was reported.

Conclusions Within the limitations of this study, digital customized subperiosteal implants demonstrated favorable short-term survival rates. However, a significant number of complications related to soft tissue were observed. Additional research is required to evaluate their clinical performance over the medium and long term.

Keywords Customized Subperiosteal Implant; 3D Printing; Biomedical Engineering; Titanium

Introduction

Initially described by Dahl in 1943, subperiosteal dental implants emerged in Sweden and the United States [1] as an alternative for edentulous patients who had poor results with conventional rehabilitations. These implants were custom-made fixtures placed beneath the periosteum, stabilized by contact with the underlying bone through fixation screws and the fibro-mucous tissue that covered them [2–5]. Typically fabricated from cobalt-chrome or titanium alloys, they were prosthetized with transmucosal abutments emerging within the oral cavity [2–4]. The technical process of manufacturing subperiosteal implants was intricate and involved capturing a detailed impression of the residual bone, which required a preliminary surgical session that often caused considerable discomfort to patients [6]. During the subsequent surgical implantation, the accuracy of these implants was notably imprecise, leading to unpredictable clinical outcomes [5–7]. Moreover, the necessity to modify these implants during the procedure could extend surgery times, increasing the risk of infections and other complications [6,7]. They were utilized for many years, but due to challenges in their placement [5] and elevated rates of complications [6,7], were eventually supplanted by endosseous root-form dental implants in the 1960s with the advent of the concept of osseointegration by Brånemark, which marked a pivotal shift from experimental treatments to highly predictable solutions for tooth replacement [2].

Adequate bone quantity and quality is essencial for endosseous implant insertion. If there is insufficient bone, there are currently three available options. The first involves using reconstructive materials and techniques such as bone grafting [8], guided bone regeneration [9], alveolar ridge splitting [10], distraction osteogenesis [11], or sinus augmentation [12]. The second approach for placing endosseous implants in challenging anatomical sites, without relying on bone regeneration, involves the use of short [13], narrow [14] , or tilted implants [15]. Additionally, zygomatic [16] and pterygomaxillary implants [17] are available, though they are less commonly used in routine practice. The challenge with these methods lies in their extended treatment duration and the potential for intraoperative and postoperative complications, stemming from the complexity of the procedures. Furthermore, these approaches can result in increased costs for the patient [18].

Advancements in digital technology has marked a transformative era in dentistry [19] and have led to a reevaluation of earlier concepts, such as subperiosteal implants [20,21]. These advances, including cone beam computed tomography (CBCT) (that significantly minimized the radiation exposure to patients) [22], intraoral scanners [23], digital software, 3D printers, and other innovative tools [24] have streamlined, enhanced, and accelerated numerous procedures, mading it feasible to fabricate patient-specific implants [25]. Customized subperiosteal implants with digital technology may present some advantages in treating patients with bone atrophy, such as a single surgical session, the possibility of ambulatory realization, reduction of surgical time, lower costs for the patient, precision that increases predictability and safety in the short term have renewed clinicians' interest in subperiosteal implants. This review aims to evaluate the clinical performance of digital customized subperiosteal implants by examining the available literature on their survival rates and complication frequencies.

Materials and methods

An electronic search was performed on MEDLINE via PubMed. The search was restricted to English-language reports on subperiosteal implants created using digital technology. Furthermore, manual searches were carried out within the reference lists of the selected articles.

The PubMed database was searched with the following keywords: “Dental Implantation, Subperiosteal” [MeSH Terms] OR “Subperiosteal Implant” [All Fields] OR “Subperiosteal Implants” [All Fields] OR “Juxta-osseous Implants” [All Fields] and manual searches within the same databases using additional free-text terms such as “Custom-made Implants,” “Direct Metal Laser Sintering,” “Patient-specific Implants,” and “Additively Manufactured Implants” without date restrictions.

Two reviewers independently assessed the relevant publications (ICD and TF). They reviewed the titles and abstracts, and thoroughly read the full text of any articles considered pertinent. The inclusion criteria were as follows: the study population had to involve individuals treated with subperiosteal implants made using digital technology, specifically in severely atrophied jaws among both completely and partially edentulous groups, as well as patients with congenital and acquired defects resulting from tumor resections in the maxilla and mandible. The outcomes evaluated included the implant survival rate, any kind of complications such as implant mobility, dehiscence, or framework exposure and prosthetic issues such as fractures of temporary or permanent

dentures. Articles involving the same patient series that is already part of another research project [26], complex reconstructive surgery [27], articles involving traditional subperiosteal implants [28] were excluded. The search included articles published up to May 2024.

Results

The initial search provided 414 articles. Additional searches identified 7 more articles. Before screening, 373 articles were removed. Additionally, 31 articles were removed after the abstract review. 17 articles were selected for full-text analysis, but after a deep analysis of the articles, 3 were excluded.

- Not meeting the inclusion criteria [28].
- Same patient series as in another already included study [26].
- Complex reconstrutive surgery, such as microvascular bone reconstruction [27].

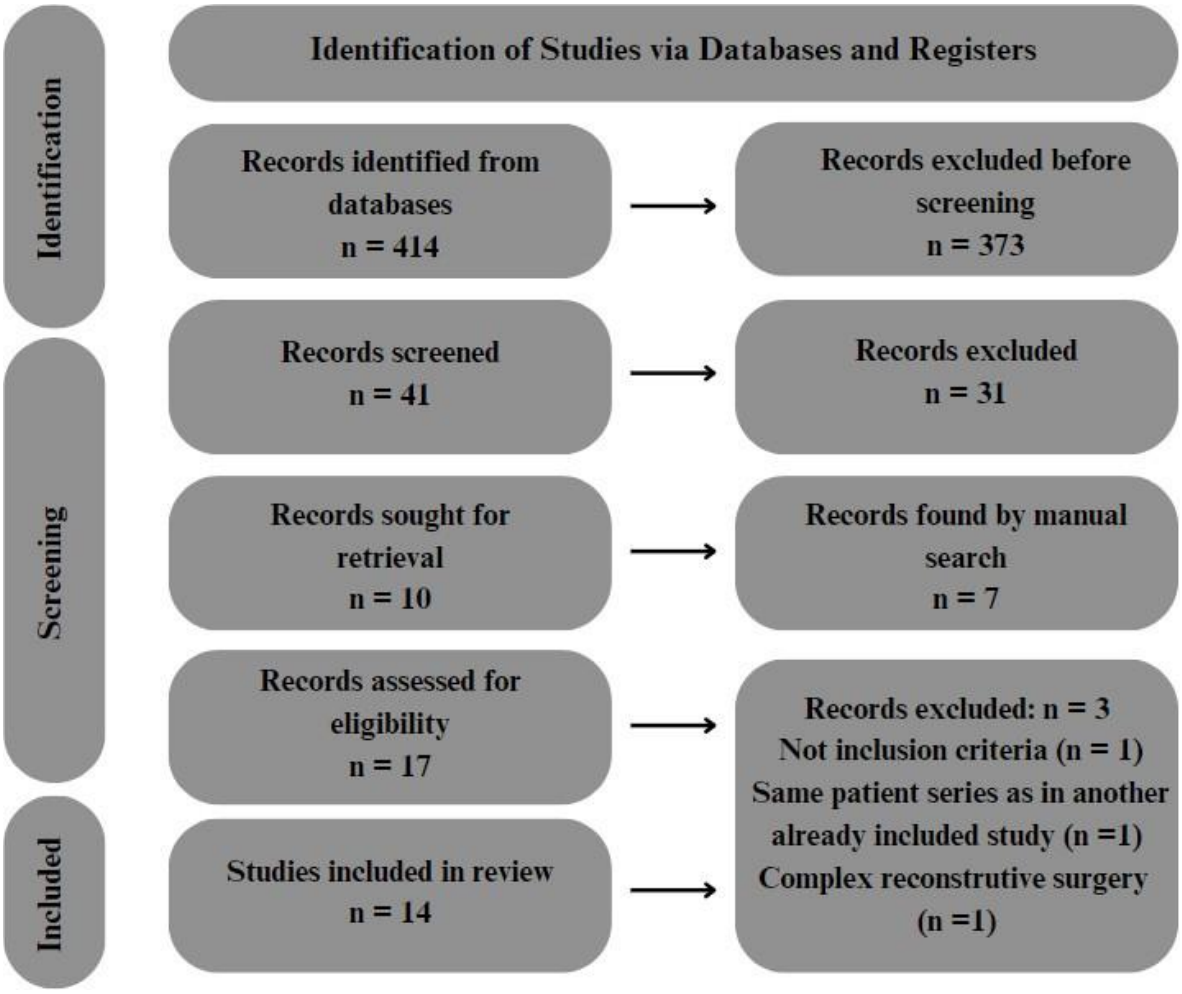

Fig 1 Summarizes the study selection process.

Study characteristics

The 14 articles included in the review corresponded to 6 cohort studies (1 prospective, 3 retrospective multicentric, 1 retrospective and 1 observational clinical study) and 8 case series, that involved a total of 305 patients and 383 unilateral/bilateral, maxillary/mandibular implants. No RCTs were found during the literature search. All the included articles had been published from 2017 onwards.

Synthesis of results

Sample Characteristics

The selected articles included data from 383 implants placed in 305 patients (165 female / 140 male) with a mean age of 59.9 years-old. The location of the implants was specified for 313 implants (252 maxilla/61 mandible) and not reported for 70.

The main reason for implantation was bone atrophy. A Cawood-Howell atrophy type V or higher was the inclusion criteria in 6/14 studies, responsible for 191 out of 383 implants (50%). In 5 patients (1,6%) a resective/maxillectomy had been previously performed. In another study, the presence of cleft lip and palate deformity (CLP) were the cause of bone atrophy (6 patients) and oral malignancy treatment or agressive oral lesion treatment was the reason in another 19 patients. Details on sample description are available on Table1.

Device Characteristics

All the implants were manufactured in titanium alloys (Table 2). Ti Grade V was used in 4 studies, Ti Grade 23 in 5, while one study used Ti64 1/14 and one Ti Grade IV. The type of alloys was not reported in another 3 studies. In the study of Mounir et al.[29], 5 implants included in one group were manufactured in polyether-ether-ketone (PEEK). Data from these 5 PEEK implants not included in our manuscript.

The manufacturing technique in all studies were additive 3D printing, Direct Metal Laser Sintering (DMLS) in 4/14, Selective Laser Melting (SLM) in 5/14, Sinterization 2/14, Electron Beam Melting (EBM) 1/14 and in 2/14 technique was not specified in the text. Different implant designs were used, but in all cases a variable number of osteosynthesis screws were employed to anchor the framework to the bone, with diameters ranging from Ø1.5-2.3mm. The surface in contact with the bone was porous (rough) in 5 studies (66 implants), polished (electroerosion) in 2 studies (100 implants) and not stated in 7 studies (217 implants).

Prosthetic Characteristics

In the prosthetic rehabilitation, 252 (66%) required a full-arch rehabilitation, 41 (10%) a partial restoration and in 90 patients (22,5%) the type of rehabilitation was not specified. Two hundred and seventy-three implants (71%) supported a fixed denture and six implants (1,5%) supported a removable denture, while in 104 (26,06%) implants it was not reported (Table 3).

In 11 out of 14 studies, provisional prostheses were used, while in 3 studies, this information was not reported, varying from immediate installation to 2 weeks post-surgery. The prosthetic connection was screw-retained in 7 out of 14 cases (50%), cemented in 4 out of 14 cases (28,5%), and not reported in 3 out of 14 cases (21,5%). In most of the studies, the prosthesis impression technique was not specified (8 out of 14 studies). Definitive prostheses were highly variable in terms of manufacturing techniques, materials, and time of loading.

Clinical Procedures

Surgical procedures were conducted under local anesthesia in 50% of the studies (243 implants), while general anesthesia was utilized in 3 studies (40 implants). The anesthesia type was not specified in 3 out of 14 studies (100 implants).

Of the 14 studies reviewed, 7 utilized postoperative antibiotics, specifically amoxicillin combined with clavulanic acid, with varying dosages and durations. Four studies employed anti-inflammatory medications, and five studies included postoperative rinses with 0.12% chlorhexidine gluconate. One study reported the use of either 10 million units of penicillin or 600 mg of clindamycin administered intravenously during surgery, while another study mentioned the application of ice as part of postoperative care. Data on medication use and postoperative instructions were not provided in 6 of the studies.

The surgical time was reported in 50% of studies and the mean time was 103.1 minutes.

Table 1. Summary of included studies: study design, demographic data and defect description of the included sample

AUTHORS YEAR COUNTRY	TYPE OF STUDY	N (PATIENTS)	MEAN AGE (YEARS)	SEX	N (IMPLANTS)	CAUSE OF BONE DEFECT	INCLUSION CRITERIA
Cerea et al., 2018, Italy[30]	Retrospective Multicenter	70	62.8 (range 62 to 79)	31F/39 M	70	Bone atrophy	Age > 60 years Nonsmoker and not bruxist Treated with DMLS manufactured subperiosteal implant - 2-year minimum follow-up
Cebrián et al., 2022, Spain [31]	Case series	4	66.2 (range 59 to 72)	1F/3M	20	Maxillectomy	Maxillary oncological defect that had been reconstructed with a subperiosteal implant
Dimitroulis et al., 2023, Australia [32]	Case series	21	59.1 (range 31 to 80)	14F/7M	21	Bone atrophy Maxillectomy (1/21)	Nonsmoker Partial or fully edentulous arches Not suffering from a terminal ill or severe medical condition (as radiotherapy of the jaws) Cawood–Howell atrophy (CHA) ≥ 5
Mangano et al., 2020, Russia [33]	Case series	10	69.6 (range 68 to 75)	6F/4M	10	Bone atrophy	Age > 65 years Nonsmoker - Healthy patients Partially edentulous (≥ 2 teeth) Residual bone < 10 mm Regenerative bone surgery unwillingness

Nemtoi et al., 2022, Romania [34]	Retrospective Cohort Multi-Center Study	16	65.1 (range 55 to 69)	7F/9M	16	Bone atrophy	Age > 55 years Nonsmoker Treated with DMLS manufactured subperiosteal implant Equilibrated general and oral health Available bone height ≤ 10 mm Regenerative bone surgery unwillingness
Van den Borre et al, 2023 Belgium [35]	Retrospective Multi-center	40	Male: 64.6 Female: 65.2	25F/15M	40	Bone atrophy	Patients who underwent bilateral maxillary additively manufactured subperiosteal jaw implant placements at least one year ago Maxillary defect reconstructions were excluded Maxillary severe atrophy (CHA ≥ 5)
Vaira et al., 2024, Italy [36]	Case series	17	60.4 Range 48 to 77	15F/2M	30 (13 bilateral)	Bone atrophy	CHA ≥ 5
Onică et al., 2024, Romania [37]	Case series	36	61.9 Range 38 to 71	17F/19M	61	Bone atrophy due to severe periodontal disease and failure of conventional implants, which involved ongoing bone resorption around older implants.	> 60 years or younger with severe bone loss, thin zygomas (<4 mm), or reduced vertical height, Stable general and oral health status; Good oral hygiene; Complete or significantly partial edentulism accompanied by severe bone atrophy Opting out of bone regeneration procedures; Consent to attend postoperative follow-up appointments.

Van den Borre et al., 2022, Belgium [38]	Prospective Multicenter	15	Male 54.4 Female 62.2	7F/8M	15	Bone atrophy	CHA ≥ 5 Consecutive patients Bilateral placement in the maxilla
Rahlf et al., 2022, Germany [39]	Case series	6	51 Range 18 to 68	3F/3M	6	Cleft lip and palate deformity (CLP)	CLP-associated deformity Maxillary partial or total edentulism
Mounir et al., 2017, Egypt [29]	Observational clinical study	5*	27.4 Range 18 to 55	1F/4M	5	Bone atrophy	Anterior maxillary bone defect Less than 3 mm of diameter and 8 mm height of bone volume No systemic disease or oral pathosis that may affect bone healing No previous grafting procedure at the implant site
Korn et al, 2021, Germany [40]	Case series	19	65 Range 30 to 85	9F/10M	20 (1 bilateral)	Bone atrophy due to oral malignancy treatment or aggressive oral lesion treatment	Previous tumor resection No history of failed augmentation procedure, trauma, or cleft palate
Korn et al, 2022 Germany [41]	Case series	10	66 Range 50 to 90	7F/3M	13 (3 bilateral)	Bone atrophy	CHA ≥ 5 No head-neck cancer history or previous irradiation No cleft lip or palate or trauma history
Vaira et al., 2024 Italy [42]	Retrospective Multicenter	36	61.1 years Range 51 to 71	22F/14M	72	Bone atrophy	CHA ≥ 5 Treated with additively manufactured subperiosteal implant

*This study has two groups of implants. Only group 1 (5/10 Ti implants) was included. Group 2 (5/10 PEEK implants) was excluded

Table 2. Characteristics of implant devices and fixation technique.

AUTHORS YEAR COUNTRY	IMPLANT MATERIAL	MANUFACTURING TECHNIQUE	IMPLANT LOCATION (MAXILLA/MANDIBLE)	IMPLANT DESIGN	IMPLANT SURFACE	IMPLANT FIXATION
Cerea et al., 2018, Italy[30]	Ti Grade V	DMLS (direct metal laser sintering)	Maxilla or mandible (no further information available)	Buccal and lingual arms for implant fixation. Tapered posts for prosthetic cementation	Polished (electroerosion)	Osteosynthesis screws
Cebrián et al., 2022 Spain [31]	Ti	Sinterization	Maxilla	Titanium mesh/plate and prosthetic connecting posts (4 or 6). External hexagonal connection (universal, 4.1 mm)	N.R	Osteosynthesis screws
Dimitroulis et al.,2023, Australia [32]	Ti	Laser sintering	18/21 Maxilla; 3/21 Mandible	Buccal and lingual arms for implant fixation. At least 8 screws buccally and2 or more in lingual/palatal.	N.R.	Osteosynthesis screws (Ø2mm mandible / Ø1.6mm maxilla)
Mangano et al.,2020, Russia [33]	Ti Grade V	DMLS	Posterior mandible	Buccal and lingual arms for implant fixation. Tapered posts for prosthetic cementation	Porous	Osteosynthesis screws Buccal and lingual

Nemtoi et al., 2022, Romania [34]	Ti	DMLS	11/16 Maxilla; 5/16 Mandible	0.7 mm thickness. Arms for fixation with osteosynthesis screws	Rough	Osteosynthesis screws
Van den Borre et al, 2023 Belgium [35]	Ti Grade 23	Additive manufacture (technique not specified in the text)	Maxilla	2-piece implants (bilateral) splinted by the prostheses. On each piece: Fixation vestibular arms (2), prosthetic connecting posts (3)	Porous	Osteosynthesis screws Buccal arms
Vaira et al., 2024, Italy [36]	Ti grade V	SLM	Mandíble	Anchorage framework with holes for multiple osteosynthesis screw	Polished	Osteosynthesis screws (Ø2 mm)
Onică et al., 2024, Romania [37]	Ti64	DMLS	Maxilla 48/61 Mandible 13/61	Buccal and lingual arms for implant fixation with mult-unit posts	N.R.	Osteosynthesis screws (Ø5.5-13mm)
Van den Borre et al., 2022, Belgium [38]	Ti Grade 23	Additive manufacture (technique not specified)	Maxilla	2-piece implants (bilateral) splinted by the prostheses. On each piece: Fixation vestibular arms (2) prosthetic connecting posts (3)	Porous	Osteosynthesis screws Buccal arms
Rahlf et al., 2022, Germany [39]	Ti Grade 4	SLM (selective laser melting)	Maxilla	Anchorage framework with holes for multiple osteosynthesis screw. Two to four connection posts	N.R.	Osteosynthesis screws (Ø1.5 mm)

Mounir et al., 2017, Egypt [29]	Ti Grade 23	EBM (electron beam melting)	Maxilla	Buccal plate/mesh, buccal holes for the osteosynthesis screws (Ti implants meshed with 2.3 mm holes) and cylindric posts (3 to 6) for prosthetic connection	Rough (acid-etching)	Osteosynthesis screws (Ø2 mm)
Korn et al, 2021, Germany [40]	Ti Grade 23	SLM	Maxilla	Anchorage framework with holes for multiple osteosynthesis screw. Four connection posts	N.R.	Osteosynthesis screws (Ø1.5–2 mm)
Korn et al, 2022 Germany [41]	Ti Grade 23	SLM	Maxilla	Anchorage framework with holes for multiple osteosynthesis screw. Two to four connection posts	N.R.	Osteosynthesis screws (Ø1.2–2 mm)
Vaira et al., 2024 Italy [42]	Ti Grade V	SLM	Maxilla	Two arms with holes for osteosynthesis screws: 1 arm nasomaxillary pillar and 1 maxillomalar pillar, extending to the anterior face of the zygomatic arch, equipped with multiunit abutments.	N.R	Osteosynthesis screws (Ø2-2,3mm)

Table 3. Prosthetic rehabilitation; characteristics of temporary and definitive prosthesis

AUTHORS YEAR COUNTRY	REHABILITATION TYPE (PARTIAL / FULL-ARCH)	PROSTHESIS TYPE (FIXED / REMOVABLE)	PROVISIONAL PROSTHESIS (USE & FEATURES)	PROSTHESIS FIXATION	PROSTHESIS IMPRESSION TECHNIQUE	DEFINITIVE PROSTHESIS
Cerea et al., 2018, Italy[30]	Full-arch or partial	Fixed	Yes. Fixed acrylic resin prosthesis. Within 48 h after surgery	Cemented	Analogical (polyvinylsiloxane)	CAD/CAM metallic suprastructure veneered in ceramic. Delivered after 3–4 months
Cebrián et al., 2022 Spain [31]	Full-arch	Fixed	Yes. Two weeks after surgery	Screw-retained. 4 or 6 connecting posts	Analogical (open tray)	Metal (CAD/CAM) suprastructure veneered with porcelain. Delivered after 2 months
Dimitroulis et al.,2023, Australia [32]	18/21 Full-arch; 3/21 partial (maxillary)	Fixed	Yes. CAD/ CAM Ti suprastructure and cemented acrylic overlay	Screw-retained	N.R.	Delivered after 2 to 6 months
Mangano et al.,2020, Russia [33]	Partial	Fixed	Yes 2 sets Milled in PMMA	Cemented	Digital Intraoral scanner	Zr framework Delivered after 2 months
Nemtoi et al., 2022, Romania [34]	14/16 full-arch 2/16 partial	N.R.	Yes. After 12h surgery. Fixed acrylic resin prosthesis	Screw-retained	N.R.	Delivered after 6 months

Van den Borre et al, 2023 Belgium [35]	Full-arch	Both	N.R.	Screw-retained. 6 connecting posts	N.R.	Fixed or removable (no further information available
Vaira et al., 2024, Italy [36]	4/17 Partial 13/17 Full-arch	Fixed	Yes. 10 days after surgery.	Cemented	Digital	Delivered after 6 months
Onică et al., 2024, Romania [37]	Partial 13/61 Full-arch 48/61	Fixed	Yes. 7 days after surgery.	Screw-retained	Analogical/Digital	Delivered after 6-12 months
Van den Borre et al., 2022,Belgium [38]	Full-arch	Both	Yes. Additively manufactured	Screw-retained. 6 connecting posts	N.R.	Delivered after 2 months
Rahlf et al., 2022,Germany [39]	2/6 Partial 4/6 Full-arch	Removable	1/6 provisional prosthesis	N.R	N.R.	N.R. 5/6 implants loaded
Mounir et al., 2017,Egypt [29]	Partial	Fixed	Acrylic bridges. Delivered after 1 month at least	Cemented	N.R.	Delivered after 1 month at least
Korn et al, 2021, Germany [40]	Full-arch	N.R.	N.R.	N.R.	Analogical/Digital	11/14 loaded implants
Korn et al, 2022, Germany [41]	N.R.	Fixed/Removable	N.R.	N.R.	N.R.	N.R.
Vaira et al., 2024 Italy [42]	Full-arch	Fixed	Yes. Right after surgery.	Screw-retained	N.R.	Delivered after 6 months.

Table 4. Follow-up time, surgery characteristics and summary of clinical outcomes

AUTHORS YEAR COUNTRY	SURGERY TIME (MEAN)	LOCAL OU GENERAL	FOLLOW-UP (MONTHS)	IMPLANT SURVIVAL	POST-OP	IMPLANT FITTING	COMPLICATIONS
Cerea et al., 2018, Italy[30]	N.R.	Local anesthesia infiltration with 4% articaine 1:100,000 adrenaline	24	95.8%	Amoxicillin plus clavulanic acid 1g/12h/6d ibuprofen 600mg for 2-3 days. 0.12% chlorhexidine mouth rinse 2-3x day for 5 days.	N.R.	3/70 failure due to infection 4/70 postoperative pain/ discomfort/swelling 1/70 recurrent infections 4/70 fracture of provisional prosthesis 2/70 ceramic chipping in the definitive prosthesis
Cebrián et al., 2022 Spain [31]	N.R.	General anesthesia Infiltration with articaine 1:200.000 epinephrine	Mean: 20 Range: 9 to 38	100%	Amoxicillin/clavulanic acid 1 g/8 h/7 days; 0.12% chlorhexidine mouthwashes, 2-3x a day, during the first week	N.R.	No complications reported
Dimitroulis et al.,2023, Australia [32]	N.R.	General anesthesia	Mean: 22.1 range: 5 to 57	95% (85.7% success rate)	N.R.	Satisfactory 21/21	1/21 Failure (explanted because chronic pain) 4/21 Salvaged (replacing exposed frames or adding more bone screws) 2/21 Failure (exposure of the framework)

Mangano et al.,2020, Russia [33]	44.3 ± SD 19.4	Local anaesthesia 4% articaine 1:100,000 adrenaline	12	100%	Amoxicillin plus clavulanic acid 1 g/12 h/6d ibuprofen 600 mg 3-2d and 0.12% chlorhexidine, 2-3x per day, for 5-6d	Mean rating: 7 out of 10 Satisfactory 8/10 Insufficient 2/10 *adapted during surgery and placed	1/10 patient immediate postoperative complications (pain, discomfort, swelling) 2/10 patient late complications (provisional restoration fracture)
Nemtoi et al., 2022, Romania [34]	86	Local anaesthesia	12	93%	N.R.	5/16 not fully satisfactory Mean satisfaction rate: 4/5	3/16 bleeding 6/16 implant exposure 1/16 implant failure 1/16 fracture of temporary prosthesis
Van den Borre et al, 2023 Belgium [35]	N.R.	N.R.	30.1	100%	N.R.	N.R.	12/40 postoperative inflammation (i.e., swelling, marked redness,pain) 6/40 apparent soft tissue infection, drainage, exploration and/or mechanical debridement needed 3/40 required one connecting post removaldue to persistentand uncontrollable, infection 26/40 Partial exposure of the arms 1/40 Mobility of the implant (> 1 mm)

Vaira et al., 2024, Italy [36]	57.5	Local anesthesia, articaine with 1:100,000 epinephrine	Mean: 22.5	100%	Amoxicillin + clavulanic acid 1 g twice daily for 6 days and analgesics.	1/17 Unsatisfactory	6/17 Temporary hypoesthesia (resolved) 10/17 Discomfort while chewing with the provisional prosthesis Bleeding on probing in 10% of the abutments over 2 years
Onică et al., 2024, Romania [37]	N.R.	Local anesthesia, articaine 4% with 1:100,000 epinephrine	72	25%	For the first week after surgery, Amoxicillin + clavulanic acid, analgesics, anti-inflammatories and 0.12% chlorhexidine	15/36 Infection, pain, discomfort, and mobility	15/36 Infection, pain, discomfort, and mobility requiring implant removal 12/36 Under observation
Van den Borre et al., 2022,Belgium [38]	N.R.	Local or general anesthesia	12	100%	N.R.	N.R.	No complications reported
Rahlf et al., 2022,Germany [39]	146	General anaesthesia	Mean: 18.2	100%	During surgery, either 10 million units of penicillin or 600 mg of clindamycin IV.	N.R.	6/6 Chronic mucositis 3/6 Exposure of the structure around the abutments

Mounir et al., 2017,Egypt [29]	N.R.	Local anesthesia mepivacaine 2% with 1:100,000 adrenaline	12	100%	Ice pack for 10 min every 30 min for 24 h; amoxicillin–clavulanic acid for 10 days; chlorhexidine gluconate 0.1% mouthwash for 14d.	N.R.	1/5 wound dehiscence and exposure of the implant. Fully covered after removal of uncovered rim of the implant 5/5 Ti implants showed 1–2 mm exposure of the platform around the posts.
Korn et al, 2021, Germany [40]	127	N.R.	Mean 26	100%	N.R.	N.R.	1/20 severe infection 1/20 exposed screws needed remotion 9/20 Exposure of the framework
Korn et al, 2022, Germany [41]	135	N.R.	Mean: 8.2	100%	N.R.	N.R.	Infection 1/10 patients Exposure of the framework 2/10 patients Screw-loss 1/10 patients
Vaira et al., 2024 Italy [42]	89.4	Local anesthesia articaine with 1:100 000 adrenaline; superficial intravenous sedation with diazepam	30.1	100%	Amoxicillin with clavulanic acid, 1 g twice daily for a duration of 6 days); pain relief medication	N.R.	7/36 Exposure metal framework 1/36 Infection w/ screw mobility 4/36 Edema treated with corticosteroids 1/36 Fracture of the provisional prosthesis

Complication rates

After a mean follow-up time of 22.9 months (mean range 1 to 74 months), 93% of implants were in function (20 failures reported). In 2 studies [32-33] including 19 implants (6.2%) no complications were reported. Post-operative complications (pain, discomfort, bleeding, swelling) were reported in 45 patients (14.7%), while 27 patients (8.8%) suffered from biological complications such as soft tissue infection or persistent infection (in 2 patients (0.6%) exposed screws had to be removed) and partial exposure of the metal frame was present in 66 implants (1.9%).

In one study [30] temporary hypoesthesia of the innervation area of the mental nerve was reported for 6/17 implants and recovered completely in all cases in an average of 3.2 weeks.

The use of a provisional prosthesis was reported in 225 (73,7%) patients. Mechanical complications such as fracture of the interim prosthesis was reported in 8 patients (2.6%) Implant fitting during surgery was assessed in 5/14 studies including 77 implants and rated as not satisfactory in 23 (30%).

Discussion

This review synthesized data from 14 studies involving a total of 383 subperiosteal implants placed in 305 patients, with an average age of 59.9 years-old. The studies varied in design, including cohort studies and case series, and focused primarily on implants used to address bone atrophy, particularly in cases of Cawood-Howell atrophy type V or higher. All the implants were manufactured from titanium alloys and employed advanced additive manufacturing techniques such as Direct Metal Laser Sintering (DMLS) and Selective Laser Melting (SLM). The analysis highlighted significant variability in surgical protocols, postoperative care and prosthetic rehabilitation approaches. Even though, the implants demonstrated a high success rate of 93% remaining functional after a mean follow-up of 22.94 months. Most reported complications were biological. Among these, partial framework exposure was the most common occurrence, yet it appeared to have no significant impact on short-term survival rates. Other frequent complications included infections and prosthesis fractures.There was a significantly higher number of implants in the maxilla compared to the mandible (282:31). A significant proportion of the studies employed a uniform design concept for manufacturing.

Despite the issues associated with traditional subperiosteal implants, some researchers have reported success rates extending from 30 to 50 years [43,44]. These authors suggested that such long-term success might be attributed to factors such as precise patient selection, optimal design, proper implantation of the framework, and diligent patient cooperation and maintenance. With ongoing advancements in digital technology, it is expected that success rates will continue to improve. When comparing the findings of our review with those reported by Anitua et al. [45] and El-Sawy and Hegazy [46], some differences and similarities emerge. Our study reports a 93% success rate for implants after a mean follow-up of 22.9 months, which is slightly lower than the 97.8% success rate observed by Anitua et al. and higher than the 87.7% reported by El-Sawy and Hegazy. This small variation in success rates may be attributed to the heterogeneity within the studies included in the reviews.

Recent developments in CT scanning technology and image processing software have significantly enhanced the accuracy of virtual 3D model creation. Innovations in design and manufacturing methods—such as selective laser melting, electron beam melting, direct metal laser sintering, 3D printing, and CAD-CAM—have expanded the use of CT imaging from merely diagnostic applications to surgical planning and the creation of patient-specific implants. These advancements have reduced treatment durations and improved outcomes, including implant fitting, which is crucial for ensuring proper adaptation of the implant. Effective implant fitting not only enhances the accuracy of implant placement but also reduces surgical time, thereby minimizing the risk of complications [47,48]

Bone implant fitting during surgery was assessed in 64 implants and was satisfactory in most of the cases, however, the method of rating of this outcome relied on personal feedback, which could be subjective. Dimitroulis et al. [32] found that in certain cases, the accuracy of the device fit to the bone was suboptimal, particularly when there was a prolonged interval (i.e., over 3 months) between the CT scan and the delivery of the subperiosteal frame, which was due to further bone remodeling. He also noted that if the CT slices exceeded 1 mm in thickness, the accuracy and tolerance of the device were compromised.

The analysis of complications associated with subperiosteal implants reveals several key issues that impact overall success rates. The primary complications found in our study werebiological, such asdehiscence and framework exposure.). Partial framework exposure was the most frequently reported issue This complication, while common, did not significantly affect short-term survival rates, indicating that the implants remained functional despite the exposure. According to most authors, the biological complication did not affect the patient’s comfort, chewing, or speech, the stability of the prosthesis and this seems not to conditionate

the survival in the short-term [48]. One author [42] suggest a new design in full-arch rehabilitation, with two separate implants, that could allow to manage one operative field at a time, reduce bleeding and in case of framework exposure or infeccion, only the affected part would be removed. Another author [32] suggests that major design modifications, which significantly reduce the extent of the metal frame covering the underlying alveolar bone, can effectively address the issue of frame exposure and also the importance of preserve keratinized gingiva around each post, avoid sacrificing excess gingival tissue to expose the posts. Excess keratinized tissue will naturally adapt around the posts as the prosthesis is fitted [33,46]. Recent use of mucosal and connective tissue grafts at the base of each post has significantly decreased the exposure of the metal framework. Given the unpredictability of soft tissue thickness and contours, authors advise to delay the construction of the final dental prosthesis for at least six weeks to allow for proper soft tissue healing and remodeling [32].

The outcomes related to health of the surrounding soft tissue has been significantly under-researched; however, according to Van den Borre et al. [49] a thin gingival biotype and the presence of mucositis were identified as risk factors for recession and exposure of the implant's framework. The author also found that although not statistically significant, smokers exhibited a nearly sevenfold increased risk of developing recession compared to non-smokers.

Post-operative issues such as pain, discomfort, and swelling are typical following any surgical procedure but generally resolve quickly. The mechanical complications were primarily related to prosthetic fractures. When in use, the interim prosthesis was fractured in 8 patients (2.6%) and 4–6 prosthetic posts were preferred in most studies. Since no additional information is available to investigate the reasons, it is suggested that modifications to the post design, including a reduction to only 4 posts in a full arch case and the use of conical shapes instead of cylindrical posts, significantly simplified the insertion path and proper seating of the dental prosthesis onto the frame. This adjustment can make it easier for the surgeon to attach the provisional prosthetic teeth during the operation, eliminating the need for help from a restorative dentist or prosthodontist [29]. No differences in clinical performance between cemented and screw-retained fixed prostheses were observed. However, this does not imply that the choice of retention system is clinically insignificant. From a technical perspective, screw-retained prostheses provide a key advantage in terms of retrievability. For patients who are at risk or have a history of malignancy or soft tissue complications, screw-retained prostheses facilitate the necessary periodic inspection of the tissues beneath fixed rehabilitations [34].

Limited information on practices in anesthesia and postoperative care is available on the literature. Local anesthesia was used in 50% of cases, general anesthesia in three studies, and was unspecified in three. Postoperative management varied across the studies: seven studies administered antibiotics (amoxicillin with clavulanic acid), four used anti-inflammatory medications, and five employed 0.12% chlorhexidine rinses. Additionally, one study utilized intravenous penicillin or clindamycin, while another incorporated ice therapy in the postoperative regimen. Medication and care details were not provided in six studies. Surgical duration was reported in half of the studies, with a mean time of 103.1 minutes. This variation highlights the need for more standardized protocols to improve treatment outcomes.

This study features a broad search strategy, which included literature without restrictions on publication date and including recent research from the last seven years, with three articles from the current year. Nevertheless, the significant heterogeneity among study designs and methodologies, combined with variations in reporting practices and postoperative management, hindered the ability to perform a meta-analysis and impacted the consistency of the findings. The relatively short follow-up periods across many studies prevent definitive conclusions about the long-term outcomes of subperiosteal implant rehabilitations. more conclusive and reliable insights into the effectiveness and durability of these implants.

Conclusion

Based on the results of this review, customized subperiosteal implants (CSI) manufactured with digital technology show promising short-term outcomes. However, efforts must be focused on minimizing biological complications associated with these implants. To better understand their impact on tissues, it is essential to conduct longer-term prospective studies with larger sample sizes. Successful treatment outcomes are heavily reliant on precise design, accurate fitting, effective fixation, and thorough patient selection and maintenance.

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3 CONCLUSÃO

Os implantes subperiosteais têm sido utilizados por décadas, porém, na década de 1960, com a descoberta da osseointegração, perderam relevância entre os clínicos devido ao desempenho clínico insatisfatório. Os avanços tecnológicos e ampliação dos recursos digitais trouxeram uma nova perspectiva para esses implantes. Com base nos estudos disponíveis, que são predominantemente observacionais, os implantes subperiosteais fabricados com design CAD e técnicas de manufatura aditiva mostraram uma taxa de sobrevivência satisfatória no curto prazo. A exposição parcial do implante foi a complicação mais comum relatada, seguida por complicações pós-operatórias, infecção de tecidos moles e fraturas de próteses provisórias. Embora novos designs de implantes subperiosteais possam ajudar a prevenir algumas dessas complicações, é essencial fortalecer a evidência por meio de novos estudos clínicos para confirmar esses achados e garantir a eficácia e segurança desses implantes a longo prazo.

Contudo, mais pesquisas são necessárias para avaliar a taxa de sucesso e o comportamento clínico desses implantes no médio e longo prazo.

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