Aus der Poliklinik für Zahnärztliche Prothetik
der Ludwig-Maximilians-Universität München

Direktor: Prof. Dr. med. dent. Daniel Edelhoff

Keramische Kronen auf Zähnen und Implantaten: Klinische Ergebnisse aus der Praxis

Dissertation

zum Erwerb des Doktorgrades der Zahnmedizin

an der Medizinischen Fakultät
der Ludwig-Maximilians-Universität zu München

vorgelegt von
Friederike Catherine Cantner
aus Lindau
2020

Mit Genehmigung der Medizinischen Fakultät
der Universität München

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Kumulative Dissertation

Gemäß § 4a der Promotionsordnung:

* Platzierung des Journals laut Impact Factor listing for journals on Dentistry, Oral Surgery & Medicine (2017 JCR Science Edition)

1. Abkürzungsverzeichnis

SVK	Sinterverbundkronen
CAD	Computer-aided design
CAM	Computer-aided manufacturing

2. Publikationsliste

<u>Erstautorschaft:</u>

Cantner F, Cacaci C, Mücke T, Randelzhofer P, Hajtó J, Beuer F.

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

Clin Oral Investig. 2019 Mar 18. (IF: 2.453*)

<u>Zweitautorschaft:</u>

Cacaci C, Cantner F, Mücke T, Randelzhofer P, Hajtó J, Beuer F.

Clinical performance of screw-retained and cemented implant-supported zirconia single crowns: 36-month results.

Clin Oral Investig. 2017 Jul;21(6):1953-1959. (IF: 2.386*)

* Platzierung des Journals laut Impact Factor listing for journals on Dentistry, Oral Surgery & Medicine (2017 JCR Science Edition)

3. Einleitung und Zielsetzung

In den letzten Jahren war die Entwicklung der dentalen Keramiken einer stetigen Wandlung unterworfen, um wachsende ästhetische aber auch mechanische Anforderungen zu erfüllen.

Die Vorzüge der Vollkeramik liegen im Vergleich zu metallkeramischen Alternativen vor allem in der überragenden Ästhetik, der geringen Plaqueanlagerung sowie der hohen biologischen Verträglichkeit [1-4]. Hier sind heute mit modernen Vollkeramikrestaurationen fast naturidentische Resultate zu erzielen.

Gegenüber den genannten Vorteilen, liegt der Nachteil der dentalen Vollkeramik in ihrer Sprödigkeit und ihrer Neigung zu unterkritischem Risswachstum. Wegen ihrer geringen Biegefestigkeit reagiert Keramik auf Zugspannung besonders sensibel, während ein hoher Druck, wie er beispielsweise beim Kauen entsteht weniger problematisch zu sein scheint.

Mit der Einführung hochfester Oxidkeramiken, vor allem des Zirkoniumdioxids, wurde die Herstellung mehrgliedriger Brückenkonstruktionen auch im Seitenzahnbereich möglich. Diese Versorgungen waren bis dahin ausschließlich den Metallkeramiken vorbehalten [5].

Während Zirkoniumdioxid als Gerüstwerkstoff von vollkeramischen Konstruktionen durch hohe Überlebensraten gekennzeichnet ist, zeigen sich bei der Verblendkeramik erhebliche Misserfolgsraten [6-8]. Am häufigsten findet man hier ein Abschilfern innerhalb des Verblendmaterials, welches als „Chipping“ bezeichnet wird. Charakteristischer Weise verbleibt hierbei eine dünne Schicht Verblendkeramik auf dem Gerüst, was auf einen funktionierenden Verbund zwischen Verblendung und Gerüst hindeutet und eine Schwäche im Verblendmaterial selbst nahelegt.

Auf der Suche nach möglichen Ursachen für das Abplatzen der Verblendkeramik, werden zahlreiche Möglichkeiten diskutiert. Hier scheinen vor allem eine inadäquate, insbesondere eine zu grazile Gerüstgestaltung mit fehlender Höckerunterstützung und demzufolge zu dicken Verblendschichten, sowie die unterschiedlichen Wärmeausdehnungskoeffizienten der keramischen Materialien eine Rolle zu spielen [9, 10]. Des Weiteren ist noch nicht abschließend geklärt, welchen Einfluss eine nachträgliche Oberflächenbearbeitung auf die Festigkeit der Verblendkeramik hat. Es wird diskutiert, dass Frakturen der Verblendung von okklusalen Frühkontakten oder auch von ungenügend polierten Oberflächen beispielsweise nach Einschleifkorrekturen, ausgehen können.

Vieles deutet demnach darauf hin, dass die Verblendung das schwächste Glied bei den Zirkonoxid basierten Rekonstruktionen ist und das Festigkeitsdefizit des Verblendmaterials letztlich zum Misserfolg der gesamten Restauration führen kann.

Gegenstand dieser Arbeit war die Untersuchung der Langzeitstabilität und Oberflächenbeschaffenheit von Sinterverbundkronen, sowohl auf Implantaten als auch auf natürlichen Zähnen. Bei dieser Art der Vollkeramikkronen wird die Lithiumdisilikatverblendung auf das mittels CAD/CAM hergestellte Zirkonoxidkäppchen gesintert. Hierbei lag der Schwerpunkt auf der Untersuchung der folgenden Fragen:

1. Überlebensrate bzw. Chippingverhalten von Sinterverbundkronen (SVK-Kronen) auf Zähnen und Implantaten, verglichen mit Ergebnissen früherer Erhebungen bezüglich Zirkonoxidkeramikrestaurationen
2. Hat bei Implantatkronen die Befestigungsart (verschraubt vs. zementiert) Einfluss auf den Langzeiterfolg bezüglich Chippingverhalten und periimplantäre Situation?

4. Eigene Arbeit

Nachfolgend werden zwei Originalarbeiten, in englischer Sprache verfasst, vorgestellt und diskutiert.

4.1. Originalarbeit: Cantner F, Cacaci C, Mücke T, Randelzhofer P, Hajtó J, Beuer F. Clinical performance of tooth- or implant-supported veneered zirconia single crowns: 42-month results. Clin Oral Investig. 2019 Mar 18.

Zusammenfassung:

Ziel: Die vorliegende Studie mit dem Namen „Clinical performance of tooth- or implant-supported veneered zirconia single crowns: 42-month results“ untersuchte zahn- und implantatgestützte Keramikkronen auf Molaren im Hinblick auf ihr klinisches Verhalten und ihre Leistungsfähigkeit.

Material und Methode: Insgesamt wurden bei 118 Patienten über einen Zeitraum von 42 Monaten 114 Implantatkronen und 106 Kronen auf natürlichen Zähnen im Hinblick auf ihre Oberflächenbeschaffenheit sowie eine mögliche Randspaltentwicklung untersucht. Der Zustand der marginalen Gingiva wurde mit Hilfe des modifizierten Plaque- und Gingival-Index nach Silness und Löe und des modifizierten Blutungs-Index nach Mühlemann beurteilt. Die natürlichen überkronten Zähne wurden hinsichtlich Sekundärkaries und Hypersensibilitäten überprüft. Ein Recall fand alle 6 Monate statt.

Ergebnisse: Die statistische Auswertung nach Kaplan-Meier ergab eine Erfolgsrate bezüglich Chipping von 98.2% für Implantatkronen und 100% für Kronen auf natürlichen Zähnen.

Im Hinblick auf das Chippingverhalten wurde ein signifikanter Unterschied zu Gunsten der natürlichen Zähne festgestellt (p= 0.039). Abplatzungen der Verblendkeramik traten an zwei Implantatkronen auf (1.8%). Die Plaque- u. Gingival-Indizes sowie der Sulkusblutungsindex zeigten in beiden untersuchten Gruppen gesunde parodontale bzw. periimplantäre Verhältnisse. Die überkronten natürlichen Zähne wiesen weder Karies noch Sensibilitätsauffälligkeiten auf.

Schlussfolgerung: Sinterverbundkronen zeigten gute Ergebnisse, sowohl auf natürlichen Zähnen als auch auf Implantaten, wobei die implantatgetragenen Sinterverbundkronen anfälliger für Komplikationen waren.

Klinische Relevanz: Im klinischen Alltag wiesen Sinterverbundkronen eine gute Stabilität auf, v.a. im Hinblick auf ihr Chippingverhalten und können als prothetische Versorgung von Implantaten und natürlichen Zähnen im Molarenbereich empfohlen werden.

Clinical Oral Investigations
https://doi.org/10.1007/s00784-019-02878-0

ORIGINAL ARTICLE

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

Friederike Cantner[1] · Claudio Cacaci[1] · Thomas Mücke[2] · Peter Randelzhofer[1] · Jan Hajtó[3] · Florian Beuer[4]

Received: 9 August 2018 / Accepted: 11 March 2019

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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Published online: 18 March 2019

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, 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

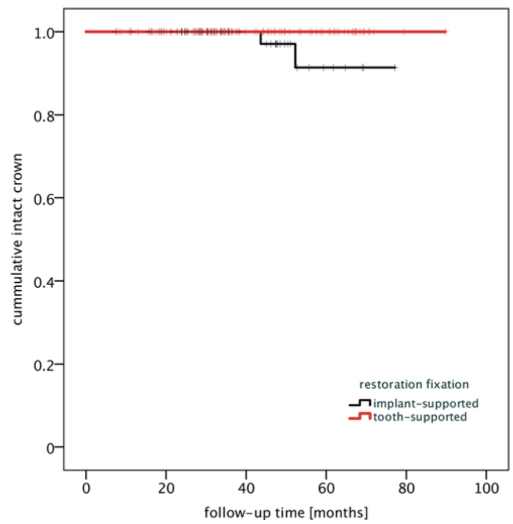

Fig. 3 Kaplan-Meier graph showing all events for implant-supported and tooth-supported single crowns in relation to the time of occurrence. Comparing both groups, a statistically significant difference was detected using the univariate log-rank test (p = 0.039)

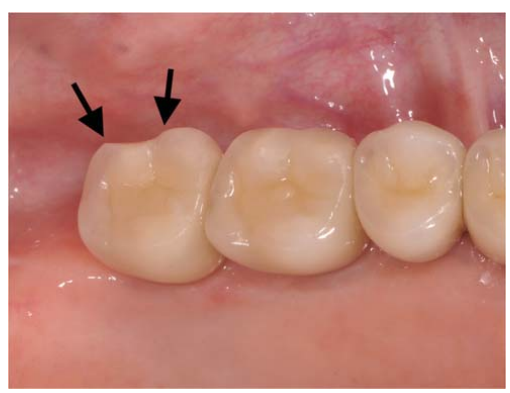

Fig. 4 Occlusal view on veneering porcelain fractures of cemented implant-supported crown (second molar); fractured area is highlighted by black arrows

($p = 0.025$). 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.

References

1. Devaud V (2005) Guidelines for success with zirconia ceramics: the changing standards. Pract Proced Aesthet Dent 17:508–510
2. Bremer F, Grade S, Kohorst P, Stiesch M (2011) In vivo biofilm formation on different dental ceramics. Quintessence Int 42:565–574
3. Holand W, Schweiger M, Frank M, Rheinberger V (2000) A comparison of the microstructure and properties of the IPS Empress 2 and the IPS Empress glass-ceramics. J Biomed Mater Res 53:297–303
4. Conrad HJ, Seong WJ, Pesun IJ (2007) Current ceramic materials and systems with clinical recommendations: a systematic review. J Prosthet Dent 98:389–404

5. Nakamura K, Kanno T, Milleding P, Ortengren U (2010) Zirconia as a dental implant abutment material: a systematic review. Int J Prosthodont 23:299–309
6. Koenig V, Vanheusden AJ, Le Goff SO, Mainjot AK (2013) Clinical risk factors related to failures with zirconia-based restorations: an up to 9-year retrospective study. J Dent 41:1164–11674
7. Luthardt RG, Holzhuter MS, Rudolph H, Herold V, Walter MH (2004) CAD/CAM-machining effects on Y-TZP zirconia. Dent Mater 20:655–662
8. Gherlone E, Mandelli F, Cappare P, Pantaleo G, Traini T, Ferrini F (2014) A 3 years retrospective study of survival for zirconia-based single crowns fabricated from intraoral digital impressions. J Dent 42:1151–1155
9. Sailer I, Feher A, Filser F, Gauckler LJ, Luthy H, Hammerle CH (2007) Five-year clinical results of zirconia frameworks for posterior fixed partial dentures. Int J Prosthodont 20:383–388
10. Larsson C, Vult von Steyern P (2010) Five-year follow-up of implant-supported Y-TZP and ZTA fixed dental prostheses. A randomized, prospective clinical trial comparing two different material systems. Int J Prosthodont 23:555–561
11. Jung RE, Pjetursson BE, Glauser R, Zembic A, Zwahlen M, Lang NP (2008) A systematic review of the 5-year survival and complication rates of implant-supported single crowns. Clin Oral Implants Res 19:119–130
12. Schwarz S, Schroder C, Hassel A, Bomicke W, Rammelsberg P (2012) Survival and chipping of zirconia-based and metal-ceramic implant-supported single crowns. Clin Implant Dent Relat Res 14(Suppl 1):119–125
13. Aboushelib MN, Kleverlaan CJ, Feilzer AJ (2006) Microtensile bond strength of different components of core veneered all-ceramic restorations. Part II: zirconia veneering ceramics. Dent Mater 22:857–863
14. Heintze SD, Rousson V (2010) Survival of zirconia- and metal-supported fixed dental prostheses: a systematic review. Int J Prosthodont 23:493–502
15. Pelaez J, Cogolludo PG, Serrano B, Serrano JF, Suarez MJ (2012) A four-year prospective clinical evaluation of zirconia and metal-ceramic posterior fixed dental prostheses. Int J Prosthodont 25:451–458
16. Vigolo P, Mutinelli S (2012) Evaluation of zirconium-oxide-based ceramic single-unit posterior fixed dental prostheses (FDPs) generated with two CAD/CAM systems compared to porcelain-fused-to-metal single-unit posterior FDPs: a 5-year clinical prospective study. J Prosthodont 21:265–269
17. Larsson C, Vult von Steyern P, Sunzel B, Nilner K (2006) All-ceramic two- to five-unit implant-supported reconstructions. A randomized, prospective clinical trial. Swed Dent J 30:45–53
18. Rosentritt M, Steiger D, Behr M, Handel G, Kolbeck C (2009) Influence of substructure design and spacer settings on the in vitro performance of molar zirconia crowns. J Dent 37:978–983
19. Swain MV (2009) Unstable cracking (chipping) of veneering porcelain on all-ceramic dental crowns and fixed partial dentures. Acta Biomater 5:1668–1677
20. Schmitter M, Mueller D, Rues S (2012) Chipping behaviour of all-ceramic crowns with zirconia framework and CAD/CAM manufactured veneer. J Dent 40:154–162
21. Schmitter M, Mueller D, Rues S (2013) In vitro chipping behaviour of all-ceramic crowns with a zirconia framework and feldspathic veneering: comparison of CAD/CAM-produced veneer with manually layered veneer. J Oral Rehabil 40:519–525
22. Du Q, Swain MV, Zhao K (2014) Fractographic analysis of anterior bilayered ceramic crowns that failed by veneer chipping. Quintessence Int 45:369–376
23. Broseghini C, Broseghini M, Gracis S, Vigolo P (2014) Aesthetic functional area protection concept for prevention of ceramic chipping with zirconia frameworks. Int J Prosthodont 27:174–176
24. Zhang Z, Guazzato M, Sornsuwan T, Scherrer SS, Rungsiyakull C, Li W, Swain MV, Li Q (2013) Thermally induced fracture for core-veneered dental ceramic structures. Acta Biomater 9:8394–8402
25. Sailer I, Muhlemann S, Zwahlen M, Hammerle CH, Schneider D (2012) Cemented and screw-retained implant reconstructions: a systematic review of the survival and complication rates. Clin Oral Implants Res 23(Suppl 6):163–201
26. Teichmann M, Gockler F, Weber V, Yildirim M, Wolfart S, Edelhoff D (2017) Ten-year survival and complication rates of lithium-disilicate (Empress 2) tooth-supported crowns, implant-supported crowns, and fixed dental prostheses. J Dent 56:65–77
27. Larsson C, Wennerberg A (2014) The clinical success of zirconia-based crowns: a systematic review. Int J Prosthodont 27:33–43
28. Monaco C, Caldari M, Scotti R, ACR Group (2013) Clinical evaluation of 1,132 zirconia-based single crowns: a retrospective cohort study from the AIOP clinical research group. Int J Prosthodont 26:435–442
29. Monaco C, Caldari M, Scotti R, ACR Group (2015) Clinical evaluation of zirconia-based restorations on implants: a retrospective cohort study from the AIOP clinical research group. Int J Prosthodont 28:239–242
30. Klages U, Weber AG, Wehrbein H (2005) Approximal plaque and gingival sulcus bleeding in routine dental care patients: relations to life stress, somatization and depression. J Clin Periodontol 32:575–582
31. Schiffman E, Ohrbach R, Truelove E, Look J, Anderson G, Goulet JP, List T, Svensson P, Gonzalez Y, Lobbezoo F, Michelotti A, Brooks SL, Ceusters W, Drangsholt M, Ettlin D, Gaul C, Goldberg LJ, Haythornthwaite JA, Hollender L, Jensen R, John MT, de Laat A, de Leeuw R, Maixner W, van der Meulen M, Murray GM, Nixdorf DR, Palla S, Petersson A, Pionchon P, Smith B, Visscher CM, Zakrzewska J, Dworkin SF, International RDC/TMD Consortium Network, International association for Dental Research, Orofacial Pain Special Interest Group, International Association for the Study of Pain (2014) Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) for Clinical and Research Applications: recommendations of the International RDC/TMD Consortium Network* and Orofacial Pain Special Interest Group†. J Oral Facial Pain Headache 28:6–27
32. Happe A, Roling N, Schafer A, Rothamel D (2015) Effects of different polishing protocols on the surface roughness of Y-TZP surfaces used for custom-made implant abutments: a controlled morphologic SEM and profilometric pilot study. J Prosthet Dent 113:440–447
33. Dornbush JR, Reiser GM, Ho DK (2014) Platform switching and abutment emergence profile modification on peri-implant soft tissue. Alpha Omegan 107:28–32
34. Beuer F, Schweiger J, Eichberger M, Kappert HF, Gernet W, Edelhoff D (2009) High-strength CAD/CAM-fabricated veneering material sintered to zirconia copings—a new fabrication mode for all-ceramic restorations. Dent Mater 25:121–128
35. Simeone P, Gracis S (2015) Eleven-year retrospective survival study of 275 veneered lithium disilicate single crowns. Int J Periodontics Restorative Dent 35:685–694
36. Galindo ML, Sendi P, Marinello CP (2011) Estimating long-term survival of densely sintered alumina crowns: a cohort study over 10 years. J Prosthet Dent 106:23–28
37. Rinke S, Tsigaras A, Huels A, Roediger M (2011) An 18-year retrospective evaluation of glass-infiltrated alumina crowns. Quintessence Int 42:625–633
38. Valenti M, Valenti A (2009) Retrospective survival analysis of 261 lithium disilicate crowns in a private general practice. Quintessence Int 40:573–579
39. Sailer I, Makarov NA, Thoma DS, Zwahlen M, Pjetursson BE (2015) All-ceramic or metal-ceramic tooth-supported fixed dental

prostheses (FDPs)? A systematic review of the survival and complication rates. Part I: single crowns (SCs). Dent Mater 31:603–623
40. Molin MK, Karlsson SL (2008) Five-year clinical prospective evaluation of zirconia-based Denzir 3-unit FPDs. Int J Prosthodont 21: 223–227
41. Miyazaki T, Nakamura T, Matsumura H, Ban S, Kobayashi T (2013) Current status of zirconia restoration. J Prosthodont Res 57:236–261
42. Raigrodski AJ, Hillstead MB, Meng GK, Chung KH (2012) Survival and complications of zirconia-based fixed dental prostheses: a systematic review. J Prosthet Dent 107:170–177
43. Jung RE, Zembic A, Pjetursson BE, Zwahlen M, Thoma DS (2012) Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. Clin Oral Implants Res 23(Suppl 6):2–21
44. Glauser R, Sailer I, Wohlwend A, Studer S, Schibli M, Scharer P (2004) Experimental zirconia abutments for implant-supported single-tooth restorations in esthetically demanding regions: 4-year results of a prospective clinical study. Int J Prosthodont 17:285–290
45. Pjetursson BE, Sailer I, Zwahlen M, Hammerle CH (2007) A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part I: single crowns. Clin Oral Implants Res 18(Suppl 3):73–85
46. Beier US, Kapferer I, Dumfahrt H (2012) Clinical long-term evaluation and failure characteristics of 1,335 all-ceramic restorations. Int J Prosthodont 25:70–78
47. Heintze SD, Rousson V (2010) Fracture rates of IPS Empress all-ceramic crowns—a systematic review. Int J Prosthodont 23:129–133
48. Wang X, Fan D, Swain MV, Zhao K (2012) A systematic review of all-ceramic crowns: clinical fracture rates in relation to restored tooth type. Int J Prosthodont 25:441–450
49. Takeichi T, Katsoulis J, Blatz MB (2013) Clinical outcome of single porcelain-fused-to-zirconium dioxide crowns: a systematic review. J Prosthet Dent 110:455–461

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4.2. Originalarbeit: Cacaci C, Cantner F, Mücke T, Randelzhofer P, Hajtó J, Beuer F. Clinical performance of screw-retained and cemented implant-supported zirconia single crowns: 36-month results. Clin Oral Investig. 2017 Jul;21(6):1953-1959.

Zusammenfassung:

Ziel: Die vorliegende Studie mit dem Titel „Clinical performance of screw-retained and cemented implant-supported zirconia single crowns: 36-month results“ untersuchte das klinische Verhalten von verschraubten und zementierten Sinterverbundkronen im Molarenbereich, wobei besonders ein möglicher Einfluss der Verankerungsart (verschraubt vs. zementiert) analysiert wurde.

Material und Methode: Insgesamt wurden 114 Implantatkronen bei 58 Patienten untersucht, wovon 53 verschraubt und 61 Kronen zementiert worden waren.

Ergebnisse: Es zeigte sich, dass die Verankerungsart keinen signifikanten Einfluss auf das „Chippingverhalten“ hatte. Abplatzungen der Verblendung traten bei zwei zementierten Implantatkronen auf (1.8%), jedoch keine an verschraubten Kronen.

Das periimplantäre Gewebe blieb in beiden Gruppen (verschraubt vs. zementiert) stabil.

Schlussfolgerung: Implantatgetragene Sinterverbundkronen weisen eine gute klinische Stabilität in distalen Kieferbereichen auf, sowohl in verschraubter als auch in zementierter Form.

Klinische Relevanz: Im Hinblick auf die klinische Anwendung können sowohl zementierte als auch verschraubte SVK-Implantatkronen zum Einsatz kommen, da ihr Langzeitverhalten im Patientenmund nicht zu differieren scheint.

Clin Oral Invest
DOI 10.1007/s00784-016-1982-1

ORIGINAL ARTICLE

Clinical performance of screw-retained and cemented implant-supported zirconia single crowns: 36-month results

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Received: 26 April 2016 / Accepted: 13 October 2016

Abstract
Objectives The objective of this clinical study was to evaluate the clinical performance of implant-supported zirconia crowns with a sintered veneering cap. Furthermore, the influence of the type of retention (screw-retained vs cemented single crowns) was analysed.
Materials and methods Fifty-eight patients were accommodated with 114 implants, inserted in the molar and premolar regions. Zirconia-based crowns with a sintered veneering cap were either screw-retained (n = 53) or cemented (n = 61) on the implant. Recalls were performed every 6 months. The state of soft tissue was documented by the modified plaque and gingiva index (mPI) and sulcus bleeding index (mSBI). The restorations were evaluated for technical failures like veneering porcelain fractures, surface qualities and marginal fitting.
Results Neither implant loss nor crown fractures occurred. After a mean clinical service time of 36.9 months, fractures of the veneering porcelain were registered in 1.8 % of the cases. The Kaplan-Meier survival probability regarding eventless restorations was 98.2 %. Chipping of the veneering porcelain was registered in two cemented crowns without statistical influence of the type of retention. The indices showed healthy soft periimplant tissues in both groups.
Conclusions Implant-supported zirconia crowns with a sintered veneering cap demonstrated good clinical performance. The type of retention had no influence on technical complications.

Keywords Implat · Implant-supported crown · Screw retention · Cementation · Single crown

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Introduction

Prosthetic restorations made of all-ceramic materials have proved suitability in the aesthetic zone due to their high aesthetics and outstanding biocompatible parameters [1–7]. Nevertheless, clinically based evidence is a key factor in distinguishing survival and longevity of one material versus those of another.

Dental ceramic materials have been developed to match with the demands of different indications like aesthetics, biocompatibility, wear resistance, low thermal conductivity and colour stability. Ceramic restorations are frequently placed in contemporary practice [8].

With the introduction of the high-strength ceramic zirconia, even the treatment of posterior teeth with all-ceramic restorations and the application of ceramic abutments for implant restorations became possible [9–11]. In addition to its high strength, zirconia exhibits lower plaque accumulation and bacterial adhesion compared to other ceramic materials used in the oral cavity [12]. Zirconia is processed by milling either presintered or fully sintered blanks with the aid of computer-aided design/computer-aided manufacturing (CAD/CAM) systems in order to achieve industrial quality standards [13]. Studies of layered zirconia have reported that chipping of the veneering porcelain is the major clinical problem [14–20] and influenced by several factors [21–27]. One technical solution might be the digital veneering of zirconia-based copings

Published online: 29 October 2016

described several years ago, showing promising mechanical strength [24, 25].

Although implant-supported zirconia-based restorations exhibit high clinical survival rates [17], resembling the ones of tooth-borne reconstructions [28], the rate of chipping is higher than for tooth-supported restorations [16, 29, 30] due to missing periodontal receptors on implant-supported restorations [31, 32].

Implant restorations can either be screw-retained on the implant or cemented on standard or customized abutments. Both options have shown similar outcomes in clinical studies [28]. While cemented restorations exhibit more serious biological complications (periimplant inflammation), as a consequence of possible remaining excess cement [33–35], screw-retained reconstructions are retrievable but show more technical problems [28, 36–38].

The aim of the current study was to investigate the clinical survival rate of zirconia implant-supported all-ceramic single crowns with a sintered veneering cap with two different types of retention. The null hypothesis was that the used zirconia crowns show no adequate stability regarding chipping. The working hypotheses of this study were that the ziconia implant-supported crowns with sintered veneering caps show comparable survival rates to outcomes in the literature. The effect of retention was compared between both cemented and screw-retained restauration in a prospective study design.

Material and methods

Fifty-eight patients were included in this randomized prospective study between March 2008 and November 2013 from two dental offices in Munich. Inclusion criteria were in need of at least one implant-supported single crown, adult (≥18 years), good oral hygiene (API < 10 %, SBI < 10 %), non-smokers or moderate smokers (less than five cigarettes per day), no TMD problems according to the RDC criteria [39, 40], and no contraindications for surgery. After gathering detailed preimplant medical history (general as well as specific) from all patients, individual surgical implant planning was made based upon a panoramic radiograph and dental model analysis following a standardized protocol.

All clinical investigations have been conducted according to the principles expressed in the Declaration of Helsinki. Registration of the study was performed after conduction of the study as a result of changes in ethics policies. The study was approved by the institutional ethics committee of Munich University (no. 434/14). Patient gave their written consent.

Surgical and restorative treatment

A crestal incision was made, followed by the preparation of a mucoperiosteal flap to expose the alveolar bone. In cases of reduced vertical bone height in the maxilla, augmentation in the sense of a sinus lift augmentation surgery was performed before inserting the implants (Camlog Promote/Promote Plus; Conelog, Wimsheim, Germany) at a maximum torque of 50 N cm, using a drilling template (according to the insertion protocol). Additionally, simultaneous bone augmetation procedure with autologous bone, bovine bone graft substitute and resorbable collagen membrane (BioOss & BioGide, Geistlich Pharma, Wolhusen, Switzerland) was performed in cases where vestibular augmentation was needed. In all cases, a closed healing was performed by saliva-proof (resorbable/non-resorbable) sutures. For postoperative control, a panoramic X-ray was taken and patients were supplied with ibuprofen 800 in addition to the preoperative antibiotic and anti-inflammatory single-shot treatment (clindamycin, cortison). The surgical part was completed by the re-entry and insertion of the healing abutment 4 months after implant placement. Two weeks after re-entry, impressions were taken to transfer the implant position by the open tray technique by using polyether material (Impregum, 3M ESPE, Landsberg, Germany).

Dental laboratory

After producing the master casts and mounting them in a semi-adjustable (SAM PX 2, SAM, Gauting, Germany) articulator, the titanium abutments were selected by the technician depending on the implant axis and level of soft tissue. The models were treated to create an emergence profile [41–43]. If needed, the titanium abutment was customized by grinding, before the coping was fabricated in wax. Particular attention was paid to the minimum thickness of 0.5 mm. The wax pattern of the coping was scanned (D 700, 3shape, Copenhagen, Denmark) and then milled out of a presintered zirconia block (IPS e.max ZirCAD, Ivoclar Vivadent, Ellwagen, Germany) by a CAD/CAM system (Corona, Starnberg, Germany) and sintered to full density (Denta-Star S1 plus, Thermostar, Aachen, Germany) to obtain the zirconia coping of the crown.

The veneering was fabricated from lithium disilicate according to the CAD-on technique described earlier [44]. However, deviant from the traditional protocol, the veneering caps were fabricated in 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 by using a special lithium disilicate glass ceramic (IPS e.max Press, Ivoclar Vivadent). The two components (CAD/CAM framework and overpressed veneering cap) were sintered together in a conventional ceramic furnace (Austromat, Dekema, Freilassing, Germany) at a temperature of 780 °C by the means of a low-fusing ceramic material (Hotbond Fusio Sytem, DCM, Rostock, Germany). In order to create a suitable surface quality, several glaze firings were performed after necessary adjustments were made by using diamond grinding tools (Table 1).

In cases of screw retention, the ceramic crown was bonded on the titanium abutment by using a resin-based luting material (Multilink Implant, Ivoclar Vivadent).

If a customized zirconia abutment was required for aesthetic reasons, also a wax pattern was fabricated; this wax pattern was scanned (LAVA TM ScanST2, 3M ESPE, Landsberg, Germany) and milled by a CAD/CAM system (Corona, Starnberg, Germany) from presintered zirconia (LAVA, 3M ESPE) and sintered in the furnace of the system (LAVA-Therm, 3M ESPE). The sintered zirconia abutment was bonded to the titanium base by a dual-curing composite resin (Multilink Implant). After the custom zirconia abutment was finished, the allceramic superstructure was produced in the same way as described above.

Prosthetic procedure

Prosthetic restorations were either screwed-in or cemented implant single crown based on a computer-generated randomized list. Fifty-three crowns were screw-retained (Figs. 1 and 2), whereby the access was sealed with Ketac Fil and flowable composite. The other 61 crowns were fixed on the abutment by using a resin-modified glass ionomer cement (Fuji Plus, GC, Alsip, IL (USA)/Ketac Cem, 3M ESPE, Landsberg, Germany). A postoperative radiograph was performed additionally to clinical observation for possibly remaining excess cement. The insertion of the implant crowns was carried out by the following proven prosthetic occlusion concept. Static, dynamic and approximal contacts were checked and removed if necessary. The objective was to avoid dynamic contacts on molars and to achieve less static occlusion contact on implant-supported crowns than on natural teeth, checked by the 8-μm-thick Shimstock foil (Bausch, Köln, Germany). Less static occlusion contacts of implant-supported crowns were achieved when the Shimstock foil was hold tight only at the adjacent teeth in maximum intercuspation. The occlusion was adjusted so that

Table 1 Furnace program for sintering

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
Temperature 3	... °C	...°C/min	–
VAC	780 °C	100 %	–

Fig. 1 Occlusal view on a screw-retained crown at the time of delivery

each tooth presented at least one stable occlusal contact in maximum intercuspation. Contacts in lateral excursions on the restorations were eliminated. If occlusal adjustments were necessary after cementation, diamond burs with 30–40 μm grain size were used (contra-angle handpiece; 100,000 rpm; water cooling 50 ml/min). Finally, the occlusal surface was polished again with ceramic polishing instruments in three steps (Zirconium Polishers fine and extra fine, Oridima, Ortenburg, Germany).

Recall

One week after insertion of the crown, the occlusion was checked again. At the next follow-up appointment after 6 weeks, crowns and periimplant tissues were inspected again and patients were reinstructed concerning adequate oral hygiene. Depending on necessity, professional tooth cleaning was performed two up to four times a year in addition to the 6-month recall monitoring. Contact wear was checked based on the Shimstock protocol as described above. Occlusal adjustments were protocolled by photographs in which each modification was indicated by one calibrated dentist.

Statistics

The monitoring and documentation of the results was performed by one calibrated dentist who was neither involved

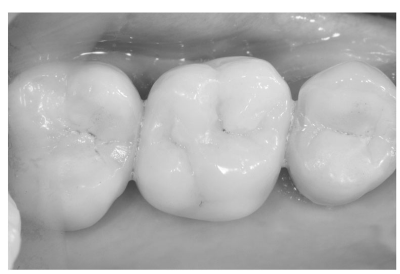

Fig. 2 Occlusal view on a screw-retained crown at the 6-month recall

in placing the implants nor in delivering the crowns. The following parameters were gathered: the modified plaque and gingiva index (mPI) by Silness and Löe and modified sulcus bleeding index (mSBI) described by Muehlemann. The modified Silness and Löe plaque and gingiva index is defined by a score from 0 (=no plaque and no inflammation), 1 (=mild inflammation and a film of plaque adhering to the free gingival margin which cannot be seen with the naked eye but only by using probe), 2 (=moderate inflammation with moderate glazing, redness, bleeding on probing and moderate accumulation of deposits within the gingival pocket and on the gingival margin, which can be seen with the naked eye) to 3 (=abundance of soft matter within the gingival pocket and/or on the tooth and gingival margin; severe inflammation with redness, hypertrophy and tendency to spontaneous bleeding). The modified Mühlemann sulcus bleeding index is scored from 0 (=no bleeding), 1 (=a single discreet bleeding point), 2 (=several isolated bleeding points or a single line of blood appears), 3 (=the interdental triangle fills with blood shortly after probing) to 4 (=profuse bleeding occurs after probing). The restorations were evaluated for technical failures like chipping behaviour, surface qualities and marginal fitting, as well as the interface quality of coping and sintered veneering and contact wear according to the modified US Public Health Service (USPHS) criteria rating system. Results of this rating system were evaluated by using the Mann-Whitney *U* test. Descriptive statistics for quantitative variables are given as the mean ± standard deviation. The data were analysed with the "Statistical Package for the Social Sciences" software (IBM SPSS Statistics for Windows, Version 22.0; IBM Corp., Armonk, NY, USA). Association of possible predictor variables with the dependent variable chipping was determined by 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 were considered to be statistically significant for a two-sided p value of less than 0.05.

Results

Patients

A total of 58 patients were successfully treated in this study and were prospectively evaluated based on the study protocol. Over the observational time period, eight patients were excluded as dropouts because they did not agree to participate in the follow-up intervals in five cases, two patients moved, and one patient did not want to have his follow-up data collected. There were 36 women and 22 men included in this study. Of the 114 implant-supported zirconia-based crowns veneered with a high-strength ceramic by sintering, 53 crowns were inserted in a screw-retained manner, and 61 crowns were fixed on the abutment by using a resin-modified glass ionomer cement. The distribution of crowns applied is shown in Table 2.

The mean observation period for the restaurations of all patients included was 36.9 months (Fig. 3).

Prosthetic restoration

The cumulative incidence of veneering fractures was 1.8 % (Figs. 3 and 4), resulting in a 98.2 % overall success rate. After 3 years of follow-up, no chipping was detected in any group. Chipping occurred on two cemented crowns (3.3 %) after a mean time of 48 ± 5.7 months, whereas no chipping was found on screw-retained ones. Comparing both groups, no significant difference was detected between cemented and screw-retained implant crowns by using the univariate log-rank test ($p = 0.518$, Fig. 3).

The mean plaque index in all groups was 0.5 ± 0.6. In patients with cemented crowns, the mean plaque index was 0.6 ± 0.1 compared with 0.4 ± 0.1 in patients with screw-retained fixated crowns. There was no significant difference between both groups ($p = 0.08$). The mean gingival index was 0.4 ± 0.5. Patients with cemented crowns showed a mean gingiva index of 0.4 ± 0.1, whereas patients with screw-retained crowns had a mean value of 0.3 ± 0.1. Between both groups, no difference was detected ($p = 0.41$). The mean bleeding index was 0.6 ± 0.6 in all patients, for patients with cemented crowns with an index of 0.7 ± 0.1 compared with 0.5 ± 0.1 in screw-retained crowns. There was no difference between both groups ($p = 0.66$). Patients were restored with crowns at different gingival levels depending on the aesthetic and functional results. In cemented crowns, 15 were localized at the gingival level (isogingival), 3 above (supragingival), and 43 were applied under the level of gingiva (subgingival). There was no association with the gingiva, bleeding or plaque index in any group. Custom abutments were used for 27 crowns, while standard abutments were used in 34 cases. Again, there was no association between the type of abutment applied or chipping ($p = 0.196$). There was no influence on the plaque index ($p = 0.254$), gingival index ($p = 0.377$), nor the bleeding index ($p = 0.102$) of the soft tissue around the crowns. In comparison, crowns with screw retention, 7 were located at the gingival level (isogingival), 6 above (supragingival), and 40 were applied under the level of gingiva (subgingival). In these cases, no association detected with the gingival, bleeding or plaque index was found.

Table 2 Number of implant teeth restorations depending on the position of the applied crown

Tooth position [upper jaw]	17	16	15	14	24	25	26	27
Number of restaurations	3	5	4	6	2	5	3	3
Tooth position [lower jaw]	37	36	35	34	44	45	46	47
Number of restaurations	4	10	3	0	2	1	9	1

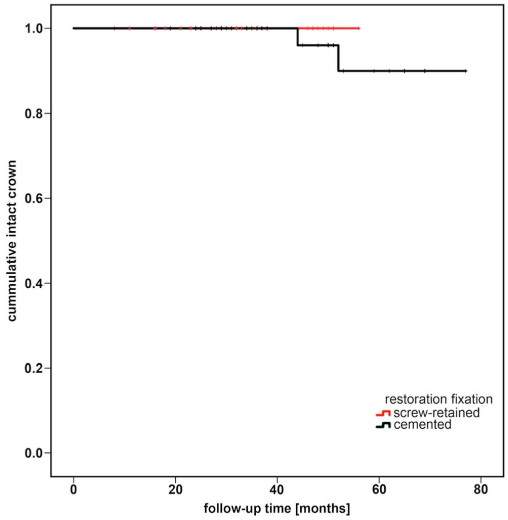

Fig. 3 Kaplan-Meier graph showing all events for screw-retained and cemented crowns in relation to the time of occurrence. Between both groups, no significant difference was noted evaluated by the log-rank test ($p = 0.518$)

The detailed clinical inspection revealed an apparently proper condition of the crown surfaces in general (beside the two chipping cases mentioned above). There were no irregularities or marginal gaps detectable on dental probe over time. On a range from alpha, bravo, charlie, to delta, 112 crowns could be classified to alpha and two crowns were bravo (modified USPHS criteria). Between both groups, no significant differences were detected.

Furthermore, it was investigated whether the all-ceramic superstuctures or antagonistic dentition showed any contact wear. The cemented restorations did show visible contact wear in 1.8 % of cases, whereas contact wear was found on screw-retained implant crowns in 4.6 % of cases without exhibiting statistical differences ($p = 0.480$).

Fig. 4 Occlusal view on veneering porcelain fractures of a cemented crown (first molar); the tooth-supported crown on the second molar also exhibits a fracture of the veneering structure

Cemented restorations caused contact wear on the antagonistic teeth more frequently than screw-retained crowns (16.5 vs 10.7 %). Comparing these results by using the Mann-Whitney *U* test did not reveal any significant difference ($p = 0.318$). These traces of contact wear were found in patients who showed crossbite or extreme deep bite situations as well at those lacking a clear canine guidance.

Discussion

Regarding the survival rates of zirconia implant-supported crowns with a sintered veneering cap, the first working hypothesis of this study has to be rejected. The current study shows that zirconia-based crown copings being veneered with a high-strength ceramic cap show better performance with respect to their chipping behaviour and demonstrate potential significant lower risk of ceramic fractures compared with the literature. Based on the finding of this study, the null hypothesis could be rejected. Chipping of veneering ceramics has been reported in various clinical studies [14, 15, 45–48]. In a systematic review of the survival and complication rates of implant-supported single crowns, Jung et al. reported 4.5 % chipping after 5 years [17].

In a retrospective study, Schwarz et al. revealed an incidence of chipping in implant-supported all-ceramic single crowns of 24.5 % after an observation period up to 5.8 years [18].

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, taking into account that the majority of the treatments were performed in anterior regions [49]. The results of the present study are similar, as chipping occurred after 48 ± 5.7 months.

In a systematic review, Sailer et al. detected that fractures of the veneering porcelain occurred more frequently on tooth-supported zirconia single crowns than on metal-ceramic single crowns ($p < 0.001$) after 5 years. They recommended that zirconia-based single crowns should not be considered a primary option due to their high incidence of technical problems [50].

According to the systematic review, conducted by Sailer et al. in 2007, all-ceramic crowns on natural teeth showed survival rates after 5 years comparable to those seen in metal-ceramic crowns when used in anterior regions. Lower survival rates of 90.4 and 84.4 % were found in glass-infiltrated alumina crowns and glass-ceramic crowns when used in the treatment of premolars and molars [51].

In vitro studies have demonstrated that CAD/CAM-produced veneerings were significantly less sensitive to ageing than hand-layered veneerings and show significantly lower initial load-bearing capacities (mean 1165.86 vs 395.45 N). During chewing simulation, 87.5 % of the crowns in the hand-layered group failed, whereas no crown in the CAD/CAM group failed [25]. The CAD/CAM production of veneers for restorations with zirconia framework is a promising way to reduce failures originating from material fatigue [24, 44].

In vitro studies showed as well that zirconia-based crown copings being veneered with a high-strength ceramic cap have a better performance in terms of fracture load and demonstrate potential significant lower risk of chipping [44].

The second working hypotheses concerning the difference between cemented and screw-retained implant crowns can be accepted. In the present clinical study, chipping of parts of the veneering ceramic was registered on two cement-retained single crowns in the first molar of the lower jaw. According to Kaplan-Meier, there was no significant difference detectable in the chipping rate between cemented and screw-retained implant crowns ($p = 0.518$). Anyway, screw-retained implant crowns are more favoured by the clinician, due to their reduced risk of biological complications as a consequence of remaining excess cement. In the present study, we found no significant difference between both groups, either screw-retained or cemented. Based on these findings, both methods showed comparable results which offers the clinician both possibilities of retention without any disadvantage regarding the outcome in terms of plaque, bleeding or gingival indexes. In addition, the antagonistic teeth exhibited all-ceramic crowns in the first case and composite fillings in the second case.

With regard to the contact wear behaviour of the antagonistic teeth (14.1 %), no tendency is preferable. Abrasion occurred in natural teeth, as well as in teeth that had been provided with composite fillings, also in ceramic crowns or bridges and restorations made of gold and acrylic resin dentures. Further specific investigations are needed to answer the question if high-strength ceramic reconstructions as described above might even be too strong.

Most studies evaluating chipping after restorations with ceramics are limited by the fact that the patients are surveyed in a retrospective manner. Only large, controlled, prospectively designed studies can resolve clinical questions completely. Although the present study was performed in a prospective manner, there are also some limitations associated with the patients' selection over a long time period as well as with the limited number of patients, which still requires for more studies or participation of multiple centres. In addition, the cause of chipping cannot be deduced from the current study. The present results are promising, but still, more data is needed concerning hygiene, stability and patients' satisfaction.

Conclusions

Within the limitations of the study, the following conclusions can be drawn:

Within the limited mean observation time of 36.9 months, implant-supported zirconia-based crown copings being veneered with a high-strength ceramic by sintering, both cement-retained and screw-retained, demonstrated a satisfying success rate under clinical conditions for premolar and molar regions. In regards of technical and biological outcomes, screw-retained single crowns showed comparable clinical performance to cemented single crowns.

Compliance with ethical standards

Conflict of interest Author FC and TM state that no conflict of interest exists.

The author CC lectures for Camlog and Ivoclar for an adequate honorarium.

The author PR lectures for Camlog and Ivoclar for an adequate honorarium.

The author JH lectures for Camlog and Ivoclar for an adequate honorarium.

The author FB lectures for Camlog and Ivoclar for an adequate honorarium and conducts third-party research for both companies.

Funding The work was not funded.

Ethical approval All procedures performed in studies involved were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the ethical review board of the Munich University (no. 434 14).

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

References

1. Devaud V (2005) Guidelines for success with zirconia ceramics: the changing standards. Pract Proced Aesthet Dent 17(8):508 510
2. Della Bona A (2004) J.J. Mecholsky, Jr., and K.J. Anusavice, *Fracture behavior of lithia disilicate- and leucite-based ceramics*. Dent Mater 20(10):956–962
3. Raigrodski AJ (2005) All-ceramic full-coverage restorations: concepts and guidelines for material selection. Pract Proced Aesthet Dent 17(4):249–256 quiz 258
4. Sorensen JA et al (1998) In-Ceram fixed partial dentures: three-year clinical trial results. J Calif Dent Assoc 26(3):207–214
5. Sorensen JA et al (1998) IPS empress crown system: three-year clinical trial results. J Calif Dent Assoc 26(2):130–136
6. Coli P, Karlsson S (2004) Precision of a CAD/CAM technique for the production of zirconium dioxide copings. Int J Prosthodont 17(5):577–580
7. Edelhoff D, Sorensen JA (2002) Retention of selected core materials to zirconia posts. Oper Dent 27(5):455–461
8. Conrad HJ, Seong WJ, Pesun IJ (2007) Current ceramic materials and systems with clinical recommendations: a systematic review. J Prosthet Dent 98(5):389–404
9. Kohorst P et al (2007) Load-bearing capacity of all-ceramic posterior four-unit fixed partial dentures with different zirconia frameworks. Eur J Oral Sci 115(2):161–166
10. Kohorst P et al (2008) Influence of cyclic fatigue in water on the load-bearing capacity of dental bridges made of zirconia. Acta Biomater 4(5):1440–1447

11. Nakamura K et al (2010) Zirconia as a dental implant abutment material: a systematic review. Int J Prosthodont 23(4):299–309
12. Bremer F et al (2011) In vivo biofilm formation on different dental ceramics. Quintessence Int 42(7):565–574
13. Luthardt RG et al (2004) CAD/CAM-machining effects on Y-TZP zirconia. Dent Mater 20(7):655–662
14. Sailer I et al (2007) A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part II: fixed dental prostheses. Clin Oral Implants Res 18(Suppl 3):86–96
15. Sailer I et al (2007) Five-year clinical results of zirconia frameworks for posterior fixed partial dentures. Int J Prosthodont 20(4):383–388
16. Larsson C, Vult P (2010) Von Steyern, *Five-year follow-up of implant-supported Y-TZP and ZTA fixed dental prostheses. A randomized, prospective clinical trial comparing two different material systems*. Int J Prosthodont 23(6):555–561
17. Jung RE et al (2008) A systematic review of the 5-year survival and complication rates of implant-supported single crowns. Clin Oral Implants Res 19(2):119–130
18. Schwarz S et al (2012) Survival and chipping of zirconia-based and metal-ceramic implant-supported single crowns. Clin Implant Dent Relat Res 14(Suppl 1):e119–e125
19. Aboushelib MN, Kleverlaan CJ, Feilzer AJ (2006) Microtensile bond strength of different components of core veneered all-ceramic restorations. Part II: zirconia veneering ceramics. Dent Mater 22(9):857–863
20. Aboushelib MN et al (2005) Microtensile bond strength of different components of core veneered all-ceramic restorations. Dent Mater 21(10):984–991
21. Rosentritt M et al (2009) Influence of substructure design and spacer settings on the in vitro performance of molar zirconia crowns. J Dent 37(12):978–983
22. Rosentritt M et al (2009) Fracture performance of computer-aided manufactured zirconia and alloy crowns. Quintessence Int 40(8): 655–662
23. Swain MV (2009) Unstable cracking (chipping) of veneering porcelain on all-ceramic dental crowns and fixed partial dentures. Acta Biomater 5(5):1668–1677
24. Schmitter M, Mueller D, Rues S (2012) Chipping behaviour of all-ceramic crowns with zirconia framework and CAD/CAM manufactured veneer. J Dent 40(2):154–162
25. Schmitter M, Mueller D, Rues S (2013) In vitro chipping behaviour of all-ceramic crowns with a zirconia framework and feldspathic veneering: comparison of CAD/CAM-produced veneer with manually layered veneer. J Oral Rehabil 40(7):519–525
26. Du Q, Swain MV, Zhao K (2014) Fractographic analysis of anterior bilayered ceramic crowns that failed by veneer chipping. Quintessence Int 45(5):369–376
27. Broseghini C et al (2014) Aesthetic functional area protection concept for prevention of ceramic chipping with zirconia frameworks. Int J Prosthodont 27(2):174–176
28. Sailer I et al (2012) Cemented and screw-retained implant reconstructions: a systematic review of the survival and complication rates. Clin Oral Implants Res 23(Suppl 6):163–201
29. Larsson C, Vult P (2010) Von Steyern, and K. Nilner, *A prospective study of implant-supported full-arch yttria-stabilized tetragonal zirconia polycrystal mandibular fixed dental prostheses: three-year results*. Int J Prosthodont 23(4):364–369
30. Pjetursson BE et al (2007) 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 18(Suppl 3):97–113
31. Hammerle CH et al (1995) Threshold of tactile sensitivity perceived with dental endosseous implants and natural teeth. Clin Oral Implants Res 6(2):83–90
32. Ciftci Y, Canay S (2000) The effect of veneering materials on stress distribution in implant-supported fixed prosthetic restorations. Int J Oral Maxillofac Implants 15(4):571–582
33. Linkevicius T et al (2011) The influence of margin location on the amount of undetected cement excess after delivery of cement-retained implant restorations. Clin Oral Implants Res 22(12):1379–1384
34. Agar JR et al (1997) Cement removal from restorations luted to titanium abutments with simulated subgingival margins. J Prosthet Dent 78(1):43–47
35. Wilson TG Jr (2009) The positive relationship between excess cement and peri-implant disease: a prospective clinical endoscopic study. J Periodontol 80(9):1388–1392
36. Chee W, Jivraj S (2006) Screw versus cemented implant supported restorations. Br Dent J 201(8):501–507
37. Michalakis KX, Hirayama H, Garefis PD (2003) Cement-retained versus screw-retained implant restorations: a critical review. Int J Oral Maxillofac Implants 18(5):719–728
38. Chee WW, Torbati A, Albouy JP (1998) Retrievable cemented implant restorations. J Prosthodont 7(2):120–125
39. Schiffman E et al (2014) Diagnostic criteria for temporomandibular disorders (DC/TMD) for clinical and research applications: recommendations of the international RDC/TMD consortium network* and Orofacial pain special interest Groupdagger. J Oral Facial Pain Headache 28(1):6–27
40. Hansson TL (2004) RDC/TMD criteria. J Orofac Pain 18(3):178 author reply 178
41. Khoury F, Happe A (2000) Soft tissue management in oral implantology: a review of surgical techniques for shaping an esthetic and functional peri-implant soft tissue structure. Quintessence Int 31(7):483–499
42. Happe A et al (2015) Effects of different polishing protocols on the surface roughness of Y-TZP surfaces used for custom-made implant abutments: a controlled morphologic SEM and profilometric pilot study. J Prosthet Dent 113(5):440–447
43. Dornbush JR, Reiser GM, Ho DK (2014) Platform switching and abutment emergence profile modification on peri-implant soft tissue. Alpha Omegan 107(2):28–32
44. Beuer F et al (2009) High-strength CAD/CAM-fabricated veneering material sintered to zirconia copings—a new fabrication mode for all-ceramic restorations. Dent Mater 25(1):121–128
45. Molin MK, Karlsson SL (2008) Five-year clinical prospective evaluation of zirconia-based Denzir 3-unit FPDs. Int J Prosthodont 21(3):223–227
46. Raigrodski AJ et al (2006) The efficacy of posterior three-unit zirconium-oxide-based ceramic fixed partial dental prostheses: a prospective clinical pilot study. J Prosthet Dent 96(4):237–244
47. Tinschert J et al (2008) Clinical behavior of zirconia-based fixed partial dentures made of DC-Zirkon: 3-year results. Int J Prosthodont 21(3):217–222
48. Vult von Steyern P, Carlson P, Nilner K (2005) All-ceramic fixed partial dentures designed according to the DC-Zirkon technique. A 2-year clinical study. J Oral Rehabil 32(3):180–187
49. Glauser R et al (2004) Experimental zirconia abutments for implant-supported single-tooth restorations in esthetically demanding regions: 4-year results of a prospective clinical study. Int J Prosthodont 17(3):285–290
50. Sailer I et al (2015) All-ceramic or metal-ceramic tooth-supported fixed dental prostheses (FDPs)? A systematic review of the survival and complication rates. Part I: single crowns (SCs). Dent Mater 31(6):603–623
51. Pjetursson BE et al (2007) A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part I: single crowns. Clin Oral Implants Res 18(Suppl 3):73–85

5. Diskussion

In diesem Abschnitt werden die jeweiligen Untersuchungen einzeln diskutiert.

5.1 Klinisches Verhalten von Sinterverbundkronen auf Implantaten und natürlichen Zähnen: Ergebnis nach 42 Monaten

Diese Studie hat ergeben, dass die klinische Erfolgsrate der hier untersuchten Sinterverbundkronen auf Implantaten und Zähnen höher ist (98.2% bzw. 100%), als die in der Literatur angegebenen Überlebensraten von vollkeramischen Einzelzahnversorgungen.

Die erste Arbeitshypothese, welche lautete, dass implantatgetragene und zahngetragene Sinterverbundkronen bessere klinische Ergebnisse im Hinblick auf ihr Chippingverhalten zeigen würden als Keramikkronen in früheren Studien, kann somit bestätigt werden.

Trotz ihrer hohen Gerüststabilität sind Abplatzungen der Verblendung das Hauptproblem bei Zirkonoxidkeramikkronen. Dies ist das Ergebnis einiger klinischer Studien [11-13]. Ungenügende Festigkeitswerte der Verblendkeramik führen hier häufig zu Chippings innerhalb der Verblendung, den sogenannten Kohäsionsfrakturen [14].

In einer Langzeitstudie berichteten Teichmann et al. von Chippingraten bei Vollkeramikeinzelkronen auf natürlichen Zähnen von 15.4% nach 5 Jahren und 16.6% nach 10 Jahren [15].

Jung et al. beobachteten bei implantatgetragenen Keramikkronen Chippingraten von 3.5% nach 5 Jahren [16]. Die retrospektive Studie von Schwarz et al. ergab eine

Chippingrate von 24.5% nach 5.8 Jahren [17], während Teichmann et al. nach 5 Jahren 0% Chipping beobachteten und nach 10 Jahren 5.9% [15].

In der Literatur werden unterschiedliche Ursachen für Keramikchipping diskutiert.

Hier sind beispielsweise starke innerere Spannungen in der Verblendmasse, schlecht aufeinander abgestimmte Wärmeausdehnungskoeffizienten oder störende Vorkontakte zu nennen [18-20].

Oftmals sind Einschleifmaßnahmen zur Vermeidung von Frühkontakten und dem gelegentlich hieraus resultierenden Chipping erforderlich. Eine Bearbeitung der Verblendkeramikoberfläche zur Korrektur der Okklusion, kann jedoch neben einer erhöhten Plaqueakkumulation ebenfalls einen negativen Einfluss auf die Festigkeitswerte der Konstruktion haben und zu Abplatzungen der Verblendung führen [21, 22].

Auch ist auf eine "keramikgerechte" Präparationsart zu achten, wobei insbesondere scharfe Kanten vermieden und Mindestmaterialstärken eingehalten werden sollten. Eine anatomische Gestaltung des Gerüstes zur Erzielung einer gleichmäßigen Verblendschicht und die Vermeidung zu dünner Gerüstwandstärken scheint von besonderer Bedeutung zu sein [9].

In vitro Studien haben ergeben, dass mittels CAD/CAM-Verfahren hergestellte Verblendungen weniger anfällig für Alterung sind als handgeschichtete Verblendungen und eine signifikant höhere Bruchlastzähigkeit aufweisen. Während der Kausimulation zerbrachen 87.5% der handgeschichteten Verblendungen, wobei kein Schaden an den Kronen mit CAD/CAM Verblendung auftrat [23].

Die Herstellung von Verblendungen mit Hilfe von CAD/CAM Verfahren scheint demnach für Zirkonoxidgerüste vielversprechend zu sein, um die Bruchanfälligkeit durch Materialermüdung zu reduzieren [24, 25].

In der vorliegenden Studie wurden Kronen bestehend aus einem Zirkonoxidgerüst und einer Verblendung aus Lithiumdislikatkeramik untersucht. Die zwei Komponenten (CAD/CAM Gerüst und gepresstes Verblendkäppchen) sind mit Hilfe einer niedrig viskösen keramischen Masse in einem Brennofen zusammengesintert worden.

Ein Grund für die geringe Anzahl an Chippings könnte die anatoforme okklusale Gerüstgestaltung zur optimalen Unterstützung der Höcker und die Vermeidung scharfer Innenkanten und Unterschnitte sein.

Beim Einsetzen der Kronen war darüber hinaus darauf geachtet worden, dass durch eine funktionierende Eckzahnführung dynamische Kontakte bei der Lateralbewegung im Molarenbereich vermieden wurden und statische Kontakte auf den Implantatkronen etwas geringer waren als die der natürlichen Zähne.

In der Studie hatte die Art des Abutments (vitaler Zahn/ endodontisch behandelter Zahn/ Implantat) einen signifikanten Einfluss auf die Überlebensrate der Restauration.

Die implantatgetragenen Sinterverbundkronen dieser Studie wiesen eine signifikant höhere Chippingrate auf, verglichen mit Kronen auf natürlichen Zähnen ($p=0.039$), wodurch sich eine Überlebensrate von 98.2% ergab. Dies könnte auf die starre Verankerung der Implantate im Knochen zurückzuführen sein.

Die Auswertung der 3-Jahres Daten von Sinterverbundkronen auf natürlichen Zähnen ergab eine Überlebensrate von 100%, sowohl für vitale als auch für endodontisch behandelte Zähne. Dies stimmt nicht mit Ergebnissen anderer klinischer Studien überein, welche von reduzierten Überlebensraten von Vollkeramik- und Metallkeramikkronen auf wurzelbehandelten Zähnen berichteten [13, 26].

Desweiteren hatte in der vorliegenden Studie die Kronenlokalisation keinen signifikanten Einfluss auf die Erfolgsrate der Sinterverbundkronen. Dies steht ebenfalls in Kontrast zu den Ergebnissen anderer Studien [13, 27, 28], in welchen Vollkeramikkronen im Molarenbereich hohe Komplikationsraten aufwiesen.

Verglichen mit weiteren klinischen Untersuchungen von Zirkonoxidkronen auf natürlichen Zähnen [29, 30], konnte auch in der vorliegenden Arbeit ein Vorkommen von Sekundärkaries nicht festgestellt werden.

Trotz einer konischeren Präparation mit einem etwas erhöhten Substanzabtrag waren biologische Komplikationen wie beispielsweise ein möglicher Vitalitätsverlust nach dem Einsetzen nicht zu finden. Auch wurde kein Retentionsverlust beobachtet, weder an den Kronen noch an Implantaten.

Die zweite Arbeitshypothese, welche besagte, dass implantatgetragene Kronen und SVK-Kronen auf natürlichen Zähnen ähnliche klinische Ergebnisse hinsichtlich ihres Chippingverhaltens aufweisen würden, ist nicht zu bestätigen, da in der vorliegenden Studie an zwei zementierten Implantatkronen im Molarenbereich des Unterkiefers Abplatzungen auftraten. Dies ergibt nach Kaplan-Meier einen signifikanten Unterschied in der Chippingrate zwischen zahn- und implantatgetragenen Sinterverbundkronen ($p=0.039$).

Keine Unterschiede zwischen den beiden Gruppen zeigten sich allerdings im Hinblick auf das periimplantäre bzw. periodontale Gewebe. Weder Gingivahyperplasien, Rezessionen noch schmerzhafte Taschenbildungen mit Blutung auf Sondierung waren zu beobachten. Dies dürfte auf die vor der Implantation durchgeführten

Parodontalbehandlungen zurückzuführen sein, sowie auf konsequente Mundhygieninstruktionen während der Beobachtungszeit.

Ferner wurden bei den implantatgetragenen Sinterverbundkronen keine biologischen Komplikationen, wie beispielsweise ein Knochenverlust von mehr als einem Millimeter festgestellt.

Keine der zahngetragenen Sinterverbundkronen entwickelte in der Folgezeit eine Hypersensitivität.

Hinsichtlich des Abrasionsverhaltens der Antagonisten sind weiterführende Untersuchungen nötig, um die Frage zu klären, ob prothetische Versorgungen aus Sinterverbundkeramik, wie sie in dieser Studie untersucht wurden, möglicherweise zu abrasiv sind.

Die begrenzte Patientenzahl sowie die Tatsache, dass häufig mehr als eine Restauration pro Patient eingegliedert worden waren, haben einen limitierenden Einfluss auf die Aussagekraft der Studie. Auch konnte durch die vorliegende Untersuchung der Grund für das Vorkommen von Chippings nicht abschließend geklärt werden.

Über die in dieser Arbeit gewonnenen Erkenntnisse hinaus sind weiterführende Erhebungen hinsichtlich Hygiene, Stabilität sowie Patientenzufriedenheit erforderlich.

5.2 Klinisches Verhalten von verschraubten und zementierten Sinterverbundkronen auf Implantaten: Ergebnis nach 36 Monaten

Die Ergebnisse dieser Studie haben gezeigt, dass implantatgestützte Sinterverbundkronen im Molarenbereich in der klinischen Anwendung ein signifikant geringeres Risiko von Abplatzungen der Verblendkeramik aufweisen als in der Literatur angegeben. Demnach kann die erste Arbeitshypothese, dass Sinterverbundkronen auf Implantaten mit den in der Literatur beschriebenen Daten vergleichbare Überlebensraten zeigen, nicht bestätigt werden.

Im klinischen Alltag stellen Chippings der Verblendkeramik bei Implantatkronen ein häufiges Problem dar.

Zu diesem Thema sind zahlreiche Studien mit unterschiedlichen Ergebnissen durchgeführt worden [8, 11, 12, 31, 32]. Jung et al. berichteten in ihrer Studie von einer 3.5%igen Chippingrate nach 5 Jahren [16], während Schwarz et al. bei 24.5% der untersuchten Implantatkeramikkronen Abplatzungen nach durchschnittlich 5.8 Jahren feststellten [17]. In einer prospektiven Studie, fanden Glauser et al. nach einer Beobachtungszeit von 49.2 Monaten keine Abplatzungen der Verblendkeramik an Implantatkronen, wobei überwiegend Kronen im anterioren Bereich untersucht worden waren [33].

In der vorliegenden Studie wurden bei zwei zementierten Implantatkronen an unteren ersten Molaren Abplatzungen der Verblendkeramik festgestellt, während keine Chippings an verschraubten Kronen auftraten. Dies ergibt nach Kaplan-Meier jedoch keinen signifikanten Unterschied zwischen zementierten und verschraubten Implantat-Sinterverbundkronen (p=0.518), womit die zweite Arbeitshypothese akzeptiert werden kann.

Viele Anwender bevorzugen im klinischen Alltag verschraubte Implantatkronen wegen des geringeren Risikos, durch Restzement biologische Komplikationen zu verusachen.
In dieser Studie wurden jedoch keine signifikanten Unterschiede im Hinblick auf die periimplantären Gewebe festgestellt. Beide Befestigungsarten zeigten in Bezug auf ihre Plaqueakkumulation sowie bei ihren Blutungs- und Gingivaindizes gleichwertige Resultate.
Auch was die Abrasionstendenz der antagonistischen Bezahnung angeht, konnte keine Überlegenheit einer Versorgungsform festgestellt werden. Abrasionen traten sowohl bei natürlichen Zähnen als auch bei gefüllten bzw. mit Keramik versorgten oder mit Gold überkronten Antagonisten auf. Hier stellt sich die Frage, ob die untersuchten Sinterverbundkronen in der klinischen Anwendung möglicherweise zu hart sind. Dies sollte Gegenstand weiterführender Studien sein.

6. Zusammenfassung und Ausblick

6.1 Deutsche Version

Aufgrund der vorliegenden Untersuchungen kann festgestellt werden, dass die klinische Stabilität von zahn- und implantatgetragenen Sinterverbundkronen im Molarenbereich sehr zufriedenstellend ist.

In der ersten Publikation mit dem Titel "Klinisches Verhalten von Sinterverbundkronen auf Implantaten und natürlichen Zähnen: Ergebnis nach 42 Monaten" wurden insgesamt 220 Kronen bei 118 Patienten untersucht. Hiervon befanden sich 106 Kronen auf natürlichen Zähnen und 114 auf Implantaten.

Die Untersuchungen ergaben, dass SVK-Kronen im klinischen Alltag gute Ergebnisse liefern, wobei SVK-Kronen auf Implantaten etwas komplikationsanfälliger zu sein scheinen. Hier traten an zwei SVK-Implantatkronen Abplatzungen der Verblendkeramik auf (1.8%). Dies führte in der Auswertung zu einem signifikanten Unterschied im Chippingverhalten zwischen beiden Gruppen zu Gunsten der SVK-Kronen auf natürlichen Zähnen ($p= 0.039$). Keine signifikanten Unterschiede zeigten sich hingegen bei den Plaque- u. Gingival-Indizes sowie dem Sulkusblutungsindex – hier wiesen beide untersuchten Gruppen gesunde parodontale bzw. periimplantäre Verhältnisse auf.

Mit der zweiten Studie „Klinisches Verhalten von verschraubten und zementierten Sinterverbundkronen auf Implantaten: Ergebnis nach 36 Monaten" wurde das klinische Verhalten von verschraubten und zementierten Sinterverbundkronen auf Implantaten untersucht. Hier stand besonders ein möglicher Einfluss der Verankerungsart (verschraubt vs. zementiert) im Mittelpunkt des Interesses.

Insgesamt wurden 114 Implantatkronen bei 58 Patienten untersucht, wovon 53 verschraubt und 61 Kronen zementiert worden waren.

Im Ergebnis hatte die Verankerungsart keinen signifikanten Einfluss auf das Chippingverhalten. Abplatzungen der Verblendung traten an zwei zementierten Implantatkronen auf (1.8%). Auch das periimplantäre Gewebe zeigte sich in beiden Gruppen (verschraubt vs. zementiert) ähnlich stabil.

Sinterverbundkronen wiesen im klinischen Alltag eine gute Stabilität auf und können demnach als prothetische Versorgung sowohl von Implantaten als auch von natürlichen Zähnen im Molarenbereich empfohlen werden.

6.2. Englische Version

The objective of the first clinical study was to compare and assess the clinical performance of tooth-supported and implant-supported zirconia single crowns with sintered veneering caps. In this current 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 [34]. 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 [34]. 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[34].

The objective of the second clinical study was to evaluate the clinical performance of implant-supported zirconia crowns with a sintered veneering cap. Furthermore the influence of the type of retention (screw-retained vs. cemented single crowns) was analyzed [35]. Fifty-eight patients were accommodated with 114 implants, inserted in the molar and premolar regions. Zirconia-based crowns with a sintered veneering cap were either screw-retained (n=53) or cemented (n=61) on the implant [35].

Within the limited mean observation time of 36.9 months, implant-supported zirconia-based crown copings veneered with a high strength-ceramic by sintering, both cement-retained and screw- retained, demonstrated a satisfying success rate under clinical conditions for premolar and molar regions. In regards of technical and biological outcomes, screw-retained single crowns showed comparable clinical performance to cemented single crowns [35].

After a mean clinical service time of 36.9 months, fractures of the veneering porcelain were registered in 1.8% of the cases. The Kaplan-Meier survival probability regarding eventless restorations was 98.2%. Chipping of the veneering porcelain was observed in two cases (1.8%) without statistical influence with respect to the type of retention. The indices showed healthy soft periimplant tissues [35].

Implant supported zirconia crowns with a sintered veneering cap demonstrated good clinical performance [35]. The type of retention did not have a significant influence on the technical complications like the chipping behavior.

Within the mean observation periods (42 and 36 months respectively) 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 [34].

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 and premolar regions [34].

7. Literaturverzeichnis

1. Bremer, F., S. Grade, P. Kohorst, and M. Stiesch (2011) In vivo biofilm formation on different dental ceramics. Quintessence Int. 42(7): p. 565-74.
2. Christel, P.S. (1992) Biocompatibility of surgical-grade dense polycrystalline alumina. Clin Orthop Relat Res. (282): p. 10-8.
3. Covacci, V., N. Bruzzese, G. Maccauro, C. Andreassi, G.A. Ricci, C. Piconi, E. Marmo, W. Burger, and A. Cittadini (1999) In vitro evaluation of the mutagenic and carcinogenic power of high purity zirconia ceramic. Biomaterials. 20(4): p. 371-6.
4. Warashina, H., S. Sakano, S. Kitamura, K.I. Yamauchi, J. Yamaguchi, N. Ishiguro, and Y. Hasegawa (2003) Biological reaction to alumina, zirconia, titanium and polyethylene particles implanted onto murine calvaria. Biomaterials. 24(21): p. 3655-61.
5. Luthy, H., F. Filser, O. Loeffel, M. Schumacher, L.J. Gauckler, and C.H. Hammerle (2005) Strength and reliability of four-unit all-ceramic posterior bridges. Dent Mater. 21(10): p. 930-7.
6. Sailer, I., J. Gottnerb, S. Kanelb, and C.H. Hammerle (2009) Randomized controlled clinical trial of zirconia-ceramic and metal-ceramic posterior fixed dental prostheses: a 3-year follow-up. Int J Prosthodont. 22(6): p. 553-60.
7. Larsson, C., P. Vult von Steyern, B. Sunzel, and K. Nilner (2006) All-ceramic two- to five-unit implant-supported reconstructions. A randomized, prospective clinical trial. Swed Dent J. 30(2): p. 45-53.
8. Sailer, I., B.E. Pjetursson, M. Zwahlen, and C.H. Hammerle (2007) A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part II: Fixed dental prostheses. Clin Oral Implants Res. 18 Suppl 3: p. 86-96.
9. Swain, M.V. (2009) Unstable cracking (chipping) of veneering porcelain on all-ceramic dental crowns and fixed partial dentures. Acta Biomater. 5(5): p. 1668-77.
10. Fischer, J., B. Stawarczyk, and C.H. Hammerle (2008) Flexural strength of veneering ceramics for zirconia. J Dent. 36(5): p. 316-21.
11. Sailer, I., A. Feher, F. Filser, L.J. Gauckler, H. Luthy, and C.H. Hammerle (2007) Five-year clinical results of zirconia frameworks for posterior fixed partial dentures. Int J Prosthodont. 20(4): p. 383-8.
12. Molin, M.K. and S.L. Karlsson (2008) Five-year clinical prospective evaluation of zirconia-based Denzir 3-unit FPDs. Int J Prosthodont. 21(3): p. 223-7.
13. Pjetursson, B.E., I. Sailer, M. Zwahlen, and C.H. Hammerle (2007) A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part I: Single crowns. Clin Oral Implants Res. 18 Suppl 3: p. 73-85.
14. Fischer, J., P. Grohmann, and B. Stawarczyk (2008) Effect of zirconia surface treatments on the shear strength of zirconia/veneering ceramic composites. Dent Mater J. 27(3): p. 448-54.
15. Teichmann, M., F. Gockler, V. Weber, M. Yildirim, S. Wolfart, and D. Edelhoff (2017) Ten-year survival and complication rates of lithium-disilicate (Empress 2) tooth-supported crowns, implant-supported crowns, and fixed dental prostheses. J Dent. 56: p. 65-77.

16. Jung, R.E., A. Zembic, B.E. Pjetursson, M. Zwahlen, and D.S. Thoma (2012) Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. Clin Oral Implants Res. 23 Suppl 6: p. 2-21.
17. Schwarz, S., C. Schroder, A. Hassel, W. Bomicke, and P. Rammelsberg (2012) Survival and chipping of zirconia-based and metal-ceramic implant-supported single crowns. Clin Implant Dent Relat Res. 14 Suppl 1: p. e119-25.
18. Fischer, J., B. Stawarzcyk, A. Trottmann, and C.H. Hammerle (2009) Impact of thermal misfit on shear strength of veneering ceramic/zirconia composites. Dent Mater. 25(4): p. 419-23.
19. Fischer, J., B. Stawarczyk, A. Trottmann, and C.H. Hammerle (2009) Impact of thermal properties of veneering ceramics on the fracture load of layered Ce-TZP/A nanocomposite frameworks. Dent Mater. 25(3): p. 326-30.
20. Drummond, J.L., T.J. King, M.S. Bapna, and R.D. Koperski (2000) Mechanical property evaluation of pressable restorative ceramics. Dent Mater. 16(3): p. 226-33.
21. Kontos, L., C. Schille, E. Schweizer, and J. Geis-Gerstorfer (2013) Influence of surface treatment on the wear of solid zirconia. Acta Odontol Scand. 71(3-4): p. 482-7.
22. Pospiech, P. (2010) Chipping - systemimmanente oder verarbeitungsbedingte Probleme? Quintessenz. 61(2): p. 173-181.
23. Schmitter, M., D. Mueller, and S. Rues (2013) In vitro chipping behaviour of all-ceramic crowns with a zirconia framework and feldspathic veneering: comparison of CAD/CAM-produced veneer with manually layered veneer. J Oral Rehabil. 40(7): p. 519-25.
24. Schmitter, M., D. Mueller, and S. Rues (2012) Chipping behaviour of all-ceramic crowns with zirconia framework and CAD/CAM manufactured veneer. J Dent. 40(2): p. 154-62.
25. Beuer, F., J. Schweiger, M. Eichberger, H.F. Kappert, W. Gernet, and D. Edelhoff (2009) High-strength CAD/CAM-fabricated veneering material sintered to zirconia copings--a new fabrication mode for all-ceramic restorations. Dent Mater. 25(1): p. 121-8.
26. Beier, U.S., I. Kapferer, and H. Dumfahrt (2012) Clinical long-term evaluation and failure characteristics of 1,335 all-ceramic restorations. Int J Prosthodont. 25(1): p. 70-8.
27. Heintze, S.D. and V. Rousson (2010) Fracture rates of IPS Empress all-ceramic crowns--a systematic review. Int J Prosthodont. 23(2): p. 129-33.
28. Wang, X., D. Fan, M.V. Swain, and K. Zhao (2012) A systematic review of all-ceramic crowns: clinical fracture rates in relation to restored tooth type. Int J Prosthodont. 25(5): p. 441-50.
29. Takeichi, T., J. Katsoulis, and M.B. Blatz (2013) Clinical outcome of single porcelain-fused-to-zirconium dioxide crowns: a systematic review. J Prosthet Dent. 110(6): p. 455-61.
30. Larsson, C. and A. Wennerberg (2014) The clinical success of zirconia-based crowns: a systematic review. Int J Prosthodont. 27(1): p. 33-43.
31. Raigrodski, A.J., G.J. Chiche, N. Potiket, J.L. Hochstedler, S.E. Mohamed, S. Billiot, and D.E. Mercante (2006) The efficacy of posterior three-unit zirconium-oxide-based ceramic fixed partial dental prostheses: a prospective clinical pilot study. J Prosthet Dent. 96(4): p. 237-44.

32. Vult von Steyern, P., P. Carlson, and K. Nilner (2005) All-ceramic fixed partial dentures designed according to the DC-Zirkon technique. A 2-year clinical study. J Oral Rehabil. 32(3): p. 180-7.
33. Glauser, R., I. Sailer, A. Wohlwend, S. Studer, M. Schibli, and P. Scharer (2004) Experimental zirconia abutments for implant-supported single-tooth restorations in esthetically demanding regions: 4-year results of a prospective clinical study. Int J Prosthodont. 17(3): p. 285-90.
34. Cantner, F., C. Cacaci, T. Mücke, P. Randelzhofer, J. Hajtó, and F. Beuer (2018) Clinical performance of tooth- or implant-supported veneered zirconia single crowns: 42-month results. Clin Oral Investig.
35. Cacaci, C., F. Cantner, T. Mücke, P. Randelzhofer, J. Hajtó, and F. Beuer (2016) Clinical performance of screw-retained and cemented implant-supported zirconia single crowns: 36-month results. Clin Oral Investig.

8. Danksagung

Mein ganz besonderer Dank gilt meinem Doktorvater Herrn Prof. Dr. Florian Beuer, der mir – auch nach seinem Wegzug von München nach Berlin – unzählige Male mit Rat und Tat zur Seite gestanden und mich mit vielen zielführenden Gesprächen und durch die Bereitstellung seines Fachwissens bei der Durchführung und Erstellung der Arbeit unterstützt hat.

Desweiteren danke ich sehr herzlich Herrn PD Dr. Dr. Thomas Mücke für seine stets freundliche Unterstützung und die vielen fachlichen Hinweise und Hilfestellungen bei der Abfassung der paper.

Besonders möchte ich mich bedanken bei Herrn Dr. Claudio Cacaci und Herrn Dr. Peter Randelzhofer für die Möglichkeit der Durchführung dieser Arbeit und die Bereitstellung der Patienten in ihrer Praxis.

Desweiteren danke ich Herrn Dr. Jan Hajtó für die Hilfe bei der Auswertung von Daten in seiner Praxis.

Ein freundlicher Dank geht auch an Herrn ZTM Uwe Gehringer und Herrn ZTM Thomas Frei für die zahntechnische Unterstützung.

Für die statistische Auswertung der Daten möchte ich außerdem Frau Daniela Keller danken.