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# A Multicenter Study of Factors Related to Early Implant Failures—Part 1: Implant Materials and Surgical Techniques

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## ABSTRACT

**Background:** Dental implant materials, designs as well as general concepts for surgical techniques have evolved during the last decades. It has been validated that primary stability followed by bone apposition around implants is crucial for implant survival as most implant failures occur during the first year. However, new implant materials and different micro and macro designs have improved implant survival in more challenging clinical conditions. Therefore, clinical research with large patient groups is needed to investigate the effects of different implant designs and surgical protocols with the aim to improve early implant outcomes.

**Purpose:** The purpose of the study is to investigate the clinical use of dental implant materials, designs, and surgical techniques related to early implant complications and failures.

**Materials and Methods:** All patients who had received implant surgery in 2007 and 2017 at three specialist centers in Sweden were identified using charge codes. Data were retrieved from a dental record system as well as from digital and analog registries on implant surgeries. Information on anamnestic data, bone status, implant materials and designs, surgery techniques, and early implant failures and complications during the first year was compiled and analyzed. Descriptive statistics were used for comparison of the time cohorts. The data were statistically analyzed with a multivariable logistic regression model with a significance level of $p < 0.05$ using early implant failures and complications as the dependent variables.

**Results:** For 2007, 799 patients with 2473 implants were identified. For 2017, 1076 patients with 2287 implants were identified. However, 74 (3.7%) patients were excluded, mainly due to lack of data. Differences were observed when comparing the two cohorts. In 2017, fewer preoperative antibiotics were prescribed, more incidences of exposed implant threads were reported, more non-submerged implant surgeries were performed, shorter implant lengths were used, more implants were placed in augmented bone, and tapered implants with a variable design were used. Implants of commercially pure titanium (CP Ti) Grades 1–4 with moderately and minimally rough surfaces were used in 2007, whereas CP Ti Grade 4 and alloy titanium zirconium (TiZr) with moderately rough surfaces were used in 2017. Significantly higher number of implant failures were reported in 2017 at the implant level: 56 (2.4%) in 2017 compared to 26 (1.1%) in 2007. Eleven variables were shown to increase the risk of failure including exposed implant threads OR 3.56 (1.60, 7.91) $p = 0.0018$ and increased number of implants per patients 1.26 (1.14, 1.39) $p < 0.001$

analyzed at the patient level. Nine variables were shown to increase the risk of early implant complications, including exposed implant threads OR 4.52 (2.60, 7.87) $p < 0.001$, sinus membrane perforations OR 8.14 (2.46, 26.93) $p < 0.001$, and no prescription of preoperative antibiotics OR 4.52 (2.60, 7.87) $p < 0.001$ analyzed at the patient level.
**Conclusions:** This study reports on changes in implant materials, designs, and surgical techniques between 2007 and 2017. Significantly higher numbers of implant failures and complications were reported in 2017. Factors related to early implant complications and failures were identified.

## 1 | Introduction

For more than 30 years, dental implants have successfully been used to rehabilitate partially or completely edentulous patients [1–3]. In recent decades, the development and research on dental implants have improved the treatment options and contributed to the macro and micro designs currently used [4].

Initially, the bulk material used by implant dentistry was commercially pure titanium (CP Ti) [5]. Although CP Ti Grade 4 is still the most widely used implant material, newer materials such as titanium zirconium alloys (TiZr) have attracted interest. Increased material strength has enabled the production of narrow dental implants made of TiZr [6]. Yet, more long-term follow-ups and studies with larger patient groups are required to scientifically confirm the clinical performance of this alloy [7–12].

The threaded macro design has evolved to be adapted to different clinical conditions and contribute to the primary stability [13–15]. The first phase of stabilization, achieved through mechanical insertion of the implant into the bone, is influenced by clinical- and implant-related factors [16]. Surgical techniques and implant designs are based on the assessment of patent-related factors such as bone quality and quantity [17, 18]. For example, tapered implants achieve a higher primary stability in bone with low quality [19]. Moreover, deeper threads, smaller pitch, more threads, and micro threads as well as longer and wider implants, contribute to stability in poor-quality bone by increasing bone-to-implant contact [20–22].

The primary stability phase is followed by the biological stabilization phase, which is influenced by the microstructure of the implant surface. Similar modification and coating techniques for CP Ti implants have also been applied to newer implant materials. However, each modification leads to changes at the micrometer and nanometer levels, which could impact clinical outcomes [23, 24].

Most implant failures during the first year are related to loss of osseointegration [25]. The osseointegration process is an immunological reaction to implanted material [3, 26]. The bone healing mechanism is influenced by implant characteristics, surgery, and patient-related factors. Several clinical factors have been suggested to increase the risk for early implant failures and complications, such as reduced bone volume, smoking habits, healing complications, implant jaw placement, poor primary stability, surgical trauma, and infections [27–29]. Moreover, patients' history of periodontitis and reduced ridge dimensions increase the risk for biological complications and early implant failures [30, 31].

Few studies have examined how the use of different implant materials, designs, and surgical techniques has changed. Contemporary consensus on surgical technique and the availably of different implant materials and designs may be evident when comparing different years when major engineering and research developments have taken place. Clinical studies with large patient cohorts are needed to improve the understanding of early implant complications and failures related to implants and surgical techniques. To this end, the aim of this study is to investigate the clinical use of dental implant materials, macro and micro designs, and surgical techniques in relation to early implant complications and failures in two patient cohorts—that is, patients treated in 2007 and in 2017.

## 2 | Materials and Methods

This retrospective study is based on implant surgeries made in the region of Västra Götaland, Sweden. Patient records were investigated for the two cohorts and included all implants inserted at three specialist centers.

### 2.1 | Patient Inclusion

A search in the digital dental record system T4 (Carestream Dental AB, Stockholm, Sweden) was conducted to identify patients who had received implant surgery in 2007 and 2017 at three specialist centers in Sweden. The patients were found using charge codes in the patient record system. These codes are for implant surgeries used by the Swedish general insurance system. Patients with partial and complete edentulism were included.

### 2.2 | Data Collection

Data were retrieved from the dental record system T4 as well as from digital and analog registries on implant surgeries. In 2007, the surgery reports were archived as paper journals at the clinics and in the regional archive. In 2017, the surgery reports were scanned into the records as files. The information concerns only the surgical part of the treatment. Following surgery, patients were referred back to their dentist for continued prosthetic rehabilitation.

The following data were collected from surgical reports and journals from both 2007 and 2017: anamnestic information, assessment of bone volume and bone quality, use of preoperative antibiotics, implant jaw placement, implant surgery procedure including submerged or non-submerged surgery, primary

stability, bone augmentation, sinus lifts, sinus membrane perforations, bone perforations and exposed threads, implant specifications for material and design, and early implant complications and failures.

### 2.3 | Definition

Early implant failures and complications that occurred immediately after insertion or within the first year were included.

### 2.4 | Statistics

Statistical data analysis was performed in SPSS (IBM SPSS Statistics for Windows, Version 28.0. Armonk, NY: IBM Corp). Descriptive statistics was used for numbers, means, and frequencies. Fisher's exact test and Fisher's permutations with significance level of $p < 0.05$ were used to compare the outcome of the two cohorts. The main data analysis for implant complications and failures was done with a multivariable logistic regression model with significance level of $p < 0.05$. In the univariable analysis, all variables were compared with significance level of $p < 0.2$ for further variable selection and inclusion in the multivariable logistic regression model. Early implant failures and complications were classified as the dependent variable; all other data were classified as the independent variables.

The multivariable logistic regression analyses were done at the patient, jaw, and implant levels. For each level, the following variables were analyzed: age, gender, diseases, allergies, smoking, bone quality, bone volume, primary stability, preoperative antibiotics, number of implants per patient, early implant failure, early implant complications, bone augmentation, bone perforation and exposed threads, sinus membrane perforation, sinus lift, implant length, implant diameter and implants placed in the maxillae vs. mandible. In addition, implant-specific variables were analyzed at the implant level: submerged or non-submerged surgery, implant position (incisive/canine, premolar or molar region), implant materials, implant manufacturer, and one specific brand due to its special character. The presence or absence of general diseases, allergies, and smoking habits was statistically analyzed as binary outcomes (yes/no) as well as the incidence of early implant failure, early implant complications, exposed threads, sinus membrane perforation, and bone augmentation (event/no event). The variables primary stability, bone quality, and bone volume were reported and analyzed on a three-, four-, or five-step ordinal scale. At the patient and jaw level, data on implant length, diameter, primary stability, bone quality, and bone volume were analyzed as mean values for patients with multiple implants. At the patient level, implant jaw placement in both maxillae and mandible was calculated as a ratio of number of implants placed in the maxillae divided by the number of implants per patient.

### 2.5 | Ethical Protection

The study was approved by the Ethical Review Board, Sweden (2019-01330).

## 3 | Results

### 3.1 | Patient Inclusion and Exclusion

A total of 1949 patients were registered as having received implants: 862 patients from 2007 and 1087 patients from 2017. In total, 74 (3.8%) patients were excluded from the study—63 patients from 2007 and 11 patients from 2017. As the surgical reports were not found for 52 patients from 2007 and 8 patients from 2017, these patients were excluded. Eleven patients from 2007 and three patients from 2017 had their implants inserted the previous year (i.e., 2006 and 2016, respectively) but were charged in 2007 and 2017, respectively. Therefore, these patients were excluded. Two zygoma implants were excluded from 2007 due to deviant design and surgical technique.

### 3.2 | Patient and Implant Data

The implant treatment was performed at three specialist clinics for maxillofacial surgery (Table 1). In 2007, 799 patients—443 (55.4%) women and 356 (45.6%) men—with 2473 implants were included. In 2017, 1076 patients—596 (55.4%) women and 480 (44.6%) men—with 2287 implants were included. There was no statistically significant difference between the cohorts regarding gender distribution ($p > 0.30$). The mean age was 55.7 years (SD 22.1) for the 2007 cohort and 54.0 years (SD 18.2) for the 2017 cohort ($p = 0.068$).

The number of implants per patient was significantly lower in the 2017 cohort: 2.1 implants per patient in 2017 and 3.1 implants in 2007 ($p < 0.001$). The proportion of implants placed in the maxillae and mandible was similar ($p > 0.30$) for the two cohorts. Some implants were recorded as re-entry operations: 13 (0.5%) implants in 2007 and 24 (1.0%) implants in 2017.

### 3.3 | Surgical Aspects

Statistically significantly fewer patients were given a single dose of preoperative antibiotics in 2017. Cortical bone plate perforations at implant surgery and exposed threads were significantly more prevalent in 2017 at both the patient and implant levels. More bone augmentations were performed before or in conjunction with implant surgery in 2017 at the implant level. In 2017, fewer submerged implants and more non-submerged implants were performed (Table 2).

**TABLE 1** | Distribution of patients and implants at the centers of maxillofacial surgery for each cohort, 2007 and 2017.

| | 2007 | | 2017 | |
|---|---|---|---|---|
| | **Patients** | **Implants** | **Patients** | **Implants** |
| Centers, *n* (%) | | | | |
| I | 341 (42.7) | 1047 (42.3) | 401 (37.3) | 935 (40.9) |
| II | 135 (16.9) | 379 (15.3) | 306 (28.4) | 695 (30.4) |
| III | 323 (40.4) | 1047 (42.3) | 369 (34.3) | 657 (28.7) |

**TABLE 2** | Bone status information and surgical variables, analyzed at the patient and implant level for each cohort, 2007 and 2017.

| | | | 2007 vs. 2017 |
|---|---|---|---|
| | **2007** | **2017** | **Two-tailed *p*** |
| Patient level | | | |
| Surgical variables, *n* (%) | | | |
| Preoperative antibiotics | 742 (92.9) | 835 (77.6) | **< 0.001** |
| Bone augmentation | 92 (11.5) | 152 (14.1) | 0.11 |
| Exposed threads | 13 (1.6) | 60 (5.6) | **< 0.001** |
| Sinus lift | 39 (4.9) | 51 (4.7) | > 0.30 |
| Sinus perforation | 6 (0.8) | 7 (0.7) | > 0.30 |
| Bone status, mean ± SD (min; max) | | | |
| Bone quality | 2.72 ± 0.59 (1; 4) | 2.67 ± 0.66 (1; 4) | 0.12 |
| Bone volume | 2.33 ± 0.62 (1; 4) | 2.34 ± 0.59 (1; 5) | > 0.30 |
| Primary stability | 1.0 ± 0.1 (1; 3) | 1.0 ± 0.1 (1; 3) | > 0.30 |
| Implant level | | | |
| Surgical variables, *n* (%) | | | |
| 1-stage surgery | 1072 (43.3) | 1255 (54.9) | **< 0.001** |
| 2-stage surgery | 1401 (56.7) | 1032 (45.1) | **< 0.001** |
| Preoperative antibiotics | 2297 (92.9) | 1745 (76.3) | **< 0.001** |
| Bone augmentation | 184 (7.4) | 243 (10.6) | **< 0.001** |
| Exposed threads | 30 (1.2) | 72 (3.1) | **< 0.001** |
| Sinus lift | 77 (3.1) | 83 (3.6) | > 0.30 |
| Sinus perforations | 8 (0.3) | 7 (0.3) | > 0.30 |
| Bone quality, *n* (%)[a] | | | |
| 1 | 39 (1.6) | 68 (3.0) | |
| 2 | 571 (23.1) | 326 (14.3) | |
| 3 | 1183 (47.8) | 717 (31.4) | |
| 4 | 182 (7.4) | 86 (3.8) | |
| Missing data | 498 (20.1) | 1090 (47.7) | |
| Bone quality mean ± SD (min; max)[a] | 2.76 ± 0.64 (1; 4) | 2.69 ± 0.69 (1; 4) | **0.016** |
| Bone volume, *n* (%)[b] | | | |
| A | 87 (3.5) | 22 (1.0) | |
| B | 1053 (42.6) | 661 (28.9) | |
| C | 767 (31.0) | 286 (12.5) | |
| D | 77 (3.1) | 62 (2.7) | |
| E | 3 (0.1) | 8 (0.3) | |
| Missing data | 486 (19.7) | 1248 (54.6) | |
| Bone volume mean ± SD (min; max)[a] | 2.42 ± 0.65 (1; 5) | 2.40 ± 0.67 (1; 5) | 0.28 |
| Primary stability, *n* (%)[c] | | | |
| Good | 1551 (62.7) | 1982 (86.7) | |

(Continues)

**TABLE 2** | (Continued)

| | 2007 | 2017 | 2007 vs. 2017 Two-tailed *p* |
|---|---|---|---|
| Moderate | 16 (0.6) | 42 (1.8) | |
| Poor | 3 (0.1) | 5 (0.2) | |
| Missing data | 903 (36.5) | 258 (11.3) | |
| Primary stability mean ± SD (min; max)[a] | 1.01 ± 0.13 (1; 3) | 1.03 ± 0.17 (1; 3) | **0.033** |

*Note:* Results from Fisher's exact test and Fischer's permutation test reported as two-tailed *p* values. Significant values were mentioned in bold.
[a]Bone quality is reported on a 1–4 ordinal scale, analyzed stepwise for each 1 (one) unit difference.
[b]Bone volume is reported on a 1–5 ordinal scale, analyzed stepwise for each 1 (one) unit difference.
[c]Primary stability is reported on a 1–3 ordinal scale, analyzed stepwise for each 1 (one) unit difference.

Bone quality and quantity were reported according to the Lekholm and Zarb classification system [32], and primary stability was reported on a three-step ordinal scale—good, moderate, or poor. These variables were not fully reported at all clinics. At the implant level, bone quality was more frequently reported as value 1 and less as value 2–4 in 2017, which resulted in lower mean bone quality value. There was no statistically significant difference between the cohorts for the mean bone volume. Moderate primary stability was more frequently reported in the 2017 cohort, which resulted in a higher mean primary stability value than in the 2007 cohort (Table 2).

### 3.4 | Implant Materials and Micro and Macro Design

In 2007 and 2017, the most used bulk material was CP Ti Grade 4. In 2007, CP Ti Grades 1–4 were used; in 2017, CP Ti Grade 4 and TiZr were used (Table 3). Implants with moderately rough surfaces ($S_a$ 1–2 μm) were used in 2007 ($n = 2408$, 97.4%) and 2017 ($n = 2287$, 100.0%). In 2007, machined minimally rough surfaces ($S_a$ 0.5–1.0 μm) were still used ($n = 65$, 2.6%).

Seven implant manufacturers were used in 2007 and four manufacturers were used in 2017. More implants with external abutment connections were used in 2007 than in 2017. In 2017, internal abutment connections were the most often used connection. In 2007 and 2017, bone-level design was used in a majority of patients; however, in 2017, more implants with the soft tissue-level design were used (Table 3). Implants with straight or conical macro designs with varying tapers were available. In 2017, tapered implants with a deeper thread design were used. There was a new implant brand introduced (NobelActive Nobel Biocare, Gothenburg, Sweden), unlike the other tapered implants with a widely spaced, expanding double-threaded design, with drilling blades at apex (Table 3).

The implant length decreased in 2017 compared to 2007, but the implant diameter increased in 2017 compared to 2007 (Table 3). The portion of short implants (≤ 8 mm) was 128 (5.2%) in 2007 and 254 (11.1%) in 2017. Narrow dental implants (≤ 3.3 mm) were used in both years: 324 (13.1%) in 2007 and 287 (12.5%) in 2017. In 2017, most of these implants were made of TiZr ($n = 191$, 63.1%).

### 3.5 | First-Year Implant Loss

In 2007, 23 (2.9%) patients lost one or more implants; in 2017, 40 (3.7%) patients lost one or more implants ($p > 0.30$). At the implant level, significantly more implants were lost in 2017 than in 2007 ($p < 0.001$). In 2007, 26 (1.1%) of the implants were recorded with implant failure compared to 56 failed (2.4%) implants in 2017. In 2007 and 2017, most implants were lost during the first 6 months—19 (73.1%) and 41 (73.2%), respectively.

Implants were mainly lost due to biological reasons and were reported as infections, osseointegration loss, major bone loss, or a combination of these factors. In 2007, two implants were lost due to technical reasons and were reported as fractures caused by external facial trauma. In some cases, the reason for implant failure was unknown (Table 4).

A multivariable logistic analysis showed two statistically significant variables that increased the risk for implant failure at the patient level: exposure of threads and number of implants per patient. When calculated at the jaw level, similar results were obtained. A multivariable logistic analysis showed 11 statistically significant variables that increased the risk for implant failure at the implant level (Table 5). The variables sinus lifts, manufacturer D, manufacturer G, and implant material CP Ti Grade 2 were excluded from the multivariable logistic analysis of early implant failures, as no failures were reported for these variables. Implant manufacturer F was totally correlated with the material CP Ti Grade 1, as all implants of this material were manufactured by manufacturer F.

### 3.6 | First-Year Implant Complications

Significantly more return visits for postoperative complications were recorded in 2017 at both the patient and implant level ($p < 0.001$). In 2017, 145 (13.5%) of the patients experienced one or multiple complications compared to 56 (7.0%) of the patients in 2007. The reported complication rates at the implant level were 241 (10.5%) in 2017 and 94 (3.8%) in 2007.

The reported complications for the 2007 and 2017 cohorts included implant mobility and bone loss at the marginal or peri-implant level, postoperative infections, including pus, fistula,

**TABLE 3** | Information on implant materials and designs, analyzed at the implant level for each cohort 2007 and 2017.

| Implant level | 2007 | 2017 | 2007 vs. 2017 Two-tailed *p* |
|---|---|---|---|
| Implant materials, *n* (%) | | | |
| CP Ti Grade 1 | 98 (4.0) | 0 (0.0) | **< 0.001** |
| CP Ti Grade 2 | 3 (0.1) | 0 (0.0) | **< 0.001** |
| CP Ti Grade 3 | 216 (8.7) | 0 (0.0) | **< 0.001** |
| CP Ti Grade 4 | 2157 (87.2) | 1999 (87.4) | > 0.30 |
| TiZr | 0 (0.0) | 288 (12.6) | **< 0.001** |
| Implant messurements, mean ± SD (min; max) | | | |
| Length | 12.61 ± 2.55 (5; 23) | 10.98 ± 2.15 (6; 18) | **< 0.001** |
| Diameter | 3.79 ± 0.31 (3.3; 6.0) | 3.96 ± 0.46 (2.9; 5.5) | **< 0.001** |
| Implant desgin, *n* (%) | | | |
| External abutment | 1750 (70.8) | 782 (34.2) | **< 0.001** |
| Internal abutment | 723 (29.2) | 1505 (65.8) | **< 0.001** |
| Bone level | 2146 (86.8) | 1679 (73.4) | **< 0.001** |
| Tissue level | 327 (13.2) | 608 (26.6) | **< 0.001** |
| Manufacturer and brands, *n* (%) | | | |
| A. Nobel Biocare (Gothenburg, Sweden) | 1616 (65.3) | 1064 (46.5) | **< 0.001** |
| Brånemark System MK III TiUnite/Groovy/Shorty | | | |
| Brånemark System MK IV TiUnite | | | |
| NobelSpeedy Groovy | | | |
| NobelReplace Tapered Groovy | | | |
| Replace Select Tapered TiUnite | | | |
| NobelParallel Conical conection | | | |
| NobelActive[a] | 0 (0.0) | 60 (2.6) | **< 0.001** |
| B. Astra Tech/Dentsply Sirona (Mölndal, Sweden) | 131 (5.3) | 527 (23.0) | **< 0.001** |
| Astra Tech Implant System | | | |
| Astra Tech Implant System EV | | | |
| C. Straumann (Basel, Schweiz) | 337 (13.6) | 690 (30.2) | **< 0.001** |
| Straumann Bone level Implant, Bone level Tapered | | | |
| Straumann Standard Implant, Standard Plus | | | |
| Straumannn Roxolid | | | |
| D. Neoss (Gothenburg, Sweden) | 70 (2.8) | 6 (0.3) | **< 0.001** |
| Neoss Biomodal Implants | | | |
| Neoss ProActive Implants | | | |
| E. Lifecore Biomedical (Chaska, Minnesota, USA) | 218 (8.8) | 0 (0.0) | **< 0.001** |
| Restore RBM Self-Taping Threaded Implant | | | |
| F. Brånemark Integration (Gothenburg, Sweden) | 98 (4.0) | 0 (0.0) | **< 0.001** |
| Brånemark Integration Fixture Original | | | |

(Continues)

**TABLE 3** | (Continued)

| Implant level | 2007 | 2017 | 2007 vs. 2017 Two-tailed *p* |
|---|---|---|---|
| Brånemark Integration Biohelix Implant G. Friadent GmbH (Mannheim, Germany) | 3 (0.1) | 0 (0.0) | **<0.001** |
| Ankylos Dental Implant | | | |

*Note:* Results from Fisher's exact test and Fisher's permutation test reported as two-tailed *p* values. Significant values were mentioned in bold.
[a]NobelActive is reported separately due to its special implant character.

**TABLE 4** | Information on reported reasons for early implant failure and complications, analyzed at the implant level.

| | 2007 | 2017 | Total |
|---|---|---|---|
| Early implant failure | | | |
| Number of implant failure, *n* (%) | 26 (1.1) | 56 (2.4) | 82 (1.7) |
| Reasons for implant failure, *n* (%) | | | |
| Biological | 19 (73.1) | 53 (94.6) | 72 (87.8) |
| Technical | 2 (7.7) | 0 (0.0) | 2 (2.4) |
| Unknown | 5 (19.2) | 3 (5.4) | 8 (9.8) |
| Early implant complications | | | |
| Number of complications, *n* (%) | 94 (3.8) | 241 (10.5) | 335 (7.0) |
| Reasons for implant complications, *n* (%) | | | |
| Mobility and bone loss | 35 (37.2) | 131 (54.4) | 166 (49.6) |
| Infection | 22 (23.4) | 58 (24.1) | 80 (23.9) |
| Redness, minor swelling | 19 (20.2) | 39 (16.2) | 58 (17.3) |
| Bone necrosis | 8 (8.5) | 1 (0.4) | 9 (2.7) |
| Other | 14 (14.9) | 65 (27.0) | 79 (23.6) |

*Note:* Multiple complications were reported for some implants.

abscess, and granulation tissue and sometimes in combination with swelling and fever, bone necrosis and minor postoperative symptoms, including edematous tissue, tenderness, trismus, redness, minor swelling, and symptoms due to poor oral hygiene. Other surgical complications included removal of small bone fragments, mucosal penetrations, bone exposure, bone overgrowth over abutments, loss of healing abutments, complications after external facial trauma, and healing complications related to early implant overload (Table 4).

A multivariable regression analysis revealed five significant variables that increased the risk for complications at the patient level. When calculated at the jaw level, equivalent results were obtained. Nine significant variables indicated an increased risk for complications at the implant level (Table 6). The variable manufacturers D and G were excluded from the multivariable logistic analysis of early implant complications, as no complications were reported for these implants.

Complications and implant failure at the implant level were significantly related ($p < 0.001$). Complications were reported before implant failure for 59 (72.0%) of the lost implants at a follow-up visit at one of the specialist clinics. The most reported complications before implant failure were implant mobility and bone loss ($n = 44$, 53.7%) and infection symptoms ($n = 26$, 31.7%).

## 4 | Discussion

The results confirm that major changes were made in dental implant treatment protocol between 2007 and 2017. Comparing these years, several variables regarding surgical technique and implant material and design were shown to be statistically significant. Some of these differences were related to early implant failures and complications. Expanded inclusion criteria for patients receiving implants are assumed to have a substantial impact on the outcome.

The analyses were performed at the patient, implant, and jaw level. All the variables were dependent on patient-related factors and natural biological variations. From a patient perspective, analyses at the patient level may be the most interesting as the outcome of the treatment as a whole is considered rather than the outcome of each individual implant. However, because bone status may differ between the posterior and frontal region as well as between the mandible and maxillae [33], some variables can be analyzed at the implant or jaw level.

A slight shift towards the use of the new material (i.e., TiZr) was seen in 2017. TiZr was mainly used for narrow dental implants (≤3.3 mm). This finding suggests that TiZr implants increase the risk of complications. However, TiZr implants in narrower diameters can be used for implant sites with small gaps or less bone volume [34, 35], which may result in more complications.

For both the 2007 and the 2017 cohorts, implants of titanium Grade 4 were used the most, but CP Ti Grades 1–4 implants were used in 2007. Lower titanium grades were replaced by higher

**TABLE 5** | Multivariable logistic regression analyses on early implant failure, analyzed at the patient, jaw, and implant level.

| | Odds ratio (95% CI) | Two-tailed *p* |
|---|---|---|
| Patient level | | |
| Diseases | 1.47 (0.85, 2.54) | 0.17 |
| Smoking | 1.60 (0.88, 2.92) | 0.13 |
| Bone volume | 1.48 (0.89, 2.45) | 0.13 |
| Number of implants per patient[a] | 1.26 (1.14, 1.39) | **<0.001** |
| Bone augmentation | 1.20 (0.60, 2.38) | >0.30 |
| Exposed threads | 3.56 (1.60, 7.91) | **0.0018** |
| Sinus perforations | 3.60 (0.73, 17.68) | 0.12 |
| Jaw level | | |
| Jaw maxillae | 1.53 (0.88, 2.65) | 0.13 |
| Diseases | 1.56 (0.90, 2.68) | 0.11 |
| Smoking | 1.60 (0.88, 2.90) | 0.12 |
| Bone volume | 1.58 (0.96, 2.58) | 0.070 |
| Number of implants per patient[a] | 1.18 (1.08, 1.30) | **<0.001** |
| Bone augmentation | 1.45 (0.74, 2.86) | 0.29 |
| Exposed threads | 4.08 (1.85, 8.98) | **<0.001** |
| Sinus perforations | 4.54 (0.94, 22.04) | 0.060 |
| Decreasing diameter[b] | 1.27 (0.65, 2.49) | >0.30 |
| Implant level | | |
| Male gender | 1.73 (1.10, 2.73) | **0.018** |
| Smoking | 1.99 (1.21, 3.29) | **0.0070** |
| 1-stage surgery | 2.97 (1.77, 5.00) | **<0.001** |
| CP Ti Grade 1 | 3.46 (1.11, 10.78) | **0.033** |
| Decreasing length[c] | 1.19 (1.08, 1.32) | **<0.001** |
| Jaw maxillae | 2.29 (1.39, 4.09) | **0.0015** |
| Position: incisors and canines | 1.48 (0.90, 2.44) | 0.13 |
| Manufacturer A | 2.97 (1.73, 5.11) | **<0.001** |
| Brand NobelActive[d] | 2.73 (1.01, 7.38) | **0.048** |
| Exposed threads | 6.86 (3.09, 15.26) | **<0.001** |
| Sinus perforations | 6.32 (1.28, 31.25) | **0.024** |

*Note:* Level of significance $p < 0.05$. Significant values were mentioned in bold.
[a]Number of implants per patient analyzed for each 1 (one) implant unit difference.
[b]Decreasing implant diameter analyzed for each 1 mm unit difference.
[c]Decreasing implant length analyzed for each 1 mm unit difference.
[d]NobelActive analyzed separately due to its special character.

titanium grades because fractures were observed in implants made of CP Ti Grades 1 and 2 [36]. In the present study, implants of CP Ti Grade 1 were shown to increase the risk for early implant failure, which may be related to the microstructure of these implants. In 2017, the original implants with minimally rough surfaces were replaced with implants with moderately rough surfaces. Clinical research confirms improved primary stability and bone apposition and a reduced risk of implant failure for implants with moderately rough surfaces ($S_a$ 1–2 μm) [3, 23, 37]. Moreover, in general, shorter and wider implants were used in 2017. The advantage of adapting the implant length to anatomical boundaries is to avoid complex surgery and biological complications [38, 39]. Implant length seems to support primary stability up to a certain length [40], but moderately rough surfaces, taper design, and wider diameters also increase the bone-to-implant contact area and may be more crucial for achieving primary stability in low-density bone [38, 41, 42].

Early implant failures are defined as failure to establish bone formation around the implants with fibrous tissue healing rather than bone healing [33, 43]. In this study, implant failure rates of 2.9% and 3.7% at the patient level, and 1.1% and 2.4% at the implant level were reported in 2007 and 2017, respectively. In previous studies, lower failure rates have been reported for implants lost during the initial healing period, before connection of abutment or supra construction, or up to the second stage of surgery [44–47]. However, these studies include a shorter period of time than defined for early failures in this study. Derks et al. reported an early failure rate of 4.1% at the patient level and 1.4% at the implant level for randomized collected patients from a Swedish national register in 2003 [31]. Nevertheless, different implant materials and designs have been used over time and a patient cohort selected from a national sample is different from a patient cohort treated at specialist clinics, making them not fully comparable. Still, there are other studies reporting a higher early failure rate [48, 49]. In a retrospective study of patients treated in 2010–2016 at a university clinical setting, a failure rate of 3.1% at the implant level was reported [49]. In reference to this, it can be assumed that the variation of failure rates depends, among other things, on the definition of early implant failure, the selected patient cohort, the included time period, the used implants and whether the treatment is performed at specialist clinic or at a general dental clinic.

This study found that several factors could impact implant survival. Previous studies have confirmed that perforations of the

**TABLE 6** | Multivariable logistic regression analyses on implant complications, analyzed at the patient, jaw, and implant level.

| Implant complications | | |
|---|---|---|
| | **Odds ratio (95% CI)** | **Two-tailed *p*** |
| Patient level | | |
| Diseases | 1.31 (0.95, 1.81) | 0.098 |
| Smoking | 2.30 (1.61, 3.29) | **< 0.001** |
| No preoperative antibiotics | 1.92 (1.32, 2.80) | **< 0.001** |
| Number of implants per patient[a] | 1.20 (1.12, 1.29) | **< 0.001** |
| Bone augmentation | 1.02 (0.65, 1.58) | > 0.30 |
| Exposed treads | 4.52 (2.60, 7.87) | **< 0.001** |
| Sinus perforation | 8.14 (2.46, 26.93) | **< 0.001** |
| Jaw level | | |
| Diseases | 1.29 (0.94, 1.75) | 0.11 |
| Smoking | 2.52 (1.80, 3.54) | **< 0.001** |
| No preoperative antibiotics | 1.88 (1.32, 2.67) | **< 0.001** |
| Number of implants per patient[a] | 1.14 (1.07, 1.21) | **< 0.001** |
| Bone augmentation | 1.12 (0.72, 1.73) | > 0.30 |
| Exposed threads | 4.84 (2.83, 8.27) | **< 0.001** |
| Sinus perforation | 9.62 (2.96, 31.25) | **< 0.001** |
| Implant level | | |
| Age | 0.99 (0.99, 1.0) | 0.076 |
| Male gender | 1.34 (1.06, 1.68) | **0.013** |
| Diseases | 1.25 (0.99, 1.59) | 0.065 |
| Smoking | 2.85 (2.25, 3.62) | **< 0.001** |
| Bone volume | 1.17 (0.95, 1.45) | 0.14 |
| 2-stage surgery | 1.43 (1.12, 1.83) | **0.0042** |
| No preoperative antibiotics | 1.67 (1.27, 2.20) | **< 0.001** |
| Material TiZr | 1.97 (1.23, 3.15) | **0.0048** |
| Material CP Ti Grades 1–3 | 1.00 (0.57, 1.76) | > 0.30 |
| Position: incisors and canines | 1.00 (0.99, 1.26) | > 0.30 |
| Manufacturer A | 1.57 (1.19, 2.05) | **0.0012** |
| Manufacturer B | 0.60 (0.36, 1.00) | 0.0501 |
| Brand NobelActive[b] | 1.91 (0.88, 4.17) | 0.10 |
| Number of implants per patient[a] | 1.00 (0.95, 1.05) | > 0.30 |
| Exposed threads | 3.83 (2.30, 6.38) | **< 0.001** |
| Sinus lift | 0.46 (0.20, 1.07) | 0.071 |
| Sinus perforation | 6.00 (1.75, 20.64) | **0.0045** |

*Note:* Level of significance $p < 0.05$. Significant values were mentioned in bold.
[a]Number of implants per patient analyzed for each 1 (one) implant unit difference.
[b]NobelActive analyzed separately due to its special character.

cortical bone plate and exposed threads are risk factors for complications. Dehiscence and fenestrations may increase the risk of compromised aesthetics, gingival retraction and periimplantitis [50–52].

In this study, the number of implants placed per patient was also shown to be related to early implant failures, which agrees with results from previous studies [29, 53]. Implant surgery of multiple implants may result in longer treatment time, increased contamination, and reduced blood supply [54]. Moreover, the higher the number of implants, the higher the hazard rate for implant complications and failures [55]. Still, loss of teeth is related to the biological process of osteoclastic activation and bone alteration [56]. Jaw atrophy may be a consequence of multiple tooth loss over time [57]. Minor bone volume at the implant insertion site is related to a higher implant failure rate [58]. Hence, bone resorption could be an underlying risk factor for implant failure related to number of implants inserted.

Extended inclusion criteria for patients eligible for implant treatment planning may result in implant insertions in compromised implant sites. The results of the variables bone quality, bone volume, and primary stability should be interpreted with caution as these variables were not fully reported by all clinics, and data are missing. However, the use of short implants (≤ 8 mm) and the need for augmented bone may indicate implant insertions in sites with bone resorption or generally less bone volume [33, 57, 59]. Moreover, implants with

pronounced tapers and deeper thread designs for use in compromised bone quality were used in 2017. Implants from manufacturer A were most frequently used in both years, which led to a greater exposure and statistically higher risk for implant complications and failures. Nevertheless, one specific implant brand from the same manufacturer used in 2017 had a significantly higher risk for implant loss (NobelActive). These implants, with expanding conical body and double-thread design, may generate high primary stability even in low-quality bone [60]. However, implants placed in poor bone sites are more prone to fail [33, 61]. Bone status is a critical factor for implant success and therefore highly influences the choice of implant. Furthermore, bone status is probably a more decisive factor for the risk of implant failure than the implant material and macro design per se [33, 62, 63].

Perforation of the maxillary sinus membrane also increases the risk of early implant failure and complications. However, results based on a limited number of cases and characterized by large confidence intervals should be interpreted with caution. The cause of implant failure is complex with several factors interacting. Limited bone height could be considered as an aggravating condition that increases the risk for sinus perforations [64]. Similar results have been observed in other studies [65–67]. However, generally high implant survival rates are shown for implants inserted in augmented sinuses after sinus perforations [68]. Yet, other studies have confirmed an increased risk for postoperative complications, including symptoms associated with infections and sinusitis after sinus perforations [69–71].

A non-submerged surgical technique was significantly more common in 2017 than in 2007, which reflects the trend toward an increased number of treatments in partially edentulous patients with implant-supported prostheses [72]. A non-submerged surgery technique may be preferred as it shortens the treatment time, reduces costs, and improves the convivence of the patient [72, 73]. However, non-submerged surgery was shown to give significantly higher risk for implant failure. Most studies have found that both techniques could be used depending on the clinical condition [4, 74], but, as in previously published studies, the present study's results suggest that patients at risk of implant failure may benefit from submerged healing, which helps prevent functional overloading [63, 75]. Submerged surgery, on the other hand, was shown to generate more postoperative complications, which may be a natural consequence of a two-stage wound healing.

The consensus on the routine use of preoperative antibiotics has evolved. Less preoperative antibiotics were given in 2017 than in 2007. This difference is possibly an effect of the treatment strategies for rational antibiotic use and reduced antibiotic resistance (STRAMA) adopted as a global action plan by the World Health Assembly in 2015 [76]. Yet, the result from the present study indicates that a single preoperative dose of antibiotics may decrease the risk of implant complications, a finding that agrees with previous studies [77, 78]. Still, the patient's medical history and health condition should be considered as well as the difficulty of the surgery procedure when discussing the indications of preoperative antibiotics [79, 80].

Moreover, male gender and smoking were also shown to increase the risk for early implant failure and complications. Several studies have concluded that smoking in the initial phase of implant insertion results in poorer wound healing and therefore poorer osseointegration [29, 81–83]. Male patients had a significantly higher risk for implant failure, a finding that agrees with previously published studies [81, 84]. However, the results in the literature diverge. For example, gender differences in smoking habits have been discussed as a confounding factor [47, 58].

The present cohort study has a high external validity as it represents a total patient inclusion with no patient selection and a low dropout rate. The results reflect the effectiveness of implant treatment in specialist clinics. A limitation of the study might be that the referred patients may not be representative of patients in general. Patients may also have sought dental care at other clinics for early postoperative complications and therefore the complication rate could be underestimated. According to the data in this study, more postoperative symptoms were reported in 2017. Since 2007, there has been an increased emphasis on patient safety and quality assurance in dentistry [85–87] that may have led to a greater focus on the reporting and management of complications. Thus, the risk of underestimation is likely higher in 2007 than in 2017. A wide range of complications was observed in this study, with varying degrees of severity. A possible limitation is that the severity of complications was not assessed. However, the effect of postoperative symptoms should be interpreted with caution when evaluated retrospectively. Still, clinical risk factors of increased return visits were identified as all reported complications were included. Moreover, the retrospective study design may be a limitation, as the data are based on patient dental records written for medical documentation and not standardized for clinical research.

## 5 | Conclusions

This study compares implant materials, designs, and surgical techniques used in 2007 and 2017. The analyses of early implant complications and failures are consistent with previous studies.

- Notable changes were observed in the cohorts. By 2017, the use of moderately rough surfaces had totally replaced the minimally rough surfaces and a new dental implant material, in particular TiZr, were introduced. In addition, in 2017, treatments were characterized by more non-submerged surgeries, more bone augmentation procedures, less use of ordinated preoperative antibiotics, and tapered implants with variable thread-design for soft bone indications. The increased use of these treatment options reflects less standardized implant protocols and more individualized treatment planning in 2017 than in 2007.
- The cause of significantly more frequent early implant complications and failures in 2017 than in 2007 may partly be explained by extended patient inclusion criteria for dental implant treatment.
- Observed differences related to increased risk for implant failure in 2017 were higher incidence of exposed

implant threads and cortical bone perforations, more non-submerged surgeries, increased use of shorter implants, and the use of one specific implant brand with sharp and tapered thread design. Many of these factors may indicate treatment performed in a compromised bone.

- There was an increased risk for complications in 2017 that might be related to less frequently ordinated preoperative antibiotics, more implants with exposed threads and cortical bone plate perforations, and frequent use of implants made of TiZr, most of them in narrow diameters to compensate for reduced bone volume.
- Further research is required to investigate the influence of other patient-related factors, such as patient general health and clinical conditions, including implant jaw position in relation to bone status.

### Author Contributions

Concept and design, data collection, planning of statistics, data analysis in collaboration with biostatistician, data interpretation, drafting of article, critical revision, and approval of the article: Rachel Duhan Wåhlberg. Concept and design, funding secured by scholarship from government research support in Public Dental Service Region Västra Götaland (TUA), planning of statistics, data interpretation, critical revision, and approval of the article: Victoria Franke Stenport. Concept and design, funding secured by scholarship from The Swedish Research Council, and critical revision: Ann Wennerberg. Concept and design, planning of statistics, data interpretation, critical revision, and approval of article: Lars Hjalmarsson.


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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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