

## ORIGINAL ARTICLE

# Long-Term Evaluation of Narrow-Diameter Dental Implants in Posterior Sites in Patients With History of Periodontitis: A Retrospective Study With an 11.5-Year Mean Follow-Up

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## ABSTRACT

**Aim:** To assess the factors influencing the survival and success rates of narrow diameter implants (NDIs) placed in the posterior area; additionally, the study evaluated marginal bone changes, along with biological and prosthetic complications.

**Materials and Methods:** This retrospective single-center study investigated the clinical and radiographic outcomes of 227 NDIs placed in the premolar and molar regions of 119 patients. The analysis focused on implant survival and success rates, marginal bone levels (MBL), and the incidence of biological and mechanical complications. Generalized estimating equations (GEE) were employed to assess the impact of patient- and implant-related characteristics on these outcomes.

**Results:** Over a mean follow-up period of 11.51 years (SD: 4.03) the study recorded the loss of 12 NDIs in seven patients. The Kaplan–Meier survival rates were 90.3% (95% CI: 85.4%–95.4%) and 85.7% (95% CI: 77.2%–95.0%) respectively. The average marginal bone loss (MBL) was estimated at  $-0.75$  (SD 1.34) mm. Mucositis was observed in 33.18% of the implants and peri-implantitis in 9.86% of the sample.

**Conclusion:** This study offers valuable understanding of NDIs as a predictable option in implant dentistry, particularly for patients with challenging anatomical conditions. However, careful case selection and comprehensive treatment planning are crucial to minimize the risk of implant fractures.

## 1 | Background

Dental implants are widely recognized as an effective solution for replacing missing teeth (Esposito et al. 2005; Leonhardt et al. 2002). Recent research highlights favorable trends in implant dentistry, with studies reporting improved success rates and fewer complications (Kupka et al. 2024). These advancements are largely attributed to innovations in biomaterials and dental methodologies (Buser et al. 2017). Nevertheless, insufficient bone volume remains a common challenge in treatment planning. To address this, various surgical techniques have

been developed to enhance horizontal and vertical bone dimensions, either prior to or during implant placement (Benic and Hämmerle 2014; Sanz-Sánchez et al. 2018; Thoma et al. 2019). However, these augmentation procedures often require advanced surgical skills, extend the treatment timeline, increase costs, and heighten patient morbidity (Thoma et al. 2019).

To overcome these limitations, alternative approaches, such as narrow-diameter implants (NDIs) have gained growing clinical and scientific attention (Romeo et al. 2006; de Souza et al. 2018; Schiegnitz and Al-Nawas 2018). NDIs, typically

defined as implants with a diameter of  $\leq 3.5$  or  $\leq 3.75$  mm (Klein et al. 2014; Al-Johany et al. 2017), were initially designed for sites with restricted interdental space, particularly for the replacement of narrow teeth, such as maxillary lateral incisors and mandibular incisors (Romeo et al. 2006). NDIs have recently been classified into three different categories according to their diameter: Category 1 ( $< 2.5$  mm), Category 2 (2.5 to  $< 3.3$  mm) and Category 3 (3.3–3.5 mm) (Schiegnitz and Al-Nawas 2018). Category 3 NDIs have demonstrated promising results, comprising high survival and success rates, significant patient satisfaction, and marginal bone loss comparable to that of standard-diameter implants (SDIs) (de Souza et al. 2018; Schiegnitz and Al-Nawas 2018; Klein et al. 2014; Parize et al. 2019; Shi et al. 2018; Tolentino et al. 2014). Consequently, NDIs are increasingly used in posterior regions among patients who would otherwise require horizontal bone augmentation to enable the placement of SDIs (Parize et al. 2019; Assaf et al. 2023).

Despite these favorable results, in vitro studies have suggested that NDIs may be less resistant to load fatigue and more prone to structural deformation compared to SDIs (Allum et al. 2008; Santos et al. 2024). In addition, clinical studies have suggested that the reduced diameter of NDIs may increase their susceptibility to mechanical complications, including both implant fractures and screw loosening (Chrcanovic et al. 2018; Lee et al. 2019; Yeh et al. 2025). In fact, a recent meta-analysis identified screw loosening as the most frequently reported complication, with an incidence rate of 17.28% (Yeh et al. 2025). However, proper control of occlusal forces on the implant appears to significantly reduce the risk of such complications. In fact, a recent 11-year follow-up study reported only a single case of crown–abutment assembly loosening, highlighting the effectiveness of careful occlusal management (Xu et al. 2025).

On the other hand, certain implant features, such as the implant–abutment connection (Bordin et al. 2018) and surface characteristics (Lustosa et al. 2024) as well as clinical conditions, appear to support the success of NDIs in posterior regions (Arisan et al. 2010). These findings are particularly relevant in molar areas, where masticatory forces can reach up to 700 N, especially in the second molar region (van Eijden 1991).

In light of the current evidence, the aim of this retrospective study was to assess the factors influencing the survival and success rates of NDIs in the posterior area. Additionally, marginal bone changes, as well as biological and prosthetic complications, were evaluated.

## 2 | Material and Methods

### 2.1 | Study Design

This retrospective observational case-series study included patients who received at least one NDI in a premolar or molar position between 2003 and 2018. All implants were placed by a single EFP-certified periodontist (C.S) in a private periodontal practice (Studio Dentistico SBM, Vicenza, Italy).

The study was approved by Comitato Etico per le Sperimentazioni Cliniche (CESC) della Provincia di Vicenza, Italy (Protocol number: 93/22). Written informed consent was obtained from each enrolled patient before study initiation, in accordance with the Declaration of Helsinki (1975, revised in 2013). The study is reported following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (Vandenbroucke et al. 2007).

### 2.2 | Study Population

#### 2.2.1 | Patient Selection

Medical records of patients with at least one NDI in a premolar or molar site, placed between January 2003 and December 2018, were reviewed. All candidates were approached during their routine supportive peri-implant care (SPIC) appointments and informed about the study by a certified periodontist (M.C.S). Eligible subjects who could not attend their SPIC visits were contacted by telephone and invited to a follow-up examination. Unwilling participants were excluded from the study.

#### 2.2.2 | Surgical and Prosthetic Treatment

All implant placements and prosthetic rehabilitations were carried out by the same EFP-certified periodontist (C.S.). Standard surgical prophylaxis and post-operative protocols were followed. Specifically, pre-operative antimicrobial prophylaxis consisted of 1 g of amoxicillin (Zimox Pfizer Italia S.R.I.) 1 h before surgery and continued for up to 6 days post-operatively, depending on the complexity of the surgical procedure. In case of penicillin allergy, clindamycin 600 mg (DALACIN, Zimox Pfizer Italia S.R.I.) was administered.

The surgical procedure involved the elevation of a full-thickness flap to allow the placement of one or more NDIs (the implants have diameters ranging from 3.25 to 3.75 mm) using either a submerged or non-submerged approach; when needed, simultaneous guided bone regeneration was performed. All implants were placed according to the manufacturer's recommendations, and all prosthetic components were original from the respective manufacturers. NDIs included in the study were bone-level implants from various brands (e.g., Ankylos [Dentsply-Friudent GmbH], Astra OsseoSpeed [Astra TechAB], CLC CONIC implants [CLC Scientific], Kontakt implants [Biotech]).

Post-operative instructions included rinsing with 0.12% chlorhexidine solution (Corsodyl, GlaxoSmithKline Spa) twice a day for 14 days. Ibuprofen 600 mg (Brufen, Mylan Italia SRL) was prescribed for pain management, two to four times a day for 7 days after surgery, if needed. Suture removal was performed 1–2 weeks post-surgery. Definitive impressions or second-stage surgery (for submerged implants) were carried out 12–16 weeks later, confirming osseointegration by manual torque testing. All implants were restored following a conventional loading (dental implants are allowed a healing period of more than 2 months after implant placement with no connection of the prosthesis). Patients were then enrolled in a supportive maintenance therapy (SPIC) at 3- or 6-month

intervals, according to the individual risk profile (Lang and Tonetti 2003).

### 2.2.3 | SPIC (Supportive Peri-Implant Care)

At each SPIC appointment, the following procedures were performed:

- Updating the patients' medical and dental history.
- Supragingival debridement using ultrasonic and manual instruments.
- Reinforcement of oral hygiene instructions.
- Assessment of implant survival.
- Evaluation of the prosthesis cleanability with an appropriate interproximal brush (TePe, Cornaredo, MI, Italy).
- Detection and removal of any excess luting cement.
- Reporting of any biological and/or technical complications.

In addition, once a year during SPIC appointment, the following measures were obtained at four sites per implant using a PCP-UNC15 periodontal probe (HuFriedy, Rockwell St):

- Peri-implant probing pocket depth (PPD). PPD > 4 mm was recorded.
- Plaque index (PI) as presence/absence of plaque along the mucosal margin (O'Leary et al. 1972).
- Bleeding on probing (BOP) as presence/absence of bleeding within 15 s after gentle probing (Mombelli and Lang 1994).
- Suppuration on probing (SOP) as presence/absence of suppuration within 15 s after probing.

In addition, standardized parallel radiographs were taken using the long-cone paralleling technique with a film holder (Dürr Dental AG, Bietigheim-Bissingen, Germany). For cases treated before 2010, analog radiographs were obtained using the same technique and an analog film holder. From 2010 onward, radiographs were captured with an intraoral phosphor plate digital system.

## 2.3 | Inclusion Criteria

- Patients age  $\geq 18$  years old.
- Patients rehabilitated with at least one NDI between January 2003 and December 2018.

## 2.4 | Exclusion Criteria

- Lack of radiographic records at implant placement (T0).
- Lack of radiographic records at the last SPIC.
- NDIs placed in the anterior region (canine to canine).
- Patients unwilling to participate or those who refused to sign informed consent.

## 2.5 | Data Collection

A single examiner (I.A.) retrieved all patient and implant-related data from clinical records and entered it into a dedicated database created for this study.

### 2.5.1 | Subjects

Patients' medical histories were examined, and information regarding age, race, sex (female/male), relevant systemic conditions, and medication was obtained. Hypertension was defined as a documented medical diagnosis recorded in the patient's clinical records (referral letters from his physician) and/or the reported use of antihypertensive medications at the time of implant placement or during follow-up (Yamamoto et al. 2020). Smoking status (current smoker, former smoker, or never-smoker; Spiekerman et al. 2003 and reported smoking exposure [pack-years, calculated by multiplying the number of cigarettes per day by the number of years smoked, then divided by 20; a standard pack of cigarettes]; Scott et al. 2001) were also registered. Periodontal stage and grade at the time of implant placement were assessed retrospectively (Caton et al. 2018). Bruxism was noted based on tooth-wear signs, in accordance with the American Academy of Sleep Medicine criteria (American Academy of Sleep Medicine 2014; Carra et al. 2015).

Regarding SPIC adherence, patients were categorized into four groups based on the frequency of the maintenance appointments: non-compliers (i.e., patients missing sporadically or not attending the scheduled SPIC intervals), 1 time/year (i.e., patients attending to one SPIC intervals each year during the observation period with a maximum delayed of 1 month), 2 times/year (i.e., patients attending to two SPIC intervals each year during the observation period with a maximum delayed of 1 month), 3 times/year (i.e., patients attending to three SPT intervals each year during the observation period with a maximum delayed of 1 month).

### 2.5.2 | Implants

The implant characteristics were obtained from the patient records and included the following parameters: number of NDIs, their positions according to the F.D.I. notation system, implant brand, implant location (maxilla or mandible, further categorized as anterior [canine to canine] or posterior), implant diameter (mm) and length (mm), surgical approach (one-stage [non-submerged] or two-stage [submerged]), and details of bone grafting procedures. Information on the type of prosthesis (single, partial, or complete, including fixed full arch restorations or overdentures) and the prosthesis retention method (cemented, screw-retained, ball attachment, or bar attachment) was also recorded.

Radiograph assessments were performed by two previously calibrated examiners (R.P. and E.R.) using an image analysis software (ImageJ64; National Institutes of Health, Bethesda, MD, USA). The two examiners were calibrated at the start of the study on 10 patients with 22 implants, resulting in an intraclass

correlation coefficient (ICC) of 0.88 ( $p < 0.001$ ). Radiographs were calibrated using the known implant dimensions as reference values.

## 2.6 | Outcome Assessment

### 2.6.1 | Survival Rate

Survival rate was defined as the percentage of implants that remained in situ at the time of the last follow-up, regardless of any biological or technical modifications (Shi et al. 2018).

### 2.6.2 | Success Rate

The success rate was calculated based on implants that underwent prosthetic loading, using the criteria proposed by Misch et al., which include: (a) absence of pain or tenderness upon function; (b) lack of implant mobility; (c) radiographic bone loss of less than 2 mm; and (d) no history of exudates (Misch et al. 2008). In order to incorporate prosthetic complications into the overall definition of treatment success, a patient-level success criterion was also applied. Under this definition, a case was considered successful when no biological or prosthodontic complications were observed throughout the follow-up period. Accordingly, patients were coded as 1 in the absence of any such complications, and as 0 if at least one biological or prosthodontic complication occurred during follow-up, as previously described by Ravidà et al. (2019).

### 2.6.3 | Mean Bone Level Changes

Mean bone level (MBL) was defined as the distance (mm) from the implant shoulder to the first radiographically visible bone-to-implant contact at the mesial and distal aspects. The average of these two measurements was calculated (Nart et al. 2020). Changes in MBL from baseline (T0) to subsequent follow-ups were determined. A negative value indicated that the crestal bone level was apical to the implant shoulder; zero indicated that the crestal bone was at the level of the implant shoulder; and a positive value indicated that the crestal bone level was located coronal to the implant shoulder.

### 2.6.4 | Biological Complications

- Peri-implant mucositis was diagnosed retrospectively based on the presence of bleeding (more than one spot at a location around the implant or presence of a line of bleeding or profuse bleeding at any location) and/or suppuration on gentle probing evaluated during the SPIC, in the absence of bone loss beyond crestal bone level changes resulting from initial bone remodeling (Tonetti et al. 2023).
- Peri-implantitis was identified in the presence of bleeding and/or suppuration upon gentle probing, with probing depth  $\geq 6$  mm, and radiographic bone levels  $\geq 3$  mm apical to the most coronal intraosseous portion of the implant (Berglundh et al. 2018).

### 2.6.5 | Technical Complications

Technical complications were classified as fractures of the implant, screws, or abutments; abutment/screw loosening; chipping or fracture of the ceramic material; and fractures or deformations of the prosthetic framework (Pjetursson et al. 2004).

## 2.7 | Data Analysis

A descriptive analysis was performed for all recorded variables. Categorical variables were summarized as absolute and relative frequencies, while continuous variables were expressed as mean, standard deviation, median, and range.

At the implant level, simple binary logistic regression models were estimated using generalized estimating equations (GEE) to explain the probability of survival, success, peri-implant mucositis, peri-implantitis, and mechanical complications, according to patient- and implant-specific characteristics. For each variable, unadjusted odds ratios (OR) and 95% confidence intervals (CI) were derived from the Wald Chi2 statistic. A multiple model was then used to adjust the results for all independent variables simultaneously. The GEE approach was employed to account for within-subject correlations, given that some patients contributed multiple implants. In addition, the MBL was analyzed using a similar methodology (GEE) but

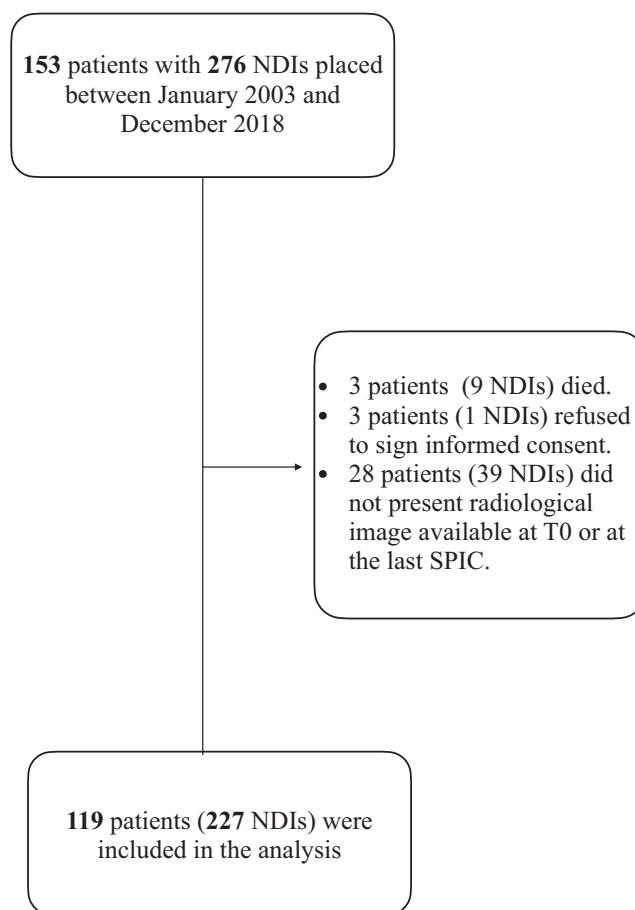


FIGURE 1 | Flowchart of the study.

**TABLE 1** | Description of the studied patients and implants at initial examination.

| <i>Description of the studied patients</i>          |                   |                         |
|-----------------------------------------------------|-------------------|-------------------------|
| Overall (N=119)                                     |                   |                         |
| Variable                                            |                   | Mean $\pm$ SD or n (%)  |
| Mean follow-up (range) (years)                      |                   | 11.52 $\pm$ 4.03 (4–19) |
| Age (n = 119) (years), mean (SD)                    |                   | 67.29 $\pm$ 10.85       |
| Sex (n = 119)                                       | Male              | 53 (44.54)              |
|                                                     | Female            | 66 (55.46)              |
| Smoking status (n = 118)                            | Non-smokers       | 90 (76.27)              |
|                                                     | Former smokers    | 1 (0.85)                |
|                                                     | Current smokers   | 27 (22.88)              |
| Smoking exposure (pack/year) mean $\pm$ SD (n = 13) |                   | 20.44 $\pm$ 13.55       |
| Diabetes (n = 118)                                  | No                | 112 (94.92)             |
|                                                     | Yes               | 6 (5.08)                |
| HTA (n = 119)                                       | No                | 68 (57.14)              |
|                                                     | Yes               | 51 (42.86)              |
| Periodontal disease (n = 119)                       | No                | 0 (0.00)                |
|                                                     | Yes               | 119 (100.0)             |
| Periodontitis extension (n = 119)                   | Generalized       | 91 (76.47)              |
|                                                     | Localized         | 28 (23.53)              |
| Periodontitis stage (n = 119)                       | 1                 | 7 (5.88)                |
|                                                     | 2                 | 38 (31.93)              |
|                                                     | 3                 | 28 (23.53)              |
|                                                     | 4                 | 46 (38.66)              |
|                                                     |                   |                         |
| Periodontitis grade (n = 119)                       | A                 | 41 (34.45)              |
|                                                     | B                 | 57 (47.90)              |
|                                                     | C                 | 21 (17.65)              |
| SPIC (n = 118)                                      | < 1 times a year  | 12 (10.17)              |
|                                                     | 1 time a year     | 26 (22.03)              |
|                                                     | 2 times a year    | 73 (61.86)              |
|                                                     | 3 times a year    | 7 (5.93)                |
| Parafunctional habit (n = 113)<br>(Bruxism)         | No                | 85 (75.22)              |
|                                                     | Yes               | 28 (24.78)              |
| Number of implants (n = 119) mean (SD) (range)      |                   | 1.87 $\pm$ 1.22 (1–7)   |
| <i>Description of the studied implants</i>          |                   |                         |
|                                                     | Overall (N = 227) |                         |
| Arch (n = 227)                                      | Maxilla           | 110 (48.46)             |
|                                                     | Mandible          | 117 (51.54)             |
| Tooth type (n = 227)                                | Premolar          | 151 (66.52)             |
|                                                     | Molar             | 76 (33.48)              |

(Continues)

**TABLE 1** | (Continued)

|                                                     |                 |             |
|-----------------------------------------------------|-----------------|-------------|
| Prosthesis type ( $n = 223$ )                       | Single crown    | 60 (26.90)  |
|                                                     | Splinted crown  | 163 (73.10) |
| Retention ( $n = 223$ )                             | Screwed         | 129 (57.84) |
|                                                     | Cemented        | 88 (39.46)  |
|                                                     | Ball attachment | 3 (1.34)    |
|                                                     | Bar attachment  | 3 (1.34)    |
|                                                     |                 |             |
| Brand ( $n = 219$ )                                 | Astra           | 48 (21.92)  |
|                                                     | Ankylos         | 43 (19.63)  |
|                                                     | CLC CONIC       | 112 (51.14) |
|                                                     | Biotech         | 13 (5.94)   |
|                                                     | Others          | 3 (1.37)    |
|                                                     |                 |             |
| Diameter ( $n = 227$ )                              | 3.25            | 2 (0.88)    |
|                                                     | 3.50            | 210 (92.51) |
|                                                     | 3.60            | 13 (5.73)   |
|                                                     | 3.75            | 2 (0.88)    |
| Length ( $n = 225$ )                                | 8.0             | 89 (39.56)  |
|                                                     | 9.0             | 27 (12.00)  |
|                                                     | 9.5             | 15 (6.67)   |
|                                                     | 10.0            | 38 (16.89)  |
|                                                     | 11.0            | 33 (14.67)  |
|                                                     | 12.0            | 13 (5.78)   |
|                                                     | 13.0            | 6 (2.67)    |
|                                                     | 14.0            | 4 (1.78)    |
|                                                     |                 |             |
| Surgical protocol ( $n = 225$ ) (1-stage, 2-stages) | 1               | 120 (53.33) |
|                                                     | 2               | 105 (46.67) |
| GBR ( $n = 224$ )                                   | No              | 180 (80.36) |
|                                                     | Yes             | 44 (19.64)  |

Abbreviations: GBR, guided bone regeneration; HTA, hypertension; SD, standard deviation; SPIC, supportive peri-implant care.

with linear regression models. Unadjusted beta coefficients were obtained from simple models and adjusted in the subsequent multiple models. For survival analysis, multivariate Cox regression models for clustered data by patient were used, and unadjusted hazard ratios (HRs) with corresponding 95% confidence intervals were calculated. For the multivariate Cox regression, a backward stepwise selection was applied to retain only those variables with a significant contribution to the overall model fit.

Statistical analyses were conducted using R version 4.3.1 (R Core Team, 2023. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: <http://www.R-project.org>) and SPSS version 15.0 (IBM Corp., Chicago, IL, USA).

### 3 | Results

#### 3.1 | Demographic Data

The records of 153 patients with 276 NDIs placed between January 2003 and December 2018 were initially reviewed and considered for inclusion. Of these, 119 patients with 227 NDIs met the inclusion criteria (Figure 1).

The study sample consisted of 53 men (45.00%) and 66 women (55.00%), with a mean age of 67.29 (SD 10.85) years. Each patient contributed a varying number of implants, ranging from 1 to 7 (mean: 1.88 [SD 1.22] implants per patient). More than half of the subjects (62.19%) had a history of severe periodontitis (Stage III and IV), and 90 patients (76.27%) were non-smokers, while

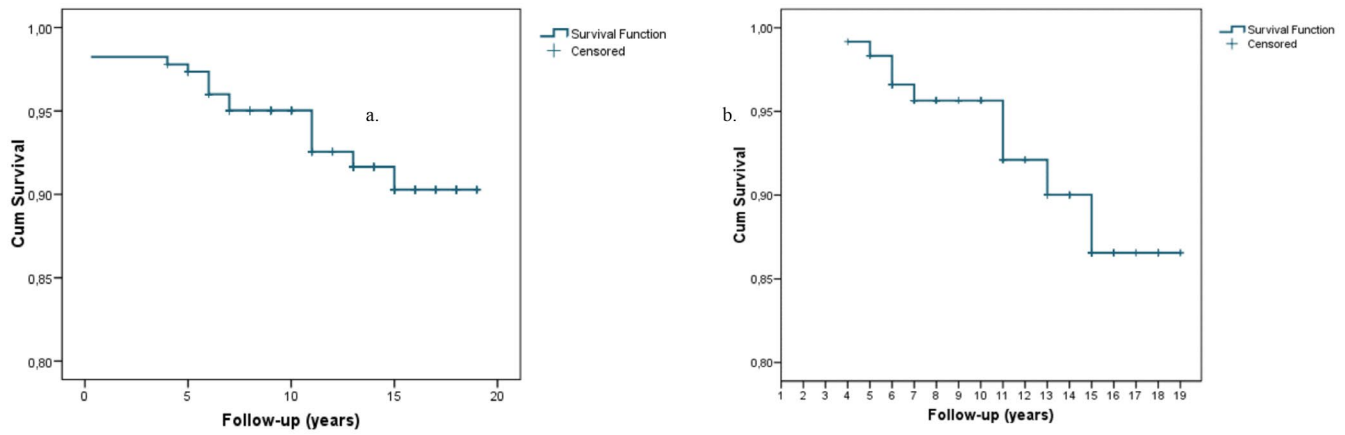


**FIGURE 2** | Overall survival function at the implant level (a) and patient level (b).

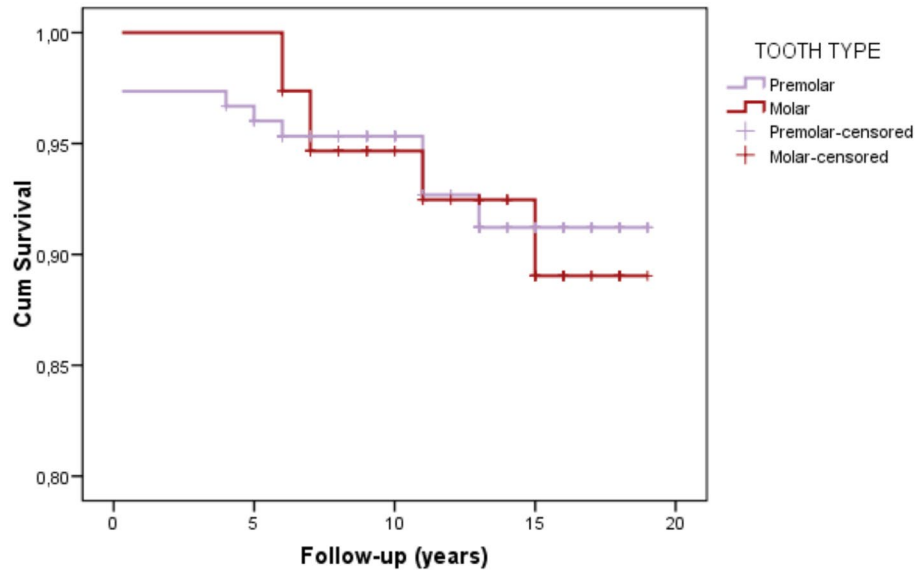


**FIGURE 3** | Overall implant-level survival function by tooth type (premolar or molar).

30 patients (23.73%) were former or current smokers. Regarding implant characteristics, 151 implants (66.52%) were used to rehabilitate premolar regions. Among the 163 implants (73.10%) included in splinted restorations, only 24 were involved in full-arch rehabilitations, comprising full-arch fixed restorations, overdentures, and Toronto prostheses. Further demographic characteristics of the study sample are summarized in Table 1.

### 3.2 | Survival Rate and Related Factors

During the observation period (mean: 11.51 [SD 4.03] years), 16 NDIs were lost in seven patients. Three of these patients lost a total of four NDIs before loading; eight NDIs were lost between 5 and 10 years after placement, while four patients each lost a single implant over a period ranging from 3 to 14 years. Kaplan–Meier survival rates for NDIs were 90.3% (95% CI: 85.4%–95.4%) and 85.7% (95% CI: 77.2%–95.0%) at the implant- and patient-level, respectively (Figures 2–4; Table 2, Table S1).

Cox regression analysis identified age as the only variable significantly associated with implant failure (HR: 1.07;  $p=0.028$ ). In addition, BOP (HR=1.43;  $p=0.036$ ) and surgical protocol (HR=0.16;  $p=0.020$ ) were significantly associated with implant failure in the univariate analysis; however, his association did not persist in the multivariate model (Table S2).

### 3.3 | Success Rate and Related Factors

The success rates of NDIs were 83.33% at the implant level and 78.45% at the patient level (Table 2). Results of multivariate GEE analysis revealed that an increased number of sites with BOP during the various SPIC appointments reduced the probability of implant success (OR: 0.51;  $p<0.001$ ) (Table S3). According to the second definition of success—based on the absence of biological and prosthetic complications during the follow-up period—90 out of 119 patients experienced no such complications, corresponding to a clinical success rate of 75.6%.

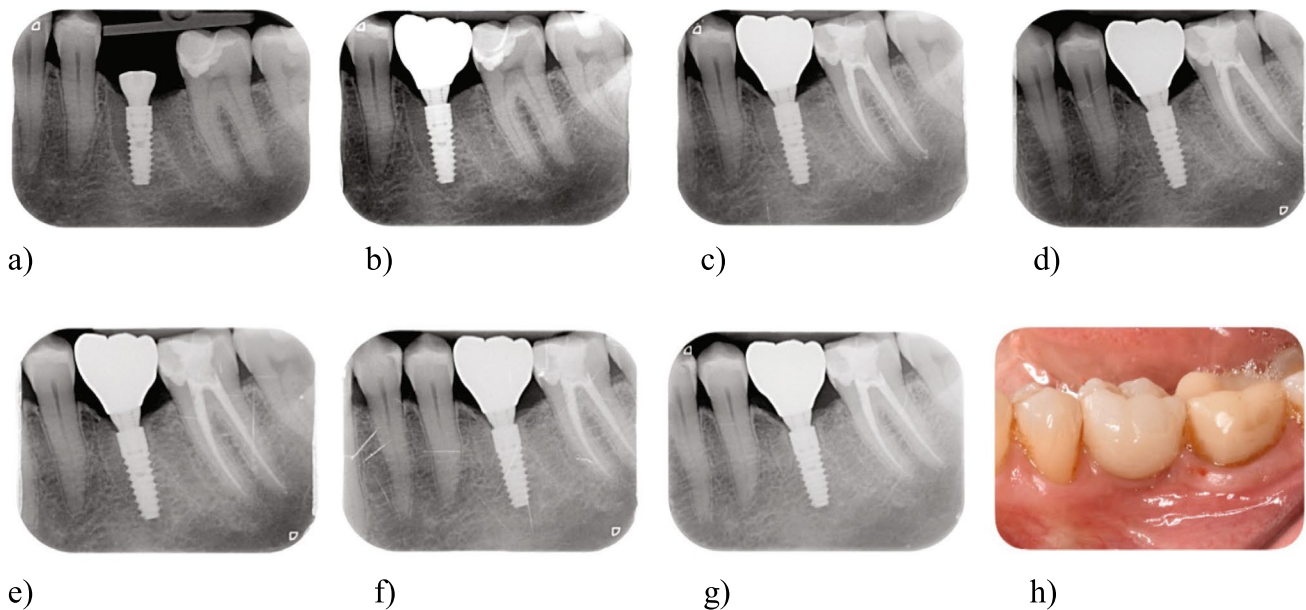


**FIGURE 4** | Radiographic and clinical follow-up of a NDI over a 9-year observation period. Radiographic monitoring of an NDI implant in position 3.6, from implant placement (a), baseline at the time of crown placement (b), 1 year after implant loading (c), 2 years (d), 4 years (e), 6 years (f), 8 years (g), and the final follow-up at 9 years after crown placement (h); clinical image of the crown at the 9-year follow-up after implant placement.

**TABLE 2** | Cumulated survival rate at patient and implant level: Estimation of Kaplan–Meier’s method and log-rank test.

|                      | <i>N</i> | Survival | 95% CI    | <i>p</i> |
|----------------------|----------|----------|-----------|----------|
| <i>Patient level</i> |          |          |           |          |
| Overall              | 119      | 85.7     | 77.2–95.0 | —        |
| <i>Implant level</i> |          |          |           |          |
| Overall              | 227      | 90.3     | 85.4–95.4 | —        |
| Premolar             | 151      | 91.2     | 85.8–97.0 | 0.881    |
| Molar                | 76       | 89.0     | 80.4–98.6 |          |
| Single crown         | 60       | 90.9     | 81.1–100  | 0.930    |
| Splinted crown       | 163      | 92.1     | 86.8–97.7 |          |

### 3.4 | Marginal Bone Level Changes

Table 3 displays the MBL changes for 208 implants between implant placement and the last follow-up. On average, the mean MBL change was  $-0.75$  mm (SD 1.34). Most of the implants (42.31%) exhibited a loss of 0–1 mm (Figure 5), while one-fourth of the sample experienced a certain amount of MBL gain (30.77%) and 13.95% lost more than 2 mm of MBL. Table S4 shows the distribution of bone changes at different time points. Results of the multivariate GEE analysis revealed that implants with higher MBL loss throughout the study had those with a greater number of BOP sites (OR:  $-0.51$ ;  $p < 0.001$ ) (Table 4).

### 3.5 | Biological Complications

Biological complications were evaluated in terms of peri-implant diseases (i.e., peri-implant mucositis and peri-implantitis).

Mucositis was present in 33.18% of the implants and 44.54% of patients, while peri-implantitis was observed in 9.86% of implants and 14.29% of patients (Table 5).

Regarding peri-implant mucositis, results of multivariate GEE analysis revealed that the most significant predictor was the number of sites with plaque at each follow-up visit. Specifically, for each additional site with plaque, the risk of developing mucositis increased by 1.5 times (OR: 1.54;  $p < 0.001$ ). Furthermore, two other factors exhibited some degree of association with the development of mucositis: diagnosis of hypertension and a longer follow-up period; however, these associations did not reach statistical significance (Table S5).

Concerning peri-implantitis, the multivariate GEE analysis determined that patients with hypertension had a significantly higher probability of developing peri-implantitis (OR: 3.79;  $p < 0.001$ ). Additionally, a greater number of BOP sites during follow-up was significantly associated with a higher likelihood of peri-implantitis development (OR: 1.80;  $p < 0.001$ ) (Table S6).

### 3.6 | Mechanical Complications

Of the 223 implants undergoing functional loading, 10.76% ( $n = 24$ ) experienced some mechanical complications during the follow-up period. The most common complications included abutment loosening (4.04%), prosthetic screw loosening (2.24%), and implant fracture (1.79%) (Table 5). Throughout the entire follow-up period, only three prostheses required a modification in the laboratory: one to improve access for oral hygiene, one to modify the emergence profile, and one to replace the resin teeth of an overdenture. No statistically significant differences were observed in the incidence of mechanical complications between

splinted and single-unit restorations, nor between maxillary and mandibular arches.

## 4 | Discussion

This retrospective study, with a mean follow-up of 11.53 years (SD 4.03 years), aimed to assess the survival and success rates, changes in MBL and clinical parameters, as well as mechanical and biological complications of NDIs placed in posterior areas.

In the present retrospective analysis, the survival rate of NDIs was 90.3% (95% CI: 85.4%–95.4%) at the implant level and 85.7% (95% CI: 77.2%–95.0%) at the patient level. Corresponding cumulative success rates were 83.33% and 78.45%, respectively. These outcomes are marginally lower than those reported in the broader implant literature. For instance, a systematic review with a 5-year follow-up period documented an implant-level survival rate of 97.1% (95% CI: 95.6%–98.1%) (Pjetursson et al. 2014). Despite this difference, the present findings align with an expanding body of evidence indicating that NDIs placed in posterior regions—both in the maxilla (de Souza et al. 2018; Assaf et al. 2023; Pieri et al. 2017; Park et al. 2023) and mandible (de Souza et al. 2018; Assaf et al. 2023; Pjetursson et al. 2004; Pieri et al. 2017; Park et al. 2023)—can achieve survival and success rates comparable to those of standard-diameter implants. It is noteworthy that this study incorporated early implant failures, defined as those occurring prior to prosthetic loading, within the survival estimates. In contrast, a 10-year retrospective study on NDIs reported a 96.9% survival rate at the implant level, excluding implants that failed

before loading (Shi et al. 2018). If a similar approach were adopted, excluding the four implants lost prior to prosthetic loading, the calculated survival rate would increase to 94.67%.

Among the factors influencing implant failure, Cox multivariate analysis revealed that only older age was modestly associated with an increased risk of implant failure. Implant failure remains a complex and multifactorial phenomenon in implant dentistry, and numerous confounding factors—such as patient-related variables, implant site characteristics, surgical technique, and prosthetic considerations—may contribute to the variability in clinical outcomes (Jemt 2019). Implant failures and patient age at the time of surgery have been previously investigated in several studies with contradictory results (Jemt 2019; Moy et al. 2005; Park et al. 2017). However, in the present study, this association appeared to be only moderate, possibly due to the relatively high mean age of the study population.

In contrast, univariate analysis showed that the two-stage surgical protocol was significantly associated with a lower risk of implant failure; while BOP was linked to an increased risk.

Regarding the BOP, this finding may be attributed to the strong association with peri-implant diseases, such as mucositis and peri-implantitis (Monje et al. 2018). Moreover, more severe BOP levels have been associated with increased peri-implant bone loss (Monje et al. 2018), suggesting a potential link between BOP, peri-implant diseases, marginal bone loss, and implant failure. Supporting this hypothesis, our study demonstrated that a greater number of BOP sites has a significant negative impact on marginal bone levels (OR = −0.51;  $p < 0.001$ ). Notably, most

**TABLE 3** | Marginal bone change between implant placement and the last follow-up.

| Patients level    |                 | Overall (N=115) |                  |                     |                        |
|-------------------|-----------------|-----------------|------------------|---------------------|------------------------|
| Mean ± SD (mm)    |                 | −0.69 ± 1.12    |                  |                     |                        |
| Range (mm)        |                 | n (%)           |                  |                     |                        |
| MBL < 0 mm        |                 | 31 (26.96)      |                  |                     |                        |
| 0 mm ≤ MBL < 1 mm |                 | 54 (46.96)      |                  |                     |                        |
| 1 mm ≤ MBL < 2 mm |                 | 18 (15.65)      |                  |                     |                        |
| 2 mm ≤ MBL < 4 mm |                 | 10 (8.70)       |                  |                     |                        |
| MBL ≥ 4           |                 | 2 (1.74)        |                  |                     |                        |
| Implant level     | Overall (N=208) | Position        |                  | Prosthesis          |                        |
|                   |                 | Molar (N=71)    | Premolar (N=137) | Single crown (N=57) | Splinted crown (N=151) |
| Mean ± SD (mm)    | −0.75 ± 1.34    | −0.92 ± 1.54    | −0.66 ± 1.22     | −0.71 ± 1.14        | −0.77 ± 1.41           |
| Range (mm)        | n (%)           | n (%)           | n (%)            | n (%)               | n (%)                  |
| MBL < 0 mm        | 64 (30.77)      | 20 (28.17)      | 44 (32.12)       | 15 (26.32)          | 49 (32.45)             |
| 0 mm ≤ MBL < 1 mm | 88 (42.31)      | 29 (40.85)      | 59 (43.07)       | 24 (42.11)          | 64 (42.38)             |
| 1 mm ≤ MBL < 2 mm | 27 (12.98)      | 9 (12.68)       | 18 (13.14)       | 13 (22.81)          | 14 (9.27)              |
| 2 mm ≤ MBL < 4 mm | 21 (10.10)      | 9 (12.68)       | 12 (8.76)        | 4 (7.02)            | 17 (11.26)             |
| MBL ≥ 4           | 8 (3.85)        | 4 (5.63)        | 4 (2.92)         | 1 (1.75)            | 7 (4.64)               |

Abbreviation: MBL, marginal bone level.

implant failures (8 out of 16) occurred in three patients, primarily due to peri-implantitis, and four occurred before functional loading. These findings suggest that more frequent and pronounced BOP is associated with greater bone loss and an increased likelihood of biological complications, which may ultimately compromise implant success and survival.

The changes in MBL observed in this study are consistent with several clinical investigations that reported less than 1 mm of peri-implant bone loss (Tolentino et al. 2014; Al-Nawas et al. 2012; Galindo-Moreno et al. 2012). At this point, it is important to emphasize that when assessing changes in MBL, the study's follow-up duration—as well as the frequency of radiographic evaluations—must be taken into account in order to allow for meaningful and comparable interpretations across studies. In this regard, studies with shorter follow-up periods than the present study reported considerably lower mean MBL change values compared to those observed in our study ( $-0.75$  mm, SD 1.34). For example, Al-Nawas et al. reported a mean bone loss of  $-0.3$  mm (SD 0.5 mm), while Galindo-Moreno et al. observed  $-0.065$  mm (SD 1.017) at 1 year after implant placement (Al-Nawas et al. 2012; Galindo-Moreno et al. 2012). However, when analyzing the amount of bone change at

different time points, the MBL change at 1-year post-implant placement in the present study was  $-0.29$  mm (SD 0.62), and therefore consistent with the findings of the aforementioned studies. Nevertheless, when the follow-up period is extended, MBL changes after 11.5 years observed in our study are comparable to those reported in more recent retrospective studies, such as  $-1.19$  mm (SD 1.07) after a relatively similar follow-up period of 8 years (Shi et al. 2018).

Interestingly, no significant differences regarding survival rate, success, and MBL changes were found when comparing different restoration types (single crowns vs. splinted restoration) or implant locations (molar vs. premolar). This finding aligns with the study by Shi et al. and may be attributed to the comprehensive pretreatment diagnostic evaluation that was performed in this private clinic (Shi et al. 2018). Such evaluation included defining the prosthetic objectives, determining the ideal prosthetic-oriented implant position, and assessing local risk factors (e.g., distal cantilevers and parafunctional habits, among others) before implant placement (Sailer et al. 2022).

Regarding biological complications, peri-implant mucositis was detected in one-third of the implants (33.18%), while

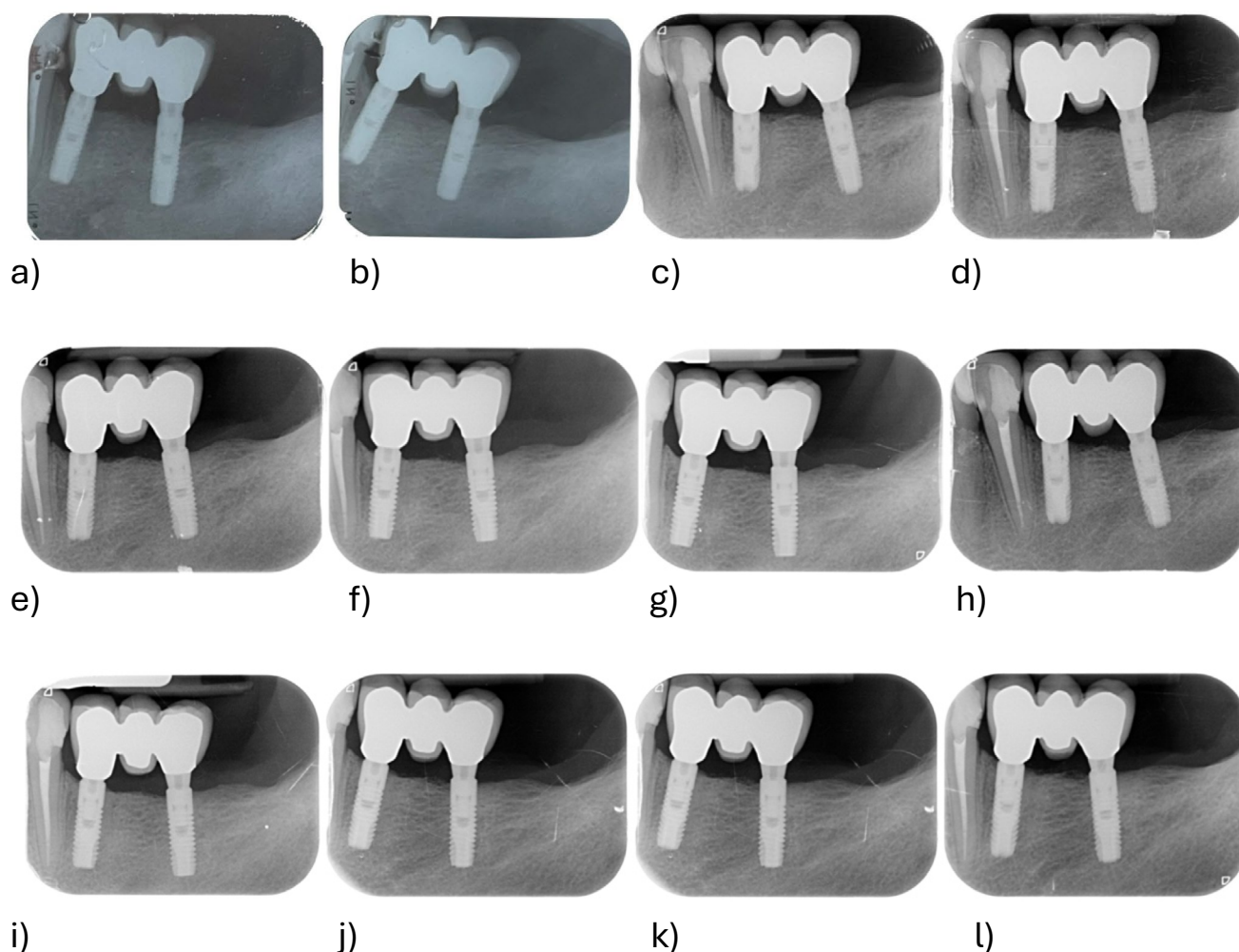


**FIGURE 5** | Radiographic evaluation of two NDI implants over a 19-year follow-up period. Radiographic monitoring of NDI implants in position 3.4 and 3.6 from baseline at the time of crown placement (a), 1 year after implant loading (b), 2 years (c), 4 years (d), 6 years (e), 8 years (f), 9 years (g), 10 years (h), 12 years (i), 14 years (j), 16 years (k) and the final follow-up at 19 years after crown placement (l).

peri-implantitis was observed in nearly one in 10 implants (9.86%). These results are comparable with those reported in long-term studies ( $\geq 9$  years), where peri-implant mucositis ranges from 33.42% to 60.2% (Derks et al. 2016; Tenenbaum et al. 2017) and peri-implantitis from 12% to 15.1% (Shi et al. 2018; Tenenbaum et al. 2017). The prevalence of peri-implantitis observed in our

study may be influenced by a high level of compliance with SPIC: approximately 90% of participants attended at least one annual visit. Moreover, the periodontist's expertise likely enabled early diagnosis and management of peri-implant mucositis, preventing progression to peri-implantitis and reducing the risk of bone loss and implant failure.

**TABLE 4** | Mean bone level changes according to patient profile and clinical characteristics of the implant: univariate and multivariate logistic regression models using generalized estimating equations (GEE), unadjusted OR and 95% confidence interval.

|                                     | Univariate |               |                   | Multivariate |                |                   |
|-------------------------------------|------------|---------------|-------------------|--------------|----------------|-------------------|
|                                     | OR         | 95% CI        | <i>p</i>          | OR           | 95% CI         | <i>p</i>          |
| Age                                 | −0.01      | −0.03 to 0.01 | 0.398             |              |                |                   |
| Sex: Female                         | 0.10       | −0.42 to 0.61 | 0.705             |              |                |                   |
| HTA: yes                            | −0.32      | −0.83 to 0.19 | 0.221             |              |                |                   |
| Diabetes: yes                       | −0.30      | −1.00 to 0.41 | 0.408             |              |                |                   |
| Smoker: yes                         | −0.14      | −0.74 to 0.46 | 0.639             |              |                |                   |
| Smoking exposure                    | 0.99       | 0.93–1.09     | 0.919             |              |                |                   |
| Periodontitis extension: Localized  | 0.19       | −0.24 to 0.62 | 0.377             |              |                |                   |
| Periodontitis stage: 1              |            |               | <b>0.005*</b>     |              |                | 0.131             |
| 2                                   | −0.28      | −0.66 to 0.09 | 0.145             | −0.01        | −0.38 to 0.35  | 0.948             |
| 3                                   | −0.71      | −1.13 to 0.28 | <b>0.001*</b>     | −0.33        | −0.77 to 0.12  | 0.150             |
| 4                                   | −0.60      | −1.14 to 0.06 | <b>0.030*</b>     | −0.31        | −0.71 to 0.09  | 0.125             |
| Periodontitis grade: A              |            |               | 0.212             |              |                |                   |
| B                                   | −0.23      | −0.59 to 0.13 | 0.217             |              |                |                   |
| C                                   | −0.66      | −1.55 to 0.23 | 0.148             |              |                |                   |
| SPIC: 3 times a year                |            |               | 0.445             |              |                |                   |
| 2 times a year                      | −0.34      | −0.98 to 0.29 | 0.290             |              |                |                   |
| 1 time a year                       | −0.14      | −0.77 to 0.48 | 0.653             |              |                |                   |
|                                     | 0.12       | −0.59 to 0.83 | 0.741             |              |                |                   |
| Parafunctional habit (Bruxism): yes | 0.11       | −0.36 to 0.58 | 0.651             |              |                |                   |
| Arch: Mandible                      | −0.31      | −0.71 to 0.08 | 0.114             |              |                |                   |
| Tooth type: Molar                   | −0.24      | −0.65 to 0.16 | 0.243             |              |                |                   |
| Prosthesis type: Splinted           | −0.06      | −0.47 to 0.36 | 0.789             |              |                |                   |
| Retention: Cemented                 | −0.16      | −0.71 to 0.39 | 0.566             |              |                |                   |
| Length: 8 mm                        |            |               | 0.514             |              |                |                   |
| 9–10 mm                             | 0.14       | −0.47 to 0.75 | 0.649             |              |                |                   |
| > 10 mm                             | 0.19       | −0.14 to 0.52 | 0.249             |              |                |                   |
| Surgical protocol: 2 stages         | 0.50       | 0.01–0.99     | <b>0.044*</b>     | 0.27         | −0.20 to 0.74  | 0.258             |
| GBR: yes                            | 0.26       | −0.15 to 0.68 | 0.211             |              |                |                   |
| Number of sites with BOP            | −0.54      | −0.81 to 0.27 | <b>&lt;0.001*</b> | −0.51        | −0.76 to 0.27  | <b>&lt;0.001*</b> |
| Number of sites with plaque         | −0.06      | −0.26 to 0.15 | 0.596             |              |                |                   |
| Follow-up (years)                   | −0.04      | −0.09 to 0.02 | 0.174             | −0.03        | −0.08 to −0.03 | 0.334             |

Abbreviations: BOP, bleeding on probing; CI, confidence interval; GBR, guided bone regeneration; HTA, hypertension; OR, odds ratio; SPIC, supportive peri-implant care.

\* $p < 0.05$ .

It is important to underscore that this study identified several factors associated with peri-implant diseases. Hypertension appears to be linked to a higher risk of peri-implant mucositis (OR: 1.96;  $p=0.061$ ) and peri-implantitis (OR: 3.79;  $p=0.022$ ). This finding aligns with a recent cross-sectional study by Papi et al., which reported an association between peri-implant mucositis and increased carotid intima-media thickness, a marker of subclinical atherosclerosis. The authors suggested that, similar to periodontitis, peri-implantitis may affect the systemic host-immune responses and increase bacterial loads, thus increasing the risk of vascular complications (Papi et al. 2023). Nevertheless, evidence supporting systemic conditions (other than diabetes) as risk factors or indicators for peri-implant diseases remains limited (Schwarz et al. 2018).

Furthermore, data from the present study also revealed that the presence of plaque at multiple sites significantly increased the risk of peri-implant mucositis (OR: 1.52;  $p<0.001$ ). In this

context, outcomes of several cross-sectional clinical studies have indicated an association between biofilm accumulation and inflammation of the peri-implant mucosa (Ferreira et al. 2006; Konstantinidis et al. 2015). Concerning peri-implantitis, this study demonstrated that each additional site exhibiting BOP nearly doubled the risk of developing the condition (OR: 1.80;  $p<0.001$ ). Similarly, a case-control study, evaluating the diagnostic accuracy of clinical parameters for monitoring peri-implant conditions, found that BOP was significantly associated with peri-implantitis compared to peri-implant health (OR = 2.32) (Monje et al. 2018). However, it is important to highlight that BOP alone is insufficient to diagnose peri-implantitis and must be interpreted in conjunction with peri-implant marginal bone loss data (Berglundh et al. 2018; Fransson et al. 2008).

Regarding mechanical complications, previous literature has reported a higher incidence in single-unit restorations (Shi

**TABLE 5** | Biological complications and mechanical complications at follow-up.

| <b>Biological complication</b>               |                        |                         |                         |                            |                               |
|----------------------------------------------|------------------------|-------------------------|-------------------------|----------------------------|-------------------------------|
| <b>Patients level</b>                        |                        |                         | <b>Overall (N=119)</b>  |                            |                               |
| Mucositis                                    |                        |                         |                         |                            | 53 (44.54)                    |
| Peri-implantitis                             |                        |                         |                         |                            | 17 (14.29)                    |
| <b>Implant level</b>                         | <b>Overall (N=223)</b> | <b>Position</b>         |                         | <b>Prosthesis</b>          |                               |
|                                              |                        | <b>Molar (N=76)</b>     | <b>Premolar (N=147)</b> | <b>Single crown (N=60)</b> | <b>Splinted crown (N=163)</b> |
| Mucositis                                    | 74 (33.18)             | 25 (32.89)              | 49 (33.34)              | 26 (43.33)                 | 48 (29.45)                    |
| Peri-implantitis                             | 22 (9.86)              | 11 (14.47)              | 11 (7.48)               | 4 (6.67)                   | 18 (11.04)                    |
| <b>Mechanical complication</b>               |                        |                         |                         |                            |                               |
| <b>Patients level</b>                        |                        |                         | <b>Overall (N=119)</b>  |                            |                               |
| All mechanical complication                  |                        |                         |                         |                            | 20 (16.81)                    |
| <b>Implant level</b>                         | <b>Overall (N=223)</b> | <b>Position</b>         |                         | <b>Prosthesis</b>          |                               |
|                                              |                        | <b>Premolar (N=147)</b> | <b>Molar (N=76)</b>     | <b>Single crown (N=60)</b> | <b>Splinted crown (N=163)</b> |
| All mechanical complication                  | 24 (10.76)             | 17 (11.56)              | 7 (9.21)                | 8 (13.33)                  | 16 (9.82)                     |
| Implant fracture                             | 4 (1.79)               | 2 (1.36)                | 2 (2.63)                | 0 (0.00)                   | 4 (2.45)                      |
| Abutment fracture                            | 0 (0.00)               | 0 (0.00)                | 0 (0.00)                | 0 (0.00)                   | 0 (0.00)                      |
| Prosthetic screw fracture                    | 2 (0.90)               | 1 (0.68)                | 1 (1.32)                | 1 (1.67)                   | 1 (0.61)                      |
| Prosthetic screw loosening                   | 5 (2.24)               | 2 (1.36)                | 3 (3.95)                | 1 (1.67)                   | 4 (2.45)                      |
| Abutment loosening                           | 9 (4.04)               | 8 (5.44)                | 1 (1.32)                | 3 (5.01)                   | 6 (3.68)                      |
| Chipping or fracture of the ceramic material | 3 (1.35)               | 3 (2.04)                | 0 (0.00)                | 3 (5.00)                   | 0 (0.00)                      |
| Fractures of metal framework                 | 0 (0.00)               | 0 (0.00)                | 0 (0.00)                | 0 (0.00)                   | 0 (0.00)                      |
| Occlusal wear resin teeth of toronto         | 1 (0.45)               | 1 (0.68)                | 0 (0.00)                | 0 (0.00)                   | 1 (0.61)                      |

et al. 2018). However, in our study, no statistically significant association was found between the type of restoration and the occurrence of mechanical complications. Nevertheless, the use of NDIs in the posterior area is often associated with a lower load fatigue performance, leading to an increased risk of fracture compared to SDIs (Quek et al. 2006; Allum et al. 2008). However, it should be mentioned that, in this study, 1.79% of the implants (4 out of the 223 loaded implants) fractured during the follow-up period, and similar results were reported by Lustosa et al. (1.05%) and Chrcanovic et al. (1.35%), where NDIs were used also in the anterior area (Chrcanovic et al. 2018; Lustosa et al. 2024). Although NDI fractures are relatively rare, these percentages are still higher than the overall fracture incidence observed when both NDIs and SDIs are considered (ranging from 0.5% to 0.75%) (Chrcanovic et al. 2018; Pjetursson et al. 2012). It is interesting to point out that in the study of Lustosa et al., most of the fractures in NDIs occurred in patients that showed signs of parafunctional habits (Lustosa et al. 2024) and Chrcanovic et al. found a 13.0% failure rate in bruxers compared to 4.6% in non-bruxers ( $p < 0.001$ ) (Chrcanovic et al. 2018; Lustosa et al. 2024). While our study did not reveal an association between bruxism and implant fracture, all fractures occurred in patients who did not use a nightguard. This underscores the importance of managing parafunctional habits in patients with NDIs.

In addition, occlusal factors must be carefully considered when planning treatments involving NDIs, as these implants are significantly more prone to mechanical failure under functional loading. This susceptibility underscores the need for caution when placing NDIs in areas exposed to high masticatory forces (Allum et al. 2008). Moreover, an increased crown-to-implant (C/I) ratio has been associated with elevated stress on implant components, potentially leading to mechanical complications such as screw loosening or implant fracture. These observations highlight the importance of comprehensive prosthetic and occlusal planning, particularly in cases involving short implants or prostheses with extended crown height (Leitão-Almeida et al. 2020; Nissan et al. 2011).

This study presents several limitations that should be acknowledged. First, its retrospective design inherently limits control over confounding variables and may introduce selection and information bias. Moreover, the retrospective nature of the study has precluded the collection of patient-reported outcome measures (PROMs), which are undoubtedly essential for accurately assessing the success of posterior rehabilitations with NDIs from the patient's perspective. Second, as a single-center study, the generalizability of the findings to other clinical settings or broader populations may be restricted. In addition, although peri-implantitis was reported, the available data did not include sufficiently detailed longitudinal records to assess changes in probing depth over time. Consequently, the diagnosis of peri-implantitis was based on indirect clinical and radiographic criteria. Finally, the success criteria employed in this study do not fully account for a more robust and contemporary evaluation of implant success; it should encompass both biological and prosthetic outcomes, as well as PROMs, in accordance with current consensus and recommendations in the literature.

## 5 | Conclusion

NDIs offer a reliable and long-term solution for rehabilitating posterior regions, especially in patients with limited bone volume who prefer to avoid invasive grafting procedures, which are often associated with potential complications (Urban et al. 2023). NDIs are particularly advantageous for individuals with anatomical limitations, as they can eliminate the need for bone augmentation while still providing predictable and stable outcomes. The findings of this study demonstrate that, over a prolonged follow-up period, NDIs can achieve survival and success rates comparable to those of SDIs. However, to minimize the risk of implant fracture, careful patient selection and thorough prosthetic planning are essential. This includes strategies such as splinting implants or implementing other protective measures (e.g., nightguard), particularly in high-risk cases.

### Author Contributions

**Maria Costanza Soldini:** conceptualization, writing – original draft, methodology, writing – review and editing, validation. **Isabel Arroyo:** methodology. **Riccardo Peragine:** methodology. **Enrique Roldán:** methodology. **Cristina Valles:** writing – review and editing, validation. **Ramón Pons:** writing – original draft, methodology, writing – review and editing, validation.

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### Conflicts of Interest

The authors declare no conflicts of interest.

### Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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### Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** clr70028-sup-0001-AppendixS1.docx.