# Implant Survival and Complication Prevalence in Complete-Arch Implant-Supported Fixed Dental Prostheses: A Retrospective Study with a Mean Follow-up of 5 Years

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***Purpose:*** To evaluate the implant survival and the prevalence of biologic and mechanical complications in edentulous patients restored with complete-arch implant-supported fixed dental prostheses (IFDPs). ***Materials and Methods:*** Patients restored with complete-arch screw-retained IFDPs between January 2012 and December 2019 with a minimum 2-year follow-up were included. Outcome measures were cumulative survival rate (CSR) for implants and prostheses, biologic complications, and mechanical complications. A generalized estimating equation model was used to estimate potential risk factors for mechanical complications. Patient satisfaction was investigated using a standardized questionnaire. ***Results:*** A total of 44 prostheses supported by 268 implants in 30 patients were included for a mean duration of 4.8 years (range: 2 to 9 years). Eighteen of the prostheses were zirconia-ceramic (group ZC), and 26 were titanium-ceramic (group TC). The CSR for the implants and IFDPs was 99.3% (95% CI: 98.2% to 100.3%) and 92.5% (95% CI: 84.2% to 100.8%), respectively. The most common biologic complication was peri-implant mucositis (4.5%), followed by peri-implantitis (3.0%). The most common mechanical complication was ceramic chipping (45.5%), followed by crown debonding (13.6%) and framework fracture (4.5%). There was no significant difference in the prevalence of complications between groups TC and ZC ($P > .050$). The presence of cantilever (OR = 5.54, $P = .048$) and maxillary arch (OR = 5.94, $P = .041$) were significantly associated with mechanical complications. Patient satisfaction scores were generally high, but some continued to be bothered by speech problems (13.6%). ***Conclusion:*** Complete-arch IFDPs presented reliable clinical outcomes for edentulous patients with a high implant survival rate and a high level of patient satisfaction. However, a high incidence of mechanical complications occurred in the long term. *Int J Oral Maxillofac Implants 2023;38:84–93. doi: 10.11607/jomi.9808*

***Keywords:*** dental implants, fixed prosthesis, full edentulism, implant survival, mechanical complications

Complete-arch implant-supported fixed dental prostheses (IFDPs) are proven to be a predictable treatment modality for edentulous patients, providing excellent comfort, masticatory function, and significant improvement of quality of life.[1] Several articles reported a cumulative survival rate (CSR) of > 95% for IFDPs during long-term clinical observation.[2–4] Although they have relatively high survival rates, biologic and mechanical complications routinely occur, such as fracture of veneering material, screw loosening, and peri-implant diseases.[5–7] However, data specifically regarding the complication prevalence of complete-arch IFDPs over 5 years of clinical observation are somewhat scarce.[8–10]

One recent 10-year retrospective study revealed that the prevalence of peri-implantitis was 13.1% of implants and 39.2% of patients, respectively.[11] Another 3-year prospective study on metal-acrylic prostheses showed that mechanical complications occurred in 17% of the prostheses, mainly due to fracture of artificial teeth, which required additional maintenance and treatment costs for repair.[12] Therefore, it is essential for clinicians to understand the prevalence, type of complications, and potential risk factors for complete-arch IFDPs to enhance the predictability and cost-effectiveness of treatment.

Various restorative designs and material choices have been reported to rehabilitate the edentulous arch. For more than 30 years, titanium frameworks have been widely used for metal-resin reconstructions.[13] With the development in CAD/CAM technology, zirconia-based

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prostheses, such as zirconia-ceramic or monolithic zirconia (3Y zirconia), have been proposed as an alternative to titanium materials, with good esthetics, high flexural strength, and better biocompatibility.[14,15] Nevertheless, veneered ceramic chipping has been reported as the most frequent prosthetic complication in titanium/zirconia-ceramic prostheses, ranging between 8% and 69%.[16–19] Currently, limited data are available on whether or not the restorative material, especially concerning novel zirconia materials, may be a parameter affecting implant survival and complication prevalence.

The purpose of the present study was to: *(1)* evaluate the survival rate of implants and complete-arch IFDPs; *(2)* compare the prevalence of biologic and mechanical complications of titanium-ceramic prostheses and zirconia-ceramic prostheses; and *(3)* identify risk factors for mechanical complications.

## MATERIALS AND METHODS

### Patient Selection

The study was a retrospective cohort study authorized by the Ethics Committee of Peking University Hospital of Stomatology (approval number PKUSSIRB-201631115). The study was performed under the guidelines in the Declaration of Helsinki (World Medical, 2013). All patients involved provided their informed consent prior to inclusion in the study. The records of all edentulous patients treated with complete-arch IFDPs between January 2012 and December 2019 in the 4th Division of Peking University School and Hospital of Stomatology were screened.

The inclusion criteria were as follows:

- Patients with edentulous or potentially edentulous arches
- Patients restored with complete-arch screw-retained IFDPs between January 2012 and December 2019 with a minimum 2-year follow-up
- Complete arches where all the implants were from the same manufacturer and had the same type of surface modification
- All the implants were placed with a standard surgical procedure by the same clinician
- Presence of opposing occlusion

The exclusion criteria were as follows:

- Patients treated with provisional prostheses who had not received definitive restorations
- The edentulous arch restored with a complete denture, implant-supported overdenture, or implant-supported segmented prosthesis
- Inability to access complete patient records and follow-up information due to any reason

### Clinical Procedure

Before the implant surgery, panoramic radiography and CBCT were used to assess the alveolar bones and related anatomical structures. The surgeries were conducted by the same experienced surgeon (L.X.Q) following standard procedures. For the edentulous patients, a transverse incision was conducted on the alveolar crest, and a full-thickness flap was raised. For potentially edentulous patients, extraction of residual teeth was performed in a minimally invasive manner. The extraction sockets were thoroughly debrided to remove granulation tissue remnants. When the interarch distance was < 24 mm or the alveolar crests of the maxilla and mandible were not parallel, alveoloplasty was required. Alveoloplasty was performed in 13.6% of the arches. Implant sites were prepared sequentially following manufacturer instructions. All implants were cylindrical or tapered with moderately rough sandblasted and acid-etched (SLA) surfaces (Thommen Medical). Guided bone regeneration was performed using bone substitutes (Bio-Oss, Geistlich) and resorbable collagen membrane (Bio-Gide, Geistlich) when there were bone defects around the implants. Bone grafting was used in 12.7% of the implants.

If the implants achieved enough primary stability (at least 35 Ncm insertion torque), straight or angled multiunit abutments (17 or 30 degrees) were tightened to the implants. Postoperatively, the open-tray transfer copings were fixed to the abutments and connected with autopolymerizing composite resin. The splinted pick-up technique was used to make impressions. Immediate restorations were fabricated in the laboratory using heat-cured acrylic resin and artificial teeth and delivered within 48 hours after surgery.

After a healing period of 3 months, patients returned to begin definitive implant prosthodontic rehabilitation. Definitive impressions were taken with a splinted pick-up technique, and the maxillomandibular relationship was recorded. Then, the screw-retained resin prototype was tried to evaluate tooth arrangement, centric relationship, esthetics, and functional movement in the next appointment. Thereafter, the modified prototype was sent to the laboratory for prosthesis fabrication. The prosthesis was digitally designed in Exocad software and fabricated. The prosthesis was divided into two categories according to material. Group TC was made up of titanium-ceramic prostheses containing a titanium framework (Adentatec) with layered-zirconia or individual zirconia crowns (Dental Direkt). Group ZC was made up of zirconia-ceramic prostheses containing a zirconia framework (Dental Direkt) bonded to prefabricated titanium cylinders with minimal layering in esthetic areas

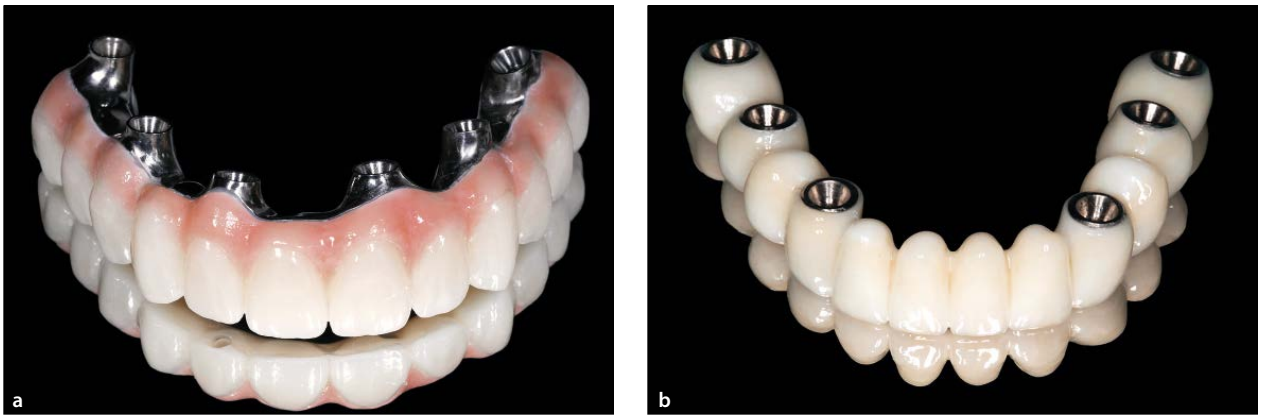



**Fig 1** Images of prostheses. *(a)* Titanium-ceramic IFDP (group TC). *(b)* Zirconia-ceramic IFDP (group ZC).

(Cerabien ZR, Noritake). The zirconia was 3 mol% $Y_2O_3$ stabilized tetragonal zirconia polycrystal (3Y-TZP-LA, Dental Direkt). Dual-curing resin (3M RelyX U200) was used to bond titanium cylinders. After confirming the passive fit, all restorations were preloaded based on the manufacturer's recommendations (15 Ncm for retaining screws and 25 Ncm for abutment screws).

## Data Collection and Classification

Standardized hygiene protocol was conducted by teaching each patient how to brush and use an interdental brush or Waterpik through videos, which allowed for the exclusion of bias due to differences in the patients' hygiene cleaning abilities. Patients were recommended for follow-up visits once a year after delivery of the definitive prosthesis. This periodic review included evaluation of the restoration, peri-implant soft tissue, and oral hygiene maintenance. In addition, at the beginning of this retrospective study, all the patients were called back to the clinic for a systematic clinical and radiologic examination. Therefore, the outcome measures were determined by combining historic records from routine follow-ups with data from the last visit for the study purpose. The enrolled arches were divided into two groups according to the prosthesis material: Group ZC was made up of zirconia-ceramic prostheses, while group TC was made up of titanium-ceramic prostheses (Fig 1). The follow-up period for implants was calculated from the time of implant placement. The follow-up period for prostheses was calculated from the time of delivery of the definitive prosthesis. Two evaluators (Y.M.T. and H.J.Y.) were aligned and calibrated. Interexaminer agreement was calculated with an intraclass correlation coefficient (ICC) and showed an agreement of 0.79 (95% CI: 0.74 to 0.84).

## Outcome Measures

***Implant/prosthesis failure.*** For the present investigation, implants remaining in situ supporting a functional prosthesis were considered for implant survival. Implant loss or removal was considered as implant failure.[11,12] An event resulting in the replacement of the restoration was considered as prosthesis failure.[20]

## Radiographic Examination

Panoramic radiographs were acquired with the Planmeca ProMax Dimax3 Ceph device, with the normalized condition described in the present authors' previous studies.[21] The distance from the implant shoulder to the most coronal point of bone-to-implant contact (DIB) was measured using the ImageJ 1.52a software program (National Institutes of Health). To ensure standardization and avoid possible radiographic distortion of the panoramic radiographs, internal calibration was performed with the known distance of the thread pitch (1.00 mm). Peri-implant marginal bone loss (MBL) was obtained from the difference between the DIB values calculated at the time of definitive prosthesis placement and the final follow-up visit.

## Biologic and Mechanical Complications

Biologic complications included peri-implant mucositis and peri-implantitis. The diagnostic criteria for peri-implant mucositis were bleeding and/or suppuration on light probing, without bone loss beyond initial bone remodeling. The diagnostic criteria for peri-implantitis were bleeding and/or suppuration on light probing, probing depth ≥ 6 mm, combined with marginal bone loss of > 3 mm.[22] Mechanical complications included implant fracture, framework fracture, fracture or loosening of the screws, fracture or loosening of the abutments, fracture or debonding of the crowns, and veneer chipping.[23]

## Patient Satisfaction

Based on the reported questionnaires[24,25] and the fundamental criteria for the creation of a valid tool,[26] a new standardized questionnaire was adapted to evaluate patient satisfaction. The questionnaire consisted of five variables: masticatory function, esthetics, comfort,

**Table 1 Patient Satisfaction Questionnaire**

| Questions | Scores | | | | |
|---|---|---|---|---|---|
| | 1. Very dissatisfied | 2. Dissatisfied | 3. Neither bad nor good | 4. Satisfied | 5. Very satisfied |
| 1. How satisfied are you with your ability to chew foods with your prosthesis? | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2. How satisfied are you with the esthetics of your prosthesis? | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3. How satisfied are you with the comfort of your prosthesis? | ☐ | ☐ | ☐ | ☐ | ☐ |
| 4. How satisfied are you with the stability of your prosthesis? | ☐ | ☐ | ☐ | ☐ | ☐ |
| 5. How satisfied are you with your ability to speak with your prosthesis? | ☐ | ☐ | ☐ | ☐ | ☐ |

**Table 2 Patient Demographics and Clinical Data of the Study Sample**

| | IFDPs group | | |
|---|---|---|---|
| | Group TC (n = 26, impl=159) | Group ZC (n = 18, impl =109) | *P* value |
| Follow-up (mo) | 55.3 ± 25.6 | 61.2 ± 22.9 | .322 (MW) |
| Age (y) | 56.1 ± 8.6 | 50.2 ± 13.1 | .321 (MW) |
| Male | 22 (84.6%) | 8 (44.4%) | .005* ($Chi^2$) |
| Systemic diseases | 12 (46.2%) | 10 (55.6%) | .540 ($Chi^2$) |
| History of periodontitis | 25 (96.2%) | 15 (83.3%) | .357 ($Chi^2$) |
| History of smoking | 11 (42.3%) | 4 (5.6%) | .167 ($Chi^2$) |
| Maxillary restorations | 11 (42.3%) | 10 (55.6%) | .387 ($Chi^2$) |
| Immediate loading (no. of prostheses) | 13 (50%) | 5 (27.8%) | .140 ($Chi^2$) |
| Immediate implants (no. of implants) | 36 (22.6%) | 32 (29.4%) | .215 ($Chi^2$) |

Data were presented as mean ± SD, numbers (proportion). *$P < .050$.
$Chi^2$ = Chi-square tests; MW = Mann-Whitney tests; n = number of prostheses; impl = number of implants.

stability, and pronunciation (Table 1). Patients were invited to express their subjective opinions about the prosthesis on a scale of five scoring levels: 1 (very dissatisfied), 2 (dissatisfied), 3 (neither bad nor good), 4 (satisfied), and 5 (very satisfied).

### Statistical Analysis

Quantitative data were expressed as mean ± standard deviation. Categorical data were expressed as frequencies and percentages. For ease of description, each edentulous arch corresponded to one case of a complete-arch IFDP. The sociodemographic and clinical characteristics of the enrolled sample were compared by Student *t* test, Mann-Whitney test, and chi-square test. Survival analysis of the implants and prostheses was conducted using Kaplan-Meier methods, estimating the CSR with 95% confidence intervals (CI). The log-rank test was used to compare the survival curves between two groups. The chi-square test was used to compare the prevalence of complications between two groups. Considering situations where there was more than one implant in one patient, possible risk factors for mechanical complications were analyzed using a generalized estimating equation (GEE), estimating odds ratios (ORs), and corresponding 95% confidence intervals (CI). Risk factor analysis included univariate and multivariate models. Specific variables in the univariate analysis ($P < .150$) were included in the multivariate analysis, and the final statistically significant variables were selected as risk factors. Statistical analysis was performed by SPSS 20.0 software ($\alpha = .05$).

## RESULTS

### Descriptive Patient Data

A total of 114 edentulous arches were treated with implant-supported prostheses from January 2012 to December 2019. Of these, 70 arches were excluded for the following reasons: *(1)* 41 implant-supported overdentures; *(2)* 7 implant-supported segmental fixed prostheses; *(3)* 3 arches in which a different system was used for the implants; *(4)* 16 arches were not definitively restored or restored for < 2 years; and *(5)* 3 arches lost to follow-up. Finally, there were 44 complete-arch IFDPs supported by 268 implants among 30 patients (10 women and 20 men) enrolled in the study. The median age of these patients was 56 years (age range: 26 to 78 years). The average follow-up time of the implants was 4.8 ± 2.0 years (range: 2 to 9 years).

Of the 44 IFDPs, 26 were titanium-ceramic prostheses (group TC) supported by 159 implants, and 18 were zirconia-ceramic prostheses (group ZC) supported

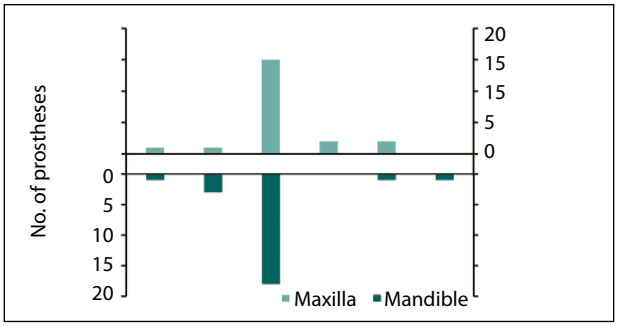



**Fig 2** Frequency distribution of number of implants per prosthesis.

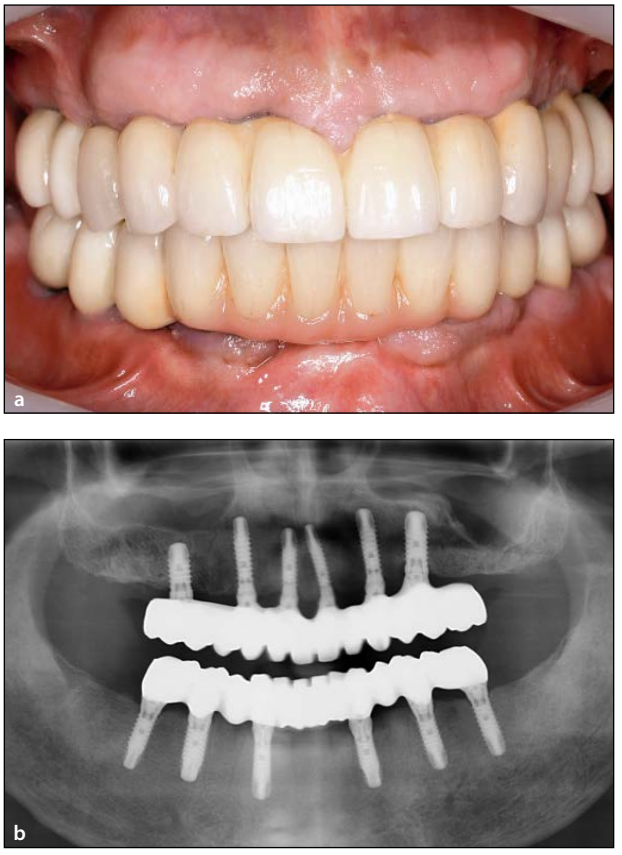



**Fig 3** Representative follow-up data of a patient rehabilitated with a complete-arch fixed prosthesis supported by six implants, currently with 7 years of follow-up. *(a)* Intraoral view of the patient. *(b)* Panoramic radiograph of the patient.

**Table 3 Overview of Failures of the Implants**

| Patient no. | Sex | Site | Size | Time to failure from implant placement | Loading time | Reason for failure |
|---|---|---|---|---|---|---|
| 10 | Male | 44 | 4.5 × 12.5 | 8 mo | Delayed | Peri-implantitis |
| 16 | Male | 15 | 5.0 × 9.5 | 3 mo | Delayed | Lack of integration |

by 109 implants. Their basic information is shown in Table 2. No statistically significant differences were observed regarding age, systemic condition, smoking, and history of periodontitis between the two groups. Similarly, clinical parameters such as location of prostheses, immediate implants, and implant loading were found to not be statistically different between groups.

There was a total of 127 implants in 21 maxillae and a total of 141 implants in 23 mandibles, with an average of 6 implants per arch. The number of implants per arch, separately for the maxilla and mandible, is reported in Fig 2. As shown in Appendix Table 1 (see Appendix in online version of this article at quintpub.com), the diameters of the implants inserted were 3.5, 4, 4.5, 5, and 6 mm, with lengths of 6.5 to 14 mm. The most common dimensions were 4.5 × 12.5 mm (30 implants). The representative clinical data of an edentulous patient rehabilitated with a six-implant–supported fixed prosthesis with a 7-year follow-up are shown in Fig 3.

## Implant and Prosthesis Survival

Out of 268 implants placed at the baseline, 2 implants belonging to two patients failed to osseointegrate during the first year after implant insertion, which were withdrawn and replaced before definitive treatment. The detailed information of the failed implants is presented in Table 3. The estimated CSR of the implants was 99.3% at 9 years (95% CI: 98.2% to 100.3%). The CSR of implants was 100% in group TC and 98.2% (95% CI: 95.6% to 100.7%) in group ZC, with no statistically significant difference between the groups ($P = .087$), which was illustrated as Kaplan-Meier curves (Fig 4a). Of 44 complete-arch IFDPs, a total of 3 failed, yielding a CSR of 92.5% at 8 years (95% CI: 84.2% to 100.8%). Two of the failures were because of framework fracture at the mesial junction of the most distal implant: one in a titanium-ceramic prosthesis and another in a zirconia-ceramic prosthesis. The last failure was because of multiple instances of ceramic chipping in 1 titanium-ceramic prosthesis. The CSR of the prostheses was 92.3% (95% CI: 82.1% to 102.6%) in group TC and 93.1% (95% CI: 80.1% to 106.1%) in group ZC, with no statistically significant difference between the groups ($P = .666$; Fig 4b).

## Marginal Bone Loss

The marginal bone loss of implants in group TC was 1.05 ± 1.09 mm, while that of implants in group ZC was 0.88 ± 0.90 mm. There were no significant differences in marginal bone loss between groups TC and ZC.

## Biologic Complications

Biologic complications were observed in 20 implants (7.5% or n = 20/268). The most common observed biologic complication was peri-implant mucositis

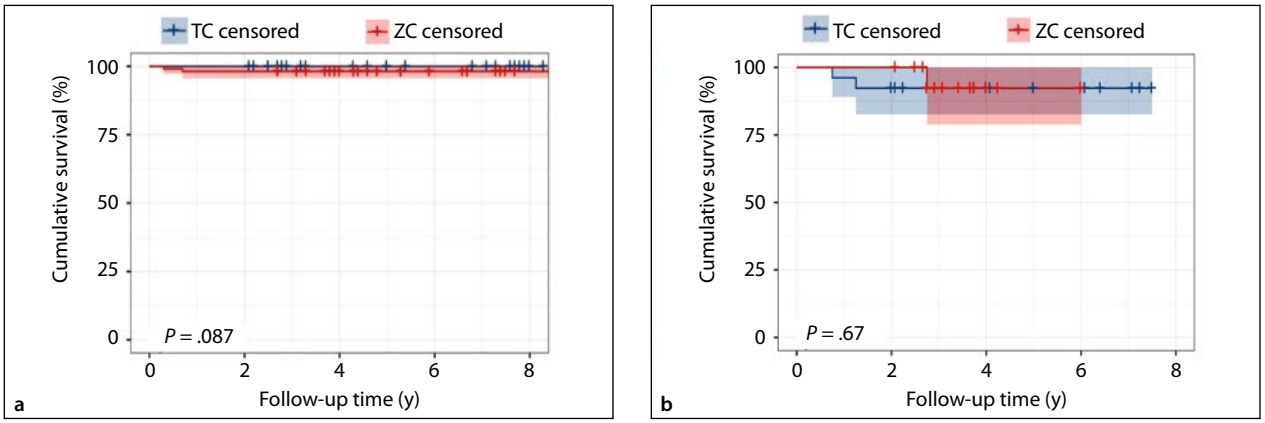



**Fig 4** *(a)* Kaplan-Meier curve with 95% CI for implant survival of groups TC and ZC. *(b)* Kaplan-Meier curve with 95% CI for prosthesis survival of groups TC and ZC.

(4.5% or n = 12/268), followed by peri-implantitis (3.0% or n = 8/268; Table 4). Of the implants experiencing biologic complications, 15% (n = 3/20) were in grafted bone. Figure 5 shows a clinical image of peri-implantitis. There were no significant differences in the occurrence of biologic complications between groups TC and ZC.

## Mechanical Complications

Mechanical complications occurred in 29 prostheses (65.9% or n = 29/44). The most frequently observed mechanical complication was ceramic chipping (45.5% or n = 20/44), followed by ceramic crown debonding (13.6% or n = 6/44), framework fracture (4.5% or n = 2/44), and crown fracture (2.3% or n = 1/44; Table 4). A clinical example of framework fracture is shown in Fig 6. A clinical example of crown fracture is shown in Fig 7. There were no significant differences in the occurrence of mechanical complications between groups TC and ZC.

Table 5 shows the analysis of risk factors for mechanical complications, using both univariate and multivariate models. The presence of cantilever (OR = 5.54; *P* = .048) and maxillary arch (OR = 5.94; *P* = .041) were significant risk indicators for mechanical complications. The rate ratio for mechanical complications of IFDPs with cantilever was 5.54 (95% CI: 1.02 to 30.13) times compared with that of IFDPs without cantilever.

## Patient Satisfaction

Patient satisfaction with the IFDP is shown in Fig 8. More than 80% of the patients were completely satisfied with the masticatory function, stability, comfort, and esthetics of the IFDP. However, for the perception of pronunciation function, 68.2% of the patients were completely satisfied, 18.2% were very satisfied, and 13.6% were neither dissatisfied nor satisfied.

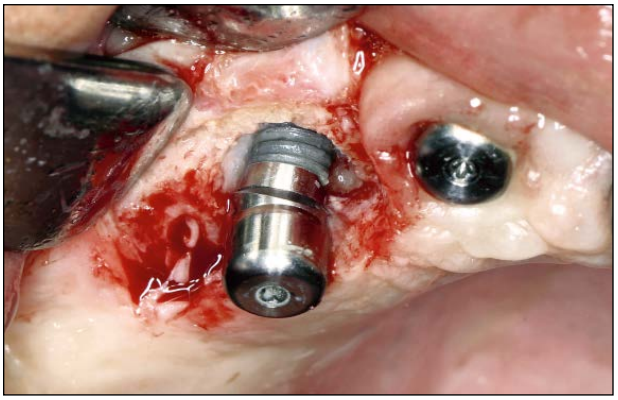
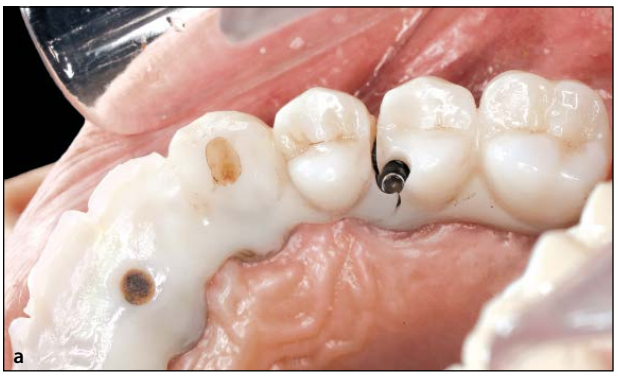


**Fig 5** Intraoral image of peri-implantitis in the maxilla before definitive prosthesis loading.



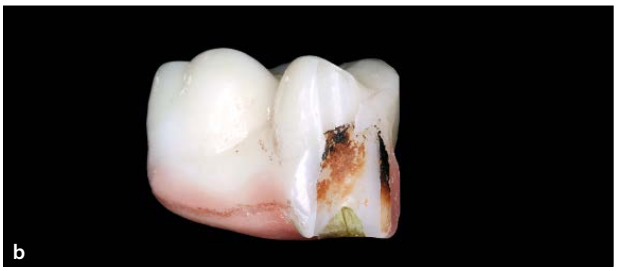




**Fig 6** *(a and b)* Framework fracture of the zirconia framework in a maxillary complete-arch IFDP. Note that inadequate thickness of zirconia around the screw access hole will result in framework fracture.

**Table 4 Comparison of Types of Complications and Statistical Analysis Between Groups**

| | IFDP group | | | | |
|---|---|---|---|---|---|
| | Total (n = 44, impl = 268) | Group TC (n = 26, impl = 159) | Group ZC (n = 18, impl = 109) | OR (95% CI) | *P* value |
| **Biologic complications (calculated by implants)** | | | | | |
| Peri-implant mucositis | 12 (4.5%) | 4/159 | 8/109 | 0.33 (0.09, 1.11) | .115 |
| Peri-implantitis | 8 (3.0%) | 6/159 | 2/109 | 2.10 (0.42, 10.59) | .479 |
| **Mechanical complications (calculated by prostheses)** | | | | | |
| Framework fracture | 2 (4.5%) | 1/26 | 1/18 | 0.68 (0.04, 11.63) | 1.000 |
| Ceramic chipping | 20 (45.5%) | 12/26 | 8/18 | 1.07 (0.32, 3.59) | .911 |
| Crown fracture | 1 (2.3%) | 1/26 | 0/18 | — | 1.000 |
| Crown debonding | 6 (13.6%) | 6/26 | 0/18 | — | .67 |

Data were presented as numbers (proportion). *$P < .050$.
n = number of prostheses; impl = number of implants.

**Table 5 Potential Risk Indicators for the Prevalence of Mechanical Complications**

| | Univariate analysis | | Multivariate analysis | |
|---|---|---|---|---|
| **Factor** | **OR (95% CI)** | ***P* value** | **OR (95% CI)** | ***P* value** |
| Sex | 3.11 (1.04, 9.35) | .043* | 3.91 (0.97, 15.80) | .055 |
| Age | 2.19 (0.75, 6.40) | .153 | | |
| Opposing arch | 4.60 (0.83, 25.61) | .082* | 3.84 (0.87, 16.98) | .076 |
| Arch (maxilla) | 3.93 (1.07, 14.45) | .039* | 5.94 (1.07, 32.89) | .041† |
| Cantilever | 3.42 (0.69, 17.01) | .132* | 5.54 (1.02, 30.13) | .048† |
| Prosthetic material | 0.74 (0.25, 2.17) | .582 | | |
| Angled abutment | 2.37 (0.75, 7.51) | .142* | 0.84 (0.16, 4.49) | .840* |

*Covariate selected for multivariate analysis ($P < .150$); †Significant influence derived from generalized estimating equation analysis ($P < .050$).

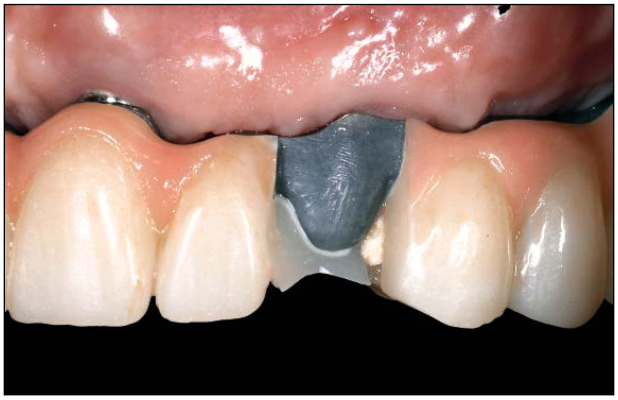


**Fig 7** Crown fracture in a maxillary complete-arch IFDP.

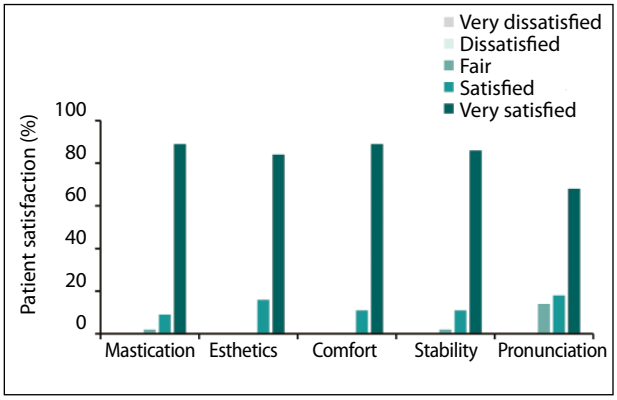



**Fig 8** Results of patient questionnaire related to satisfaction with the prostheses.

## DISCUSSION

The present study showed an overall reliable and predictable clinical outcome for complete-arch IFDPs with an up-to-9-year observation period. The cumulative survival rates of the implants and IFDPs were 99.3% and 92.5%, respectively, which compared favorably or were slightly better than the reported rates in previous studies.[6,27,28] The implant failures recorded in the present study appeared in the first year after implant surgery and were regarded as early failures, which were in accordance with previous longitudinal studies.[29,30] Peri-implantitis has been considered as the main biologic factor of implant failure, resulting in progressive bone resorption and loosening or removal of implants.[31] The 3.0% rate of peri-implantitis for the present investigation was lower than that for implants reported in previous studies.[32,33] One possible explanation was that the present study performed probing on the implants with the prosthesis remaining in

situ, and the accuracy of the probing depth was affected when the contour of the prosthesis was protruding, which may have led to a missed diagnosis of peri-implantitis.

The present study showed that biologic complications occurred in 20 implants (7.5%), while mechanical complications occurred in 29 prostheses (65.9%); the most commonly observed complication was ceramic chipping (45.5%). Similarly, previous studies demonstrated that mechanical complications were a widespread concern, the prevalence of which was much higher than that of biologic events.[18,34] Chipping and fracture of veneering materials were documented to be quite frequent in IFDPs in other studies, with different prevalence rates: 39.3%,[17] 69.2%,[18] and 13.5%.[19] On the one hand, ceramic layering to the titanium framework tended to have a high risk of veneer chipping.[35] On the other hand, Chinese patients favored hard food, leading to unfavorable occlusal force to the restoration during chewing. Dentists should consider reducing the occlusal force by adjusting the occlusal early contact point and the buccolingual reduction of the artificial tooth.[36] For patients with chipping and fracture, soft occlusal guards were provided to prevent further prosthesis damage.

It is noteworthy that no abutment or screw fractures were observed for the present investigation. Most likely, the lack of problems with abutments and screws in this system might be attributed to the verifiable advantages of internal-hexagon connections and unique reinforcement collar in terms of excellent sealing and high rotational stability.[37] Also, the fixation sequence of the screws may affect the accuracy of prosthesis fit and range of passivity. A standard protocol for preloading the screws was used in the present study. The abutment in the center of the prosthesis was first slightly attached with finger pressure. When stable, the adjacent abutments were engaged with screws; then, the next two adjacent screws were attached. After completion, the central screw was fixed last. The screws were torqued to a firm finger pressure in the same order. Finally, the screws were tightened with a torque wrench in the same order.

An important complication that was easily overlooked, in addition to the biologic and mechanical complications, was speech or phonetic issues. The present study reported that 31.8% of the patients exhibited speech problems. There were various reasons for this problem, including overbulked prostheses, enlarged tongue, loss of proprioception, and prosthesis air spaces. The present study tried to solve the prosthesis-caused problems by performing volumetric reduction of the prosthesis or changing the position of the prosthesis to minimize interference with tongue movement.[38] For speech problems caused by inadaptation of the patients, the present study instructed patients on the use of musculature and phonetic exercises. An ideal exercise plan included instructing patients to speak or read from a book or magazine out loud for 30 minutes twice a day.

Material selection, including framework and veneering material, was regarded as a critical factor for complete-arch IFDPs. Ceramic-based restorations with either titanium or zirconia frameworks exhibit superior long-term esthetic results and less-abrasive properties compared to metal-resin restorations.[39] However, no literature comparing clinical outcomes between metal-ceramic and zirconia-ceramic IFDPs has been found so far. The present study revealed that there was no significant difference in the CSR and complication occurrence between metal-ceramic and zirconia-ceramic IFDPs, thus providing novel evidence of material selection for clinicians. The zirconia-ceramic prosthesis in the study was monolithic zirconia in occlusal contact areas, with minimal layering in esthetic areas. Comparing the results of this study with those of studies reporting on fully monolithic zirconia IFDPs, the present study found a significantly increased number of prosthetic complications.[14] Comparing the results of the present study with those of studies on conventional veneered zirconia IFDPs, similar results of veneering chipping were found.[18] To alleviate this problem, use of monolithic zirconia with gingival stains or zirconia veneered only at the gingiva and adoption of slower heating and cooling rates during porcelain firing may help reduce the risk of material failure.[40] Design considerations for the fabrication of zirconia-based prostheses include but are not limited to restorative space, the framework cross-sectional area of connectors, and cantilever design:

- Inadequate restorative space leads to the fracture of veneering materials or the complete framework. Zirconia-ceramic restorations require a minimum space of 12 mm from the implant platform to the opposing dentition.
- A minimum connector size of 16 $mm^2$ in the area of channels or connectors was recommended.[41]
- Limiting the distal cantilever length and occlusion on the cantilever.
- Thickening the buccal and lingual walls of the chimney around the most distal implant, especially when the implant was very close to the embrasure.[42]

The causes of mechanical complications were complex. Regarding the factors the present study focused on, a significant association between cantilever and mechanical complications was discovered. Similarly, a previous study indicated that the presence of cantilevers might be related to a greater frequency of complications.[43] A systematic review by Storelli et al revealed

a prosthetic complication rate of 39.46% in cantilever-fixed complete-arch IFDPs.[44] However, the OR = 5.54 value of the "cantilever" variable should be explained cautiously in actual patients because of the small sample size and large confidence interval. In addition, the present study also found a higher risk of complications for maxillary prostheses (OR = 5.94). Some studies showed that bruxism was a potential hazard for mechanical complications.[45,46] However, the present study did not include bruxism as a factor in the risk factor analysis. The reason was that all patients who reported nocturnal bruxism were advised to wear protective occlusal splints, thus reducing the risk of occlusal overload.

The present study had several limitations. First, data were not provided on the parameters of peri-implant soft tissue because the probing was performed with the prosthesis remaining in situ, which may not be accurate in specific situations. Also, the limited sample size could have affected the quality level of the study. Indeed, the results with a mean follow-up of 4.8 years were derived from a small group of the overall sample, and the results showed large confidence intervals, which limited the external validity of the results. Further prolonged, well-established randomized controlled trials are needed to help dentists make evidence-based decisions.

## CONCLUSIONS

Considering the limitations of this retrospective study, complete-arch implant-supported fixed dental prostheses were shown to be a credible treatment modality for the rehabilitation of edentulous patients, with predictable results and high survival rates validated in the up-to-9-year follow-up. However, a high incidence of mechanical complications occurred in the long term.

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# APPENDIX

**Appendix Table 1 Properties of the Implants Used in the Study**

| | | Location of Implants | |
|---|---|---|---|
| Diameter (mm) | Length (mm) | Maxilla | Mandible |
| 3.5 | 11 | 2 | 7 |
| | 12.5 | 5 | 9 |
| | 14 | 2 | 5 |
| 4 | 9.5 | 1 | 4 |
| | 11 | 1 | 7 |
| | 12.5 | 16 | 13 |
| | 14 | 9 | 8 |
| 4.5 | 8 | 4 | 6 |
| | 9.5 | 7 | 17 |
| | 11 | 5 | 9 |
| | 12.5 | 30 | 20 |
| | 14 | 14 | 7 |
| 5 | 6.5 | 0 | 2 |
| | 8 | 5 | 4 |
| | 9.5 | 7 | 10 |
| | 11 | 7 | 5 |
| | 12.5 | 5 | 4 |
| | 14 | 1 | 1 |
| 6 | 9.5 | 5 | 1 |
| | 11 | 2 | 1 |