CLINICAL ORAL IMPLANTS RESEARCH

Panos Papaspyridakos
Kunal Lal

Computer-assisted design/computer-assisted manufacturing zirconia implant fixed complete prostheses: clinical results and technical complications up to 4 years of function

Authors' affiliations:
Panos Papaspyridakos, Kunal Lal, Division of Prosthodontics, Columbia University College of Dental Medicine, New York, NY, USA
Panos Papaspyridakos, Department of Restorative Dentistry and Biomaterials Sciences, Harvard School of Dental Medicine, Boston, MA, USA

Corresponding author:
Panos Papaspyridakos, DDS, MS
Division of Prosthodontics, Columbia University College of Dental Medicine
630 W 168th Str., PH 7-E, Rm 119, New York, NY 10032, USA
Tel.: 212 305 4879
Fax: 212 305 8493
e-mail: pp2229@columbia.edu

Key words: complete prostheses, computer-assisted design/computer-assisted manufacturing, dental implants, edentulous, technical complications, zirconia

Abstract

Objective: To report the clinical results and technical complications with computer-assisted design/computer-assisted manufacturing (CAD/CAM) zirconia, implant fixed complete dental prostheses (IFCDPs) after 2–4 years in function.

Materials and methods: Fourteen consecutive edentulous patients (16 edentulous arches) were included in this study. Ten of the patients were women and four were men, with an average age of 58 years (range: 35–71). Ten mandibular and six maxillary arches were restored with porcelain fused to zirconia (PFZ) IFCDPs. Of the 16 arches, 14 received one-piece and 2 received segmented two-piece IFCDPs, respectively. The mean clinical follow-up period was 3 years (range: 2–4). At the last recall appointment, biological and technical parameters of dental implant treatment were evaluated.

Results: The implant and prosthesis survival rate following prosthesis insertion was 100% up to 4-year follow-up. The prostheses in 11 of the 16 restored arches were structurally sound, exhibited favorable soft tissue response, esthetics, and patient satisfaction. Five IFCDPs (31.25%) in four patients exhibited porcelain veneer chipping. Chipping was minor in three prostheses (three patients) and was addressed intraorally with polishing (one prosthesis) or composite resin (two prostheses). One patient with maxillary and mandibular zirconia IFCDP exhibited major porcelain chipping fractures which had to be repaired in the laboratory. Function, esthetics, and patient satisfaction were not affected in three of the four fracture incidents. Median crestal bone loss was 0.1 mm (0.01–0.2 mm). The presence of parafunctional activity, the IFCDP as opposing dentition, and the absence of occlusal night guard were associated with all the incidents of ceramic chipping.

Conclusion: CAD/CAM zirconia IFCDPs are viable prosthetic treatment after 2–4 years in function, but not without complications. The porcelain chipping/fracture was the most frequent technical complication, with a 31.25% chipping rate at the prosthesis level. Despite the technical complications, increased patient satisfaction was noted.

Zirconia has gained increasing popularity in contemporary dentistry due to its high biocompatibility, low bacterial surface adhesion, high flexural strength, toughness due to a transformation toughening mechanism, and esthetic properties (Papaspyridakos & Lal 2010; Guess et al. 2010). These properties have led to the introduction of zirconia-based restorations as alternative to the traditional porcelain fused to metal (PFM) restorations. It is currently being used for the fabrication of implant abutments and all ceramic copings, multiple unit, and complete arch frameworks for both fixed prosthodontics and implant dentistry (Sailer et al. 2007a,b, 2009; Edelhoff et al. 2008; Molin & Karlsson 2008; Papaspyridakos & Lal 2008; Tinschert et al. 2008; Schmitt et al. 2009; Larsson & Vult von Steyern 2010a; Larsson et al. 2010b; Roediger et al. 2010).

With the primary focus of improving accuracy, decreasing cost, and simplifying

Date:
Accepted 21 January 2012

To cite this article:
Papaspyridakos P, Lal K. CAD/CAM zirconia implant fixed complete prostheses: Clinical results and technical complications up to 4 years of function.
Clin. Oral Impl. Res. **24,** 2013, 659–665
doi: 10.1111/j.1600-0501.2012.02447.x

manufacturing procedures, dental implant research has invested in the development of computer-assisted design/computer-assisted manufacturing (CAD/CAM) technology (Kapos et al. 2009). The advantage of industrialized manufacturing of zirconia frameworks from homogenous blocks using CAD/CAM technology and subtractive prototyping has improved accuracy and cost effectiveness (Papaspyridakos & Lal 2008; Guess et al. 2010).

Clinical data with up to 5-year clinical follow-up confirmed the high stability of zirconia as framework material for tooth-supported fixed dental prostheses (FDPs) and crowns. As a rule and since the PFM restorations are considered as the gold standard in prosthodontics, all new materials used as alternative options must be at least equally good (Heintze & Rousson 2010). A randomized controlled clinical trial (RCT) found no difference in the survival of PFM and porcelain fused to zirconia (PFZ) tooth-supported FDPs after 3 years in function (Sailer et al. 2009). However, the ceramic chipping rate was higher in the PFZ group. An earlier systematic review by the same group based on three clinical studies with zirconia restorations had also reported that tooth-supported PFM FDPs have better performance than all ceramic FDPs in terms of chipping and technical complications (Sailer et al. 2007b). When comparing tooth- with implant-supported PFM FDPs another systematic review highlighted that implant-supported FDPs have more technical complications than tooth-supported FDPs (Pjetursson et al. 2007).

Clinical data with implant-supported zirconia prostheses are lacking. One recent RCT comparing two different material systems for 2–5 unit zirconia FDPs showed that one of the systems resulted in an unacceptable amount of porcelain fractures after 5 years in function (Larsson & Vult von Steyern 2010a). Moreover, reports with medium- to long-term data are scarce for the longevity of zirconia implant fixed complete dental prostheses (IFCDPs). The 3-year results with cement-retained zirconia IFCDPs for edentulous mandibles have been reported and demonstrated high rate of ceramic chipping (Larsson et al. 2010b).

As sufficient evidence of long-term clinical efficacy with implant-supported zirconia prostheses is missing at present, caution with regard to extensive implant-supported zirconia frameworks is recommended. The purpose of this retrospective case series study is: (i) to report for the first time on the 2- to 4-year clinical results and technical complications with screw-retained CAD/CAM zirconia IFCDPs for edentulous patients, and (ii) to identify risk factors associated with technical complications.

Material and methods

Between 2007 and 2009, 14 consecutive patients with a total of 16 edentulous arches received CAD/CAM zirconia IFCDPs in the division of Postdoctoral Prosthodontics at Columbia University College of Dental Medicine, New York. Twelve patients had one edentulous jaw restored with PFZ IFCDPs, whereas the remaining two patients received both maxillary and mandibular PFZ restorations. The 14 patients included in the present study, were part of a larger cohort of patients that underwent flapless CAD/CAM-guided implant surgery using virtual planning software (Nobel Guide; Nobel Biocare, Yorba Linda, CA, USA) and stereolithographic templates (Papaspyridakos & Lal 2010). The inclusion criteria that were applied prior to implant treatment with the flapless protocol consisted of the following: (i) patients that required the restoration of at least one edentulous arch with dental implants and IFCDP, (ii) there was at least 50 mm of mouth opening to accommodate for the surgical instrumentation, and (iii) the patients were in good medical health. The exclusion criteria consisted of (i) the patients that were medically compromised (recent stroke and/or myocardial infarction, uncontrolled diabetes, radiation and/or chemotherapy for tumor patients), and/or psychological problems, and (ii) the patients that did not have adequate bone to accommodate minimum 3.5 mm diameter and/or 7 mm length after the Computerized Tomography scan. Institutional Review Board approval was obtained by Columbia University Human Subjects Review Committee for the surgical protocol and written informed consent was obtained from all patients prior to implant treatment.

Ten of the patients were women and four were men, with an average age of 58 years (range: 35–71). Two patients were smokers (more than 10 cigarettes per day) and four patients showed signs of parafunctional activity (bruxism). This finding was diagnosed and/or self-reported at the stage of implant fixed provisionalization. Each jaw received 5–8 implants; the mandibular arches received five or six implants, whereas the maxillary ones received 6–8 implants. Following uneventful healing period after implant placement, the prosthodontic procedures were carried out for the 14 patients (16 edentulous arches). Ten mandibular and six maxillary arches were restored with PFZ IFCDPs. All zirconia frameworks were made with CAD/CAM technology (Procera; Nobel Biocare).

Each rehabilitated arch consisted of 12–14 dental units. Of the 16 arches, 14 received one-piece IFCDP and 2 received anteriorly segmented two-piece IFCDP, respectively. All IFCDPs were screw-retained to the implant level. For the descriptive analysis, every edentulous arch corresponds to one IFCDP whether it is one-piece or two-piece, respectively. The opposing arch included nine implant-supported PFZ and PFM IFCDPs, two class I removable partial dentures (RPDs) with anterior natural/restored dentition, one implant overdenture and two complete dentures. Patient demographics and characteristics can be seen in Table 1.

Table 1. **Patient demographics and characteristics of patient/IFCDP-specific technical complications**

Parameters	Patients (n = 14)/ IFCDPs (n = 16)	Patients (n = 4)/ IFCDPs with ceramic veneer chipping (n = 5)
Gender		
Men	10/11	2/3
Women	4/5	2/2
Occlusal scheme		
Balanced occlusion	3/3	3/4
Anterior guidance	11/13	1/1
Cantilever		
Yes	11/13	3/4
No	3/3	1/1
Opposing dentition		
Complete denture	2/2	0/0
Implant overdenture	1/1	1/1
RPDs class I	2/2	0/0
PFM IFCDPs	7/7	1/1
PFZ IFCDPs	2/4	2/3
Parafunctional activity		
Yes	4/6	4/5
No	10/10	0/0
Location		
Maxilla	6/6	3/3
Mandible	10/10	2/2
Occlusal night guard		
Yes	9/11	2/3
No	5/5	2/2
Time in function (years)		
<3	7/8	2/3
>3	7/8	2/2

IFCDP, implant fixed complete dental prosthesis.
Out of the 16 restored arches, 14 received one-piece IFCDPs and 2 received two-piece IFCDPs, respectively. In this table analysis, one IFCDP corresponds to one edentulous arch, whether it is one- or two-piece IFCDP.

Prosthodontic procedures

The prosthodontic and laboratory procedures for the fabrication of the CAD/CAM zirconia IFCDPs have been described in detail in previous publications (Papaspyridakos & Lal 2008; Papaspyridakos et al. 2011a). In brief, the following steps were followed.

One month after second stage surgery, all patients' existing complete dentures were converted into one-piece screw-retained interim restorations. For two mandibles (two patients) and one maxilla (one patient), the exact same conversion prosthesis procedure had been carried out at the implant placement for immediate loading. The open-tray implant level technique was used for the final impressions (Papaspyridakos et al. 2011b). Impression copings were connected to the implants and the seating of the copings on the implant platforms was radiographically confirmed. Then, the impression copings were connected with dental floss and splinted to each other with visible light polymerized acrylic resin (Triad gel; Dentsply, Milford, DE, USA). The assembly was sectioned between all inter-implant areas and reconnected with a small amount of the same resin to compensate for polymerization shrinkage. After the impression was taken with polyether impression material (Impregum; 3M ESPE, St Paul, MN, USA), a double pouring technique with low expansion (0.09%) type IV die stone (Silky Rock; Whipmix Corp, Louisville, KY, USA) was used to generate the implant casts. Traditional prosthodontic techniques were used to articulate the casts using the screw-retained interim restorations and interocclusal centric relation records.

A verification jig was made intraorally by connecting temporary abutments to the implants and splinting them together with resin (Triad gel; Dentsply) to fabricate a verification cast. This is essential due to the inability to section and solder zirconia in case of misfit.

Patients' interim screw-retained restorations were used as a guide for the fabrication of the definitive prostheses when esthetics was adequate. Minor changes were made as necessary to satisfy esthetics and function. Silicone putty indexes were made of the articulated interim prostheses to guide the fabrication of the framework. Temporary, non-engaging abutments were placed and acrylic resin was injected to obtain full contour mock-up, followed by 2 mm cutback to ensure adequate support of veneering porcelain. This is an essential step. The acrylic frameworks were seated in the verification casts to ensure passive fit, and then they were scanned using a scanning machine (Nobel Forte) and the CAD file was sent via email to a CAM facility for milling.

The milled zirconia frameworks were tried in and interocclusal records were verified with an anterior deprogrammer. Framework fit was assessed and confirmed both radiographically with periapical radiographs and clinically with single screw test and explorers (Abduo et al. 2010; Papaspyridakos et al. 2011b). Two different commercial laboratories were used for veneering the frameworks with feldspathic porcelain. Pink porcelain was used where applicable, based on the interim restorations, the volume of missing hard and soft tissues, and the length of the teeth. The option of using pink ceramics had been discussed beforehand with each patient and patient's consent had been confirmed. All zirconia IFCDPs were delivered after minor occlusal adjustments. Mutually protected occlusion with anterior guidance and balanced occlusion was used in cases of opposing fixed prosthesis or complete denture, respectively. Alginate impressions were taken for the fabrication of night guards in cases of opposing PFM and/or PFZ IFCDPs.

Clinical and radiographic recall examination

At the last annual recall appointment 2–4 years (mean 36 months) after the definitive prosthesis insertion, all CAD/CAM zirconia IFCDPs were evaluated for satisfactory function and esthetics and were inspected to record potential biological and technical complications (Fig. 1a, b). Dental charts were also reviewed to identify complications that had been encountered before the final recall.

The *clinical examination* included assessment of biological and technical parameters. The following biological parameters were assessed: crestal bone loss and peri-implant soft tissue recession. The following technical parameters were assessed: framework fracture, veneering porcelain fracture/chipping, and screw fracture/loosening. Porcelain fracture was characterized as minor if it did not affect esthetics, occlusal contacts, and could be polished or repaired intraorally with composite resin. A porcelain fracture was characterized major if it affected esthetics, resulted in patient dissatisfaction, and required laboratory remake (Nedir et al. 2006; Kinsel & Lin 2009). Finally, all patients were asked whether they were satisfied with the esthetic outcome and occlusal function with their IFCDPs via yes or no question.

The *radiographic examination* was performed immediately after definitive prosthesis insertion, and at the last recall appointment with digital periapical and panoramic radiographs (Fig. 2). The digital periapical radiographs at baseline and last recall were used for the radiographic measurements, since some of the panoramic radiographs presented with distortions. Linear measurements from the implant shoulder to the first bone to implant contact (FBIC) were made with available digital software (Image J; NIH, Bethesda, MD, USA). The known diameter of each implant and the known interthread distance of 0.6 mm were used for calibration of the measuring tool. The distance FBIC was measured mesially and distally at baseline and the follow-up visit. The marginal bone level resorption was calculated as the mean of the mesial and distal measurements at baseline and last follow-up. All measurements were done by a blinded examiner, not associated with the treatment.

Statistical analysis

Life table statistics was used to calculate implant/prosthesis survival rate up to 4 years of function. Survival was defined as the prosthesis remaining esthetical and functional without any or with complications/adjustments throughout the observation period. Failure was defined as the prosthesis that needs to be remade or if the patient satisfaction was poor. The Kaplan–Meier function was used to estimate the cumulative prosthesis complication-free (no chipping) rates. To

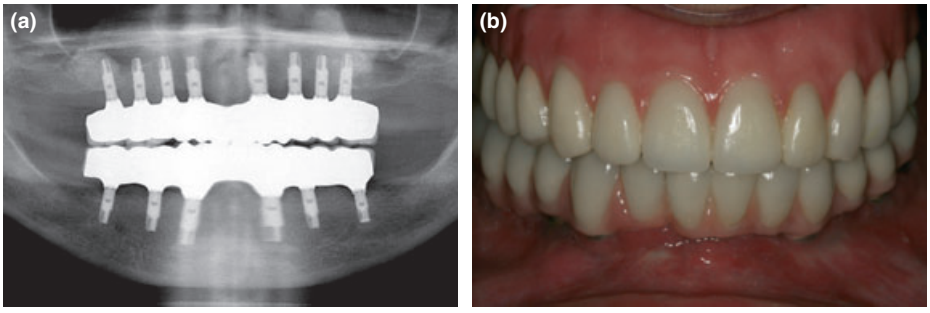

Fig. 1. (a) and (b) Maxillary zirconia prosthesis radiographically and intraorally after 4 years of function.

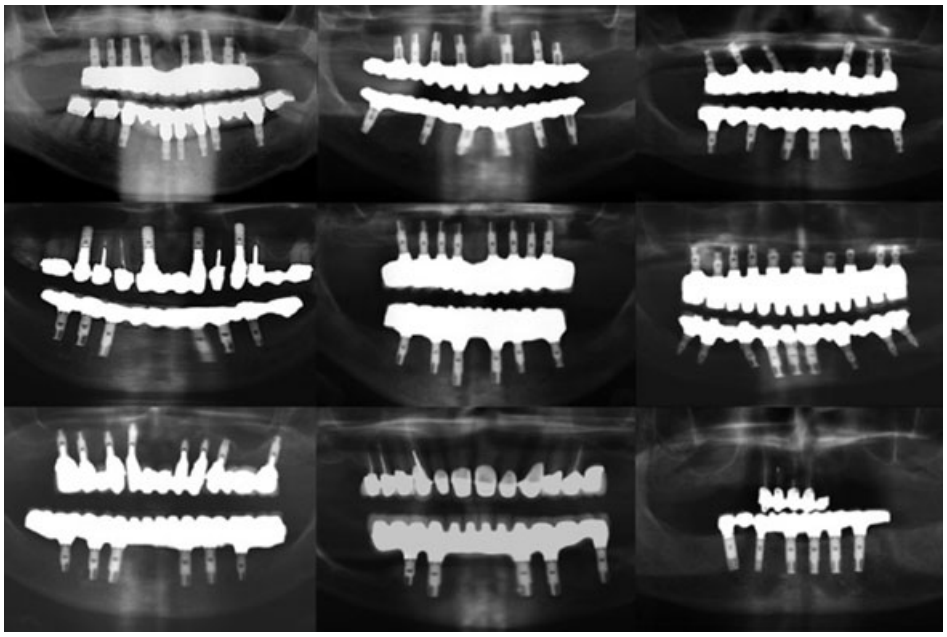

Fig. 2. Panoramic radiographs of 11 out of 16 zirconia IFCDPs.

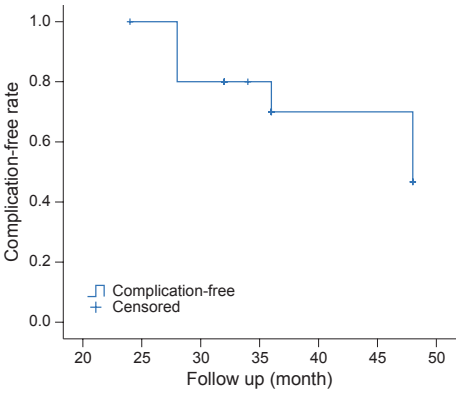

Fig. 3. Kaplan–Meier analysis for complication-free (no chipping) rate during follow-up.

Fig. 4. Zirconia IFCDP with major porcelain fractures.

identify the factors that may predispose the zirconia prostheses to technical complications, the following occlusal and functional parameters were recorded: type of opposing dentition, presence of occlusal night guard, presence of cantilevers, and presence of parafunctional activity (bruxism).

Results

All 14 patients with 16 CAD/CAM zirconia IFCDPs were followed up to 4 years (mean 36 months). The implant survival rate following definitive prosthesis insertion up to 4-year follow-up was 100% (Table 2). All prostheses were *in situ* at the end of the observation period. The prosthesis survival rate following insertion and up to 4-year follow-up was 100%. The prostheses in 11 of 16 arches were structurally sound, whereas porcelain veneer chipping/fracture was observed in five prostheses (four patients), yielding a ceramic chipping rate of 31.25% at the prosthesis level (Fig. 3).

Porcelain veneer chipping was minor in three prostheses (three patients) and was easily addressed intraorally with polishing (one prosthesis) or composite resin (two prostheses), respectively. Function and esthetics were not affected by the three fracture incidents.

In the first patient who also had antagonistic PFZ IFCDP, small chipping on the maxillary canine occurred and was easily addressed by polishing intraorally (Dialite; Brasseler USA, Savannah, GA, USA). The second patient presented at the 3-year follow-up with minor porcelain fracture on the maxillary lateral incisor area due to an accident, which was repaired with composite resin. The subject had mandibular implant overdenture as antagonistic prosthesis. The third patient presented with adhesive porcelain fracture of the mandibular left central and lateral incisor after 8 months in clinical function. The opposing dentition was PFM IFCDP. The patient had never received an occlusal night guard despite suggestion to do so. After the event, the fracture was repaired intraorally with composite resin and a night guard was subsequently fabricated.

The fourth patient, who had been restored with maxillary and mandibular zirconia IFCDP, had presented with major cohesive porcelain fractures in both prostheses involving the anterior maxillary and mandibular teeth 1 week after insertion (Fig. 4). He had been scheduled to receive a laboratory-processed night guard but the fracture incident happened prior to delivery of the night guard. The prostheses had to be removed and repaired in the laboratory, while the interim restorations were placed. The patient received his repaired prostheses coupled with a night guard and no additional fractures occurred thereafter.

As far as the opposing dentition, minor posterior ceramic chipping was also observed in two PFM IFCDPs that were opposing PFZ IFCDPs and was easily addressed by polishing. Great patient satisfaction with function and esthetics was recorded for all patients both at baseline and last recall. No screw loosening was observed throughout the follow-up period for all IFCDPs. The median (minimum–maximum) marginal bone loss

Table 2. **Life table analysis for implant/prosthesis survival rates up to 4 years of function**

Follow-up period (months)	Implants/prostheses at start of the interval	Prostheses withdrawn	Prostheses lost	Prostheses with ceramic chipping or fracture	Cumulative rate of prostheses free of ceramic chipping (%)	Cumulative implant/prosthesis survival rate (%)
0–12	103/16	0	0	4	75	100/100
12–24	103/16	0	0	0	75	100/100
24–36	82/13	0	0	0	75	100/100
36–48	52/8	0	0	1	68.75	100/100

Table 3. **Assessment of risk factors for site-specific technical complications (ceramic chipping) over 4 years in function**

Parameters	IFCDP/dental units	IFCDP/dental units with ceramic chipping	Chipping rate (%) at IFCDP level/unit level
Occlusion scheme			
Balanced occlusion	3/36	1/1	33.3/2.8
Anterior guidance	13/161	4/9	30.8/5.6
Opposing dentition			
Removable	5/60	1/1	20.0/1.7
Fixed	11/137	4/9	36.4/6.6
Cantilever			
Yes	13/160	4/8	30.8/5.0
No	3/37	1/2	33.3/5.4
Location			
Maxilla	6/74	3/5	50.0/6.8
Mandible	10/123	2/5	20.0/4.1
Occlusal night guard			
Yes	11/149	3/7	27.3/4.7
No	5/60	2/3	40.0/5.0
Parafunctional activity			
Yes	6/74	5/10	83.3/13.5
No	10/123	0/0	0.0/0.0
Total	16 IFCDPs/197 dental units	5 IFCDPs/10 dental units with chipping	31.25/5.0

IFCDP, implant fixed complete dental prosthesis.

after a minimum observation period of 2 years post-insertion was 0.1 mm (0.01 mm –0.2 mm). No gingival recession with exposed metal at the implant platform-abutment interface was observed for all the 103 supporting implants upon visual inspection at the last clinical recall. This finding was compared with the baseline observations on the master casts and patient photographs.

The presence of parafunctional activity, the IFCDP as opposing dentition and the absence of occlusal night guard were identified as risk factors for ceramic chipping (Table 3). Only descriptive analysis was performed due to limited sample size and multiple factors that had confounding effect on the survival of the zirconia prostheses.

Discussion

The objective of this retrospective case series study was to report the clinical results and technical complications encountered with zirconia IFCDPs up to 4 years of follow-up. The clinical findings of this study indicate that all zirconia IFCDPs were in function after 2–4 years but 5 of the 16 exhibited ceramic veneer fractures. Three of the five IFCDPs that presented chipping could be easily addressed intraorally with polishing or composite resin. One patient with maxillary and mandibular PFZ IFCDPs exhibited major porcelain fractures 1 week after delivery that had to be repaired in the laboratory. This yielded a 31.25% and a 5% chipping rate at the prosthesis level and at the dental unit level, respectively. All the incidents had PFM or PFZ opposing dentition, except one. This ceramic chipping rate was lower than the one reported by Larsson et al., who found a ceramic chipping rate of 90% at the prosthesis level and 34% at the dental unit level, respectively (Larsson et al. 2010b). Their study featured mandibular zirconia IFCDPs that were cement-retained and opposed by predominantly full-arch PFM FDPs. However, the authors mentioned that all fractures could be polished and all patients were fully satisfied with the treatment outcome, without any need for prosthesis replacement, which is similar to our study. A 5-year RCT with partially edentulous patients restored with implant-supported zirconia FDPs, showed ceramic chipping rate of 44% at the prosthesis level and similarly reported that none of the prostheses needed to be replaced (Larsson & Vult von Steyern 2010a). It is a common finding in the aforementioned studies that ceramic chipping occurs frequently with implant-supported PFZ prostheses but its impact on function, esthetics, and patient satisfaction is not significant.

Apparently, veneering porcelain chipping is consistently reported as the most common technical complication encountered with PFZ restorations and can be either adhesive or cohesive. Zirconia-based systems are predominantly bi-layered, using veneering ceramic over a strong supporting core (Aboushelib et al. 2008). The bond between the veneering porcelain and the zirconia substructure seems to be the weak link (Guess et al. 2010). In the present study, this was also the case since all the encountered technical complications were porcelain fractures, cohesive, and adhesive in nature. For tooth-supported zirconia restorations, the rate of porcelain veneer chipping has been reported to range from 10% to 16% after clinical follow-up of 2–5 years.

When comparing tooth- with implant-supported FDPs, a systematic review highlighted that implant-supported FDPs have more technical complications than tooth-supported FDPs (Pjetursson et al. 2007). However, data derived by clinical studies on tooth-supported restorations cannot be directly extrapolated to implant-supported ones. The reason being that, reduced proprioception and functional ankylosis of osseointegrated implants correlated with higher functional impact forces might further exacerbate porcelain fractures at implant-supported FDPs (Müller et al. 2012).

Regarding tooth-supported prostheses, a 3-year RCT found no difference in the survival of PFM and PFZ tooth-supported FDPs (Sailer et al. 2009), with higher ceramic chipping rate in the PFZ group. An earlier systematic review by the same group based on three clinical studies with zirconia restorations had also reported that tooth-supported PFM FDPs have better performance than all ceramic FDPs in terms of chipping and technical complications (Sailer et al. 2007b). Porcelain veneer failures have led to concerns regarding differences in coefficient of thermal expansions between cores and veneering porcelain. In addition to that, none of the zirconia core and veneering ceramics could attain the high bond strength values of the PFM bond (Aboushelib et al. 2008).

There are no data yet, regarding direct comparison between implant-supported PFM and PFZ restorations. Although long-term data on metal resin IFCDPs are available (Mertens & Steveling 2011), longitudinal studies on PFM IFCDPs are scarce. A 5-year follow-up study showed that PFM IFCDPs had similar survival rate with metal resin IFCPs either at the implant or the abutment level (Hjalmarsson et al. 2011). Another longitudinal study showed no difference in the survival of PFM and metal resin IFCDPs up to 18 years of follow-up (Teigen & Jokstad 2011).

Of the 16 arches, 14 received one-piece IFCDP and 2 received anteriorly segmented two-piece IFCDP, respectively. The two segmented IFCDPs were located in the maxilla. The choice of one-piece screw-retained pros-

thesis was made taking into consideration the implant angulation, number and anteroposterior spread of the implants, length of implants, and arch type. The one-piece IFCDP fabricated with CAD/CAM technology offers ease of insertion due to elimination of interproximal contact adjustments and splinting of the implants where necessary. Other options have also been proposed for the complete arch fixed rehabilitation with segmented prostheses and strategically positioned implants. The segmented design for IFCDP offers ease of fabrication (with conventional wax and cast technique) and prosthetic maintenance. Technical complications after the placement of IFCDPs occur continuously over time due to the fatigue and stress on the materials that are selected. These events may not lead to implant/prosthetic failures, but are significant in relation to the numbers of repair and maintenance sessions, time, and cost to both the clinician and patient (Papaspyridakos et al. 2012). Where applicable, a segmented prosthetic design may be recommended for the complete arch implant rehabilitation, to facilitate prosthetic maintenance in case of ceramic fractures or other technical complications (Salvi & Brägger 2009).

Parafunctional activity at fully edentulous patients is hard to diagnose due to absence of teeth and wear facets, removable prostheses, and resilient soft tissues that absorb functional loads. This case series study included four bruxers. That finding was diagnosed and/or self-reported at the stage of implant fixed provisionalization. The presence of parafunctional activity, the IFCDP as opposing dentition, and the absence of occlusal night guard were identified as risk factors for ceramic chipping. Only descriptive analysis was performed due to limited sample size and multiple factors that had confounding effect on the survival of the zirconia prostheses. The findings of the present descriptive analysis are in agreement with previous study (Kinsel & Lin 2009). In this retrospective analysis of 94 implant-supported PFM FDPs for partially edentulous patients it was shown that presence of parafunctional activity, absence of night guard, and implant-supported opposing dentition were significant risk factors for ceramic fractures. The association of parafunctional activity (bruxism) with increased number of mechanical/technical complications was also shown in a recent systematic review (Salvi & Brägger 2009). In addition, edentulous patients treated with IFCDPs should be informed about the need and responsibility to attend a customized recall protocol for the long-term stability and maintenance of their IFCDPs.

Even though functional loading is significantly higher in the posterior region as compared with anterior segments, all porcelain fractures in the present study were observed anteriorly. No patient had complete natural dentition as antagonistic dentition. During the laboratory processing of the zirconia frameworks used in this clinical study, adjustments were made especially interproximally to allow for enough clearance for porcelain. The effects of these fabrication procedures such as grinding and sandblasting the zirconia substructures on the long-term success have not been fully documented yet.

Limitations of this study pertain to the limited sample size and duration of follow-up. The absence of control group is another limitation making direct comparisons impossible. Comparisons can be made only indirectly with the clinical outcomes of other studies with PFM IFCDPs. To the authors' knowledge, this is the first study to report clinical outcomes and technical complications with screw-retained, zirconia IFCDPs. The mid-term results of the present study seem promising, but not without technical complications. Additional comparative clinical studies pertaining to PFZ and PFM IFCDPs with at least 5-years of prospective follow-up are needed.

Conclusion

Under the limitations of this clinical study, the following conclusions can be drawn:

- The implant and prosthesis survival rate following insertion and up to 4-year follow-up was 100%. All 16 zirconia IFCDPs were in place at the end of the observation period.
- The porcelain fracture/chipping of the veneering porcelain was the most common technical complication (5/16 prostheses), yielding a 31.25% ceramic chipping rate (prosthesis level).
- The presence of parafunctional activity, the IFCDP as opposing dentition and the absence of occlusal night guard were identified as risk factors for ceramic chipping.
- CAD/CAM zirconia IFCDPs seem viable prosthetic option after clinical follow-up of 2–4 years, but not without technical complications. Despite the technical complications, increased patient satisfaction was noted.

Acknowledgements: The authors wish to express their gratitude to Dr Chun-Jung Chen, Department of Dentistry, Chi Mei Medical Center, Taiwan, for assistance in the statistical analysis and the postdoctoral residents and staff, Division of Prosthodontics, Columbia University College of Dental Medicine, New York, USA, for assistance in the clinical care and subsequent recall.

Conflict of interest: The authors do not have any financial interest in the companies whose materials are included in this article.

References

Abduo, J., Bennani, V., Waddell, N., Lyons, K. & Swain, M. (2010) Assessing the fit of implant fixed prostheses: a critical review. *The International Journal of Oral and Maxillo-facial Implants* **25**: 506–515.

Aboushelib, M.N., de Kler, M., van der Zel, J.M. & Feilzer, A.J. (2008) Effect of veneering method on the fracture and bond strength of bilayered zirconia restorations. *The International Journal of Prosthodontics* **21**: 237–240.

Edelhoff, D., Florian, B., Florian, W. & Johnen, C. (2008) HIP zirconia fixed partial dentures-clinical results after 3 years of clinical service. *Quintessence International* **39**: 459–471.

Guess, P.C., Att, W. & Strub, J.R. (2010) Zirconia in fixed implant prosthodontics. *Clinical Implant Dentistry & Related Research* **13**: [Epub ahead of print].

Heintze, S.D. & Rousson, V. (2010) Survival of zirconia- and metal-supported fixed dental prostheses: a systematic review. *The International Journal of Prosthodontics* **23**: 493–502.

Hjalmarsson, L., Smedberg, J.I., Pettersson, M. & Jemt, T. (2011) Implant-level prostheses in the edentulous maxilla: a comparison with conventional abutment-level prostheses after 5 years of use. *The International Journal of Prosthodontics* **24**: 158–167.

Kapos, T., Ashy, L.M., Gallucci, G.O., Weber, H.P. & Wismeijer, D. (2009) Computer-aided design and computer-assisted manufacturing in prosthetic implant dentistry. *The International Journal of Oral & Maxillofacial Implants* **24**(Suppl.): 110–117.

Kinsel, R.P. & Lin, D. (2009) Retrospective analysis of porcelain failures of metal ceramic crowns and

fixed partial dentures supported by 729 implants in 152 patients: patient-specific and implant-specific predictors of ceramic failure. *Journal of Prosthetic Dentistry* **101**: 388–394.

Larsson, C. & Vult von Steyern, P. (2010a) Five-year follow-up of implant-supported Y-TZP and ZTA fixed dental prostheses. A randomized, prospective clinical trial comparing two different material systems. *The International Journal of Prosthodontics* **23**: 555–561.

Larsson, C., Vult von Steyern, P. & Nilner, K. (2010b) A prospective study of implant-supported full-arch yttria-stabilized tetragonal zirconia polycrystal mandibular fixed dental prostheses: three-year results. *The International Journal of Prosthodontics* **23**: 364–369.

Mertens, C. & Steveling, H.G. (2011) Implant-supported fixed prostheses in the edentulous maxilla: 8-year prospective results. *Clinical Oral Implants Research* **22**: 464–472.

Molin, M.K. & Karlsson, S.L. (2008) Five-year clinical prospective evaluation of zirconia-based Denzir 3-unit FPDs. *The International Journal of Prosthodontics* **21**: 223–227.

Müller, F., Hernandez, M., Grütter, L., Aracil-Kessler, L., Weingart, D. & Schimmel, M. (2012) Masseter muscle thickness, chewing efficiency and bite force in edentulous patients with fixed and removable implant-supported prostheses: a cross-sectional multicenter study. *Clinical Oral Implants Research* **23**: 144–250.

Nedir, R., Bischof, M., Szmukler-Moncler, S., Belser, U.C. & Samson, J. (2006) Prosthetic complications with dental implants: from an up-to-8-year experience in private practice. *The International Journal of Oral & Maxillofacial Implants* **21**: 919–928.

Papaspyridakos, P., Benic, G.I., Hogsett, V., White, G.S., Lal, K. & Gallucci, G.O. (2011a) Accuracy of implant casts generated with splinted and non-splinted impression techniques for edentulous patients: an optical scanning study. *Clinical Oral Implants Research* **22**: [Epub ahead of print].

Papaspyridakos, P., Chen, C.J., Chuang, S.K., Weber, H.P. & Gallucci, G.O. (2012) A systematic review of biologic and technical complications with fixed implant rehabilitations for edentulous patients. *The International Journal of Oral & Maxillofacial Implants* **27**: 102–110.

Papaspyridakos, P. & Lal, K. (2008) Complete arch implant rehabilitation using subtractive rapid prototyping and porcelain fused to zirconia prosthesis: a clinical report. *Journal of Prosthetic Dentistry* **100**: 165–172.

Papaspyridakos, P. & Lal, K. (2010) Immediate loading of the maxilla with prefabricated interim prosthesis using interactive planning software and CAD/CAM rehabilitation with definitive zirconia prosthesis: 2-year clinical follow-up. *Journal of Esthetic and Restorative Dentistry* **22**: 223–234.

Papaspyridakos, P., Lal, K., White, G.S., Weber, H.P. & Gallucci, G.O. (2011b) Effect of splinted and nonsplinted impression techniques on the accuracy of fit of implant fixed prostheses in edentulous patients: a comparative study. *The International Journal of Oral & Maxillofacial Implants* **26**: 1267–1272.

Pjetursson, B.E., Brägger, U., Lang, N.P. & Zwahlen, M. (2007) Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). *Clinical Oral Implants Research* **18**(Suppl. 3): 97–113.

Roediger, M., Gersdorff, N., Huels, A. & Rinke, S. (2010) Prospective evaluation of zirconia posterior fixed partial dentures: four-year clinical results. *The International Journal of Prosthodontics* **23**: 141–148.

Sailer, I., Feher, A., Filser, F., Gauckler, LJ., Lüthy, H. & Hämmerle, C.H. (2007a) Five-year clinical results of zirconia frameworks for posterior fixed partial dentures. *The International Journal of Prosthodontics* **20**: 383–388.

Sailer, I., Gottnerb, J., Kanelb, S. & Hammerle, C.H. (2009) Randomized controlled clinical trial of zirconia-ceramic and metal-ceramic posterior fixed dental prostheses: a 3-year follow-up. *The International Journal of Prosthodontics* **22**: 553–560.

Sailer, I., Pjetursson, B.E., Zwahlen, M. & Hämmerle, C.H. (2007b) 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. *Clinical Oral Implants Research* **18**(Suppl 3): 86–96. Erratum in: *Clinical Oral Implants Research* 2008;19:326–8.

Salvi, G. E. & Brägger, U. (2009) Mechanical and technical risks in implant therapy. *The International Journal Oral & Maxillofacial Implants* **24** (Suppl.): 69–85.

Schmitt, J., Holst, S., Wichmann, M., Reich, S., Gollner, M. & Hamel, J. (2009) Zirconia posterior fixed partial dentures: a prospective clinical 3-year follow-up. *The International Journal of Prosthodontics* **22**: 597–603.

Teigen, K. & Jokstad, A. (2011) Dental implant suprastructures using cobalt-chromium alloy compared with gold alloy framework veneered with ceramic or acrylic resin: a retrospective cohort study up to 18 years. *Clinical Oral Implants Research* Jun 21 [Epub ahead of print].

Tinschert, J., Schulze, K.A., Natt, G., Latzke, P., Heussen, N. & Spiekermann, H. (2008) Clinical behavior of zirconia-based fixed partial dentures made of DC-Zirkon: 3-year results. *The International Journal of Prosthodontics* **21**: 217–222.

Zembic, A., Sailer, I., Jung, R.E. & Hammerle, C.H.F. (2009) Randomized controlled clinical trial of customized zirconia and titanium implant abutments for single-tooth implants in canine and posterior regions: 3-year results. *Clinical Oral Implants Research* **20**: 802–808.