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Retrospective clinical evaluation of implant-supported single crowns: mean follow-up of 15 years

Running title: Implant-supported single crowns

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AUTHOR CONTRIBUTIONS

B.R.C.: conception and design, acquisition of data, statistical analysis, drafting the article

B.R.C., J.K., C.L.: interpretation of data, revising the article critically for important intellectual content, final approval of the version to be published

ABSTRACT

Objective. To retrospectively assess the clinical outcomes of implant-supported single crowns and the supporting implants.

Material and Methods. This retrospective study included all patients treated with implant-supported single crowns at one specialist clinic. Implant and prosthesis failure, and mechanical/technical complications (ceramic fracture/chipping; crown loss of retention/mobility; crown failure/fracture; loosening/loss/fracture of prosthetic screw; implant failure/fracture) were the outcomes analyzed. Any condition/situation that led to the removal/replacement of crowns was considered prosthesis failure.

Results. 438 patients with 567 crowns were included. Mean $\pm$ SD follow-up of 183.4 $\pm$ 69.3 months. 37 implants (6.5%) and 54 crowns (9.5%) failed. If only technical problems were considered, the crown failure rate decreased to 4.1% (23/567). Most common reasons for crown failure: esthetic issue (n=12), crown constantly mobile (n=9), change to another type of prosthesis together with other implants (n=8), crown fracture (n=7), crown in infraposition in comparison to adjacent teeth (n=7). The odds of crown failure were shown to be statistically significantly higher for the following factors: younger patients, maxillary crowns, and screw-retained crowns. Loose prosthetic screw was much more prevalent in screw-retained than in cemented crowns. Ceramic fracture/chipping was more prevalent in screw-retained crowns, maxillae, females. Crown fracture was more prevalent in

ceramic crowns, screw-retained crowns, maxillae, posterior region, females. However, these differences were statistically significant only for crown fractures in females.

Conclusions. The odds of crown failure were significant for some factors, but one must keep in mind that non-technical complications are as common as technical ones as reasons for the replacement of implant-supported single crowns.

KEYWORDS

Dental implant, fixed prosthesis, implant-supported single crown, technical complications, survival

INTRODUCTION

The original protocol of Brånemark for endosseous dental implants was aimed for the placement of multiple implants in the anterior parts of edentulous jaws. Schmitt and Zarb (1993) were probably the first ones that reported the clinical outcomes of a series of implants used for the prosthetic replacement of single teeth. Since then, more and more professionals make use of this treatment option. Today, the use of implant-supported single crowns has become a well-established and preferred approach to compensate for missing single teeth, especially when adjacent teeth are healthy or when the patient refuses preparation of teeth for the fabrication of a traditional three-unit fixed partial restoration.

Implant-supported single crowns have many advantages over a fixed partial denture, namely a decreased risk of caries and endodontic treatment of the abutment teeth (and therefore a decreased risk of abutment tooth loss from caries or endodontic failure), improved ability to clean the proximal surfaces of the adjacent teeth (decreasing the risk of decay and periodontal disease), maintenance of bone in the edentulous site, psychological advantage, among others (Misch, 2005). Despite all these advantages, single crowns supported by dental implants are not free from complications (Pjetursson et al., 2018, Sailer et al., 2012). The aim of the present retrospective

clinical study was to assess the clinical outcomes of implant-supported single crowns and the supporting implants after a mean follow-up of 15 years.

MATERIALS AND METHODS

Materials. This retrospective study included patients rehabilitated with one or more implant-supported single crown, installed by the last day of the year of 2007 at a specialist clinic (Clinic for Prosthodontics, Centre of Dental Specialist Care, Malmö, Sweden). The patients' records were scrutinized up until August 2018. As such, the authors of the present study were expecting to have as many cases with a minimum of 10 years of follow-up as possible. The study was approved by the regional Ethical Committee, Lund, Sweden (Dnr 2014/598; Dnr 2015/72).

Definitions. An implant was considered a failure if presenting signs and symptoms that led to implant removal, i.e. a lost implant (due to initial failure to osseointegrate, late loss of osseointegration or fracture of the implant). Any condition or situation that led to the removal and/or replacement of the crown was considered as a prosthesis failure. Any other condition or finding was considered as a complication.

Technical complications could have happened to the prosthesis or to the implant:

- Complications regarding the prosthesis: ceramic chipping; crown fracture (larger fracture of ceramic or fracture of crown entire thickness, which would lead to crown replacement); loss of retention of the crown; mobility of the crown;
- Complications regarding the implant: loosening, loss or fracture of connecting/abutment screws; loosening, excessive wear, deformation or fracture of prosthetic abutment; pain.

Non-technical complications (leading to replacement of the crown, or change to another prosthesis type e.g. fixed partial denture) consisted of any kind of issue other than the ones aforementioned defined as technical: use the implant for another type of prosthesis together with

other implants (usually either overdentures or fixed partial prostheses), crown in infraposition in comparison to adjacent teeth, esthetic issue and raise of the patient's bite.

Two situations characterized the crown as being mobile: (a) a screw-retained crown that had a loose screw, and (b) a cemented crown + abutment set that was loose, i.e. the crown was still well cemented to the abutment, but the prosthetic screw was loose. Loss of retention of the crown was defined as a cemented crown that was still in place, but a little bit loose from the abutment.

Anterior region was defined as the teeth positions from canine to canine. Posterior region was defined as the teeth positions of premolars and molars. The guidelines used in a recent study (Chrcanovic et al. 2017a) were applied in order to diagnose patients as bruxers.

Inclusion and exclusion criteria. Only implant-supported single crowns were included. Modern threaded cylindrical- or conical-design implants were included. The definitive crown needed to be installed by December 31st 2007.

Data collection. The data were directly entered into a SPSS file (SPSS software, version 25, SPSS Inc., Chicago, IL, USA) as the dental records of the patients were being read, and it consisted of several implant-, site-, and patient-related factors.

The patients were periodically followed up by dentists and dental hygienists at the clinic, with attendance based on individual needs.

Statistical analyses. The mean, standard deviation (SD), and percentage were calculated for several variables. The test performed were the following: Kolmogorov–Smirnov (to evaluate the normal distribution), Levene's test (to evaluate homoscedasticity), Student's t-test or Mann-Whitney (for two independent groups, continuous variables), Pearson's chi-squared or Fisher's exact test (for categorical variables). The degree of statistical significance was considered at $p < 0.05$.

A generalized estimating equation (GEE) method was used to account for the fact that repeated observations (several crowns) were available for a single patient. All models were adjusted for clustering of subject and crowns in a binary logistic regression model through GEE with a binomial distribution and a logit link function, while assuming an exchangeable working correlation

structure to assess the relationship between crown failure (dependent variable) and the risk factors (independent variables). Initially, a univariate GEE on each variable was performed. To verify multicollinearity, a correlation matrix of all predictor variables with a significant odds ratio (OR) (p -value cutoff point of 0.1) identified in the univariate GEE was scanned to see whether there were some high correlations among the predictors. Collinearity statistics obtaining variance inflation factor and tolerance statistic were also performed to detect more subtle forms of multicollinearity. Then, a multivariable model with a forced entry method was used to evaluate the effect of the factors that were univariately significant ($p < 0.1$) and did not present multicollinearity. A Wald chi-square test was used to analyze the statistical significance of each parameter within the model. The results of the final model were presented as an estimated OR of each significant prognostic variable ($p < 0.05$).

All data were statistically analyzed using the SPSS version 25 software (SPSS Inc., Chicago, IL, USA). This observational study followed the STROBE guidelines.

RESULTS

A number of 440 patients received 570 implants by the last day of the year of 2007, with the purpose of being rehabilitated with single crowns. Eight of the implants failed before the installation of a crown (6 Nobel turned, 1 Nobel MKIII TiUnite, 1 Frialit-2), of which 3 implants, in 3 patients, were not reoperated. One of these patients had another implant/crown included in the study, and therefore this one patient was not excluded from the study. Thus, the study included 438 patients that were rehabilitated with 567 implant-supported single crowns. Of these patients, 236 were male and 202 female, with a mean age of 27.9 ± 13.6 years (min-max, 12.2-80.6) at the time of prosthesis installation. The patients were followed-up for a mean $\pm$ SD of 183.4 ± 69.3 months (min-max, 1.0-367.5; median 173.9; $p < 0.001$, Kolmogorov–Smirnov test).

Nobel implants (Nobel Biocare AB, Göteborg, Sweden) were the support to 466 crowns, of which 322 were turned (machined) Brånemark implants, 143 Nobel MK III TiUnite implants, and 1 was a Nobel Replace implant. The other 101 implants were Astra TiOblast (Astra Tech, Mölndal, Sweden) (n=31), XiVE Friadent (Dentsply Friadent, Mannheim, Germany) (n=28), Frialit-2 (Dentsply Friadent, Mannheim, Germany) (n=24), Astra Osseospeed (Astra Tech, Mölndal, Sweden) (n=11), and SLA Straumann implants (Straumann, Basel, Switzerland) (n=7). The implants had a mean±SD diameter of 3.73±0.29 mm (min-max, 3.00-5.00) and a mean±SD length of 13.96±1.99 mm (min-max, 8.5-20.0). From a total of 567 implant-supported single crowns (295 in men, 272 in women, 477 in maxillae, 90 in mandibles, 418 in the anterior region, 149 in the posterior region, 478 cemented, 89 screw-retained), 331 patients had one crown included in the study, 93 patients had two crowns, 8 patients three crowns, 4 patients 4 crowns, and 2 patients had five single crowns. The second stage surgery (abutment connection) was performed after a mean±SD of 6.0±2.1 months (min-max, 0-19.8) after implant installation. Only six implants were submitted to immediate loading, and none of these failed. The materials used to manufacture the crowns were ceramic (n=391, of which in 34 cases was possible to identify as being zirconia) metal-ceramic (n=169), and metal-acrylic (n=7). 42.7% (38/89) of the screw-retained crowns were located in the posterior region, in comparison to 23.2% (111/478) of the cemented crowns ($p < 0.001$, Pearson chi-square test). Ceramic crowns were installed in the anterior region in 81.3% of the cases (318/391), the percentage being 56.2% (95/169) for metal-ceramic crowns ($p < 0.001$, Pearson chi-square test).

Of the 567 implants, 37 failed (6.5%), of which 28 due to loss of osseointegration and 8 implants fractured. Five out of these 37 implants failed before the installation of a crown. The other 32 lost implants failed a mean±SD of 89.6±95.6 months (min-max, 7-313; median 35.8; $p < 0.001$, Kolmogorov–Smirnov test) after implant installation, or a mean±SD of 82.1±94.3 months (min-max, 0.8-304.5; median 29.0; $p < 0.001$, Kolmogorov–Smirnov test) after crown installation. Fourteen of these 37 lost implants were reoperated. None of the 14 reoperated implants failed. For 2 implant fractures it was not known whether the patient was a bruxer or not, and concerning the other 6

fractured implants, only one happened in a bruxer. Bruxers presented a higher implant failure rate (8.0%, 2/25) than non-bruxers (5.8%, 25/428), as well as a higher implant fracture rate (4.0%, 1/25) than non-bruxers (1.2%, 5/428), but both differences were not statistically significant ($p = 0.448$ and $p = 0.290$, respectively; Fisher's exact test). Smokers had a higher implant failure rate (9.1%, 10/110) than non-smokers (4.8%, 16/331), but the difference was not statistically significant ($p = 0.083$, Pearson's chi-squared test).

Fifty-four of the 567 crowns failed (9.5%). The crowns failed after a mean $\pm$ SD of 98.5 $\pm$ 74.4 months (min-max, 3.5-285.7; median 74.8; $p = 0.006$, Kolmogorov-Smirnov test). Figure 1 shows the scatter plot of the reasons for failure in function of the follow-up time. The reasons for failure were the following: an esthetic issue (concerning material color/shade and/or crown shape) ($n=12$), crown constantly mobile ($n=9$), change to another type of prosthesis (usually overdentures or fixed partial prostheses), together with other implants ($n=8$), fracture of the crown ($n=7$), infraposition of crown in comparison to adjacent teeth as the crown was installed when the patient was young ($n=7$), the cemented crown + abutment set was loose but it was not possible to unscrew the abutment after many attempts and for that reason the access to the prosthetic screws was drilled through the crown ($n=4$), the crown fell off and was lost ($n=2$), constant complaints ($n=1$), the crown became completely loose ($n=1$), the patient's bite was raised ($n=1$) and information not available ($n=2$). If only technical problems were considered, the crown failure rate decreases to 4.1% (23/567).

Table 1 shows the location of the implant-supported single crowns, the crown failure rate, and the reasons for failure according to the crown location in the jaws. Most of the crowns were placed in the maxillary central incisor position. This was also the position with the highest crown failure rate. However, 2/3 of the crowns in the maxillary central incisor position were replaced due to non-technical issues. Second premolar was the only location in the mandible affected by crown failure. None of the few crowns placed in the molar region ($n=15$) failed. A higher rate of technical problems leading to the loss of the crown occurred in the posterior region of the jaws (100% of the cases of crown failure) in comparison to the anterior region (32.6% of the cases).

Table 2 shows the reasons for failure according to the crown material. One can notice, for instance, that crown fracture was more prevalent in ceramic crowns than in metal-ceramic crowns, as well as change of a crown due to esthetic issues and due to crown in infraposition in comparison to adjacent teeth.

Table 3 shows the reasons for failure according to the crown fixation method. Non-technical complications were more commonly seen than technical ones in cemented crowns, whereas similar rates of technical and non-technical complications were found in screw-retained crowns.

Table 4 shows a comparison between the different groups regarding the prevalence of bruxers, smokers, failure rate (for implants and prostheses), time to prosthesis failure and follow-up time. Information about bruxism habits was available for patients with 453 crowns, and information about smoking habits was available for patients with 441 crowns. Metal-acrylic crowns presented a higher rate of failure in comparison to metal-ceramic and ceramic crowns, but the former had a very reduced number of cases ($n=7$) and were followed up for a longer mean time. Metal-ceramic and ceramic crowns had slightly different failure rates. The following also presented higher prosthesis failure rate: screw-retained crowns in comparison to cemented crowns, maxillary in comparison to mandibular crowns and anterior in comparison to posterior crowns. Men and women presented very similar crown failure rates.

Table 5 shows the prevalence of complications, according to several factors. Some comparisons are worth noting. There was a striking difference in the prevalence of loose screw (and consequently crown mobility) between cemented and screw-retained crowns ($p < 0.001$, Pearson chi-square test). Fracture/chipping of ceramic was more commonly seen in screw-retained crowns in comparison to cemented crowns ($p = 0.229$, Pearson chi-square test), in maxillae in comparison to mandibles ($p = 0.222$, Pearson chi-square test), and in females in comparison ($p = 0.141$, Pearson chi-square test), although neither of these differences reached statistical significance. Crown fracture was more commonly seen in ceramic crowns ($p = 0.324$, Fisher's exact test), in screw-retained crowns ($p = 0.303$, Fisher's exact test), in maxillae ($p = 0.692$, Fisher's exact test), in the posterior

region ($p = 0.270$, Fisher's exact test). These differences were, however, not statistically significant. There was, however, a higher statistically significant prevalence of crown fracture in females than in males ($p = 0.006$, Fisher's exact test).

Table 6 shows a comparison between failed and non-failed crowns according to different factors, and the results of the univariate GEE model. The model showed that the following predictors had a statistically significant OR: patient's age, implant location (maxilla/mandible), crown fixation method and follow-up time. Follow-up time was the only factor that did not continue to present a statistically significant OR in the multivariate GEE model (Table 7). Thus, the odds of crown failure were shown to be statistically significantly higher for the following factors: younger patients (in relation to older patients), crowns in the maxilla (in relation to crowns in the mandible), and screw-retained crowns (in relation to cement retained crowns).

DISCUSSION

The use of implant therapy requires consideration of potential benefits to be gained from the therapy. To better appreciate this potential, the present study aimed to assess the clinical outcome of implant-supported single crowns as well as the supporting implants.

The failure rate observed for implants supporting single crowns in the present study (6.3%) presented very similar figures with the failure rate of the whole implant material of this specialist clinic (6.36%), when every kind of prosthetic design was considered (Chrcanovic et al., 2018a). Bruxers presented a higher implant failure and fracture rate than non-bruxers, although without statistically significant differences. This lack of significance does not agree with the results of several recent studies showing that bruxism has a significantly negative effect on both the implant failure (Chitumalla et al., 2018, Chrcanovic et al., 2016, Chrcanovic et al., 2017a, Chrcanovic et al., 2017b, Mohanty et al., 2018) and fracture rates (Chrcanovic et al., 2018b). No reasonable explanation for this result could be found. It must be pointed out, however, that in this study the diagnosis of the so-called bruxers was based on self-report, by means of questionnaires and/or the anamnestic part of a

clinical examination, plus the inspection part of a clinical examination. The patients were not evaluated by polysomnography. Smokers had a higher implant failure rate than non-smokers, but the difference was not statistically significant. Even if not reaching statistical significance, these figures may very well be clinically relevant, although there are no standards for calculating clinically important changes in outcomes (Page 2014).

It was observed that 9.5% of the crowns failed after a mean follow-up time of 15 years. However, one must remember that, for the present study, any condition or situation that led to the removal and/or replacement of the crown was considered as a prosthesis failure. If only technical problems were considered, i.e. 'fracture of the crown', 'crown constantly mobile', 'the crown became completely loose', 'cemented crown + abutment set was loose', 'crown fell off and was lost', then this rate decreased to only 4.1% (23/567). It is important for both the patient and the dentist to consider that many crowns will be replaced due reasons other than only mechanical and technical problems. Indeed, the other reasons for the removal or replacement of the crowns were not technical, e.g. 'esthetic issue', 'crown in infraposition in comparison to adjacent teeth', 'the patient's bite was raised', 'change to another type of prosthesis', and these accounted for more than half of the here so-called crown failure. Concerning the technical reasons, these figures are in accordance with the results of many of the clinical studies included in a recent review on the subject (Pjetursson et al., 2018) although few of those studies evaluated a similar number of single-crowns as in the present study, and none had a mean follow-up as long as in the present study.

There was a higher rate of technical problems leading to the loss of the crown in the posterior region of the jaws in comparison to the anterior region. This could be related to the fact that the occlusal biting load in the posterior jaw is usually about three times that found in the anterior (Flanagan, 2017), which could be an important factor to negatively affect the survival of crowns in the posterior region. For the same reason, this could be a significant factor explaining the higher prevalence of some complications in screw-retained crowns, which were significantly more often located in the posterior region in comparison to cemented crowns.

There was a striking difference in the prevalence of loose screws between cemented and screw-retained crowns. There is a recommendation to tighten the screw a second time a couple of days after the prosthesis is installed, in order to reduce the risk of screw loosening. Unfortunately, it was not possible to know whether this recommendation was followed by all dentists, or whether all the patients came back for an appointment in order to do so. It was also observed that chipping of ceramic was more frequent in screw-retained in comparison to cemented crowns. It is possible that the presence of an access hole in screw-retained crowns poses a design challenge and a risk of unsupported veneer which may act as a weak link in the veneering porcelain. The results are in accordance with a review (Sailer et al., 2012). Although screw-retained restorations exhibit more technical problems compared with cemented prostheses (i.e. loosening of screws and chipping of ceramic), screw-retained restorations are more easily retrievable and show less biological complications (i.e. implant failure and bone loss exceeding 2 mm) (Sailer et al., 2012). Furthermore, technical and/or biological complications in screw-retained crowns can be treated more easily. In comparison to the results of the review of Sailer et al. (2012), the implant failure rate was equal between these two methods of retention.

Ceramic crowns had a slightly higher failure rate than the metal-ceramic ones. This is probably related to the fact that ceramic crowns were more often installed in the anterior region, together with the higher rate of non-technical issues leading to the loss of the crown in the anterior region of the jaws. Crowns of both materials presented similar rates of crown fracture and ceramic chipping, although ceramic chipping that led to crown fracture was higher in ceramic crowns in comparison to metal-ceramic crowns. Chipping in ceramic restorations occurs more frequently than in metal-ceramic restorations due to different material properties, handling and design factors (Swain, 2009). The results are in agreement with a recent review on the subject (Pjetursson et al., 2018). The present results also showed that changes of crowns due to esthetic issues and due to crowns in infraposition in comparison to adjacent teeth were more prevalent for ceramic crowns

than for the metal-ceramic ones, probably as ceramic crowns were more often placed in the anterior regions.

A surprising result was the fact that all crown fractures happened in female patients. It was not possible to find any reasonable explanation for this fact.

The odds of crown failure were shown to be statistically significantly higher for the following factors according to the GEE model: younger patients, crowns in the maxilla, and screw-retained crowns. Dentists should be aware that young patients receiving crowns in the anterior region, especially because of agenesis of maxillary anterior teeth (Gjelvold et al., 2017), may in the future request crown replacement due to the infraposition in comparison to adjacent teeth, that may occur in implants placed in growing patients. Crowns in the maxilla were more often changed due to non-technical issues - 29 crowns, more than half of the crown failures -, which in much accounted for the observed higher failure rate for maxillary crowns. The 'younger patient' issue can also be a factor of influence, due to infraposition and esthetic issues. A mobile crown due to constant loosening of the prosthetic screw was the main contributor to failure of screw-retained crowns, as observed previously in a review (Sailer et al., 2012).

The limitations of the present study include the fact that this is a retrospective study, which inherently results in flaws, manifested by gaps in information and incomplete records. The lack of information on biological factors such as oral hygiene status, bleeding on probing, and probing pocket depth, is also related to the retrospective nature of the present study. Moreover, since this was not a prospective study, treatment was not standardized.

CONCLUSIONS

The odds of crown failure were shown to be statistically significantly higher for the following factors: younger patients, maxillary crowns, and screw-retained crowns. Non-technical complications are as common as technical complications as reasons for the replacement of implant-supported single crowns.

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Declaration of conflicting interests

There are no conflicts of interest to declare.

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FIGURE LEGENDS

Figure 1. Reasons for implant-supported single crown failure in function of the follow-up time.

Table 1. Location of implant-supported single crowns, crown failure rate, and reasons for failure according to the crown location in the jaws.

Position	Crown failure/total (%)	Technical (%) / non-technical (%) complication	Reason for failure	
			Technical complication	Non-technical issue
Maxilla				
Central incisive	32/194 (16.5)	10 (32.3) / 21 (67.7)*	crown constantly mobile (n=5), crown fracture (n=3), crown fell off and was lost (n=1), cemented crown + abutment set was loose (n=1)	change to another type of prosthesis (n=7), crown in infraposition in comparison to adjacent teeth (n=7), esthetic issue (n=6), constant complaints (n=1)
Lateral incisive	7/126 (5.6)	2 (33.3) / 4 (66.7)*	crown fracture (n=1), cemented crown + abutment set was loose (n=1)	esthetic issue (n=3), change to another type of prosthesis (n=1)
Canine	6/84 (7.1)	2 (33.3) / 4 (66.7)	crown constantly mobile (n=1), cemented crown + abutment set was loose (n=1)	esthetic issue (n=3), the patient's bite was raised (n=1)
First premolar	5/43 (11.6)	5 (100) / 0 (0)	crown constantly mobile (n=3), crown fracture (n=1), crown fell off and was lost (n=1)	-
Second premolar	1/25 (4.0)	1 (100) / 0 (0)	crown fracture (n=1)	-
First molar	0/5 (0)	-	-	-
Subtotal	51/477 (10.7)	20 (40.8) / 29 (59.2)*		
Mandible				
Central incisive	0/9 (0)	-	-	-
Lateral incisive	0/1 (0)	-	-	-
Canine	0/4 (0)	-	-	-
First premolar	0/9 (0)	-	-	-
Second premolar	3/57 (5.3)	3 (100) / 0 (0)	crown fracture (n=1), crown became completely loose (n=1), cemented crown + abutment set was loose (n=1)	-
First molar	0/10 (0)	-	-	-
Subtotal	3/90 (3.3)	3 (100) / 0 (0)		
Total	54/567 (9.5)	23 (44.2) / 29 (55.8)*		

* Information about the reason for failure was not available for one maxillary central incisive and one maxillary lateral incisive

Table 2. Crown failure rate, and reasons for failure according to the crown material.

Material	Crown failure/total (%)	Technical (%)/non-technical (%) complication	Reason for failure	
			Technical complication	Non-technical issue
Metallo-acrylic	3/7 (42.9)	1 (33.3) / 2 (66.7)	crown constantly mobile (n=1)	esthetic issue (n=2)
Metal-ceramic	13/169 (7.7)	6 (50.0) / 6 (50.0)*	crown fracture (n=1), cemented crown + abutment set was loose (n=1), crown constantly mobile (n=4)	change to another type of prosthesis (n=3), crown in infraposition in comparison to adjacent teeth (n=2), esthetic issue (n=1)
Ceramic	38/391 (9.7)	16 (43.2) / 21 (56.8)*	crown fracture (n=6), crown fell off and was lost (n=2), crown became completely loose (n=1), cemented crown + abutment set was loose (n=3), crown constantly mobile (n=4)	change to another type of prosthesis (n=5), constant complaints (n=1), crown in infraposition in comparison to adjacent teeth (n=5), esthetic issue (n=9), the patient's bite was raised (n=1)
Total	54/567 (9.5)	23 (44.2) / 29 (55.8)*		

* Information about the reason for failure was not available for one metal-ceramic and one ceramic crown

Table 3. Crown failure rate, and reasons for failure according to the crown fixation method.

Material	Crown failure/total (%)	Technical (%) / non-technical (%) complication	Reason for failure	
			Technical complication	Non-technical issue
Cemented	34/478 (7.1)	13 (39.4) / 20 (60.6)*	crown fracture (n=5), crown fell off and was lost (n=1), cemented crown + abutment set was loose (n=4), crown constantly mobile (n=2), crown became completely loose (n=1)	change to another type of prosthesis (n=6), constant complaints (n=1), crown in infraposition in comparison to adjacent teeth (n=5), esthetic issue (n=7), the patient's bite was raised (n=1)
Screw-retained	20/89 (22.5)	10 (52.6) / 9 (47.4)*	crown fracture (n=2), crown fell off and was lost (n=1), crown constantly mobile (n=7)	change to another type of prosthesis (n=2), crown in infraposition in comparison to adjacent teeth (n=2), esthetic issue (n=5)
Total	54/567 (9.5)	23 (44.2) / 29 (55.8)*		

* Information about the reason for failure was not available for one cemented and one screw-retained crown

Table 4. Comparison of the prevalence of bruxers, smokers, failure rate (implants, prostheses), time to prosthesis failure, and follow-up time, between the different factors. The statistical unit is the crown, not the patient.

Group	n (%)	Bruxer ^{a,c} (%)	Smoker ^{a,b,c} (%)	Implant failure ^d /total (%)	Prosthesis failure/total (%)	Time to prosthesis failure (months) mean±SD (min-max)	Follow-up (months) mean±SD (min-max)
<i>Material</i>							
Metallo-acrylic	7 (1.2)	0/6 (0)	1/6 (16.7)	0/7 (0)	3/7 (42.9)	92.4±23.4 (65.4-106.0)	290.4±71.8 (164.5-356.5)
Metal-ceramic	169 (29.8)	7/128 (5.5)	33/127 (26.0)	14/169 (8.3)	13/169 (7.7)	63.3±41.9 (18.4-156.8)	181.1±78.0 (1.9-367.5)
Ceramic	391 (69.0)	18/319 (5.6)	76/308 (24.7)	18/391 (4.6)	38/391 (9.7)	111.0±82.0 (3.5-285.7)	182.5±63.8 (1.0-356.9)
<i>Fixation</i>							
Cemented	478 (84.3)	22/390 (5.6)	92/381 (24.1)	27/478 (5.6)	34/478 (7.1)	106.0±81.8 (3.5-285.7)	181.0±63.1 (1.0-341.6)
Screw-retained	89 (15.7)	3/63 (4.8)	18/60 (30.0)	5/89 (5.6)	20/89 (22.5)	85.7±59.5 (6.7-275.4)	196.1±95.7 (3.7-367.5)
<i>Jaw</i>							
Maxilla	477 (84.1)	20/389 (5.1)	98/380 (25.8)	25/477 (5.2)	51/477 (10.7)	94.7±70.5 (3.5-284.4)	185.8±68.3 (1.0-367.5)
Mandible	90 (15.9)	5/64 (7.8)	12/61 (19.7)	7/90 (7.8)	3/90 (3.3)	162.0±126.2 (33.5-285.7)	175.9±74.5 (3.7-356.5)
<i>Region</i>							
Anterior	418 (73.7)	17/331 (5.1)	82/324 (25.3)	22/418 (5.3)	45/418 (10.8)	97.3±72.1 (3.5-284.4)	186.1±68.3 (1.0-367.5)
Posterior	149 (26.3)	8/122 (6.6)	28/117 (23.9)	10/149 (6.7)	9/149 (6.0)	104.5±89.5 (4.3-285.7)	175.9±71.8 (3.7-356.5)
<i>Sex</i>							
Male	295 (52.0)	17/232 (7.3)	50/222 (22.5)	19/295 (6.4)	28/295 (9.5)	108.7±77.7 (17.1-285.7)	182.2±73.7 (1.0-356.9)
Female	272 (48.0)	8/221 (3.6)	60/219 (27.4)	13/272 (4.8)	26/272 (9.6)	87.4±70.4 (3.5-223.7)	184.7±64.4 (3.7-367.5)

SD – standard deviation

^a cases with available information are considered

^b Former smokers were also considered as ‘smokers’

^c In 3 cases the prosthesis was installed in patients which were both bruxers and smokers (all ceramic, cemented crowns, installed in the anterior maxillae, in one man and two women)

^d The number of failed implants considered here was 32; the 5 implants lost before the installation of a crown were not counted here

Table 5. Prevalence of complications, according to the factor. The statistical unit is the crown, not the patient.

Group	Loose screw (%) ^a (n) ^b	Fractured screw (%) ^a (n) ^b	Crown loose (%) ^a (n) ^b	Crown mobile (%) ^a (n) ^b	Crown fracture (%) ^a (n) ^b	Porcelain fracture (%) ^a (n) ^b	Painful implant (%)
<i>Material</i>							
Metallo-acrylic	3/7 (42.9) (6)	0/7 (0) (0)	0/7 (0) (0)	3/7 (42.9) (6)	0/7 (0) (0)	-	0/7 (0) (0)
Metal-ceramic	33/169 (19.5) (56)	1/169 (0.6) (1)	10/169 (5.9) (10)	33/169 (19.5) (57)	1/169 (0.6) (1)	11/169 (6.5) (11)	1/169 (0.6) (1)
Ceramic	18/391 (4.6) (27)	1/391 (0.3) (1)	24/391 (6.1) (29)	13/391 (3.3) (23)	6/391 (1.5) (6)	24/391 (6.1) (27)	3/391 (0.8) (3)
<i>Fixation</i>							
Cemented	17/478 (3.6) (23)	2/478 (0.4) (2)	30/478 (6.3) (35)	13/478 (2.7) (19)	5/478 (1.0) (5)	27/478 (5.6) (30)	3/478 (0.6) (3)
Screw-retained	37/89 (41.6) (66)	0/89 (0) (0)	4/89 (4.5) (4)	36/89 (40.4) (67)	2/89 (2.2) (2)	8/89 (9.0) (8)	1/89 (1.1) (1)
<i>Jaw</i>							
Maxilla	46/477 (9.6) (79)	2/477 (0.4) (2)	29/477 (6.1) (33)	41/477 (8.6) (76)	6/477 (1.3) (6)	32/477 (6.7) (35)	4/477 (0.8) (4)
Mandible	8/90 (8.9) (10)	0/90 (0) (0)	5/90 (5.6) (6)	8/90 (8.9) (10)	1/90 (1.1) (1)	3/90 (3.3) (3)	0/90 (0) (0)
<i>Region</i>							
Anterior	37/418 (8.9) (61)	2/418 (0.5) (2)	26/418 (6.2) (30)	34/418 (8.1) (59)	4/418 (1.0) (4)	26/418 (6.2) (29)	4/418 (1.0) (4)
Posterior	17/149 (11.4) (28)	0/149 (0) (0)	8/149 (5.4) (9)	15/149 (10.1) (27)	3/149 (2.0) (3)	9/149 (6.0) (9)	0/149 (0) (0)
<i>Sex</i>							
Male	33/295 (11.2) (51)	2/295 (0.7) (2)	18/295 (6.1) (22)	30/295 (10.2) (48)	0/295 (0) (0)	14/295 (4.7) (15)	3/295 (1.0) (3)
Female	21/272 (7.7) (38)	0/272 (0) (0)	16/272 (5.9) (17)	19/272 (7.0) (38)	7/272 (2.6) (7)	21/272 (7.7) (23)	1/272 (0.4) (1)

^a at least one occurrence – the same prosthesis may have had more than one event throughout the follow-up

^b n – total number of events

Table 6. Comparison between failed and non-failed single-crown prostheses according to different factors, and a generalized estimating equation (GEE) univariate binary logistic regression model for crown failure.

Factor	Failed prosthesis (%)	Non-failed prosthesis (%)	Odds ratio (95% CI)	<i>p</i> value
<i>Sex</i>				
Men	28 (9.5)	267 (90.5)	1	
Women	26 (9.6)	246 (90.4)	1.069 (0.578, 1.978)	0.831
<i>Age</i>				
Increase by 1 year	-	-	0.949 (0.914, 0.985)	0.006
<i>Jaw</i>				
Maxilla	51 (10.7)	426 (89.3)	1	
Mandible	3 (3.3)	87 (96.7)	0.238 (0.055, 1.034)	0.055
<i>Region</i>				
Anterior	45 (10.8)	373 (89.2)	1	
Posterior	9 (6.0)	140 (94.0)	0.585 (0.243, 1.409)	0.232
<i>Bruxer^a</i>				
No	39 (9.1)	389 (90.9)	1	
Yes	4 (16.0)	21 (84.0)	1.945 (0.631, 6.003)	0.247
<i>Smoker^a</i>				
No	28 (8.5)	303 (91.5)	1	
Yes ^b	11 (10.0)	99 (90.0)	1.058 (0.454, 2.469)	0.896
<i>Fixation</i>				
Cemented	34 (7.1)	444 (92.9)	1	
Screw-retained	20 (22.5)	69 (77.5)	3.476 (1.804, 6.699)	<0.001
<i>Material</i>				
Metal-ceramic	13 (7.7)	156 (92.3)	1	
Ceramic	38 (9.7)	353 (90.3)	1.263 (0.621, 2.566)	0.519
<i>Use of night guard</i>				
No	47 (9.3)	457 (90.7)	1	
Yes	7 (11.1)	56 (88.9)	1.173 (0.436, 3.154)	0.752

Follow-up time				
Increase by 1 month	-	-	1.006 (1.000, 1.012)	0.052

^a The information about bruxism and smoking habits was not available for every patient. That is why the number of failed and non-failed prostheses do not add up to the total number of prostheses of the study

^b Smokers and former smokers included

Table 7. Generalized estimating equation (GEE) multivariate binary logistic regression model for crown failure.

Factor	Odds ratio (95% CI)	<i>p</i> value
<i>Age</i>		
Increase by 1 year	0.948 (0.906, 0.991)	0.019
<i>Jaw</i>		
Maxilla	1	
Mandible	0.195 (0.045, 0.856)	0.030
<i>Fixation</i>		
Cemented	1	
Screw-retained	3.650 (1.810, 7.362)	<0.001
Follow-up time		
Increase by 1 month	1.003 (0.998, 1.009)	0.197

95% CI, 95% confidence interval

Only the factors that were considered statistically significant ($P < 0.1$) in the univariate model and did not present multicollinearity were included in the multivariate model.

Reason for failure

Technical

Non-technical