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ORIGINAL ARTICLE

# Clinical performance of tooth- or implant-supported veneered zirconia single crowns: 42-month results

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## Abstract

**Objectives** The objective of this clinical study was to compare and assess the clinical performance of tooth-supported and implant-supported zirconia single crowns with sintered veneering caps.

**Methods** In this prospective study, 118 patients with a total of 220 single crowns placed on 106 teeth (69 vital teeth, 37 endodontically treated teeth) and 114 implants in molar and premolar regions were examined during a mean observation period of 42 months. The restorations were evaluated for technical failures such as veneering porcelain fractures (chipping), surface quality, marginal fit, and the interface quality of the coping and sintered veneering. The soft tissue status was assessed using the modified Silness and Löe's plaque and gingival index (mPI) and the modified Muhlemann sulcus bleeding index (mSBI). Tooth-supported crowns were checked for secondary caries and hypersensitivity during the follow-up period. Recalls were performed every 6 months.

**Results** The 3-year Kaplan-Meier success probability was 98.2% and 100% for implant- and tooth-supported crowns, respectively. A significant difference could be detected between the implant-supported and tooth-supported zirconia single crowns, in terms of their chipping rate ($p = 0.039$). Veneering material fractures were recorded on two implant-supported restorations (1.8%). No veneering fractures occurred on tooth-supported single crowns. The plaque and gingival index and sulcus bleeding index showed stable and healthy soft peri-implant and periodontal tissues. Neither loss of vitality nor secondary caries occurred on tooth-supported crowns.

**Conclusions** Zirconia-based single crowns with a sintered veneering cap showed promising clinical results on both tooth and implant abutments; however, the dental implants were more prone to complications. In terms of clinical significance, high-strength ceramic with a sintered veneering cap can be recommended for prosthetic treatment of both tooth- and implant-supported single crowns in molar regions.

**Clinical relevance** This study provides valuable information for further application of all-ceramic restorations.

**Keywords** Dental implants · Implant-supported restorations · All-ceramic restorations · Veneering porcelain failures

## Introduction

Over the past decade, all-ceramic materials have proved to be indispensable in prosthetic dentistry due to their good esthetics and outstanding biocompatibility [1]. The continuous improvement of ceramic dental materials offers versatile applications [2]. Glass-ceramics are not only generally used for veneering alloys and high-strength core ceramic restorations but also for the fabrication of single tooth restorations or full contour crowns [3]. Furthermore, glass-ceramics, based on lithium disilicate, can be used to manufacture three-unit, anterior-fixed, dental prostheses [4]. High-strength zirconia is one of the latest restoration materials to be introduced into clinical practice. Thus, the treatment of posterior teeth with all-ceramic restorations and the application of ceramic implant abutments have

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become feasible [5]. Yttria-tetragonal zirconia polycrystal (Y-TZP) exhibits transformation-toughening properties, which provide high strength and tenacity in comparison with other ceramic core materials [6]. In addition to its high strength, zirconia exhibits lower plaque accumulation and bacterial adhesion compared to other ceramic materials used in the oral cavity [2]. Manufacturing zirconia-core crowns requires a computer-aided design/computer-aided manufacturing (CAD/CAM) process to achieve industrial quality standards [7, 8]. Despite the aforementioned mechanical properties and framework survival rates exceeding 90% for observational periods of up to 10 years, the most common complication observed in zirconia-based restorations was the fracture of the veneering porcelain [9–13], which is reported to be significantly higher than that of porcelain-fused-to-metal (PFM) restorations [14–16]. Chipping is characterized by a thin layer of glass-ceramic remaining on the zirconia framework [17]. This indicates a reliable bond between the veneering ceramic and the framework but also reveals a weakness in the veneering porcelain. Several factors which influence this so-called chipping behavior were identified [18–23], such as an inadequate framework design or thermal stress caused by thermal incompatibility during the manufacturing process [24]. The digital veneering of zirconia-based copings which was described several years ago shows promising mechanical strength [20, 21] and might be a technical solution for avoiding chipping events. Due to a new procedure in which the CAD/CAM-fabricated high-strength zirconia copings (IPS e.max ZirCAD, Ivoclar Vivadent, Ellwangen, Germany) and a corresponding lithium-disilicate glass-ceramic veneering cap (IPS e.max Press, Ivoclar Vivadent) are sintered using a glass-ceramic powder (Hotbond Fusion System, DCM, Rostock, Germany) in one bake, it can be assumed that the mechanical strength will be superior to that of traditional techniques. Thus, the veneering ceramic's clinical chipping rates and rate of mechanical failures should be lower with this technique. Although the clinical survival rates of implant-supported zirconia-based restorations are similar to those of tooth-borne restorations [11, 25, 26], the chipping rate for implant-supported fixed dental prostheses is reported to be higher [10]. The latest published clinical trials on the clinical performance of tooth- and implant-supported zirconia single crowns revealed survival rates of 95.9% for tooth-supported crowns and 97.1% for implant-supported crowns [27–29], which is comparable to the rates published for metal-ceramic crowns. The current study's objective was to compare the clinical stability rate of implant-supported zirconia single crowns with a sintered veneering cap, with that of natural teeth, in terms of their chipping behavior. The study's working hypotheses are that the zirconia tooth-supported and implant-supported single crowns with sintered veneering caps show better success rates than those described in the literature and that implant-supported and tooth-supported crowns have similar clinical outcomes.

## Material and methods

This prospective study was conducted with 118 patients from two dental offices in Munich. Between March 2008 and November 2015, a total of 220 restorations were inserted: 106 tooth-supported crowns and 114 implant-supported crowns. Inclusion criteria were a need for at least one tooth- or implant-supported single crown, adults (≥ 18 years), good oral hygiene (API < 10%, SBI < 10%) [30], moderate or non-smokers (less than five cigarettes per day), no TMJ problems, according to the RDC criteria [31], and no contraindications for surgery. The surgical and restorative treatments were performed by two experienced clinicians in a private practice. After having taken a detailed pre-implant medical history (general as well as specific) from all patients, the individual surgical implant planning was carried out, based upon a recent panoramic radiograph and a dental model analysis of the existing situation, following a standardized protocol.

All clinical investigations were conducted according to the principles expressed in the *Declaration of Helsinki*. The study was approved by the institutional ethics committee of Munich University (No. 434/14). Patients gave their written agreement.

### Surgical and restorative treatment

Prior to the prosthetic and surgical treatment, all of the patients received instruction in oral hygiene and professional tooth cleaning or systematic periodontal treatment. If necessary, vital tooth abutments were treated with adhesively placed composite fillings (LuxaCore, DMG, Hamburg, Germany) and non-vital teeth were restored with a direct composite build-up after adequate root canal fillings. In cases where the natural tooth structures were insufficient, non-vital teeth received a pre-fabricated, adhesively placed fiberglass root post (RelyX Fiber Post, 3M ESPE, Landsberg, Germany) to ensure the long-term retention of the restorations. The abutment teeth were prepared with a 0.8- to 1.0-mm chamfer and an axial taper of 4° to 6°, using a torpedo-formed cylindrical diamond bur (Komet Dental, Lemgo, Germany). The occlusal surface reduction was approximately 1.5 mm. In order to check the volumetric reduction, a silicon impression (Optosil, Heraeus Kulzer, Hanau, Germany) was taken prior to tooth preparation and used as a guideline for the preparation. After placing retraction cords in a double-layer technique (Cleancut, Ultradent, Cologne, Germany), impressions were taken, using a polyether material (Impregum, 3M ESPE). Finally, provisional chairside crowns (Protemp Garant, 3M ESPE) were inserted using a provisional cement (Temp Bond NE, Kerr, Rastatt, Germany). Before implant surgery, the patients received an antibiotic and an antiinflammatory single-shot treatment (Clindamycin 600 mg, Ratiopharm, Ulm, Germany and Cortison 5 mg, Prednisolon, Stada, Bad Vilbel, Germany).

The surgery was performed under local anesthesia. A mid-crestal incision and, if needed, a vertical release incision were performed, and the mucoperiosteal flaps were reflected to expose the alveolar bone. In cases with reduced vertical bone height in the maxilla, adequate augmentation was carried out before the implants (Camlog Promote/Promote Plus/CONELOG, Camlog Biotechnologies, Basel, Switzerland) were inserted, with a maximum torque of 50 N cm and using a drilling template (according to the insertion protocol). If vestibular augmentation was needed in addition, a mixture of autologous bone with xenogenic bone substitute and resorbable collagen barrier was used. After completing saliva-proof suturing (resorbable/non-resorbable) for closed healing, a panoramic X-ray was taken for postoperative control and ibuprofen 800 was dispensed to the patients. After 4 months of healing, the implants were exposed and provided with healing abutments. Two weeks after re-entry, impressions were taken to transfer the implant position using the closed or open-tray technique and polyether materials (Impregum, 3M ESPE).

## Dental laboratory

Having produced the master casts and mounted them in a semi-adjustable articulator (SAM PX 2, SAM, Gauting, Germany), the copings were then fabricated in wax with particular attention being paid to the minimum thickness of 0.5 mm. When manufacturing implant-supported crowns, the titanium abutments were chosen by the technician, depending on the implant axis and level of the soft tissue. The models were treated to create an emergence profile [32, 33]. If necessary, the titanium abutment was customized by grinding before fabrication of the wax coping. The coping's wax pattern was scanned (D 700, 3shape, Copenhagen, Denmark) and then milled from a pre-sintered zirconia block (IPS e.max ZirCAD, Ivoclar Vivadent, Ellwangen, Germany) in a CAD/CAM System (Corona, Starnberg, Germany) and then sintered to full density (Denta-Star S1 plus, Thermo-Star, Aachen, Germany) to obtain the crown's zirconia coping. The veneering was manufactured from lithium-disilicate according to the CAD-on technique described earlier [34]. However, in a deviation from the traditional protocol, the veneering caps were fabricated using a pressing technique instead of CAD/CAM fabrication. Therefore, a wax pattern of the veneering cap was produced and invested (IPS PrimaVest Press, Ivoclar Vivadent), according to the manufacturer's instructions. After burning out the wax and heating up the muffle, the veneer cap was pressed using a special lithium-disilicate glass-ceramic (IPS e.max Press, Ivoclar Vivadent). The two components (CAD/CAM framework and the over-pressed veneering cap) were sintered together using a low-fusing ceramic material (Hotbond Fusion System, DCM, Rostock, Germany) at a temperature of 780 °C in a conventional ceramic kiln (Austromat, Dekema, Freilassing, Germany). In order to create a suitable surface quality, several glaze firings were carried out after necessary adjustments had been made with diamond grinding tools (Table 1). For screw-retained restorations, the ceramic crown was bonded to the titanium abutment using a resin-based luting material (Multilink Implant, Ivoclar Vivadent). If a customized zirconia abutment was required for esthetic reasons, a wax pattern was also fabricated. This wax pattern was scanned (LAVA TM ScanST2, 3M ESPE), milled by a CAD/CAM system (Corona, Starnberg, Germany) from pre-sintered zirconia (IPS e.max ZirCAD), and sintered in the system's furnace (LAVATHERM, 3M ESPE). The sintered zirconia abutment was bonded to the titanium base with a dual-curing composite resin (Multilink Implant). Once the customized zirconia abutment had been completed, the all-ceramic superstructure was produced in the manner described above (Fig. 1).

## Prosthetic procedure

All restorations were tried in before final delivery in a biscuit bake stage. Occlusal and proximal areas were checked and corrected with water cooling if necessary, using a red-ring diamond bur and a polishing kit for ceramic materials (4326 A, Komet, Gebr. Brasseler, Lemgo, Germany). Following this, the corrected areas were treated with a glaze firing in the dental laboratory.

After examining the internal and marginal fit again (Fit Checker, GC, Bad Homburg, Germany), the crowns were fixed onto the abutments (106 on natural teeth and 61 on customized titan abutments) by using a resin-modified, glass-ionomer cement (Fuji Plus, GC, Alsip, IL (USA)/ Ketac Cem, 3M ESPE, Landsberg, Germany). In the cases of screw-retained implant-supported crowns with individual zirconia abutments, the zirconia abutment and the veneering were sintered together as described above. Before the try-in, the crowns were fixed on the titanium base provisionally by the use of a cyanoacrylate glue (Loctite 401, Henkel, Dusseldorf, Germany). Finally, after necessary corrections, the provisional luting to the titanium base was removed and

**Table 1** Furnace program for sintering

| Step | Working temperature | Heating rate/min | Time [MM:SS] |
|---|---|---|---|
| Drying | | | 20:00 |
| Closing | | | 03:00 |
| Preheating | 380 °C | | 02:00 |
| Temperature 1 | 780 °C | 35 °C/min | 01:00 |
| Temperature 2 | 500 °C | 45 °C/min | 00:30 |
| VAC | 780 °C | 100% | – |

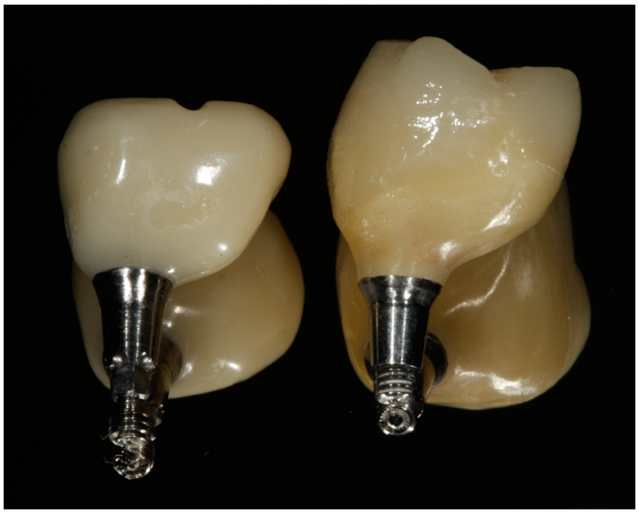

**Fig. 1** Screw-retained implant-supported crowns before insertion

the final firing glaze of the crown was performed. The titanium base was sandblasted and treated with a bonding agent. Finally, it was bonded with definitive adhesive cement (Multilink Hybrid Kit, Ivoclar Vivadent).

A postoperative radiograph was performed, in addition to clinical observation, to check for possible remaining excess cement. The insertion of the implant crowns was carried out using the following proven prosthetic occlusion concept, with preference given to achieving a canine-protected articulation. The static, dynamic, and proximal contacts were checked and adjusted, if necessary. The objective was to avoid dynamic contacts on molars and to achieve less static occlusion contacts on the implant-supported crowns than on the natural teeth, taking into account the periodontal flexibility of natural teeth. This was checked with an 8-μm-thick shimstock-foil (Bausch, Köln, Germany). Less static occlusion contacts on implant-supported crowns had been achieved when the shimstock-foil was held tightly only on the adjacent teeth in maximum intercuspation. The occlusion was adjusted so that each tooth showed at least one stable occlusal contact in maximum intercuspation. Contacts in lateral excursions were eliminated on the restorations. If occlusal adjustments were necessary after cementation, diamond burs with 30–40 μm grain size were employed (electric handpiece 100,000 rpm, water cooling 50 ml/min). Finally, the occlusal surface was polished in two steps, with ceramic polishing instruments (zirconium polishers fine and extra fine, ORIDIMA, Ortenburg, Germany).

## Recall

The occlusion was rechecked 1 week after the insertion of the crowns. At the next follow-up appointment, after 6 weeks, the crowns and peri-implant tissues were reexamined, and the patients were again instructed concerning adequate oral

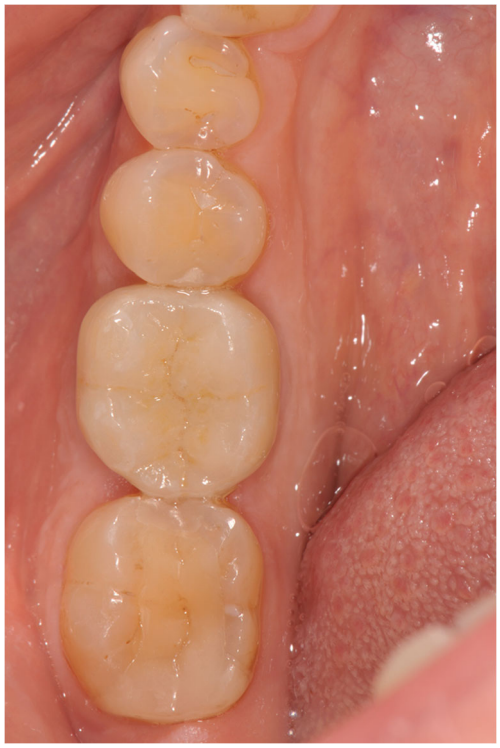

**Fig. 2** Tooth-supported crown (first molar) at the 6-month recall

hygiene. Where necessary, professional tooth cleaning was carried out two to four times a year, in addition to the 6-month recall monitoring (Fig. 2). Contacts were checked using the shim-stock protocol described above, and occlusal adjustments were protocolled with photographs.

Additionally, it was checked if any all-ceramic superstructures or antagonistic dentition showed visible contact wear, using dental probe and magnifying glasses (magnification ×3.5). It was differentiated whether the restorations or the antagonists showed visible traces of contact wear (yes or no). The examiner was calibrated with pictures of different clinical situations to detect contact wear.

## Statistical analysis

The monitoring and documentation of the results were performed by one calibrated dentist who had not been involved in either placing the implants or delivering the crowns. The tooth-based restorations were evaluated for loss of vitality, secondary caries, necessity of periodontal treatment, and endodontic failures. The implant-based restorations were assessed for technical and biological complications of the implant components. The following parameters were recorded: Silness and Löe's modified plaque and gingiva index (mPI) and the modified sulcus bleeding index (mSBI) described by Muhlemann. The restorations were evaluated for technical failures, such as chipping behavior, surface quality, and marginal fit, as well as the coping's interface quality, sintered veneering, and contact

wear, according to the modified USPHS criteria rating system. The results of this rating system were evaluated using the Mann-Whitney *U* test. Descriptive statistics for quantitative variables are given as the mean ± standard deviation. The data were analyzed with the Statistical Package for the Social Sciences (SPSS) software (IBM SPSS Statistics for Windows, Version 22.0, IBM Corp., Armonk, NY, USA). The correlation of possible predictor variables with the dependent variable chipping was determined using the Kaplan-Meier estimator and univariate log-rank test. The Kaplan-Meier method was used to plot survival curves for chipping as a putative binary prognostic factor. Differences with a two-sided *p* value of less than 0.05 were considered to be statistically significant.

## Results

### Patients

One hundred and eighteen patients (76 female/42 male) with a total of 220 restorations (97 premolar crowns/123 molar crowns), placed on 69 vital and 37 endodontically treated teeth and 114 implants, were evaluated. The patients' age ranged from 24 to 75 years. Thirteen patients, with 21 restorations, did not fulfill the inclusion criteria because they declined to participate in the study's follow-up and were therefore excluded from further statistical evaluation. The mean observation period for the restorations was 42 months (Fig. 3). Fifty-three implant-supported crowns were screw-retained, and 61 crowns were cemented onto the abutment. All the implant- and tooth-supported zirconia crowns were inserted in molar and premolar regions.

### Prosthetic restoration

The overall 3.5-year success rate was 98.2% for implant-supported and 100% for tooth-supported restorations. The cumulative incidence of veneering fractures was 1.8% (Fig. 3). When both groups were compared, a statistically significant difference was detected, using the univariate log-rank test ($p = 0.039$, Fig. 3), between the implant-supported and tooth-supported zirconia single crowns. Chipping of the veneering ceramic occurred on two cemented, implant-supported crowns (3.3%) after a mean time of 48 ± 5.7 months, whereas no chipping was found on tooth-supported crowns (Fig. 4). No zirconia framework fractures or implant losses were detected over the entire period of observation. The mean plaque index for implant-supported crowns was 0.5 ± 0.6, compared to 0.5 ± 0.5 for patients with tooth-supported crowns. There was no significant difference between the two groups ($p = 0.746$). The mean bleeding index for implant-supported crowns was 0.6 ± 0.6 and 0.8 ± 0.7 for tooth-born crowns. Furthermore,

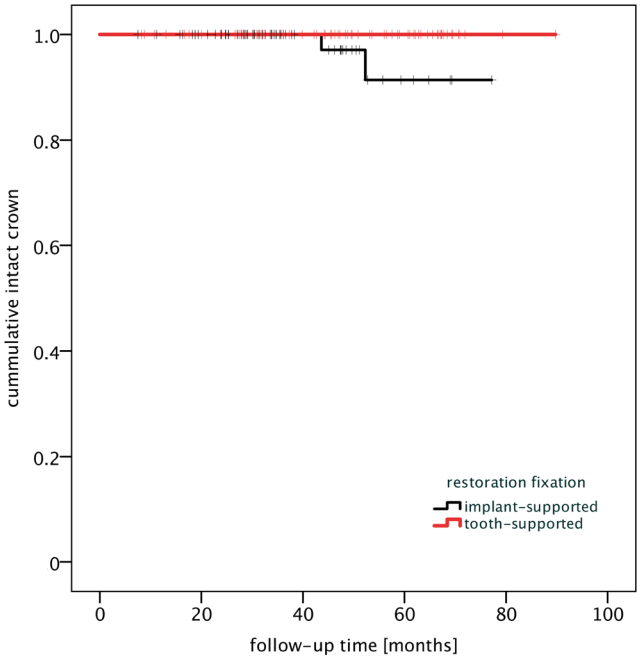


**Fig. 3** Kaplan-Meier graph showing all events for implant-supported and tooth-supported single crowns in relation to the time of occurrence. Comparing both groups, a statistically significant difference was detected using the univariate log-rank test ($p = 0.039$)

according to the Mann-Whitney *U* test ($p = 0.079$), there was no significant difference between the two groups. Regarding the gingival index, implant-supported single crowns showed values of 0.4 ± 0.5 compared to 0.7 ± 0.7 for tooth-supported crowns. A statistically significant difference was detectable ($p = 0.001$). In addition, whether the all-ceramic superstructures or antagonistic dentition showed any contact wear was checked. The implant-supported restorations showed visible contact wear in 2.6% of cases, whereas contact wear was found on 10.4% of tooth-supported crowns. Comparing these results, using Fisher's exact test revealed statistical differences

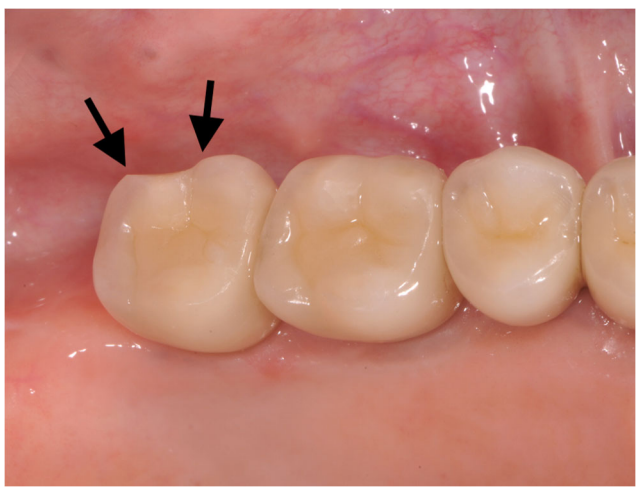

**Fig. 4** Occlusal view on veneering porcelain fractures of cemented implant-supported crown (second molar); fractured area is highlighted by black arrows

($p = 0.025$). Contact wear on the antagonistic teeth was more frequently caused by tooth-supported crowns than by implant-supported ones (17.9% vs 14.9%), without exhibiting statistically significant differences ($p = 0.588$). With regard to the antagonistic teeth's contact wear behavior (16.4%), no tendency is remarkable. Abrasion occurred in natural teeth, as well as in teeth that had been provided with composite fillings, above that in ceramic crowns or bridges and restorations made of gold or acrylic resin dentures. Patients were restored using crowns at different gingival levels, depending on the esthetic and functional demands. Of the implant-supported crowns, 22 were localized at the gingival level (isogingival), 9 above it (supragingival), and 83 were applied below the level of the gingiva (subgingival). With respect to the gingival bleeding or plaque indices, no difference between the groups could be detected. In comparison, 70 tooth-supported crowns were located at the gingival level (isogingival), 14 above it (supragingival), and 22 were applied below the level of the gingiva (subgingival). When analyzing these cases, it was also impossible to verify a significant difference regarding the gingival bleeding or plaque indices. The detailed clinical inspection generally revealed an apparently proper crown-surface condition (apart from the two chipping cases mentioned above). The marginal accuracy was considered excellent for 84.2% of the implant-supported crowns and 67.9% of the tooth-supported crowns. The implant-supported crowns (15.8%) and the tooth-supported crowns (32.1%) showed good marginal fit and were classified as "bravo," according to the modified USPHS criteria.

## Discussion

The success rates of implant- and tooth-supported single crowns with sintered veneering caps (98.2% and 100%, respectively) were higher than discussed in literature, which confirms the first part of the study's working hypothesis. In the present study, none of the zirconia frameworks were fractured during the entire observation period. Several long-term studies reported a survival rate of 76–98.2% after 10–15 years, for all ceramic, tooth-supported single crowns [35–38]. Recently reported data on the clinical performance of metal-ceramic crowns indicates that fractures of the veneering porcelain occurred more frequently in zirconia than metal-ceramic single crowns ($p < 0.001$). In a systematic review, Sailer et al. found a 5-year survival rate of 95.7% for metal-ceramic crowns. They recommended that zirconia-based single crowns should not be considered a primary option due to their high incidence of technical problems [39]. Despite zirconia restorations' high framework survival rates (exceeding 90%), chipping of the veneering ceramic, which has been reported in various clinical studies, is the most frequent technical complication [9, 40]. High incidences of veneering ceramic fractures, ranging from 0% to 54%, within the first 3 years of clinical service, have been documented [14, 41, 42]. According to the systematic review conducted by Pjeturson et al. in 2007, all-ceramic crowns had a chipping rate of 3.7% after 5 years and metal-ceramic crowns 5.7%. Another long-term study reported chipping rates of 15.4% after 5 years and 16.6% after 10 years, for all-ceramic single crowns on natural teeth [26]. A systematic review of the outcomes of implant-supported single crowns demonstrated a 5- and 10-year survival rate for implant-supported crowns of 96.3% and 89.4%, respectively, and a chipping rate of 3.5% after 5 years [43]. In a retrospective study, Schwarz et al. reported a 24.5% chipping rate for implant-supported, all-ceramic single crowns after an observation period up of to 5.8 years [12], whereas recent research by Teichmann et al. revealed a chipping rate of 0% after 5 years and 5.9% after 10 years [26]. A prospective clinical study, performed by Glauser et al., registered no chipping of implant-supported restorations after a median service time of 49.2 months. It should be taken into account that the majority of the treatments were performed in anterior regions [44].

Several reasons why zirconia veneering materials chip have been discussed in literature. According to Swain et al., residual stresses in the porcelain are almost independent of the elastic modulus of the coping material but directly related to the thermal expansion mismatch between it and the veneering material. Additionally, the risk of veneer chipping can be reduced by proper support from the zirconia framework and a reduced cooling rate after the final firing or glazing procedure [19]. In vitro studies have demonstrated that veneering produced by CAD/CAM was significantly less sensitive to aging than hand-layered veneering and showed significantly lower initial fracture loads (mean = 1165.86 vs 395.45 N). Of the crowns in the hand-layered group, 87.5% failed during simulation of chewing, whereas no crown in the CAD/CAM group failed [21]. The CAD/CAM production of veneers for restorations with zirconia frameworks is a promising approach for reducing failures originating from material fatigue [20, 34]. The zirconia substructures were veneered with lithium-disilicate. The two components (CAD/CAM framework and over-pressed veneering cap) were sintered together in a conventional ceramic kiln using a low-fusing ceramic material. The substructure with an optimized anatomic occlusal support and cusp design might be a reason for the reduced chipping numbers in this study. Sharp inner edges and undercuts were eliminated. In order to avoid load bearing points or areas that might be the starting point for cracks, resulting in chipping of the veneering porcelain, the crowns were inserted in accordance with a proven prosthetic occlusion concept, which favors a canine-protected articulation. The forces which occur during clenching and mastication are thereby distributed, thus avoiding dynamic contacts on molars in order to achieve the goal of less static occlusion contacts on implant-supported

crowns than on natural teeth. In the current study, the type of abutment (vital tooth/endodontically treated tooth/implant) had a significant effect on the restoration's survival rate. Implant-supported zirconia single crowns showed a significantly higher chipping rate compared to the tooth-supported crowns ($p = 0.039$), resulting in an overall stability rate of 98.2%. This effect can be explained by the rigid anchoring of implants in the bone compared to that of natural teeth. The 3-year Kaplan-Meier curve for tooth-supported crowns was 100%, for both vital and endodontically treated teeth. This finding does not agree with the findings of other clinical trials [45, 46] which have reported reduced survival rates for all-ceramic and metal-ceramic crowns on endodontically treated teeth. In addition, the crowns' success rate was not significantly influenced by the location of the restoration, in contrast to the findings of systematic reviews [45, 47, 48] which had found high complication rates for all-ceramic crowns placed in posterior areas. As with other clinical studies evaluating zirconia crowns, secondary caries was a rare complication in the present study [27, 49]. No loss of retention occurred either on implants or on crowns. This might be due to improved manufacturing technology and the use of luting agents with improved retentive capability. Despite a more conical preparation design, which is associated with an increased loss of substance, biological complications such as the loss of vitality after placement were rare. The second working hypothesis concerning comparison of the clinical outcome between implant-supported and tooth-supported crowns must be rejected. In the present clinical study, chipping of parts of the veneering ceramic was recorded on two cement-retained, implant-supported, single crowns in the first molar of the lower jaw. According to the Kaplan-Meier curves, a significant difference was detectable in the chipping rates of tooth-supported all-ceramic and implant-supported zirconia, single crowns with sintered veneering caps ($p = 0.039$). No gingival hypertrophy, gingival recession, pocket formation, bleeding on probing, or pain was detected in either group (tooth- and implant-born crowns). This may be related to an improved gingival state due to periodontal treatment before implant placement, as well as consistent oral hygiene motivation during the follow-up period. Further, none of the implant-supported crowns demonstrated biological complications such as marginal bone loss of more than 1 mm, and none of the tooth-supported crowns displayed secondary caries or hypersensitivity during the follow-up period. Regarding the antagonistic teeth's contact wear behavior, further specific investigations are needed to answer the question whether high-strength ceramic reconstructions, as described above, might even be too strong. Taking into account that the veneering ceramics, zirconia framework material and design, as well as the fabrication techniques were different in each study, these factors might have affected the results of recent research [49]. In addition, most studies evaluating chipping behavior are limited by the fact that the patients were surveyed retrospectively. Clinical questions can only be resolved by large controlled and prospectively designed studies. Although the present study was performed in a prospective manner, there are also some limitations associated with the selection of the patients over a long period of time, as well as with the limited number of patients. More than one restoration per patient was placed and evaluated in this study. Building up larger databases and involving multiple centers might produce additional information. Furthermore, the reason for chipping could not be deduced from the current study. The results presented are promising, but more data are still needed concerning hygiene, stability, and the patients' satisfaction.

## Conclusion

Within the limited mean observation period of 42 months, it can be concluded that tooth-supported and implant-supported zirconia single crowns with a sintered veneering cap demonstrated satisfactory clinical stability rates in posterior regions and may be considered as acceptable treatment modalities for the restoration of missing, or compromised, posterior teeth. In respect of clinical significance, both, tooth- and implant-supported single crowns, treated with sintered veneering caps, can be recommended.

### Compliance with ethical standards

**Conflict of interest** The authors declare they have no competing interests.

**Ethical approval** The requirements of the Helsinki Declaration were observed and the patients given informed consent. The ethical board of the Munich University (number 434/24) has reviewed and approved the study design.

**Informed consent** Informed consent was obtained from all individual participants included in this study.

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