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Systematic Review
Dental Implants

# Virtual surgical planning and customized subperiosteal implants: a systematic review

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*Abstract.* This systematic review was performed to evaluate the use of subperiosteal implants (SPIs) manufactured using digital workflows, focusing on their indications, performance, osseointegration, and safety by categorizing early and late biological and mechanical complications. The PubMed and Embase databases were searched, covering the years 2018–2023. The PRISMA guidelines were followed. Quality was assessed using JBI and NIH tools. Twenty-four articles (six cohort studies, six case series, 12 case reports) reporting 246 implants were analysed. After a mean follow-up of 17 months, 97.6% of implants were functional, with well-fitting results. Implants were primarily used for full-arch dentures in the maxilla and bridge prostheses in both jaws, with high survival rates (94.1–100%). Early complications included pain (25%) and swelling (24%), while late complications requiring SPI removal were infrequent (five reported failures). Partial exposure occurred in 37% of implants. Success rates, patient satisfaction, and aesthetics were reported positively, although rarely. Methods to enhance osseointegration included additively manufactured titanium, acid-etching, grit-blasting, and polyether ether ketone, but no clear superiority was found. Study heterogeneity precluded meta-analysis. The results indicate that digitally manufactured SPIs are a viable option for severely atrophic jaws, especially in elderly or compromised patients. More research with larger cohorts and longer follow-ups is needed to confirm their long-term safety and effectiveness.

Keywords: Subperiosteal implantation; Dental implants; Alveolar bone loss; Edentulous jaw; Computer-aided design; Treatment outcome.

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Subperiosteal implants (SPIs) are custom-made dental implants placed between the periosteum and the underlying bone[1–4]. They usually have a metal framework that may be fixed with small screws and two to four transmucosal elements projecting into the oral cavity, connecting the implant to the prosthesis[1,2].

SPIs were introduced in the early 1940s[1,2] and were generally made of Vitallium (cobalt–chromium–molybdenum alloy)[5]. They were widely used for the prosthetic rehabilitation of partially and completely edentulous patients until the late 1970s when their use decreased with the advent of endosseous titanium implants[1,4,6].

The transition to endosseous implants occurred for several reasons, such as the complex surgical protocol

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and the presumably high risk of failures and the complication rates associated with SPIs. The surgical protocol encompassed two surgical interventions, one for taking the impression of the patient's bone, needed for fabrication of the SPI, and the other for implant placement[1,2,4]. Since the SPIs were very bulky, extremely large flaps were needed for their placement. Their positioning was difficult and time-consuming, since it was not easy to fit them through the mouth[7]. This often resulted in patient discomfort and a high risk of postoperative complications[1,2,4]. SPIs were also associated with a rather high risk of failures and late complications[1,2,5], including implant exposure, implant mobility, recurrent infections[5], fistula formation, sinusitis[8], bone resorption[1,6] and implant loss[9]. Failure of these traditional SPIs was partly associated with substantial bony defects that could only be corrected by extensive, and sometimes highly burdensome, augmentations for patients, as demonstrated by a case series of extension implants published in 2000[8].

Recently, new materials with improved mechanical and biocompatibility features, such as titanium and polyether ether ketone (PEEK)[5,10,11], along with advances in digital technology have revolutionized oral implantology, including the use of SPIs. Modern techniques have made planning, designing, and fabricating SPIs easier and less burdensome for patients, allowing higher accuracy in manufacturing[2–4,7,12]. These advancements have led to a comeback for SPIs, particularly in cases of severe bone atrophy or poor bone quality that do not allow the placement of endosseous dental implants[1,3,4].

Specifically, new acquisition methods (i.e., cone beam computed tomography (CBCT), computed tomography (CT), and intraoral scanners), improved processing software (i.e., computer-assisted-design/computer-assisted manufacturing (CAD/CAM)), and direct metal laser sintering (DMLS) three-dimensional (3D) printing techniques have been developed. These allow the fabrication of highly accurate custom-made SPIs that perfectly fit the specific anatomy of the patient. This eliminates the need for a surgical session to capture the bone impression and reduces non-fitting problems[2,4,5,7]. The high accuracy of these methods makes the surgical intervention for SPI placement faster and more straightforward, reducing intraoperative complications, bacterial contamination, and postoperative infection risks[4].

While endosseous implants have been shown to have a high survival rate[5], their placement and longevity are dependent on the patient having sufficient bone quality and quantity[5,6]. In the case of severe bone atrophy or poor bone quality, complex regenerative procedures are usually required prior to endosseous implant placement,[4,5] leading to lengthy treatments, economic costs, and the possibility of additional intra- and postoperative complications[2,4,5].

With the increased accuracy and simplified procedures brought by the digital revolution in implantology, SPIs are now generally considered an alternative to complex regenerative solutions and endosseous implants for the rehabilitation of severely atrophic jaws[1,4,5,9].

The aim of this systematic review was to carefully evaluate the indications, performance, safety, osseointegration, and surfaces of SPIs manufactured by digital workflow, providing comprehensive insights into their effectiveness and potential in clinical practice. Anitua et al.[13] recently published a review on the clinical performance of additively manufactured SPIs, which also contributes to our understanding of this field, but their review did not focus on safety aspects in a structured way. The current comprehensive analysis is novel in examining survival rates according to the jawbone of placement and prosthesis type, while also differentiating outcomes across various indications, including bone atrophy, oncology cases, medication-related osteonecrosis of the jaw (MRONJ), congenital or developmental craniofacial anomalies (such as cleft and hypodontia), and revision cases following failed grafts and implants. Furthermore, it distinguishes between early and late complications, including systemic biological and mechanical complications.

## Materials and methods

### Study design

This systematic review focused on clinical studies investigating SPIs produced exclusively via digital workflows. Specifically, it examined (1) performance outcomes (such as the survival rate, success rate, fit, function, aesthetics, patient satisfaction); (2) indications for SPIs (e.g., bone atrophy, oncology, MRONJ, congenital or developmental craniofacial anomalies, revision cases); (3) safety indicators (including early postoperative complications, late biological and mechanical complications, implant exposure); and (4) osseointegration and surface characteristics. Additional comparisons included SPIs versus zygomatic implants, SPIs versus traditional dental implants with bone augmentation in the mandible and maxilla, success rates for bridges versus full-arch dentures, as well as infection causes, sites, and strategies for elimination.

### Search strategy and criteria

The following focused question in the Patient, Intervention, (Comparison), and Outcome (PI(C)O) style was asked[14]: "In patients with complete or partial edentulism of the maxilla or mandible (P), how do SPIs produced through digital workflows (I), (compared to zygomatic implants and traditional dental implants with bone grafting (C)), affect outcomes such as the SPI survival rate (main outcome), performance (including the success rate, fit, function, aesthetics, and patient satisfaction), safety (complication rate categorized by early/late and biological/mechanical), and characteristics of osseointegration and implant surfaces (additional outcomes)?".

The PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) were followed, and the protocol is registered in the PROSPERO international database for systematic review protocols (https://www.crd.york.ac.uk/PROSPERO/; registration number CRD42024532803)[15].

An initial search of the PubMed and Embase databases was conducted. To identify relevant studies on SPIs, taking into account the latest technological advances and the increasing adoption of digital workflows, the search period covered was January 2018 to December 2023. In addition, databases were manually searched to identify articles that may not have been detected in the initial search, and the references of included articles were reviewed. Language was restricted to English and Italian. Studies had to evaluate the above aspects and questions, considering only SPIs produced by digital workflow. A comprehensive search was conducted using the following terms:

"subperiosteal" AND "implant" for PubMed and "subperiosteal implant" OR "subperiosteal AND implant" for Embase. The specified keywords, inclusion and exclusion criteria are presented in Supplementary material Table S1.

### Study selection and data extraction

Only studies with SPIs manufactured using a digital workflow (virtual surgical planning (VSP) and customized) were included. All clinical studies in humans at all levels of evidence, including randomized clinical trials (RCTs), cohort studies, case–control studies, case series, and case reports, were eligible.

After the removal of duplicates, the authors independently screened the titles and abstracts of identified studies, and then examined the full texts for inclusion. Data extracted included the study design and year of publication, number of patients and implants, follow-up duration, indication, implant location, implant material/design and surface, manufacturing technology, prosthetic rehabilitation, implant fitting and osseointegration, implant survival and success, and complications (early vs late, biological vs mechanical). Disagreements were resolved by discussion until a consensus was reached.

### Assessment of risk of bias and the quality of evidence

Both reviewers independently assessed the risk of bias for each study using the relevant JBI critical appraisal tools (https://jbi.global/critical-appraisal-tools), tailored to the design of each study, including case reports[16] and case series[17]. For cohort studies, the risk of bias was evaluated using the National Institutes of Health (NIH) quality assessment tool for observational cohort studies and cross-sectional studies [16]. Risk of bias was defined according to the percentage of 'yes' responses to the appraisal tool questions: studies with ≤49% 'yes' responses were considered to have a high potential risk of bias, those with 50–79% 'yes' were deemed to have a moderate risk of bias, and studies with ≥80% 'yes' were considered to have a low potential risk of bias.

The level of evidence provided by each study was graded according to the Oxford Centre for Evidence-Based Medicine (March 2009). The level of evidence was rated as 5 for case reports, 4 for case series, and either 2b or 1b for the cohort studies. With this grading system, 1b indicates a high-quality randomized controlled trial, 2b denotes individual cohort studies or low-quality randomized trials, 4 corresponds to case series, and 5 represents expert opinions or case reports without critical appraisal[18].

### Data synthesis and statistical analysis

A quantitative but non-inferential summary of the published evidence was generated, focusing on the outcomes of interest in the intervention groups (and non-intervention groups if a control was available), without collecting individual patient data but using aggregated patient data. Given the expected heterogeneity, a formal meta-analysis was not performed. The descriptive analysis was conducted using Microsoft Excel 365 (Microsoft Corp., Redmond, WA, USA) to generate summary statistics and figures. A data analysis was performed for each data variable, with calculations including the number and percentage, or mean ± standard deviation (SD), as appropriate.

The data analysis provided a tabulated overview of several metrics, which are detailed in the tables in the Results section. These metrics included overall SPI survival rates and rates categorized by specific indications (bone atrophy, oncology, MRONJ, congenital craniofacial anomalies, and revision cases following failed grafts and implants). Survival rates were also analysed according to the jawbone of placement and the prosthesis type (bridge or full arch). Additionally, early postoperative complications (within 14 days of SPI placement) were detailed, covering pain, swelling, discomfort, oedema, and bleeding. For complications occurring after 14 days, the report outlined late biological complications (infection, wound/soft tissue dehiscence, chronic pain), late mechanical complications (disconnection from the post, implant mobility, provisional and final prosthetic complications), and other complications (implant exposure).

## Results

### Study selection and characteristics

The initial search strategy identified a total of 245 potential studies. After duplicates were removed, 155 studies remained for title and abstract screening. Based on the eligibility criteria (Supplementary material Table S1), 24 studies were included[1–7,9–12,19–31]. The PRISMA flowchart in Fig. 1 illustrates the review process.

The 24 publications reported six cohort studies (three prospective; five

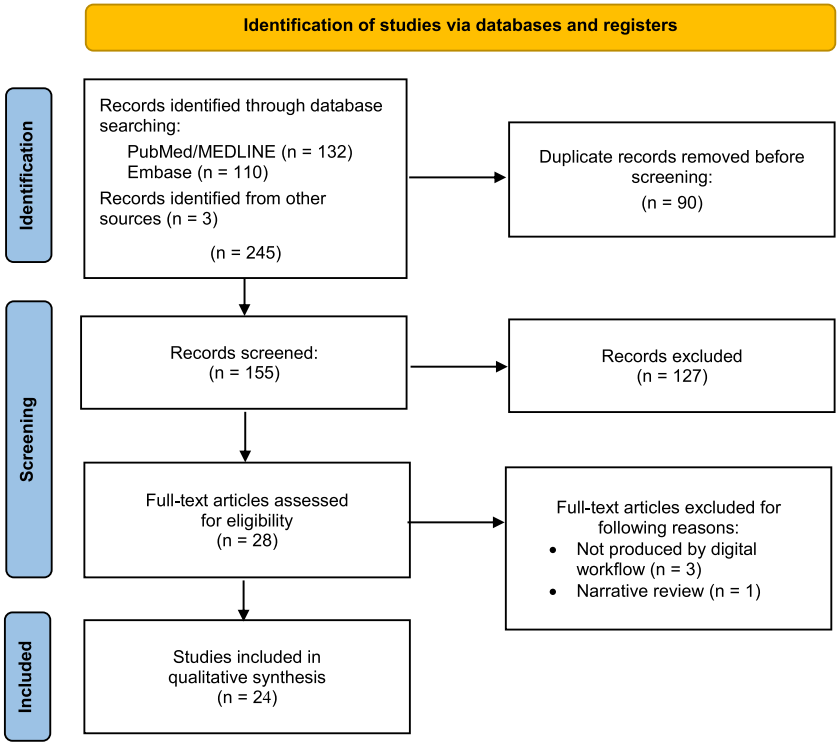


*Fig. 1.* PRISMA flowchart detailing the selection of studies.

multicentre)[1,2,6,11,24,25], six case series (one prospective; three multicentre; one that served to prepare technical guidelines)[4,7,10,19,27,29], and 12 case reports[3,5,9,12,20–23,26,28,30,31]. No RCTs or systematic reviews were found. All included articles were published from 2018 onwards. The studies involved a total of 242 patients with 246 SPIs.

Specific indications encompassed complete or partial edentulism in the (severely) atrophic maxilla or mandible[1,2,4,5,7,10,19–23]; (severely) atrophic maxilla (Cawood–Howell classification ≥V)[6,9,11,24–26] combined with vertical ostectomy for terminal maxillary dentition[27]; partially edentulous mandible[12]; and maxillomandibular deformity in congenital conditions [3]. Additional indications included post-oncological resection reconstructions of the maxilla[28,29], anterosuperior tooth absence with cleft lip/palate [30], and complete anodontia[31].

Prosthetic loading concepts varied across these publications: 11 reported immediate loading[1,2,5,7,9,12,20–22,24,26], six reported delayed loading[3,4,10,11,29,30], and seven did not specify the loading protocol[6,19,23,25,27,28,31].

Follow-up periods extended to 57 months (mean 17 months). Supplementary material Table S2 provides an overview of the study characteristics, with detailed information provided in Supplementary material Table S3.

### Risk of bias and level of evidence

The results of the risk of bias assessment for the 12 case reports and six case series studies are summarized in Fig. 2, while the results for the cohort studies are shown in Fig. 3. The quality of each study and their level of evidence are detailed in Figs. 4–6. Of the 12 case reports, seven had a low risk of bias (58.3%), three had a moderate risk (25%), and two had a high risk (16.7%) (including one abstract-only article). Among the six case series, four had a low risk of bias (66.7%) and two had a high risk (33.3%). Three of the six cohort studies had a low risk of bias (50%) and six a moderate risk (50%). The level of evidence was rated as 5 for the case reports, 4 for the case series, 2b for three cohort studies, and 1b for three cohort studies.

### Performance of subperiosteal implants

#### *Overall*

Twenty publications discussed the performance of the SPIs[1–7,9–12,20–22,24–26,28–30], whereas four did not report related outcomes[19,23,27,31]. Among nine studies providing overall survival data (212 patients, 212 implants), the survival rate ranged from 93.8% to 100% (mean 97.6%) (Table 1). Ten of the 12 case reports (13 implants) described no major complications over 6 months to 3 years[3,5,9,12,20–22,26,28,30], and two case series (8 implants) reported stable outcomes without problems in the prosthetic part[10,29]. Only one study documented the success rate, reporting this as 85.7% (18/21 implants); the authors defined success as patient comfort, pain-free chewing, normal speech, and satisfactory aesthetics[7]. They also reported device-related factors (no exposure of the metal baseplate, stable frame, absence of clinical infection, no radiological signs of screw loosening or prosthesis fracture) and healthy pink keratinized gingiva around each transmucosal post[7].

In seven publications, implant fit was described as adequate to excellent[1–3,7,11,12,29]. Minor discrepancies were occasionally noted. Mangano et al.[4] reported that two of 10 SPIs (20%) showed an insufficient fit due to CBCT scattering, which was resolved through intraoperative adaptation. In the study by El-Sawy et al.[10], the elasticity of PEEK facilitated adjustments to the bone even after a 6-month delay in placement. Most studies indicated that a less-than-ideal fit occurred when more than 3 months had elapsed between CT imaging and implant delivery, or when the CT slice thickness exceeded 1 mm. In a multicentre cohort study of 40 patients, one SPI (2.5%) showed mobility > 1 mm after removal of the final restoration[25]. Nemtoi et al.[1], reported an insufficient fit for one of 16 (6.25%) implants, which, together with recurrent and untreatable infections, eventually led to implant loss.

Additional benefits included improved function[1,9,20,29], comfort[6,7], chewing, speech[7,21], improvement in lip closure and stable jaw occlusion[3], and oral hygiene[7]. Five publications reported positive aesthetic outcomes[3,7,20,21,29], with one describing a significant improvement in facial profile and elimination of the gummy smile at the 3-year follow-up in a case of thalassemia-induced maxillomandibular deformity[3]. Van den Borre et al.[24] reported excellent Oral Health Impact Profile-14 (OHIP-14) scores and increased numerical rating scale (NRS) scores for patient satisfaction at 6 and 12 months compared with those at 1 month.

#### *Comparison of full-arch and bridge prostheses in the maxilla and mandible*

Fifteen publications provided information on the prosthesis type, jaw location, and outcomes, with follow-up of up to 57 months[1,3–5,7,9–12,20–22,26,28,30]. The most common combination was a full-arch denture in the maxilla (35 patients); nine full-arch dentures were placed in the mandible (Table 2). Regarding the bridge prostheses, 17 were placed in the maxilla and 13 in the mandible (Table 3). Of the 74 implants with reported survival rates, 72 survived (97.3%); the survival rate was 97.1% for full arches in the maxilla, 100% for full arches in the mandible, 94.1% for bridges in the maxilla, and 100% for bridges in the mandible.

Dimitroulis et al.[7] placed 15 maxillary and three mandibular full-arch dentures, and three maxillary bridge prostheses. Their overall implant success increased from 66.7% to 85.7% after salvaging four SPI cases; one maxillary SPI was removed at 18 months due to chronic pain despite no evidence of infection and full osseointegration. Nemtoi et al.[1] placed 10 maxillary and four mandibular full-arch dentures, plus one bridge prosthesis in each jaw; a single implant failed (maxillary bridge) owing to insufficient fit and recurrent infection. Other studies reported similarly high survival, implant stability, and satisfactory tissue outcomes, irrespective of the prosthesis type or jaw.

Nine publications lacked complete details on the prosthesis type or jaw location. In one of these studies, 70 patients received either a full-arch or bridge restoration without specifying which jaw(s)[2]. Seven other studies reported 99 maxillary SPIs without specifying the prosthesis type in these cases[6,19,24,25,27,29,31] and one case report described a mandibular bridge prosthesis without providing outcome data[23].

### Analysis according to indications

SPIs placed in cases of bone atrophy demonstrated a mean survival rate of 98.9% among 226 patients (226 SPIs), with a mean complication rate of 16% (e.g., implant exposure, infection) (Table 4A). Revision cases showed 100% survival, although 33.3% of implants had complications, often infections or exposures (Table 4A). Regarding oncology, MRONJ, and


*Fig. 2.* Risk of bias graphs for case reports ($n$ = 12) and case series ($n$ = 6). Studies rated according to the JBI critical appraisal tool. The graphs display the review authors' assessment of each risk of bias item for case reports (top) and case series (bottom). The risk of each item is shown as a percentage of the total number of publications included.

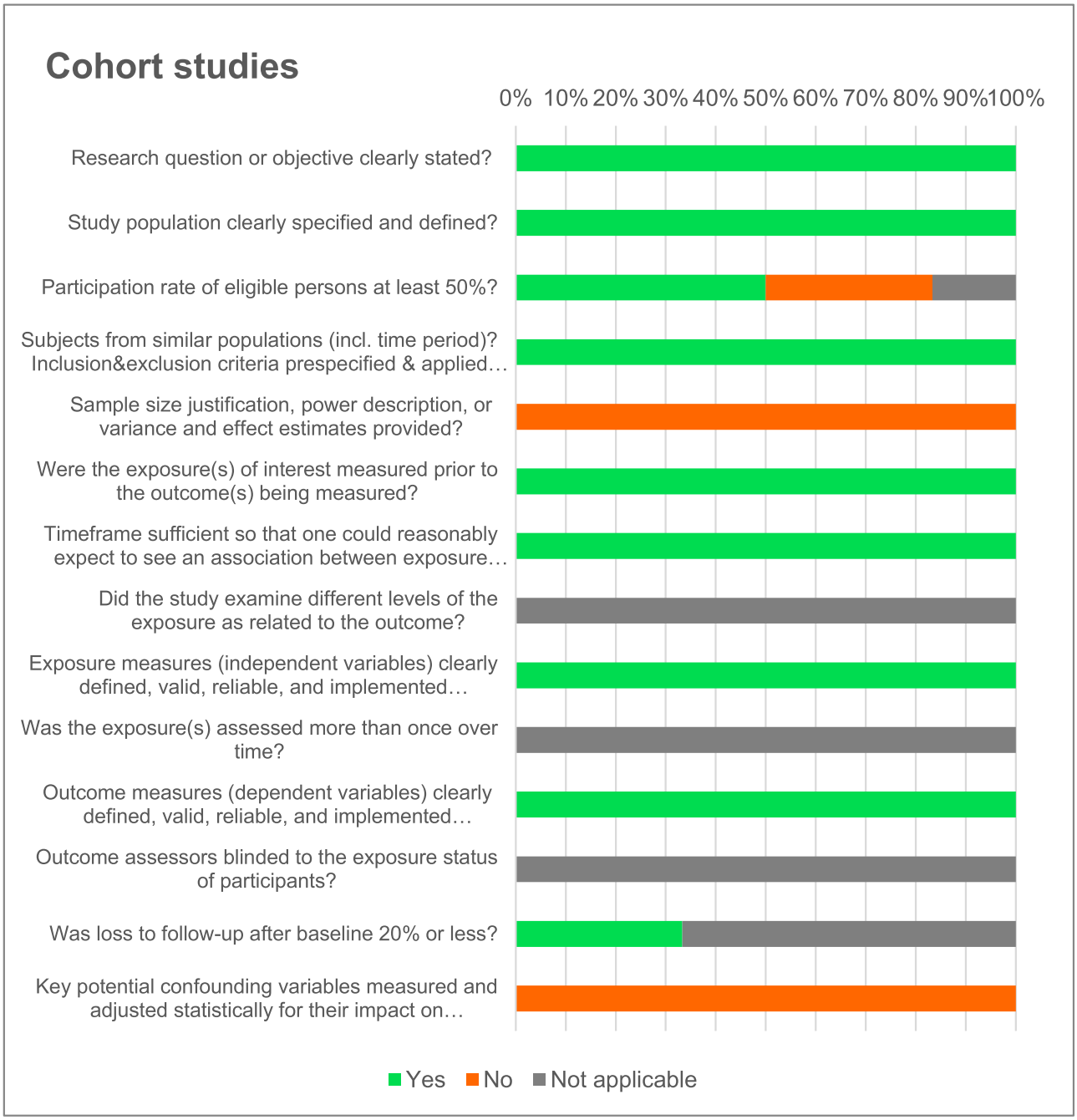


*Fig. 3.* Risk of bias graph for cohort studies ($n$ = 6). Studies rated according to National Institutes of Health (NIH) quality assessment tool for observational cohort and cross-sectional studies. The graph displays the review authors' assessment of each risk of bias item for cohort studies. The risk of each item is shown as a percentage of the total number of publications included.

cleft/hypodontia indications, the mean survival was 100% in each, with relatively few complications, most commonly superficial implant exposures that did not compromise long-term stability (Table 4B).

#### Safety of subperiosteal implants

Twenty publications addressed SPI safety[1–7,9–12,19–21,24–29]. Two reported overall complication rates of 14.9% and 30%,[2,4] respectively, while six publications reported no complications[5,6,12,26,28,30].

*Early postoperative complications (≤14 days; Table 5)*

Any complications within 2 weeks of surgery were classified as early postoperative complications. These included pain, swelling, discomfort, oedema, and bleeding. Gobbo et al.[20] reported only mild pain and oedema, with no bleeding or signs of infection, while three other studies attributed low complication rates to a reduced surgical time and excellent implant fit[1,2,4]. Mangano et al.[4] further noted that the simplified and fast surgical procedure improved patient comfort and minimized the infection risk. Three case

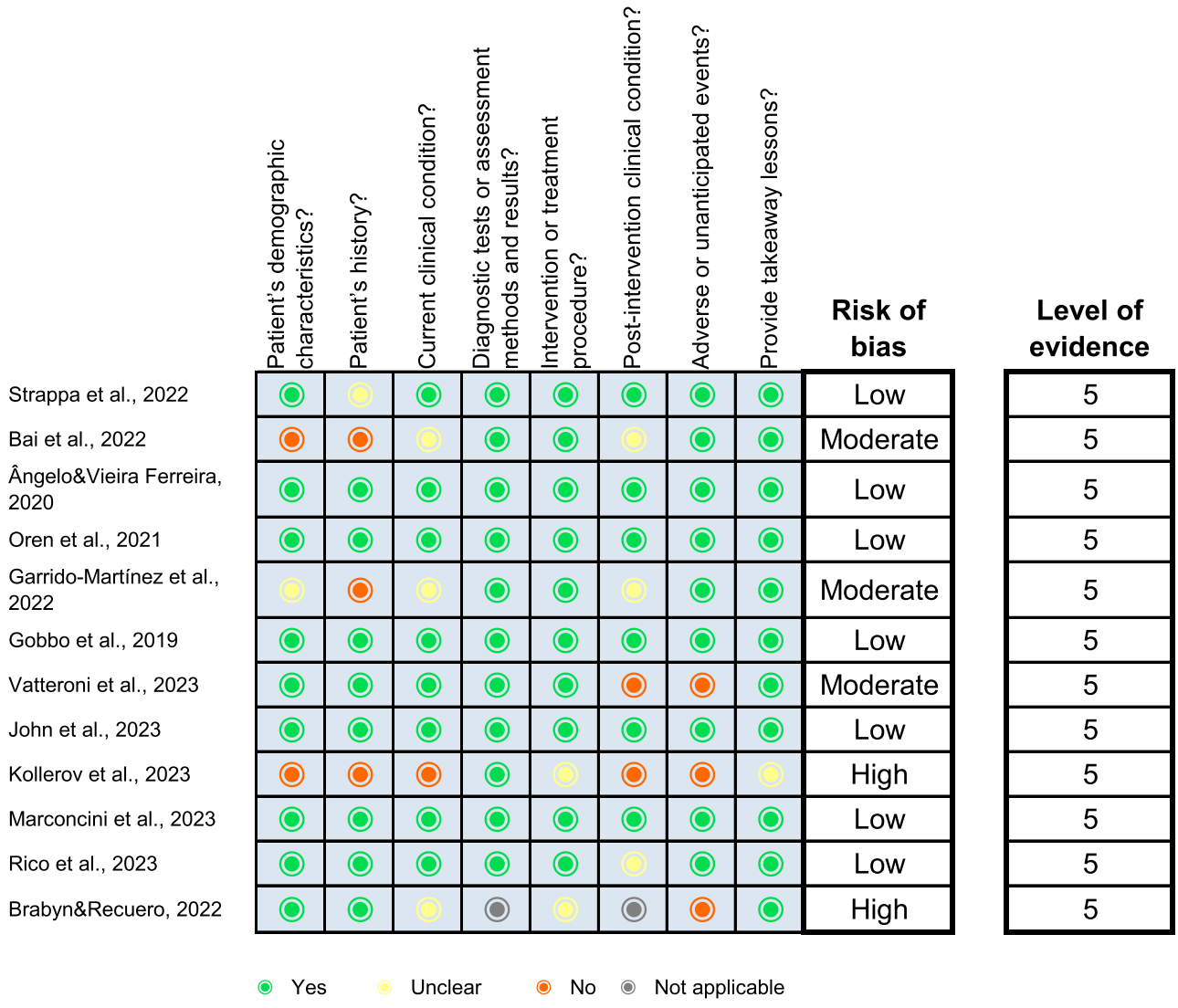


*Fig. 4.* Risk of bias and level of evidence for each included case report ($n = 12$). Risk of bias was assessed using the JBI Critical Appraisal Tool for Case Reports, and the level of evidence was determined according to the Oxford Centre for Evidence-Based Medicine. Risk of bias defined according to the percentage of 'yes' responses: high risk, ≤49% yes; moderate risk, 50–79% yes; low risk, ≥80% yes.

reports indicated no early postoperative complications at all[3,28,30].

*Late biological complications (> 14 days; Table 6)*

Complications occurring more than 2 weeks after implant placement included infection, wound/soft tissue dehiscence, chronic pain, rhinosinusitis, oedema, and tissue colour changes..

In a cohort study of 15 patients, Van den Borre et al.[24] reported oedema and tissue colour changes at 1 month, with certain sites prone to inflammation over follow-ups spanning 1–12 months; 33.3% of patients had radiological rhinosinusitis preoperatively, which stabilized or resolved postoperatively. Mommaerts[19] noted dehiscences but did not quantify them, while Cebrián Carretero et al.[29] found none. Three publications reported no bone resorption[11,12,29], while Van den Borre et al.[6] measured only minimal resorption (0.26 ± 0.65 mm at the crest) and concluded that overall bone changes were negligible.

Infection was documented in four publications at a mean rate of 9%[1,2,19,25], while 11 publications reported none[3,5–7,10–12,21,24,27,29], and nine did not specify infection status[4,9,20,22,23,26,28,30,31]. Cerea and Dolcini[2] removed 3/70 SPIs (4.3%) at 8, 12, and 14 months due to recurrent infection; another patient required prolonged antibiotics and enhanced oral hygiene. Nemtoi et al.[1] removed 1/16 SPIs (6.3%) owing to insufficient SPI fit and recurrent untreatable infections. In the study by Mommaerts[19], 1/9 patients (11.1%) required extraoral surgical drainage and partial implant wing removal to address a local infection. Van den Borre et al.[25] documented soft tissue infections in six of 40 patients (15%), with three cases (7.5%) requiring removal of a post in the affected area, although stability and prosthetic function were maintained. A case series advised delaying SPI placement if alveolar resection could not fully eliminate an infection site[27].

Dimitroulis et al.[7] removed 1/21 SPIs (4.8%) for chronic pain, despite full osseointegration and no evidence of

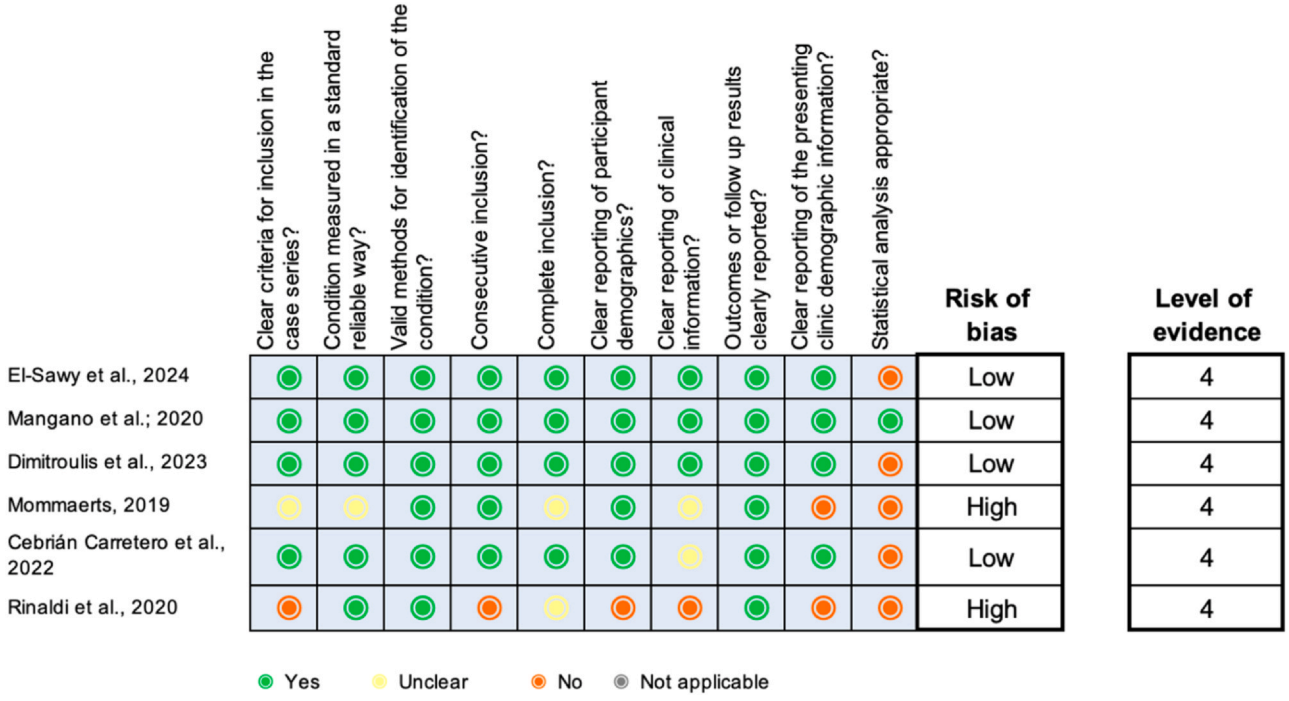


*Fig. 5.* Risk of bias and level of evidence for each included case series ($n = 6$). Risk of bias was assessed using the JBI Critical Appraisal Tool for Case Series, and the level of evidence was determined according to the Oxford Centre for Evidence-Based Medicine. Risk of bias defined according to the percentage of 'yes' responses: high risk, ≤49% yes; moderate risk, 50–79% yes; low risk, ≥80% yes.

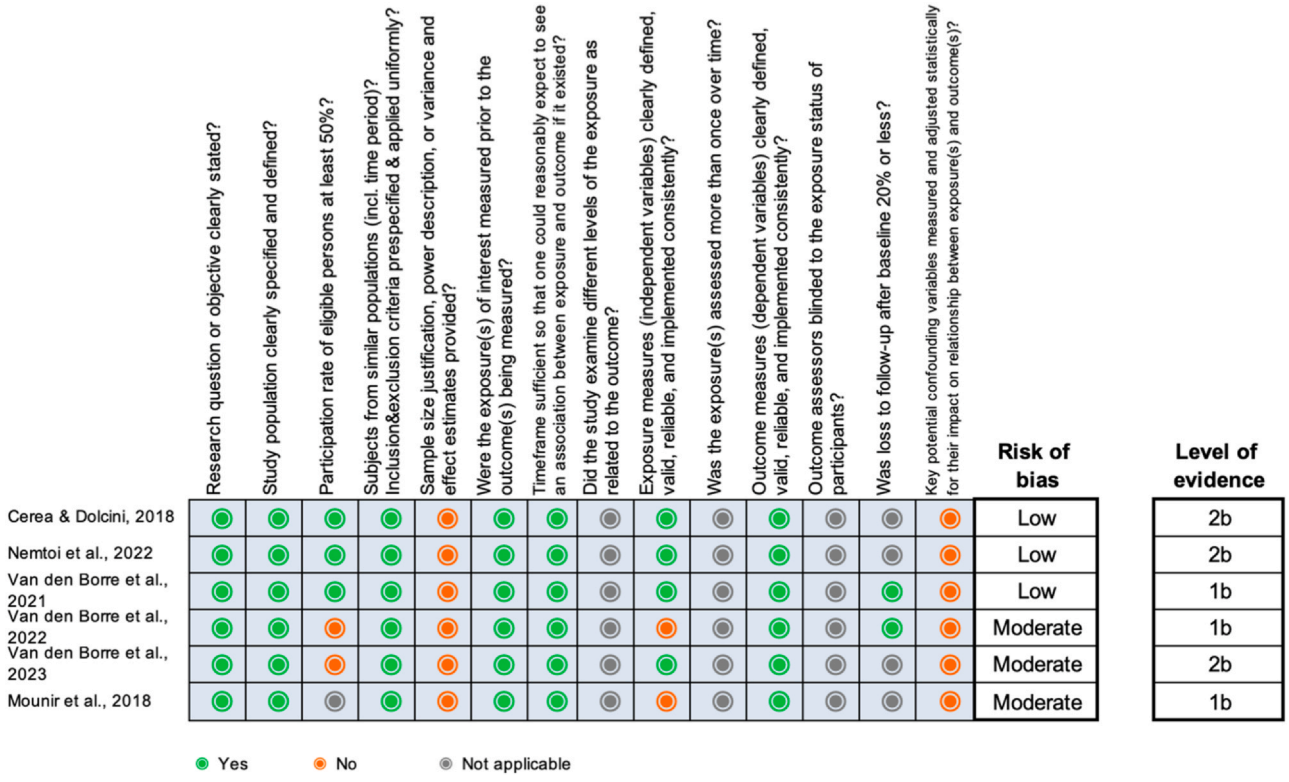


*Fig. 6.* Risk of bias and level of evidence for each included cohort study ($n = 6$). Risk of bias was assessed using the National Institutes of Health (NIH) quality assessment tool for observational cohort and cross-sectional studies, and the level of evidence was determined according to the Oxford Centre for Evidence-Based Medicine. Risk of bias defined according to the percentage of 'yes' responses: high risk, ≤49% yes; moderate risk, 50–79% yes; low risk, ≥80% yes.

*Table 1.* Subperiosteal implant survival rates (studies with ≥10 cases).

| Refs. | Immediate loading | Implant survival; survival rate | Follow-up |
|---|---|---|---|
| Cerea and Dolcini[2] 2018 | Yes | 67/70 implants; 95.7% | 2 years |
| Mangano et al.[4] 2020 | No | 10/10 implants; 100% | 1 year |
| Nemtoi et al.[1] 2022 | Yes | 15/16 implants; 93.8% | 6 months |
| Dimitroulis et al.[7] 2023 | Yes | 20/21 implants; 95.2% | 5–57 months |
| Van den Borre et al.[6] 2021 | NR | 15/15 implants; 100% | 12 months |
| Van den Borre et al.[24] 2022 | Yes | 15/15 implants; 100% | 12 months |
| Mounir et al.[11] 2018 | No | 10/10 implants; 100% | 12 months |
| Van den Borre et al.[25] 2023 | NR | 40/40 implants; 100% | > 1 year (Mean 2.5 years) |
| Rinaldi et al.[27] 2020 | NR | 15/15 implants; 100% | 8–19 months |
| Total | | 207/212 implants; 97.6% | 17 months |

NR, not reported.

*Table 2.* Survival rates of subperiosteal implants according to the jaw and prosthesis type—full arch.

| Jaw | Refs. | Patients/devices | Implant survival; survival rate |
|---|---|---|---|
| Maxilla | Strappa et al. 2022[5] | 1 patient/1 implant | 1/1 implant; 100% |
| | El-Sawy et al. 2024[10] | 4 patients/4 implants | 4/4 implants; 100% |
| | Dimitroulis et al. 2023[7] | 21 patients/15 implants | 14/15 implants; 93.3% |
| | Nemtoi et al. 2022[1] | 16 patients/10 implants | 10/10 implants; 100% |
| | Oren et al. 2021[3] | 1 patients/1 implant | 1/1 implant; 100% |
| | Garrido-Martínez et al. 2022[28] | 1 patient/1 implant | 1/1 implant; 100% |
| | Gobbo et al. 2019[20] | 1 patient/1 implant | 1/1 implant; 100% |
| | Vatteroni et al. 2023[22] | 2 patients/1 implant | 1/1 implant; 100% |
| | Ângelo and Vieira Ferreira 2020[9] | 1 patients/1 implant | 1/1 implant; 100% |
| Mandible | Dimitroulis et al. 2023[7] | 21 patients/3 implants | 3/3 implants; 100% |
| | Oren et al. 2021[3] | 1 patients/1 implant | 1/1 implant; 100% |
| | Ângelo and Vieira Ferreira 2020[9] | 1 patients/1 implant | 1/1 implant; 100% |
| | Nemtoi et al. 2022[1] | 16 patients/4 implants | 4/4 implants; 100% |

*Table 3.* Survival rates of subperiosteal implants according to the jaw and prosthesis type—bridge.

| Jaw | Refs. | Patients/devices | Implant survival; survival rate |
|---|---|---|---|
| Maxilla | Dimitroulis et al. 2023[7] | 21 patients/3 implants | 3/3 implants; 100% |
| | Nemtoi et al. 2022[1] | 16 patients/1 implant | 0/1 implant; 0% |
| | Mounir et al. 2018[11] | 10 patients/10 implants | 10/10 implants; 100% |
| | John et al. 2023[21] | 1 patient/1 implant | 1/1 implant; 100% |
| | Marconcini et al. 2023[26] | 1 patient/1 implant | 1/1 implant; 100% |
| | Rico et al. 2023[30] | 1 patient/1 implant | 1/1 implant; 100% |
| Mandible | Bai et al. 2022[12] | 1 patient/1 implant | 1/1 implant; 100% |
| | Mangano et al. 2020[4] | 10 patients/10 implants | 10/10 implants; 100% |
| | Nemtoi et al. 2022[1] | 16 patients/1 implants | 1/1 implant; 100% |
| | Vatteroni et al. 2023[22] | 2 patients/1 implant | 1/1 implant; 100% |

infection. In total, there were five failures out of a total of 246 SPIs. Several publications described uneventful and good soft tissue healing[3,5,12,20,29]; three indicated no pain[9,12,29] and El-Sawy et al.[10] noted no pus discharge.

*Late mechanical complications (> 14 days; Table 7)*

Mechanical complications that occurred more than 2 weeks after implant placement included disconnection from the post, implant mobility, and prosthetic issues (both provisional and final). Mangano et al.[4] documented the highest prosthetic complication rate (20%), although all were minor. Mounir et al.[11] reported no prosthetic

*Table 4A.* Summary of clinical outcomes of subperiosteal implants across different indications—bone atrophy and revision cases.

| Refs. | Patients/ devices/SPI design (if complete edentulism) | Mean follow-up (range) | Complications | Survival rate | SPI material and surface |
|---|---|---|---|---|---|
| Bone atrophy | | | | | |
| Cerea and Dolcini[2] 2018 | 70 pts/70 SPIs/NR | 2 years | 14.9% overall complication; 5.7% postoperative, 1.4% biological (infection); 8.9% prosthetic | 95.8% | DMLS titanium polished through electroerosion |
| Nemtoi et al.[1] 2022 | 16 pts/16 SPIs/ single-piece | 6 months | 37.5% implant exposure; 6.25% lost due to insufficient fit and infections; 27.5% early complications; 6.25% prosthetic | 93.75% (15/16) | DMLS titanium roughened contact with bone, polished soft tissue interface |
| Van den Borre et al.[6] 2021 | 15 pts/15 SPIs/ two-piece | 1–12 months | None | 100% | 3D-printed, titanium, NR |
| Van den Borre et al.[24] 2022 | 15 pts/15 SPIs/ two-piece | 1–12 months | None | 100% | 3D-printed, titanium, NR |
| Van den Borre et al.[25] 2023 | 40 pts/40 SPIs/ two-piece | 917 days (± 306.89) | 30% (12 pts) postoperative inflammation, 6 of these infection, 3 pts required post removal due to infection; 2.5% (1 pt) implant mobility; 65% (26 pts) partial exposure | 100% | 3D-printed, titanium, NR |
| Mounir et al.[11] 2018 | 8 of 10 pts/8 of 10 SPIs | 12 months | 10% wound dehiscence and exposure (titanium SPI) | 100% | Titanium and PEEK, roughened and etched for titanium group |
| El-Sawy et al.[10] 2024 | 4 pts/4 SPIs/ single-piece | 1–24 months | 25% implant exposure | 100% | PEEK, smooth surface |
| Mangano et al.[4] 2020 | 10 pts/10 SPIs | 1 year | 30% overall complication (10% postoperative; 20% prosthetic); 20% insufficient fit | 100% | DMLS titanium, porous |
| Dimitroulis et al.[7] 2023 | 21 pts/21 SPIs/ single-piece | 22.1 months (5–57) | 33.3% (7/21) overall complications (23.8% implant exposure, 4.8% implant mobility, 4.8% chronic pain) | 95.2% 4/7 pts with complications successfully salvaged, giving success rate 85.7% | 3D-printed titanium, roughened |
| Mommaerts[19] 2019 | 7 of 9 pts/7 of 9 SPIs/two-piece | 1 year | None | 100% | 3D-printed, titanium, NR |
| Rinaldi et al.[27] 2020 | 15 pts/15 SPIs/ two-piece | 8–19 months | 13.3% implant exposure | 100% | 3D-printed, titanium, NR |
| Strappa et al.[5] 2022 | 1 pt/1 SPI/ single-piece | 1–24 months | None | 100% | Titanium, roughened for bone contact |
| Bai et al.[12] 2022 | 1 pt/1 SPI | 3–12 months | None | 100% | 3D printed titanium, lattice-like, porous |
| Vatteroni et al.[22] 2023 | 2 pts/2 SPIs/ single-piece | 1 year | None | 100% | 3D-printed titanium, roughened |
| Kollerov et al.[23] 2023 | 1 pt/1 SPI/ single-piece | NR | NR | 100% | Ti6Al4V, sandblasted |
| Overall | 226 pts/226 SPIs | Mean follow-up: ~15.9 months | Mean complication rate: ~16% | Mean survival rate: 98.9% | |
| Revision cases (failed grafts and implants) | | | | | |
| Ângelo and Vieira Ferreira[9] 2020 | 1 pt/1 of 2 SPI/ single-piece (mandible) | 15 months | None | 100% | Titanium, rough for bone contact and polished for soft tissue |
| Gobbo et al.[20] 2019 | 1 pt/1 SPI | 3 years | None | 100% | Titanium, NR |
| Brabyn and Recuero[31] 2022 | 1 pt/1 SPI | NR | NR | NR | Titanium, NR |
| Mommaerts[19] 2019 | 1 pt of 9/1 SPI of 9 | 1 year | 100% infection caused by iatrogenic misjudgements followed by removal of the wing | 100% | 3D-printed titanium, NR |
| Overall | 4 pts/4 SPIs | Mean follow-up: 21 months | Mean complication rate: 33.3% (infection) | Mean survival rate: 100% | |

DMLS, direct metal laser sintering; NR, not reported; pt(s)., patient(s); PEEK, polyether ether ketone; SPI, subperiosteal implant.

*Table 4B.* Summary of clinical outcomes of subperiosteal implants across different indications—oncology, MRONJ, and cleft and hypodontia.

| Refs. | Patients/ devices/SPI design (if complete edentulism) | Mean follow-up (range) | Complications | Survival rate | SPI material and surface |
|---|---|---|---|---|---|
| Oncology | | | | | |
| Cebrián Carretero et al.[29] 2022 | 4 pts/4 SPIs/ single-piece | 20 months (9–38 months) | NR | 100% | CAD/CAM Titanium, NR |
| Garrido-Martínez et al.[28] 2022 | 1 pt/1 SPI/ single-piece | 1 year | NR | 100% | Titanium, NR |
| Mounir et al.[11] 2018 | 2 of 10 pts/2 of 10 SPIs | 12 months | 10% wound dehiscence and exposure (titanium SPI) in study of 10 pts | 100% | Titanium and PEEK, roughened and etched for titanium group |
| Overall | 7 pts/7 SPIs | Mean follow-up: 14.7 | 1 pt (implant exposure) | Mean survival rate: 100% | |
| MRONJ | | | | | |
| John et al.[21] 2023 | 1 pt/1 SPI/two-piece | 6 months | Superficial implant exposure at 6 months (1–2 mm) but did not affect stability | 100% | Titanium grade 5, NR |
| Marconcini et al.[26] 2023 | 1 pt/1 SPI | 1 year | None | 100% | Titanium grade 5, NR |
| Overall | 2 pts/2 SPIs | Mean follow-up: 9 months | 1 pt (superficial implant exposure) | Mean survival rate: 100% | |
| Cleft and hypodontia (congenital or developmental craniofacial anomalies) | | | | | |
| Rico et al.[30] 2023 | 1 pt/1 SPI | 25 months | None | 100% | Titanium grade 3, NR |
| Mommaerts[19] 2019 | 1 pt of 9/1 SPI of 9 | 1 year | 100% pressure necrosis caused by iatrogenic misjudgements resulted in partial exposure | 100% | 3D-printed titanium, NR |
| Ângelo and Vieira Ferreira[9] 2020 | 1 pt/1 of 2 SPI/ single-piece (maxilla) | 15 months | None | 100% | Titanium, rough for bone contact and polished for soft tissue |
| Oren et al.[3] 2021 | 1 pt/2 SPIs/ single-piece | 3 years | None | 100% | Titanium, NR |
| Brabyn and Recuero[31] 2022 | 1 pt/1 SPI | NR | NR | NR | Titanium, NR |
| Overall | 5 pts/5 SPIs | Mean follow-up: 22 months | Mean complication rate: 25% (implant exposure) | Mean survival rate: 100% | |

CAD/CAM, computer-aided design/computer-aided manufacturing; MRONJ, medication-related osteonecrosis of the jaw; NR, not reported; PEEK, polyether ether ketone; pt(s)., patient(s); SPI, subperiosteal implant.

fractures, and patient satisfaction remained high at 12 months. Several publications observed no mechanical complications or prosthetic failures at all[5,10,28,29]. Rico et al.[30] similarly reported no complications or implant exposure..

*Other complications—implant exposure (Table 8)*

Eight publications reported implant exposure, with incidence rates (excluding case reports) ranging from 10% to 65%[1,7,10,11,19,21,25,27]. Dimitroulis et al.[7] described five exposures; three were salvaged by placing a newly designed SPI. Van den Borre et al.[25] documented implant exposure in 65% (26/40) of patients over a follow-up period of at least 1 year (mean 917 ± 306.89 days), a rate noticeably higher than in the studies with 6–22 months of follow-up[1,7,10,11,19,21,27]. These patients did not perceive the implant exposure as a functional or aesthetic impediment. Similarly, Nemtoi et al.[1] found that exposure did not affect SPI functionality. Mounir et al.[11] reported an uneventful first month in 90% (9/10) of patients; at 2 months, a 1–2 mm platform exposure occurred in some titanium SPIs but did not compromise loading or satisfaction. John et al.[21] similarly observed 1–2 mm of superficial exposure at 6 months, with no adverse effects on stability or the prosthetic restoration. Five publications noted no implant exposure at all[9,20,26,29,30].

### Osseointegration and surfaces of subperiosteal implants

Osseointegration was examined in eight publications[4–7,11,12,19,22], with five reporting osseointegration-related outcomes at follow-ups from 1 month to 2 years[5–7,12,22]. One case report noted close SPI–bone contact on CBCT at 2 years[5], while another observed new

*Table 5.* Early postoperative complications (0–14 days after subperiosteal implant placement).

| Complication | Refs. | Affected patients |
|---|---|---|
| Pain | Cerea and Dolcini[2], 2018 | 6% (4/70) |
| | Mangano et al.[4], 2020 | 10% (1/10) |
| | Nemtoi et al.[1], 2022 | 100% (16/16) |
| | Gobbo et al.[20], 2019 | 100% (1/1) |
| | Van den Borre et al.[25], 2023 | 30% (12/40) |
| | All | 25% (34/137) |
| Swelling | Cerea and Dolcini[2], 2018 | 6% (4/70) |
| | Mangano et al.[4], 2020 | 10% (1/10) |
| | Nemtoi et al.[1], 2022 | 100% (16/16) |
| | Van den Borre et al.[25], 2023 | 30% (12/40) |
| | All | 24% (33/136) |
| Discomfort | Cerea and Dolcini[2], 2018 | 6% (4/70) |
| | Mangano et al.[4], 2020 | 10% (1/10) |
| Oedema | Nemtoi et al.[1], 2022 | 100% (16/16) |
| | Gobbo et al.[20], 2019 | 100% (1/1) |
| Bleeding | Nemtoi et al.[1], 2022 | 19% (3/16) |

*Table 6.* Late biological complications (> 14 days after subperiosteal implant placement).

| Complication | Refs. | Affected patients |
|---|---|---|
| Infection | Cerea and Dolcini[2], 2018 | 6% (4/70) |
| | Mommaerts[19], 2019 | 11% (1/9) |
| | Nemtoi et al.[1], 2022 | 6% (1/16) |
| | Van den Borre et al.[25], 2023 | 15% (6/40) |
| | All | 9% (12/135) |
| Wound/soft tissue dehiscence | Rinaldi et al.[27], 2020 | 7% (1/15) |
| | Mounir et al.[11], 2018 | 10% (1/10) |
| Chronic pain | Dimitroulis et al.[7], 2023 | 5% (1/21) |

*Table 7.* Late mechanical complications (> 14 days after subperiosteal implant placement).

| Complication | Refs. | Details |
|---|---|---|
| Disconnection from the post | Rinaldi et al.[27], 2020 | 7% (1/15) implants |
| Implant mobility | Dimitroulis et al.[7], 2023 | 5% (1/21) implants |
| | Van den Borre et al.[25], 2023 | 3% (1/40) implants |
| Provisional prosthetic complications | Mangano et al.[4], 2020 | 20% (2/10) patients |
| | Nemtoi et al.[1], 2022 | 6% (1/16) patients |
| | Cerea and Dolcini[2], 2018 | 6% (4/67) patients |
| Final prosthetic complications | Cerea and Dolcini[2], 2018 | 3% (2/67) patients |

bone formation around the implant at 12 months[12]. A cohort study of 15 patients documented bony overgrowth around the SPIs, predominantly at the upper part of the wings[6], and Vatteroni et al.[22] reported good osseointegration on panoramic X-ray at 1 year. Dimitroulis et al.[7] removed one of 21 SPIs (4.8%) despite full osseointegration due to chronic pain; another SPI with mobility was salvaged by adding bone screws. Mounir et al.[11] compared titanium and PEEK SPIs in five patients each, finding no differences in the supporting bone, but highlighting that porous titanium could reduce stress shielding. They also noted that histological confirmation of SPI osseointegration remains challenging.

Surface characteristics were discussed in nine publications[1,2,4,7,9–11,19,23], with various methods aimed at increasing roughness or porosity (grit- or sand-blasting, acid etching, additive manufacturing)[4,19,23]. Titanium SPIs often featured perforations for bone ingrowth and polished transgingival sections[1,9], while PEEK had limited osteoconductive properties without additional coating[10]. Electroerosion polishing and other methods were also mentioned[2]. Across these studies, rough or porous surfaces were utilized to promote bone integration, while highly polished transgingival posts aimed to facilitate soft tissue healing, thereby enhancing long-term stability and minimizing the baseplate footprint needed for implant placement.

## Discussion

SPIs, initially introduced in the early 1940s, have recently benefited from design and digital manufacturing advancements, resulting in more streamlined surgical protocols. This systematic review aimed to evaluate the current state of digitally manufactured SPIs, focusing on their performance, indications, safety, osseointegration, and surface characteristics. In contrast to the recently published review by Anitua et al.[13], this study distinguishes between early and late, as well as

*Table 8.* Other complications.

| Complication | Refs. | Details |
|---|---|---|
| Implant exposure | Mounir et al.[11], 2018 | 10% (1/10) |
| | Mommaerts et al.[19], 2019 | 11% (1/9) |
| | Rinaldi et al.[27], 2020 | 13% (2/15) |
| | Dimitroulis et al.[7], 2023 | 24% (5/21) |
| | El-Sawy et al.[10], 2024 | 25% (1/4) |
| | Nemtoi et al.[1], 2022 | 38% (6/16) |
| | Van den Borre et al.[25], 2023 | 65% (26/40) |
| | John et al.[21], 2023 | 100% (1/1) |
| | All | 37% (43/116) |

biological and mechanical complications, and provides an indication-specific analysis across various clinical contexts, including bone atrophy, oncology, MRONJ, congenital and developmental craniofacial anomalies, and revision cases following graft or implant failures. This broader approach aims to clarify the specific benefits and challenges of SPI usage across different patient populations, potentially guiding more tailored clinical decisions.

The literature lacks direct comparison between SPIs and other implant types, such as zygomatic or endosseous implants. The calculated short-term survival rate of SPIs was 97.6%, comparable to the long-term survival rate of 96.2% for zygomatic implants[32] and the finding of Anitua et al.[13] of 97.8%. However, data on success rates and medium- and long-term clinical outcomes of SPIs are lacking. The available data was derived exclusively from observational studies encompassing 242 patients. Notably, a significant proportion came from the same retrospective study (70 of the total 246 implants; 29%)[2] and a significant proportion from three multicentre studies conducted by the same international team using the same type of implant (70 of the total 246 implants; 29%)[6,24,25].

Traditional endosseous implants require adequate bone quantity and quality, often necessitating complex bone regeneration procedures such as onlay/inlay bone grafting, guided bone regeneration, alveolar ridge splitting, distraction osteogenesis, or sinus augmentation[33]. These techniques extend the treatment duration and increase patient risk and costs. In elderly patients with substantial bone loss and potentially compromised health, the invasive nature and heightened risks associated with bone regeneration techniques may be inadvisable[33]. Alternatives include specially designed implants, such as short, narrow, or tilted types, as well as zygomatic or pterygomaxillary implants, which require the presence of minimal bone and should be placed by experienced clinicians[34]. Similarly, SPIs allow for a single surgical session, potentially reducing costs and providing a safer, more predictable procedure in the short term. This has refocused clinician attention on using SPIs, particularly for managing complex atrophy cases[4]. Several studies have used SPIs as salvage treatments for patients in whom other implant therapies have failed. This is critical to interpreting the success and survival rates of SPIs, as patients with a history of unsuccessful implant treatments may present additional clinical challenges that could affect outcomes. SPIs offer a feasible solution in salvage scenarios, severe bone atrophy in compromised patients, or patients with limited life expectancy. Moreover, SPIs provide advantages over endosseous implants with bone augmentation, including immediate prosthetic loading and mastication, enhancing treatment efficiency and patient satisfaction[29].

In the current analysis, SPIs were primarily used for complete or partial edentulism in atrophic maxillae or mandibles, including severe Cawood–Howell atrophy (type V or higher), maxillomandibular deformities, absence of anterior teeth and premaxilla in patients with cleft lip and palate, and complete anodontia. Some studies raised questions about whether alternative treatment approaches might have been suitable for certain cases. For instance, Kollerov et al.[23] investigated the development of an SPI and its fixation methods using nitinol retainers. However, specific information on the indication and available residual bone was not provided. This demonstrates the need to discuss the relevance of different anchoring methods. All of the other authors used osteosynthesis screws established in traumatology for fixation of the framework to the bone, with some studies focusing on optimizing the screw–bone interaction by studying the dimensions, geometry, and number of screws[19,35].

Mounir et al.[11] set inclusion criteria requiring sufficient bone volume for standard root-shaped implants (≥3 mm diameter, ≥8 mm length). Nemtoi et al.[1] and Mangano et al.[4] included patients with less than 10 mm of residual bone who declined regenerative bone surgery. Without detailed information on individual cases, it remains controversial whether SPIs offer advantages over alternative endosseous implants (short, narrow, tilted) without additional bone regeneration procedures. This is especially relevant, as recent systematic reviews and meta-analyses indicate that extra-short or narrow diameter endosseous implants perform similarly to standard-length implants in terms of marginal bone loss, technical complications, and implant survival[36–38]. Factors such as the feasibility of immediate prosthesis placement, specific bone defect types, individual patient preference, and surgeon experience might have influenced these treatment decisions, although the precise reasons remain unspecified.

Overall, SPIs demonstrated high short-term survival rates and stability across various prostheses and jaw locations, with positive outcomes in functionality, aesthetics, and patient satisfaction. Methods to enhance osseointegration, such as additively manufactured titanium, acid-etching, and grit-blasting, were commonly employed[4,11,19,23]. Rough or porous surfaces promoted bone integration, while highly polished transgingival posts facilitated soft tissue healing and enhanced long-term stability[1,2,4,7,11,19]. Animal studies have suggested that post-fabrication surface modifications can improve osteogenic and angiogenic factors, although human clinical trials are pending[39]. Comparing titanium and PEEK SPIs, no differences were observed in the supporting bone beneath the implant[11].

Infections were relatively rare (9%) and manageable with antibiotics or partial implant removal. Modern SPIs facilitate easier removal of exposed components, improving the manageability of complications[7,19,25]. Fit issues, often due to delays between planning and implantation or thicker CT slices (> 1 mm), could increase the

infection risk and necessitate surgical adjustments[7,10]. Design improvements, such as reduced zygomatic wing length and optimized stabilizing posts, may help lower infection rates[19]. Finite element studies have informed biomechanical optimizations, reducing stress on bone, implants, and abutments and allowing for thinner frameworks, of approximately 0.7–1 mm[1,19,40,41].

Consistent with Anitua et al.[13], soft tissue complications were the most frequently reported issues with SPIs. However, partial framework exposure occurred in 37% (43/116) of cases, considerably higher than the 25.6% reported by Anitua et al.[13] Exposure rates for guided bone regeneration vary widely, from 7.7% to 66.7% for vertical alveolar bone augmentation with titanium mesh[42] and from 16.8% to 39.4% for lateral bone augmentation[43]. These are considered high rates. In contrast to guided bone regeneration, where exposure during the first four postoperative weeks leads to inadequate bone regeneration and possibly loss of the graft[42], exposure in SPIs does not appear to impact short-term survival. Furthermore, modern CAD implants facilitate easier trimming and partial removal, potentially reducing the adverse effects of soft tissue complications on implant longevity. However, the mid- to long-term clinical outcomes of these complications still require further investigation.

A key limitation of this review is the absence of randomized controlled trials and prospective studies, leading to reliance on lower-level evidence from observational studies and case reports. This heterogeneity precludes meta-analysis and necessitates a cautious interpretation of the findings. Despite these limitations, this review offers a comprehensive overview of current SPI outcomes, highlighting their potential as a viable option for complex cases and stimulating future research to address existing knowledge gaps.

In conclusion, modern digitally manufactured SPIs demonstrate high short-term survival rates overall and across various indications. They generally fit well and are associated with mostly minor early postoperative and late complications that very rarely necessitate implant removal. The most common complication, implant exposure, does not seem to limit functionality. However, to validate their indication compared to other therapy options, as well as their long-term safety and effectiveness, further studies involving comparison groups, patient-reported outcome measures, and extended follow-up periods are essential.

## Ethical approval

Not required.

## Patient consent

Not required.


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## Data availability

All data supporting the findings of this study are included within the article. Supplementary information files that further support these findings are available from the corresponding author upon request.

## Competing interests

B. Al-Nawas has received institutional research grants from Camlog, Dentsply, Geistlich, Logon, Nobel Biocare, Straumann, and Zimmer and provides lectures for Camlog, Dentsply, Geistlich, Mectron, Megagen, Nobel Biocare, Osstem, and Straumann. A. K. Bär declares no conflict of interest.


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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ijom.2025.04.001.

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