Clinical evaluation of implant-supported single crowns: a record-based retrospective study

Adam Larsson
Manuh Justice Agyemang

Supervisor: **Bruno Chrcanovic**

Examensarbete (30 hp)
Tandläkarutbildningen

Malmö universitet
Odontologiska fakulteten
205 06 Malmö

November 2023

Innehållsförteckning

1. Sammanfattning

Syfte
Denna retrospektiva studie syftade till att undersöka riskfaktorer som möjligen är förknippade med misslyckande och tekniska komplikationer av implantatstödda singelkronor och deras stödjande implantat.

Material och metod
Patienter som behandlats vid Odontologiska fakulteten, Malmö Universitet mellan 2009 och 2019 övervägdes för inkludering. Implantat- och protes misslyckande och mekaniska/tekniska komplikationer (keramisk fraktur/chip-off; kronförlust av retention/rörlighet; krona misslyckande/fraktur; lossning/förlust/fraktur av protesskruv; implantat misslyckande/fraktur) var resultaten som analyserades. Varje tillstånd/situation som ledde till avlägsnande/byte av kronor (implantat misslyckande ingår ej) ansågs vara protes misslyckande. Univariat/multivariat Cox-regressionsmodeller användes för att utvärdera sambanden mellan kliniska kovariater och misslyckande.

Resultat
278 patienter (358 kronor) inkluderades. Medelvärde±SD uppföljningstud var 56,5±29,7 månader. Sju implantat (76,5±43,7 månader) och tjugo kronor (21,3±23,5 månader) misslyckades. Kumulativ överlevnadsgrad för kronor: 93,5% (5 år), 92,2% (6–11 år). Vanligaste orsakerna till misslyckande av singelkronor: porslinsstor fraktur (n=6), kronan lös upprepade gånger (n=6), porslin chip-off (n=5). Män och bruxism identifierades i Cox-regressionsmodellen som associerade med singel kronans misslyckande. De vanligaste observerade tekniska komplikationerna var rörligheten hos kronan och chip-off av det keramiska materialet, där det senare observerades även i kronor tillverkade av monolitisk zirkoniumoxid. Fall med minst en teknisk komplikation (utan hänsyn till förlust av skruvhålstätning) var vanligare bland troliga bruxare än hos icke- bruxare (p = 0,002). Keramisk chip-off var vanligare bland bruxare än hos icke-bruxare (p = 0,014).

Slutsats
Bruxism och patientens kön (män) var faktorer associerade med en högre risk för misslyckande av implantatstödda singelkronor.

Nyckelord: Dentala implantat; fast protes; implantatstödd sigelkrona; tekniska komplikationer; överlevnad

2. Abstract

Purpose
The present retrospective study aimed to investigate the risk factors possibly associated with failure and technical complications of implant-supported single crowns and their supporting implants.

Materials and methods
Patients treated at the Faculty of Odontology, Malmö University, Malmö, Sweden (2009–2019) were considered for inclusion. Implant and prosthesis failure, as well as 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 (implant failure not included) was considered prosthesis failure. Univariate/multivariate Cox regression models were used to evaluate the associations between clinical covariates and failure.

Results
278 patients (358 crowns) were included. Mean±SD follow-up was 56.5±29.7 months. Seven implants (76.5±43.7 months) and twenty crowns (21.3±23.5 months) failed. Cumulative survival rate for crowns: 93.5% (5 years), 92.2% (6-11 years). Most common reasons for crown failure: porcelain large fracture (n=6), crown repeatedly loose (n=6), porcelain chipping (n=5). Men and probable bruxism were identified in the Cox regression model as being associated with crown failure. The most common observed technical complications were mobility of the crown and chipping of the ceramic material, with the latter being observed even in crowns manufactured of monolithic zirconia. Cases with at least one technical complication (not considering loss of screw hole sealing) were more common among probable bruxers than in non-bruxers (p=0.002). Cases of ceramic chipping were more common among bruxers than in non-bruxers (p=0.014).

Conclusion
Probable bruxism and patient’s sex (men) were factors associated with a higher risk of failure of implant-supported single crowns.

Keywords: Dental implant; fixed prosthesis; implant-supported single crown; technical complications; survival

3. Introduction

3.1. Dental implants

One of our most important sense organs are teeth which plays an important role in our daily functional activities like chewing, speaking, and smiling as well as many other functions. These organs could be lost due to several reasons during one's lifetime. It can be due to periodontal disease, caries, and dental trauma, which can occur at any age. This, in turn, can lead to a lower quality of life (1). In case of missing teeth, dental implants can be used (2).

By far, one of the major advances recently in dentistry is the introduction of titanium dental implants in dentistry. The establishment of dental implants evolved from experimental research to a successful and predictable treatment for the replacement of lost teeth. P.I. Brånemark from the University of Gothenburg and A. Schroeder from the University of Bern, working independently of each other, were the two pioneers of implant dentistry who established the scientific basis for modern dental implants. The Brånemark experiment took place in 1965 when he operated his first patient using machined surfaced commercially pure titanium dental implants (3).

According to the American Dental Association, an estimated number of more than 5 million dental implants treatments take place in the United States (4) On the average, each year around 30, 000 people receive dental implants in Sweden, with 82,108 implants placed in the country during the year of 2022 (5).

2022	Riket	Region	420-Implantat, per styck, tilläggsåtgärd	6 570	6 517
2022	Riket	Privat	420-Implantat, per styck, tilläggsåtgärd	32 896	36 125

The range of indications for titanium dental implants have since widened after it was first introduced primarily in edentulous jaws (3). The first well-established protocol for the oral rehabilitation with the modern dental implants advocated the placement of multiple implants in the totally edentulous jaws to support full-arch fixed dental prostheses (6). The use of the modern implants developed until reaching the stage of being used for the replacement of the loss of single teeth.

3.2. Types of rehabilitations with dental implants

Oral rehabilitation approaches with dental implants nowadays include; implant-supported overdenture, implant-supported full-arch fixed denture, implant-supported fixed partial denture and implant-supported single crown (2).

An implant-supported overdenture (ISO) is defined as any removable dental prosthesis that covers and rests on one or more dental implants (7). ISOs improve the stability of the prosthesis in the oral environment, due to the additional support provided by the implant(s), which leads to great acceptance by the patients in comparison with conventional full denture. (8). ISO may be classified in two different ways depending on their support. If the prosthesis is supported by tissue and retained on the implant, this is called implant-retained and mucous-supported overdentures. The prosthesis can also be supported and retained depending only on the implants. On this occasion, this is called an implant-retained and supported overdenture. ISO can be a good treatment option when edentulous patients are dissatisfied with their conventional full denture. This is because ISO provides better retention, support, and stability.

Other treatment indications for ISO may be patients who cannot afford a full-arch fixed prosthesis. Additional indications are if one has anatomical limitations for multiple implants or if there is a lot of lip support missing. It is also easier to take care of hygiene with ISO, as these are removable prostheses. There are various suitable ISO attachments to choose from. What governs the choice of attachment depends on various factors. These factors may include durability, patient demand, cost effectiveness, technical simplicity, and retention (9). In cases where the anatomy of the patient's fully edentulous jaw is favorable for placement of several implants as well as the patients demand for something fixed rather than a removable overdenture, an implant-supported full-arch fixed denture is considered one of the best treatment options.

Implant-supported full-arch fixed denture is seen as a successful treatment method to prosthetically rehabilitate a fully edentulous jaw. However, fixed implant-supported prostheses require several implants. It is recommended to use at least four implants in the interforaminal area of the lower jaw, although some studies have investigated the clinical outcomes of this type of prosthesis supported by only three implants and at least six implants in the upper jaw. Studies with less than six implants in the upper jaw have also been performed. It is also possible to restore a completely toothless arch with only 4 dental implants. The concept is called the All-on-4 protocol and is usually screw-retained. This treatment option would be recommended to be used only when placement of a sufficient number of implants is not possible. This is because there are several complications with the All-on-4 protocol. Another treatment option is called the Toronto Bridge or abutment hybrid prosthesis. This treatment alternative combines both merits of the screw- and cement-retained fixed prostheses. The advantage of this treatment option is to correct implant angulations whereas the passive form and esthetics are maintained (10).

In the case of partial edentulism, an implant-supported fixed partial denture could be a suitable restoration for the replacement of several adjacent missing teeth by attaching artificial teeth with dental implants. Dental implants act as abutments to support the prosthesis. When the fixed partial prosthesis is composed of less implant abutments than prosthetic units, it consists of three main components that are locked together. These are the pontic, the retainer, and the connector. The hanging tooth, also known as a pontic, has the function of replacing the missing tooth in sites where a dental implant was not placed, to restore the function. The retainer joins the abutment, which is the implant fixture, to the suspended part of the bridge. What unites the retainer(s) and pontic(s) is the final component which is a connector (11). An implant-supported partial fixed denture is not always a 3-unit implant-supported bridge over 2 implants. It can also be, for example, 3 implants supporting 3 splinted prosthetic crowns (12). A single missing tooth however can be replaced by an implant-supported single crown.

Schmitt and Zarb (13) were probably the first ones who reported the clinical outcomes of a series of implants used for the prosthetic replacement of single teeth. Implant-supported single crowns have become a routine approach for the replacement of missing single teeth, being considered as one of the most common ways of rehabilitation when adjacent teeth are healthy, and/or when the patient refuses the dental hard tissue reduction by preparation with drill bits to fit a three-unit fixed partial denture supported by natural tooth abutments (14, 15). Implant-supported single crowns have many other advantages over short-span tooth-supported fixed partial dentures besides the fact that teeth are not prepared. Adjacent teeth would have a better prognosis with a decreased risk of abutment tooth loss, as they are not subject to a higher incidence of endodontic therapy and decay resulting from tooth preparation. The patient would also have improved ability to clean the proximal surfaces of the adjacent teeth (15, 16). The outcome with the implant single crown is usually regarded as economically superior compared to the tooth-supported prosthesis (17), as well as maintenance of bone in the edentulous site, and psychological advantage (18).

An implant-supported single crown may consist of three components: the dental crown, the titanium base (the prosthetic connection), and the implant itself. The artificial tooth root in this case is the implant, whose function is to replace the part below the gum line, namely, the tooth root. The space is closed by the dental crown. On this occasion, the function is restored through the crown. Another important main component is the titanium base that unites the crown with the dental implant.

Commonly for today's dental implants, two variations often occur. The fixture or the transmucosal part can protrude above the crestal bone and is often referred to as tissue level whilst the other variation also known as bone-level describes a fully inserted implant fixture into the bone (3). ~~A separate abutment is connected for the two-piece implants (bone level). This can either be suited directly into the implant-supported crown or as a separate abutment~~

Several different types of materials can be used for the crowns, such as the porcelain fused to metal crown (PFM) and the nonmetal crown. PFM crowns consist of two parts, namely, the metal coping and the porcelain, joined together. The advantage of PFM crowns is that it combines strength and aesthetics. The strength depends on a strong metal coping, while the aesthetics depend on the porcelain veneers. This gives the crown a natural appearance, with a "[…] good wearability, and good resistance to fracture and corrosion"((19), p33). To reduce the risk with failures due to brittleness in porcelain, it is extra important to have a homogeneously thick layer of porcelain. The non-metal full crown consists of composite resin crowns or all ceramic crowns. The most frequently used nowadays is the all-ceramic crown. The composite resin crowns have low cost, good aesthetics and are easy to fabricate, but are now only used for temporary restorations due to their serious durability problems. There are several ceramic materials available with different properties. Nowadays, the strongest and most popular all ceramic crowns are fabricated from alumina or zirconia (19), and are fixed on the implant fixture or abutment in two different ways.

3.3. Fixation methods for implant-supported single crowns

The single implant restoration can either be cemented or screw-retained (3). A cemented implant-supported single crown is defined as a restoration that is cemented intraorally directly onto a standard or customized abutment whereas, a screw-retained implant-supported single crown is defined in terms of a restoration that is cast-on prefabricated metal abutment (20). ~~or cemented extraorally onto standard titanium base and screwed directly into the implant.~~

There are several factors that influence the choice of screw-retention or cementation with implant restorations, some of which include: retrievability, hygiene, esthetics, accessibility and so on. The choice of fixation method is often based on the clinician's preference. However, the major advantage of screw-retention over cementation of implant reconstructions is its retrievability (21). It is easier to retrieve (i.e., remove implant crown or re-tighten screw, when necessary, without causing any serious damage to the reconstruction) screw-retained reconstructions than cemented ones (21, 22). This makes it easier to repair and retreat biological and technical complications affecting screw-retained reconstructions than those affecting cemented ones. The retrievability and seemingly high biocompatibility makes it more preferable to choose screw-retained implant restorations over cemented ones (22). On the other hand, difficulty in accessing the screw-hole can occur. For instance, it can be challenging when placing screw-retained reconstructions in posterior regions and/or in patients with limited mouth opening, as there is limited space for insertion of the screwdriver. Also, esthetics, occlusion and the strength of porcelain may be compromised as the screw hole in screw-retained restorations passes through the central fossa of the prosthetic crown and may be visible, in anterior regions especially in crowns with wider screw diameter. This is however the major advantage of cemented reconstructions as they have anatomically correct form with no visible occlusal hole passing through the crown. The mucosa surrounding screw-retained restorations is said to be healthier than in cemented restorations. Though, there is a higher risk for soft tissue damage, inflammation, and bone loss, if excess cement is left behind subgingivally after cementation, this problem is nonetheless significantly minimized by thorough removal of excess cement (21). These two methods influence the survival or success of implant treatment as well as the possible complications that may lead to implant treatment failure.

3.4. Possible complications

At single crowns, a systematic review (22) assessing the survival rates and the rate at which complications occur with screw-retained and cemented implant reconstructions within a period of five years concluded that neither of the two fixation methods seems to have any clear-cut advantage over the other even though they both influence the clinical outcomes differently. As such, both types of fixation methods can be recommended. There was however a report on a serious biological complication with cemented reconstructions with a minimum implant bone loss of about 2 mm, whereas technical complications affected screw-retained reconstructions. A systematic review comparing the survival and complication rates of tooth-supported FDPs and implant-supported FDPs and single crowns shows almost the same survival rate of approximately 95% for both implant-supported and tooth supported reconstructions after 5 years but with an estimated reduction in survival rate to about 80 - 89% after 10 years (23). Nevertheless, implant-supported single crowns as well as other forms of reconstructions are however not free from complications despite their high survival rates (22, 24, 25). Clinically, the successful outcome of treatment with dental reconstructions is not only dependent on their survival rates but also on the occurrence of biological and technical complications during functional activities (22). The estimated rate of complication is twice as great for implant-supported reconstructions compared to tooth-supported reconstructions after 5 years in use. Examples of biological complications include implant failure due to periimplantitis and for technical complications, ceramic chipping, loose screws, fracture of abutment or implant or crown and so on (23).

The most severe mechanical complication associated with dental implants is the fracture of the osseointegrated dental implant. The results from a retrospective clinical study (26) on the possible etiological factors for implant body fracture yielded 2,3 % incidence in dental implant fracture in the investigated studies, with bruxism, time of complication setting and improper treatment planning being the major causes of this complication. The complications were mostly observed in single crown reconstructions, in combination with parafunctional activities like bruxism and unprotected implant occlusion. Occlusal overload resulting from parafunctional activities such as bruxism and/or incorrect occlusion can, as a single factor or in combination with other factors, cause implant fracture during the first year of functional activity (26).

One of the most common prosthetic complications is the loss of the material that covers the prosthetic screw-hole. Practically, the screw-hole is covered close to the abutment/implant screw with some form of impression material or a plumbing tape and then sealed with unbound composite. This makes it easier to access the screw later should any complication occur. Almost one-tenth (i.e., 12%) of all screw-hole seals come off within a period of 5 years. The major cause of this problem is insufficient retention between the composite and the screw-hole. The attachment surface is the major factor in this regard. This insufficient retention may be due to a lack of vertical space for the prosthesis, or the implant not placed deep enough. Another cause of this problem is when the screw-hole is contaminated with saliva (27).

Loosening of the fixing screw is also another complication with single implant crowns (28). This in turn, causes mobility in the crown. Today, the frequency of this complication is reported to be between 0.6 - 2.3% after 5 years, with single crowns having a higher frequency than an implant-supported fixed partial denture (27). One of the many mechanisms said to be responsible for this complication is the settling effect, that plays a major role in stabilizing the screw due to the existence of a non-smooth surface. Microscopic examination shows a certain degree of roughness on the implant surface. A similar rough surface is observed on the base of the restoration causing the two opposing surfaces to not fully make contact. According to Kourtis et al,

> "When the screw surface is subjected to external loading, micro-motion and friction occur between the surfaces, bringing them closer. About 2% to 10% of the initial loading is lost because of settling. Thus, the torque required to loosen the screw is lower than the force needed for the initial tightening. The settling degree depends on the roughness and hardness of the surfaces that come in contact, as well as the magnitude of the loading force. Rough surfaces and increased external loads aggravate the settling effect. When the total settling effect is higher than the elastic elongation of the screw, the screw loosens, as there are no longer contacts to keep it in position"((28), p242).

Other factors include wear of the screw due to parafunctional activities, the degree of rotational freedom between the implant and the prosthetic abutment and many others (27, 28).

Ceramic fracture (also known as chipping) and fracture of the crown or bridge are also other forms of complications with implant treatment. Chipping is reported to be more common with implant-supported restorations than with teeth-supported ones. Early studies suggest greater differences in chipping between metal-ceramic and full ceramic (zirconia) crowns with chipping more common with full ceramic restorations, but current overview reports a frequency comparable between these two restorations, 2.9 for metal ceramic and 2.8 percent for full ceramic crowns, over 5 years (27). The risk of ceramic chipping increases with increased flaws in the design of the restoration. The thickness of the surface porcelain should not exceed 2 mm and the core of the design should be anatomically correct in order to be able to support the surface porcelain. Usage of surface porcelain (ex. traditional mc-porcelain) not suitable for zirconia and the weaker thermal conductivity in ceramics compared to metals leads to disharmony in coefficient of thermal expansion between the surfaces which causes adverse tensions in the materials. This is seen as the main reason for ceramic chipping. Total fracture of the crown is a relatively uncommon complication but one of the most severe implants prosthetic complications. According to Pjetursson et al (25), the frequency of this complication for metal ceramic reconstruction is 0.2% and for full ceramic crowns ranges from 0.4 to 2.1% over a period of 5 years. Under dimensioned or improperly reconstructed core as well as poor material selection and handling are some of the factors leading to this complication.

The survival rates of implant-supported single crowns recently reported in the literature usually are high, with a rate variation depending mostly on the extension of the follow-up and on the definition for what failure would stand for in a particular study. According to a recent retrospective study that investigated more than 500 crowns with a mean follow-up of 15 years, the failure rate can vary between 4.1% and 9.5%, depending on whether non-technical complications that lead to crown replacement such as esthetic issue, change to another type of prosthesis, crown in infraposition, or raise of the patient’s bite, are considered or not (24). Other studies with smaller cohort groups and shorter follow-up periods reported higher survival rates, such as 97.5% after a mean of 61 months of follow-up of 40 implant-supported crowns (29), and 100% after a mean of 80.9 months of follow-up of 31 crowns (30). A study with similar cohort group size, with 482 implant-supported single crowns, reported a complication rate of 3.1%, but with a relatively short mean follow-up of 5 years (31).

3.5. Objective

The aim of the present retrospective clinical study was to investigate the risk factors that could be associated with the occurrence of implant failure and technical complications of implant-supported single crowns.

3.6. Hypothesis

The null hypothesis was that there would be no factor associated with the occurrence of failures of implant-supported single crowns, against the alternative hypothesis of some factor having an influence on crown failure.
The questions however raised are; which of the commonly investigated factors in this study pose higher risk for implant treatment failure and what is the most observed technical complication after treatment with implants?

4. Materials and methods

4.1. Patients

This retrospective study included patients treated with implant-supported single crowns from March 2009 to December 2019 at the Faculty of Odontology, Malmö University, Malmö, Sweden. This study was based on data collection from patients' dental records. The study was approved by the regional Ethical Committee, Lund, Sweden (Dnr 2018/856).
The cases were initially screened in the software (T4 Practice Management Software, Carestream Dental LLC, Atlanta, USA), by looking for cases with the help of the codes given for the treatment in focus.

4.2. Definitions

Implant failure: An implant was considered a failure if presenting signs and symptoms that led to implant removal, i.e., a lost implant. Implant failure could be either early (the inadequacy of the host to establish or promote osseointegration in the early stages of healing) or late (the failure of either the established osseointegration or function of dental implants) (32). Implant fracture was also considered as a failure.

Prosthesis failure: 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 complications.

Technical complications were defined according to a previous study (24), and 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 (decementation); mobility of the crown.
- Complications regarding the implant: loss or fracture of connecting/abutment screws; loosening, excessive wear, deformation, or fracture of prosthetic abutment; pain.

Two situations characterized the crown as being mobile: (a) a screw-retained crown that had a loose screw, and (b) a cemented cementable 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.

Non-technical complications (leading to replacement of the crown, or change to another prosthesis type, e.g., fixed partial prosthesis) consisted of any kind of issue other than the ones defined earlier as technical complications. Such issues comprised of the use of the implant for another type of prosthesis together with other implants (usually either overdentures or fixed partial prostheses), crown in infra-position in comparison to adjacent teeth, esthetic issue, and raise of the patient's bite (24).

Bruxism: The criteria for the diagnosis of 'probable' bruxism, used in a previous study (33), was adopted for the present study. Probable bruxism was based on self-report, by means of questionnaires and/or the anamnestic part of a clinical examination, together with the inspection part of a clinical examination (34). The clinical signs of bruxism could include one or a combination of the following: masticatory muscle hypertrophy, indentations on the tongue or lip, *Linea alba* on the inner cheek, mechanical wear of teeth, damage to the dental hard tissues (such as cracked teeth), and repetitive failures of restorative work and/or prosthodontic constructions (35). Only patients with both self-report and clinical signs were considered probable bruxers.

Smoker: patients smoking a minimum of one cigarette per day (an everyday smoker) (36) were classified as smokers.

4.3. Inclusion and exclusion criteria.

All patients rehabilitated with one or more implant-supported single crowns during the aforementioned period were included. The patients needed to have at least 6 months of follow-up. Only modern threaded cylindrical- or conical-design implants were considered for inclusion. Since it was observed, in a pre-analysis of the data, that some cases failed within the first month after prosthesis installation, it was decided that any case would be included based on the previous inclusion criteria, provided that some follow-up was recorded. Therefore, the cases not followed up at all, namely, patients that received the prosthetic restoration and never came back for an appointment, were excluded.

4.4. Sample size calculation.

The calculation was based on the results of Chrcanovic et al. (24), which observed a prevalence of single crown failure of 9.5% over a mean follow-up period of over 15 years. As the mean follow-up for the present study was expected to be shorter, as patients treated between 2009 and 2019 were screened for inclusion, then it was anticipated a half prevalence of prosthetic failure than observed in the aforementioned study, namely 4.75%. Therefore, there was a need of 252 cases in total, having set alpha (α) at 0.05 and power at 80%. The calculation was performed with ClinCalc.com.

4.5. Data collection

The data were directly entered into a SPSS file (SPSS software, version 28, SPSS Inc., Chicago, IL, USA) as the dental records of the patients were being read. The data collected consisted of the following: patient's sex, patient's age at the definitive crown delivery, smoking habits, probable bruxism or not, presence of a systemic health issue, region of the crown according to the FDI numbering system, location of the implant in relation to jaw (maxilla or mandible), position of the tooth within the jaw (incisor, canine, premolar and molar regions), prosthetic crown material, crown fixation method (cemented or screw-retained), and many others. The overall factors considered and entered into the SPSS file is shown in table 1.

4.6. Statistical analyses

The mean, standard deviation (SD), and percentages were presented as descriptive statistics. Kolmogorov–Smirnov test was performed to evaluate the normal distribution of the variables, and Levene's test evaluated homoscedasticity. The performed tests for two independent groups were Student's t-test or Mann-Whitney test, and for three independent groups were one-way ANOVA or Kruskal-Wallis' test, depending on the normality. Pearson's chi-squared test or Fisher's exact test was used in the analysis of contingency tables of categorical data of independent groups.

Univariate and multivariate Cox regression were used to evaluate the associations between clinical covariates and the outcomes. Hazard ratio (HR) and 95% confidence intervals (95% CI) were estimated from Cox proportional hazard models. To verify multicollinearity, a correlation matrix of all the predictor variables with a significant odds ratio (*p* value cut-off point of 0.1) identified in the univariate models was scanned, to see whether there were some high correlations among the predictors. Collinearity statistics obtaining variance inflation factor (VIF) and tolerance statistics were also performed to detect more subtle forms of multicollinearity. For final multivariable Cox regression models, all variables that were moderately associated ($p < 0.10$) with the outcomes were included. For this prosthesis-level analysis, clustering of multiple single crowns within each patient was accounted for in the Cox models using the methods outlined by Lee et al and Lin (37, 38).

The degree of statistical significance was considered $p < 0.05$. Data were statistically analyzed using the Statistical Package for the Social Sciences (SPSS) version 28 software (SPSS Inc., Chicago, IL, USA). Cox models were performed using the Stata software version 15 (StataCorp LLC, College Station, TX, USA).

5. Results

From March 2009 to December 2019 a total of 1,193 implant-supported single crowns were installed at the Faculty of Odontology, according to the registry in the software. Many cases were excluded for not really being implant-supported single crowns, namely, the prosthetic restoration was a different one, but the code given for the treatment was mistakenly entered in the software as an implant-supported single crown. This was mostly true for implant-supported partial fixed prostheses when, for example, a 2-unit prosthesis was given the code twice for an implant-supported single crown. At the end 360 cases were considered for inclusion, of which 2 cases were excluded for not having any follow-up after a prosthetic single crown was installed. Therefore, 358 implant-supported single crowns in 278 patients fulfilled the inclusion criteria.

The mean age (± SD) of the 278 patients was 54.3 ± 12.6 years (min-max, 25.3-91.7) at the day of the crown installation. The patients were followed up for a mean (± SD) of 56.5 ± 29.7 months (min-max, 0.2-146.2) after prosthesis installation.

The mean (± SD) time between implant placement and prosthesis installation was 6.8 ± 2.8 months (min-max, 1.8-38.8). Most of the implants of the study were from Straumann (n = 177), followed by Astra (n = 121), Nobel Biocare (n = 42), Biomet (n = 15), and Southern, Camlog, and Ankylos (1 each). Seven implants failed, 2 Straumann and 5 Astra implants, after a mean (± SD) of 76.5 ± 43.7 months (min-max, 24.5-134.4). One of these failures was due to implant fracture (Astra Osseospeed, diameter 4.00, length 11.0, tooth region 46).

A number of 167 crowns (out of 358; 46.6%) were followed up for at least 5 years, and only 6 (1.7%) were followed up for at least 10 years. Four patients had 4 single crowns, 7 patients had 3 single crowns, 54 patients had 2 singles crowns, and the rest 213 patients had only one implant-supported single crown. Table 1 shows the descriptive data of the single crowns included in the study.

Table 2 presents the results for the life-table survival analysis. The cumulative survival rates (CSRs) were 93.5% and 92.2% for all single crowns after 5 and 6-11 years, respectively. Twenty crowns failed, after a mean follow-up (± SD) of 21.3 ± 23.5 months (min-max, 0.3-82.1). The reasons for failure were porcelain chipping in 5 cases, where they were remade into brands new single crowns, porcelain large fracture in 6 cases, crown repeatedly presenting episodes of looseness in 6 cases, crown in infraposition in 1 case (non-technical complication), prosthesis misfit in 1 case, and crown overextended in 1 case.

Tables 3 and 4 present the results for the univariate and respective multivariate Cox proportional hazard models. Multicollinearity was not detected. The hazard ratio (HR) was statistically significant for two factors in the univariate models (men and probable bruxism), both remained statistically significant in the multivariate model. The difference of the distribution of bruxers between crowns placed in men (37/145) and in women (64/213) was not statistically significant ($p = 0.350$, Pearson's chi-squared test).

The occurrence and frequency of technical complications are described in Table 5. The most common observed complications were mobility of the crown and chipping of the ceramic material. Occurrence of ceramic chipping was more prevalent among probable bruxers (20/101) than in non-bruxers (22/257). The difference between groups was statistically significant ($p = 0.014$, Kaplan Meier analysis, log rank test). Cases with at least one technical complication (not considering loss of screw hole sealing) were more common among probable bruxers (36/101) than in non-bruxers (52/257; *p* = 0.002; Pearson's chi-squared test).

Table 1. Descriptive data of the implant-supported single crowns included in the study, with follow-up time between the different factors. The statistical unit is the single crown, not the patient.

Factor	Number of Crowns (%)	Failure (n)	Follow-up (months) Mean ± SD (min - max)
Sex			
Men	145 (40.5)	12	56.1 ± 31.5 (0.2-146.2)
Women	213 (59.5)	8	56.7 ± 28.5 (0.7-139.0
Age			
< 60 years	240 (67.0)	15	53.5 ± 29.9 (0.7-139.0)
≥ 60 years	118 (33.0)	5	62.6 ± 28.3(0.2-146.2)
Jaw			
Maxilla	166 (46.4)	9	52.0 ± 31.0 (0.2-146.2)
Mandible	192 (53.6)	11	60.4 ± 28.0 (1.4-139.0)
Prosthesis region			
Anterior	35 (9.8)	0	50.4 ± 35.5 (4.4-137.2)
Posterior	323 (90.2)	20	57.2 ± 29.0 (0.2-146.2)
Tooth type			
Incisor	27 (7.5)	0	50.0 ± 36.7 (4.4-137.2)
Canine	8 (2.2)	0	51.8 ± 33.5 (13.1-119.2)
Premolar	123 (34.4)	9	54.9 ± 33.3 (0.2-146.2)
Molar	200 (55.9)	11	58.6 ± 26.0 (1.4-137.5)
Crown fixation			
Cemented	23 (6.4)	0	65.6 ± 40.7 (1.8-137.2)
Screwed	335 (93.6)	20	55.9 ± 28.8 (0.2-146.2)
Crown material			
Metal ceramic (CoCr)	111 (31.0)	7	52.6 ± 28.6 (0.2-137.5)
Metal ceramic (Titanium)	165 (46.1)	12	63.3 ± 29.0 (0.7-146.2)
Metal ceramic (Gold)	12 (3.3)	0	51.1 ± 37.3 (7.8-137.2)
Full ceramic	70 (19.6)	1	47.6 ± 28.6 (1.4-124.7)
Porcelain veneer	2 (2.9)	0	36.7 ± 4.7 (33.4-40.0)
Porcelain monolithic	2 (2.9)	0	42.5 ± 24.3 (25.4-59.7)
Zirconia veneer	22 (31.4)	1	43.7 ± 30.1 (4.4-119.2)
Zirconia monolithic	39 (55.7)	0	50.1 ± 30.1 (1.4-124.7)
Unknown	5 (7.1)	0	51.4 ± 19.5 (22.7-73.8)
Crown occluding to			
Natural teeth	104 (29.0)	7	49.8 ± 33.1 (1.4-137.5)
Teeth with filling	143 (39.9)	6	56.1 ± 26.5 (0.2-139.0)
Tooth-supported (metal-)ceramic prosthesis	78 (21.8)	6	62.0 ± 31.0 (1.4-146.2)

Implant-supported (metal-)ceramic prosthesis	25 (7.0)	1	67.2 ± 23.5 (35.8-110.0)
Metal-acrylic prosthesis	1 (0.3)	0	43.7
Nothing	7 (2.0)	0	66.0 ± 25.8 (28.5-97.5)
Treatment provider			
Dental student	236 (65.9)	15	60.2 ± 29.7 (1.8-146.2)
Dentist	122 (34.1)	5	49.4 ± 28.5 (0.2-137.2)
Probable bruxism			
No	257 (71.8)	9	54.7 ± 29.8 (0.2-146.2)
Yes	101 (28.2)	11	61.2 ± 29.0 (1.8-139.0)
Smoking			
No	282 (78.8)	19	57.8 ± 30.0 (0.2-146.2)
Yes	76 (21.2)	1	51.6 ± 28.2 (2.5-118.9)

[a] Comparison of the mean follow-up time between the groups of each variable (Mann-Whitney test for 2 groups, Kruskal-Wallis test for 3 or more groups)

Table 2. Life-table survival analysis showing the cumulative survival rate of implant-supported single crowns.

Interval start time (years)	Number entering interval	Number withdrawing during interval	Number exposed to risk	Prosthesis failure	Survival rate within each interval – ISR (%)	Cumulative proportion surviving at end of interval – CSR (%)	Standard error (%)
0	358	31	342.5	9	97.4	97.4	0.9
1	318	26	305.0	5	98.4	95.8	1.1
2	287	23	275.5	0	100.0	95.8	1.1
3	264	58	235.0	3	98.7	94.6	1.3
4	203	48	179.0	2	98.9	93.5	1.5
5	153	57	124.5	0	100.0	93.5	1.5
6	96	43	74.5	1	98.7	92.2	1.9
7	52	26	39.0	0	100.0	92.2	1.9
8	26	14	19.0	0	100.0	92.2	1.9
9	12	8	8.0	0	100.0	92.2	1.9
10	4	1	3.5	0	100.0	92.2	1.9
11	3	3	1.5	0	100.0	92.2	1.9

Table 3. Univariate Cox proportional hazard models for implant-supported single crown failure.

Factor	Hazard ratio (95% CI)	*p* value
Sex		
Men	1	
Women	0.425 (0.174, 1.040)	0.061
Age		
< 60 years	1	
≥ 60 years	0.615 (0.223, 1.697)	0.348
Jaw		
Maxilla	1	
Mandible	0.948 (0.392, 2.289)	0.905
Prosthesis region		
Anterior	1	
Posterior	23.326 (0.030, 18201)	0.354
Tooth type		
Incisor	[a]	
Canine	[a]	
Premolar	1	
Molar	0.678 (0.281, 1.639)	0.388
Crown fixation		
Cemented	1	
Screwed	22.587 (0.011, 46390)	0.423
Crown material		
Metal ceramic (CoCr)	1	
Metal ceramic (Titanium)	1.049 (0.412, 2.673)	0.920
Full ceramic	0.234 (0.029, 1.904)	0.175
Metal ceramic (Gold)	[a]	
Crown occluding to		
Natural teeth (restored or not)	1	
Tooth-supported fixed prosthesis	1.387 (0.527, 3.653)	0.508
Implant-supported fixed prosthesis	0.648 (0.085, 4.957)	0.676
Treatment provider		
Dental student	1	
Dentist	0.713 (0.258, 1.967)	0.513
Probable bruxism		
No	1	
Yes	2.962 (1.227, 7.152)	0.016
Smoking		
No	1	
Yes	0.196 (0.026, 1.462)	0.112

[a] No events of crown failure

95% CI - 95% confidence interval

Table 4. Multivariate Cox proportional hazard model for implant-supported single crown failure.

Factor	Hazard ratio (95% CI)	*p* value
Sex		
Men	1	
Women	0.384 (0.156, 0.943)	0.037
Probable bruxism		
No	1	
Yes	3.226 (1.332, 7.814)	0.009

95% CI - 95% confidence interval

Table 5. Occurrence of technical complications.

Technical complication	Number of events (number of crowns)
Mobility of the crown	74 (49) 1x: 34 crowns, 2x: 9 crowns, 3x: 4 crowns, 5x: 2 crowns
Ceramic chipping	46 (42 [a]) 2x: 4 crowns
Loss of screw hole sealing	41 (36) 2x: 5 crowns
Large fracture of ceramic material	10 (10 [b])
Prosthetic abutment fracture	2 (2)
Crown decementation	1 (1)
Central screw fracture	0 (0)

[a] Crown material of the 42 cases (number of cases/total number of crowns): metal ceramic titanium (24/165), metal ceramic CoCr (13/111), zirconia monolithic (4/39), full ceramic of unknown specific material (1/5)

[b] Crown material of the 10 cases (number of cases/total number of crowns): metal ceramic titanium (5/165), metal ceramic CoCr (3/111), zirconia veneer (1/22), full ceramic of unknown specific material (1/5)

6. Discussion

6.1. Main findings

The present retrospective clinical study aimed to investigate the risk factors that could be associated with the occurrence of failure and technical complications of implant-supported single crowns. According to the Cox proportional hazard models, probable bruxism and men were associated with prosthesis failure.

Bruxism has been shown to significantly affect not only implant failure (39), implant fracture (40), and marginal bone loss negatively (41), but also an increase prevalence of prosthesis failure and technical complications in implant-supported restorations in comparison to patients not presenting bruxism (33, 42). When it comes to diagnosing bruxism, we have relied on self-reports of daily/nightly grinding, as well as clinical signs such as linea alba, muscle hypertrophy, tongue impressions, tooth wear, and tooth fractures. Therefore, the diagnosis of bruxism in our study is of probable bruxism, as it required both clinical signs and self-reporting of the issue in the medical history, according to an international consensus on the subject (35). The condition is suggested to generate overload of prosthetic rehabilitations on implants (43), as well as to be a risk factor for fractures of ceramics (44) and, in general, for the frequent need of technical interventions on implant-supported restorations (33, 45-47).

Even though the difference of the distribution of bruxers between crowns placed in men and in women was not statistically significant, the higher risk of crown failure in men could be related to men having a higher maximal bite force than women (48), which is associated with greater muscle mass and size usually being observed in men (49). Even if not all men were diagnosed as probable bruxers, higher bite force among male patients may predispose them not only to a higher risk of technical complications (50, 51), but also to a higher implant failure rate (52).

The CSR of 92.2% for all single crowns between 6-11 years, is in line with the results from other studies reporting 10-year CSR, such as 91.7% (31), 95.2% (53), and 95.9% (54). Small variations in the CSR may vary due to the distinct definitions for what failure would stand for, and/or for what kind of technical complications would be included as criteria for crown failure in different studies.

The most prevalent technical complication was mobility of the crown. The precise reason for the cases in the present study was unclear, but screw loosening is the most common problem, which is a greater risk to occur in single implant-supported crowns with external connection (55). Reasons for screw loosening can be many and include inadequate pre-load, the anti-rotational characteristics of the implant-to-abutment interface, lack of precise fit of the mating components (56), tension on abutment resulted from this ill-fitting (57), less than ideal implant position, and inappropriate occlusal scheme or crown anatomy (58). It is recommended to tighten the screw for the second time during the subsequent clinical appointment after the prosthesis is first screwed in place, to reduce the risk of screw loosening (59). This could be one of the possible reasons, but it was not possible to verify if this recommendation was followed by all dentists involved in the rehabilitations, unfortunately. The great advantage of screw-retained single crowns, which comprised the great majority of the cases in this study, is its possibility of easy screw re-tightening, retrievability, and repair (28).

Chipping of ceramic material was the second most prevalent technical complication. This can be associated with the nearly 94% of the cases in the present study being screw-retained crowns. The presence of unsupported ceramic around the prosthetic screw access hole in such crowns may decrease the fracture resistance (28, 60). An interesting finding was the occurrence of chipping among monolithic zirconia crowns. Veneered zirconia prostheses are more prone to chip-off fractures than monolithic zirconia prostheses, which do not have a veneering ceramic, and are expected to have less chipping and fracture complications (61). Yet, chipping in monolithic zirconia can occur, as observed here as well as in other studies (62-67). One of the possible explanations for this would be the so-called low temperature degradation (LTD). This happens when the metastable tetragonal phase in stabilized monolithic zirconia transforms into a monoclinic phase in a humid environment (68-70), which starts at the surface and propagates into the material. Chewing forces can induce phase transformation around micro-cracks in the surface, leading to chipping of the outer surface (71). Moreover, the results of an in vitro study suggest that variations in the implant-restoration angulation of one-piece screw-retained hybrid monolithic zirconia restorations with 15° may significantly affect their resistance to fractures (72). Unfortunately, it was not possible to verify these factors in the present study, due to the retrospective nature of it. Cases of ceramic chipping were more prevalent among bruxers than in non-bruxers. This can be connected to the already aforementioned possible harmful effects of bruxism to implants and implant-supported restorations.

6.2. Discussion of the methodology

The limitations of the present study include its retrospective nature, which inherently results in flaws, manifested by gaps in information and incomplete records. Moreover, since this was not a prospective study, treatment was not standardized. As several professionals were involved in the treatment of these patients for the longer time of observation of the study, and there must have been some variability of surgical and prosthetic approaches and dental laboratory techniques applied by these different professionals.

Other limiting factors connected to the materials and methods which may have affected the results may include the study being performed for patients treated only by specialists/niched dentists in prosthetics at the Faculty of Odontology, Malmö university. Even the total number of patients included in the current study may not be representative for the total Swedish population. The need to include more patients treated across the country by different dental professionals would have been the best option to achieve a result representing the total Swedish population. It should also be noted that the result only reflects treatments performed at the faculty and not the whole world, as surgical and prosthetic treatment approaches vary from country to country.

6.3. Discussion of the Ethical Aspects

The study was approved by the regional Ethical Committee, Lund, Sweden (Dnr 2018/856). Patients' personal numbers and details was however de-identified. Data collection was solely done during school hours by log in to T4 on the school computers, as well as entering the data into an Excel document where only the authors have access to, preventing patients' information from leaking to the general public.

6.4. Relevance for Dental Care

The current study will help dentist with information about the factors that may affect the outcome of technical complications affecting treatment with single crowns supported by implants. Becoming aware that patients with bruxism have a higher risk for chipping and screw loosening, will help the dental practitioner with thorough planning and other therapies before installing implant-supported single crowns in bruxers. Such therapy may include provision of hard night guard in bruxers after treatment with implant-supported single crowns so as to minimize the higher risk for the already mentioned complications.

6.5. Future Research on the Subject

There is however lack of scientific evidence to support the relationship between gender (i.e., men in this current study) and the outcome of technical complications with implant treatment, which is why it would be of interest in the future to research more as to why men in this case are more affected by the implant treatment complications.

7. Conclusions

Probable bruxism and patient's sex were factors associated with a higher risk of failure of implant-supported single crowns. The most common observed technical complications were mobility of the crown and chipping of the ceramic material.

8. Abbreviations

CI: confidence interval
CSR: cumulative survival rate
HR: hazard ratio
ISR: interval survival rate
LTD: low temperature degradation

SD: standard deviation
VIF: variance inflation factor

9. Publication in peer-review journal

The present study resulted in the following open access publication:

Larsson A, Manuh J, Chrcanovic BR. Risk Factors Associated with Failure and Technical Complications of Implant-Supported Single Crowns: A Retrospective Study. Medicina (Kaunas). 2023 Sep 5;59(9):1603. doi: 10.3390/medicina59091603. PMID: 37763722; PMCID: PMC10535933.

Impact factor (JCR 2022): 2.6

Links to the publication:
https://pubmed.ncbi.nlm.nih.gov/37763722/
https://www.mdpi.com/1648-9144/59/9/1603

10. References

1. Clark D, Levin L. In the dental implant era, why do we still bother saving teeth? Dent Traumatol 2019; 35: 368-75.

2. Gupta R, Gupta N, Weber DK. Dental Implants. StatPearls Publishing; 2022.

3. Gjelvold. B. On the clinical outcome of different single implant treatment modalities. 2020. p. 27-8.

4. Boyce RA. Prosthodontic Principles in Dental Implantology: Adjustments in a Coronavirus Disease-19 Pandemic-Battered Economy. Dent Clin North Am 2021; 65: 135-65.

5. Försäkringskassan. Antal utförda tandvårdsåtgärder [Internet]. 2023 [Available from: https://www.forsakringskassan.se/statistik-och-analys/statistikdatabas#!/tand/tand-atgard

6. Brånemark PI, Hansson BO, Adell R, Breine U, Lindström J, Hallén O, et al. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. Scand J Plast Reconstr Surg Suppl 1977; 16: 1-132.

7. The Glossary of Prosthodontic Terms: Ninth Edition. J Prosthet Dent 2017; 117: e1-e105.

8. Bajunaid SO, Alshahrani AS, Aldosari AA, Almojel AN, Alanazi RS, Alsulaim TM, et al. Patients' Satisfaction and Oral Health-Related Quality of Life of Edentulous Patients Using Conventional Complete Dentures and Implant-Retained Overdentures in Saudi Arabia. Int J Environ Res Public Health 2022; 19.

9. Martínez-Lage-Azorín JF, Segura-Andrés G, Faus-López J, Agustín-Panadero R. Rehabilitation with implant-supported overdentures in total edentulous patients: A review. J Clin Exp Dent 2013; 5: 267-72.

10. Siadat H, Rokn A, Beyabanaki E. Full Arch All-on-4 Fixed Implant-Supported Prostheses with 8.5 Years of Follow-Up: A Case Report. J Dent (Tehran) 2018; 15: 259-65.

11. James ZS, Tomaž K. Advanced Ceramics for Dentistry. First ed: Elsevier; 2014: 37-8.

12. Ravidà A, Tattan M, Askar H, Barootchi S, Tavelli L, Wang HL. Comparison of three different types of implant-supported fixed dental prostheses: A long-term retrospective study of clinical outcomes and cost-effectiveness. Clin Oral Implants Res 2019; 30: 295-305.

13. Schmitt A, Zarb GA. The longitudinal clinical effectiveness of osseointegrated dental implants for single-tooth replacement. Int J Prosthodont 1993; 6: 197-202.

14. Al-Quran FA, Al-Ghalayini RF, Al-Zu'bi BN. Single-tooth replacement: factors affecting different prosthetic treatment modalities. BMC Oral Health 2011; 11: 34.

15. Hebel K, Gajjar R, Hofstede T. Single-tooth replacement: bridge vs. implant-supported restoration. J Can Dent Assoc 2000; 66: 435-8.

16. Misch CE, Misch-Dietsh F, Silc J, Barboza E, Cianciola LJ, Kazor C. Posterior implant single-tooth replacement and status of adjacent teeth during a 10-year period: a retrospective report. J Periodontol 2008; 79: 2378-82.

17. Scheuber S, Hicklin S, Brägger U. Implants versus short-span fixed bridges: survival, complications, patients' benefits. A systematic review on economic aspects. Clin Oral Implants Res 2012; 23 Suppl 6: 50-62.

18. Misch CE. Rationale for dental implants. Dental implant prosthetics 2005: 1-17.

19. James ZS, Tomaž K. Advanced Ceramics for Dentistry. First ed: Elsevier; 2014: 32-4.

20. The Glossary of Prosthodontic Terms 2023: Tenth Edition. J Prosthet Dent 2023; 130: e7-e126.

21. Assaf M, Gharbyeh AZA. Screw-retained crown restorations of single implants: A step-by-step clinical guide. Eur J Dent 2014; 8: 563-70.

22. Sailer I, Mühlemann S, Zwahlen M, Hämmerle CH, Schneider D. Cemented and screw-retained implant reconstructions: a systematic review of the survival and complication rates. Clin Oral Implants Res 2012; 23 Suppl 6: 163-201.

23. Pjetursson BE, Brägger U, Lang NP, Zwahlen M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). Clin Oral Implants Res 2007; 18 Suppl 3: 97-113.

24. Chrcanovic BR, Kisch J, Larsson C. Retrospective clinical evaluation of implant-supported single crowns: Mean follow-up of 15 years. Clin Oral Implants Res 2019; 30: 691-701.

25. Pjetursson BE, Valente NA, Strasding M, Zwahlen M, Liu S, Sailer I. A systematic review of the survival and complication rates of zirconia-ceramic and metal-ceramic single crowns. Clin Oral Implants Res 2018; 29 Suppl 16: 199-214.

26. Stoichkov B, Kirov D. Analysis of the causes of dental implant fracture: A retrospective clinical study. Quintessence Int 2018; 49: 279-86.

27. Schittek Janda M, Mattheos N, Larsson C, Ekenbäck J. Implantat : att förebygga, diagnostisera och hantera komplikationer. Modern odontologi. Andra upplagan. ed: Gothia fortbildning; 2020: 73-159.

28. Kourtis S, Damanaki M, Kaitatzidou S, Kaitatzidou A, Roussou V. Loosening of the fixing screw in single implant crowns: predisposing factors, prevention and treatment options. J Esthet Restor Dent 2017; 29: 233-46.

29. Spies BC, Balmer M, Jung RE, Sailer I, Vach K, Kohal RJ. All-ceramic single crowns supported by zirconia implants: 5-year results of a prospective multicenter study. Clin Oral Implants Res 2019; 30: 466-75.

30. Koller M, Steyer E, Theisen K, Stagnell S, Jakse N, Payer M. Two-piece zirconia versus titanium implants after 80 months: Clinical outcomes from a prospective randomized pilot trial. Clin Oral Implants Res 2020; 31: 388-96.

31. Mangano F, Macchi A, Caprioglio A, Sammons RL, Piattelli A, Mangano C. Survival and complication rates of fixed restorations supported by locking-taper implants: a prospective study with 1 to 10 years of follow-up. J Prosthodont 2014; 23: 434-44.

32. Tonetti MS, Schmid J. Pathogenesis of implant failures. Periodontol 2000 1994; 4: 127-38.

33. Chrcanovic BR, Kisch J, Albrektsson T, Wennerberg A. Bruxism and dental implant treatment complications: a retrospective comparative study of 98 bruxer patients and a matched group. Clin Oral Implants Res 2017; 28: e1-e9.

34. Lobbezoo F, Ahlberg J, Glaros AG, Kato T, Koyano K, Lavigne GJ, et al. Bruxism defined and graded: an international consensus. J Oral Rehabil 2013; 40: 2-4.

35. Lobbezoo F, Ahlberg J, Raphael KG, Wetselaar P, Glaros AG, Kato T, et al. International consensus on the assessment of bruxism: Report of a work in progress. J Oral Rehabil 2018; 45: 837-44.

36. CDC. Centers for Disease Control and Prevention, National Center for Health Statistics. Adult Tobacco Use Information, Glossary 2023[Internet]. [Available from: https://www.cdc.gov/nchs/nhis/tobacco/tobacco_glossary.htm

37. Lee EW, Wei LJ, Amato DA, Leurgans S. Cox-Type Regression Analysis for Large Numbers of Small Groups of Correlated Failure Time Observations. In: Klein JP, Goel PK, editors. Survival Analysis: State of the Art. Dordrecht, Netherland: Springer; 1992: 237-47.

38. Lin DY. Cox regression analysis of multivariate failure time data: the marginal approach. Stat Med 1994; 13: 2233-47.

39. Häggman-Henrikson B, Ali D, Aljamal M, Chrcanovic BR. Bruxism and dental implants: A systematic review and meta-analysis. J Oral Rehabil 2023.

40. Chrcanovic BR, Kisch J, Albrektsson T, Wennerberg A. Factors influencing the fracture of dental implants. Clin Implant Dent Relat Res 2018; 20: 58-67.

41. Bredberg C, Vu C, Häggman-Henrikson B, Chrcanovic BR. Marginal bone loss around dental implants: comparison between matched groups of bruxer and non-bruxer patients: A retrospective case-control study. Clin Implant Dent Relat Res 2023; 25: 124-32.

42. Chrcanovic BR, Kisch J, Larsson C. Analysis of technical complications and risk factors for failure of combined tooth-implant-supported fixed dental prostheses. Clin Implant Dent Relat Res 2020; 22: 523-32.

43. Lobbezoo F, Brouwers JE, Cune MS, Naeije M. Dental implants in patients with bruxing habits. J Oral Rehabil 2006; 33: 152-9.

44. Kinsel RP, Lin D. Retrospective analysis of porcelain failures of metal ceramic crowns and fixed partial dentures supported by 729 implants in 152 patients: patient-specific and implant-specific predictors of ceramic failure. J Prosthet Dent 2009; 101: 388-94.

45. Brägger U, Aeschlimann S, Bürgin W, Hämmerle CH, Lang NP. Biological and technical complications and failures with fixed partial dentures (FPD) on implants and teeth after four to five years of function. Clin Oral Implants Res 2001; 12: 26-34.

46. De Boever AL, Keersmaekers K, Vanmaele G, Kerschbaum T, Theuniers G, De Boever JA. Prosthetic complications in fixed endosseous implant-borne reconstructions after an observations period of at least 40 months. J Oral Rehabil 2006; 33: 833-9.

47. Maló P, Nobre M, Lopes A. The rehabilitation of completely edentulous maxillae with different degrees of resorption with four or more immediately loaded implants: a 5-year retrospective study and a new classification. Eur J Oral Implantol 2011; 4: 227-43.

48. Palinkas M, Nassar MS, Cecílio FA, Siéssere S, Semprini M, Machado-de-Sousa JP, et al. Age and gender influence on maximal bite force and masticatory muscles thickness. Arch Oral Biol 2010; 55: 797-802.

49. Bonakdarchian M, Askari N, Askari M. Effect of face form on maximal molar bite force with natural dentition. Arch Oral Biol 2009; 54: 201-4.

50. Atlas AM, Behrooz E, Barzilay I. Can bite-force measurement play a role in dental treatment planning, clinical trials, and survival outcomes? A literature review and clinical recommendations. Quintessence Int 2022; 53: 632-42.

51. Flanagan D. Bite force and dental implant treatment: a short review. Med Devices (Auckl) 2017; 10: 141-8.

52. Chrcanovic BR, Albrektsson T, Wennerberg A. Dental implants inserted in male versus female patients: a systematic review and meta-analysis. J Oral Rehabil 2015; 42: 709-22.

53. Lai HC, Si MS, Zhuang LF, Shen H, Liu YL, Wismeijer D. Long-term outcomes of short dental implants supporting single crowns in posterior region: a clinical retrospective study of 5-10 years. Clin Oral Implants Res 2013; 24: 230-7.

54. Mangano FG, Shibli JA, Sammons RL, Iaculli F, Piattelli A, Mangano C. Short (8-mm) locking-taper implants supporting single crowns in posterior region: a prospective clinical study with 1-to 10-years of follow-up. Clin Oral Implants Res 2014; 25: 933-40.

55. Binon PP. The effect of implant/abutment hexagonal misfit on screw joint stability. Int J Prosthodont 1996; 9: 149-60.

56. Schwarz MS. Mechanical complications of dental implants. Clin Oral Implants Res 2000; 11 Suppl 1: 156-8.

57. Galante J. Stress-free prosthesis: a goal in implant dentistry. J Prosthet Dent 1994; 72: 232.

58. Binon P. Screw joints, components, and other intimate relationships. J Prosthet Dent 1994; 72: 625.

59. Xiao H, Yang Y, Liu Z, Taylor TD. Opinions Regarding Reuse or Replacement of Implant Prosthesis Retaining Screws: A Systematic Review. Int J Oral Maxillofac Implants 2017; 32: 985-91.

60. Saboury A, Mahshid M, Tabatabaian F, Moghadam L. Effect of screw access hole design on the fracture resistance of implant-supported zirconia-based restorations. Journal of Esthetic and Restorative Dentistry 2018; 30: 545-50.

61. Lameira DP, De Souza GM. Fracture strength of aged monolithic and bilayer zirconia-based crowns. BioMed research international 2015; 2015.

62. Hansen TL, Schriwer C, Øilo M, Gjengedal H. Monolithic zirconia crowns in the aesthetic zone in heavy grinders with severe tooth wear–An observational case-series. Journal of Dentistry 2018; 72: 14-20.

63. Koenig V, Wulfman C, Bekaert S, Dupont N, Le Goff S, Eldafrawy M, et al. Clinical behavior of second-generation zirconia monolithic posterior restorations: Two-year results of a prospective study with Ex vivo analyses including patients with clinical signs of bruxism. Journal of Dentistry 2019; 91: 103229.

64. Mangano F, Veronesi G. Digital versus Analog Procedures for the Prosthetic Restoration of Single Implants: A Randomized Controlled Trial with 1 Year of Follow-Up. Biomed Res Int 2018; 2018: 5325032.

65. Rammelsberg P, Bermejo JL, Kappel S, Meyer A, Zenthöfer A. Long-term performance of implant-supported metal-ceramic and all-ceramic single crowns. Journal of Prosthodontic Research 2020; 64: 332-9.

66. Skjold A, Schriwer C, Gjerdet NR, Øilo M. Fractographic analysis of 35 clinically fractured bi-layered and monolithic zirconia crowns. J Dent 2022; 125: 104271.

67. Sulaiman TA, Abdulmajeed AA, Delgado A, Donovan TE. Fracture rate of 188695 lithium disilicate and zirconia ceramic restorations after up to 7.5 years of clinical service: A dental laboratory survey. The Journal of Prosthetic Dentistry 2020; 123: 807-10.

68. Cattani-Lorente M, Scherrer SS, Ammann P, Jobin M, Wiskott HW. Low temperature degradation of a Y-TZP dental ceramic. Acta Biomater 2011; 7: 858-65.

69. Chevalier J, Cales B, Drouin JM. Low-temperature aging of Y-TZP ceramics. Journal of the American Ceramic Society 1999; 82: 2150-4.

70. Chevalier J, Gremillard L, Virkar AV, Clarke DR. The tetragonal-monoclinic transformation in zirconia: lessons learned and future trends. Journal of the american ceramic society 2009; 92: 1901-20.

71. Nakamura K, Harada A, Kanno T, Inagaki R, Niwano Y, Milleding P, et al. The influence of low-temperature degradation and cyclic loading on the fracture resistance of monolithic zirconia molar crowns. Journal of the mechanical behavior of biomedical materials 2015; 47: 49-56.

72. Bonyatpour M, Giti R, Erfanian B. Implant angulation and fracture resistance of one-piece screw-retained hybrid monolithic zirconia ceramic restorations. PLoS One 2023; 18: e0280816.