Andreas Worni

Monolithic zirconia reconstructions supported by teeth and implants: 1- to 3-year results of a case series

Andreas Worni, Dr med dent, MAS[1]/Joannis Katsoulis, Prof Dr med dent, MAS[2]/Lumni Kolgeci, Dr med dent, MAS[3]/Mathias Worni, PD Dr med, MHS[4]/Regina Mericske-Stern, Prof emer Dr med dent[5]

Objective: Today, only scarce information is available on monolithic zirconia reconstructions. The objective of this study was to evaluate the performance of monolithic zirconia for tooth- and implant-borne reconstructions. **Method and Materials:** Monolithic zirconia single crowns (SCs) and fixed dental prostheses (FDPs) supported by implants or teeth were included in this study. Implant placement and prosthetic treatment were done in the same clinical setting. One technician performed all laboratory work using the same CAD/CAM workflow (DentalDesigner, Ceramill Motion 2, Amann Girrbach). The endpoints were technical outcome, color match, marginal adaptation, anatomical form, and biologic aspects. The modified United States Public Health Service (USPHS) criteria and periodontal parameters were applied for the clinical evaluation by two independent examiners. Descriptive statistics and nonparametric tests were used for statistical comparisons. **Results:** Forty patients (17 men, 23 women, mean age 59.1 ± 14.7 years) with 109 reconstructions (74 SCs, 35 FDPs) supported by 38 implants and 71 teeth were assessed, resulting in a total of 238 monolithic zirconia units (including 62 pontics and 18 cantilevers). Median follow-up time was 23.8 months (12 to 36 months). No technical failures were observed. The total prosthesis survival rate was 99.6% (teeth, 100%; implants, 98.4%) due to the loss of one implant. The periodontal/peri-implant parameters stand for healthy tissue, and caries was not detected. The records obtained by the USPHS revealed good clinical outcomes. **Conclusion:** These short-term results indicate that monolithic zirconia reconstructions for teeth and implants may be a satisfactory treatment option, particularly in the posterior region. *(Quintessence Int 2017;48:459–467; doi: 10.3290/j.qi.a38138)*

Key words: fixed dental prosthesis, implants, monolithic, single crowns, technical complications, zirconia

Patients' esthetic demands and their desire for metal-free reconstructions has led to the development of a variety of ceramic materials. In parallel, economic limitations may trigger more efficient fabrication procedures for indirect reconstructions.[1] The interest in zirconia as a dental restorative material has rapidly increased in the dental community in the recent years. Its application in prosthodontics runs parallel with the evolution in CAD/CAM technologies, expanding into both the laboratory and chairside application. Due to its mechanical properties, such as low thermal conductivity, biocompatibility,

[1] Senior Lecturer, former Department of Prosthodontics, School of Dental Medicine, University of Bern, Bern, Switzerland; and Senior Lecturer, Department of Fixed Prosthodontics and Biomaterials, School of Dental Medicine, University of Geneva, Geneva, Switzerland.

[2] Associate Professor, Department Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland; and Adjunct Associate Professor, Department of Preventive and Restorative Sciences, University of Pennsylvania School of Dental Medicine, Philadelphia, PA, USA.

[3] Senior Lecturer, former Department of Prosthodontics, School of Dental Medicine, University of Bern, Bern, Switzerland.

[4] Senior Lecturer, Department of Visceral Surgery and Medicine, University of Bern, Inselspital, Bern, Switzerland.

[5] Chair (Professor emeritus), former Department of Prosthodontics, School of Dental Medicine University of Bern, Bern, Switzerland.

Correspondence: Dr Andreas Worni, Bahnhofstrasse 18a, 3400 Burgdorf, Switzerland. Email: andreas.worni@gmail.com

chemical stability, and esthetic potential, yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) has been introduced for the fabrication of frameworks veneered by feldspathic porcelain for single crowns (SCs) and short span fixed dental prostheses (FDPs), firstly for tooth-borne and eventually for implant-borne reconstructions.[2-11]

Zirconia is expected to become the most successful all-ceramic system in the future.[12] However, one study on tooth-supported zirconia-based reconstructions found a high caries incidence at the crown margin within a relatively short time period.[13] Therefore, attention is required to ensure optimum accuracy of fit and marginal adaptation of computer-aided design/computer-assisted manufacture (CAD/CAM) reconstructions.[14] Furthermore, the rate of chipping of the veneering porcelain for tooth-supported zirconia-based SCs and FDPs varied between 8% and 25%.[2,6-8] High chipping rates were also reported in prospective studies on implant-supported reconstructions.[9-11] According to recent systematic reviews, no difference of the survival rate between porcelain-fused-to-metal (PFM) FDPs and zirconia-based FDPs was found. The 5-year survival rate of PFM SCs and FDPs was estimated to be around 95% for veneered zirconia.[15-17] Otherwise, satisfactory treatment outcomes for zirconia-based screw-retained implant prostheses provided for over 200 patients, including SCs, short span, and full-arch FDPs were reported in two studies.[18,19] The 5-year cumulative survival rates (CSR) reached 90.6% for 156 prostheses and 96.4% for 193 prostheses respectively. Fracture of the frameworks was a very rare event.[18-20] Today, certain technical complications can be eliminated or minimized due to better understanding and the strict adherence to the manufacturing process of zirconia. However, it seems that the weakest point remains the connection between framework and veneering material.

Since it appears that the Y-TZP zirconia material provides sufficient strength when used for prosthetic frameworks, it was suggested that monolithic zirconia reconstructions, also called "fully anatomical" or "full-contour" zirconia would be a viable alternative, meaning that veneering problems are eliminated.[9] Monolithic zirconia abutments were introduced, replacing titanium implant abutments, in order to benefit from this esthetically advantageous material. It was also used for telescopic crowns.[21,22] Recently, full-contour reconstructions, SCs, and FDPs, were tentatively produced and clinically evaluated.[23-26] This technology may reduce the laboratory work time and subsequently reduce costs. At present, however, clinical studies on monolithic zirconia are still rare.

Thus, the aim of this short-term retrospective case series was to report on the prosthetic indications of monolithic zirconia for tooth- and implant-borne reconstructions and to evaluate its performance.

METHOD AND MATERIALS

Patients

Patients who consented to receive tooth- or implant-supported anatomical, monolithic zirconia reconstructions were consecutively recruited for this study during a 2-year period from December 2011 to December 2013.

Implant placement and prosthetic treatment was carried out in the same clinical setting. Patients of all ages and with different prosthetic needs participated in the study. SCs, and short- and long-span and full-arch FDPs were provided within the study protocol.

General exclusion criteria for tooth- and implant-borne reconstructions were as follows:

- severe and poorly controlled diabetes
- anticoagulation therapy that could not be discontinued
- a history of a cardiovascular incident during the last 6 months
- irradiation and/or chemotherapy as part of therapy for a tumor
- severe psychiatric problems
- unrealistic expectations regarding the esthetic treatment outcome
- any disease that would preclude the placement of an implant under local anesthesia.

Smoking was not considered to be an exclusion criterion. However, patients who smoked were informed

of the possible negative effects on periodontal and peri-implant tissues and a smoking cessation protocol was suggested to them. All included patients were subjected to a standardized planning procedure. Five experienced clinicians performed surgical and prosthetic treatment under direct clinical supervision of the study director (MSR). The patients were monitored in a strict maintenance care program after delivery of the final reconstruction. Two routine recall visits were scheduled per year.

The patients had signed the informed consent document, and all treatment provided followed the principles of good clinical practice according to the World Medical Association Declaration of Helsinki. Treatment costs were borne by the patients. This survey was part of a quality control assessment of the dental consultation and fulfilled the regulations of good clinical practice of the local ethical committee.

Tooth preparation

For all tooth-supported reconstructions a shoulder preparation of the abutment teeth was performed according to known principles with a shallow chamfer.[27] Undercuts were avoided. Endodontically treated teeth were completed with composite resin (Tetric EvoCeram, Ivoclar Vivadent) or with a post-and-core buildup (Mooser post, Cendres & Métaux), if more than 50% of the tooth-structure was lost. A ferrule of at least 2 mm had to be present.

Implant placement

Tapered implants of different manufacturers were inserted, including NobelReplace (Nobel Biocare), Thommen ELEMENT RC (Thommen Medical), and Biodenta (Biodenta Swiss). The prospective implant position was based on a tooth-setup and a thorough clinical and radiologic examination. All implant crowns were planned to be screw-retained. Surgical splints served for prosthetically driven implant placement and in order to properly locate the access hole for screw-retention. In complex cases, cone beam computed tomography (CBCT) images in combination with three-dimensional (3D) planning software were used (NobelClinician, Nobel Biocare). Implant placement was performed with an open flap procedure. The drilling protocol followed the recommendations of the manufacturers. A healing time of at least 6 weeks was maintained in the mandible and 8 to 10 weeks in the maxilla. If implants were placed in combination with major guided bone regeneration (GBR) procedures, a healing time of 4 up to 6 months was maintained.

Prosthetic procedure and laboratory workflow

Full-arch impressions were taken with individual trays and a polyether material (Impregum, 3M ESPE). In presence of implants, the pick-up technique, with screw-retained transfer copings was applied. Impressions of the opposing arches were made with alginate material (Image Dust-Free Alginate, Dux Dental) and occlusal bite registration was performed using vinyl polysiloxane (ImprintBite, 3M ESPE). The casts were scanned and with the aid of a CAD-software (DentalDesigner, 3Shape) the reconstructions were designed. The digital dataset of the virtual design can either be used to mill directly the final reconstructions or to obtain a preliminary reconstruction made from acrylic material or resin-reinforced hard wax (Ceramill Wax, Amann Girrbach) as a first step. Due to the fact that monolithic zirconia reconstructions are still in the early stages of use, the latter method appeared to be more reliable, particularly for larger reconstructions. These preliminary reconstructions allowed for assessment of esthetic and morphologic aspects. Corrections could be performed if necessary and the occlusion was checked during a try-in session. Finally, this altered form was scanned and virtually superimposed onto the existing data-file using computer software (DentalDesigner, 3Shape). Based on the final electronic dataset, the monolithic zirconia reconstructions were milled (Ceramill Motion 2, Amann Girrbach) in a fully anatomical form and with a minimum thickness of 0.5 mm. The zirconia blocs (Ceramill Zolid, Amann Girrbach) were partially sintered. The color of the pre-sintered frameworks was individualized by means of infiltration-coloring liquids (Ceramill Liquid, Amann Girrbach). The frameworks

were then sintered at 1,400°C for 9 hours whereby they shrank to their final dimensions. Final characteristic color effects were obtained by means of staining and glazing procedures (IPS e.max Essencen and Glaze, Ivoclar Vivadent). The implant-borne SCs were luted to an anti-rotational titanium hybrid-bonding base and the FDPs to non-engaging titanium hybrid-bonding bases (PanaviaTM F2.0, Kuraray Noritake Dental). One master dental technician fabricated all reconstructions in a private laboratory.

The occlusion of the reconstructions was checked again at a try-in appointment. If minimal adjustments or grinding was necessary, the reconstructions were sent back to the dental technician for polishing and further staining. The final tooth-borne reconstructions were luted by means of a resin cement (Panavia F2.0, Kuraray Noritake Dental or RelyX Cem, 3M ESPE) with no pretreatment of the tooth. All implant-borne reconstructions were screw-retained with a calibrated torque and according to the manufacturer instructions. The screw access hole was provisionally closed with a temporary material (Telio, Ivoclar Vivadent). The stability of the screw and occlusion were checked after 2 to 4 weeks and the access hole was then definitively closed with composite resin (Tetric EvoCeram, Ivoclar Vivadent) (Figs 1 to 3).

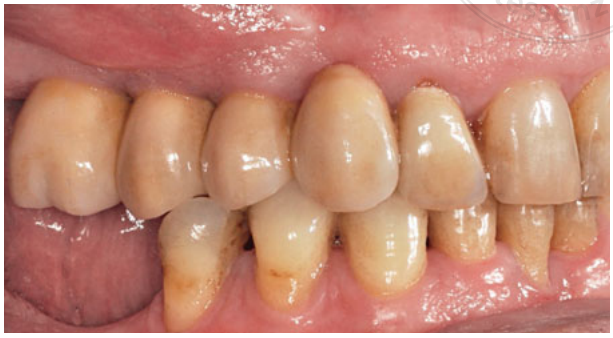

Fig 1 Buccal view of an implant-supported zirconia reconstruction from the maxillary right first molar to canine (16-15-14-x).

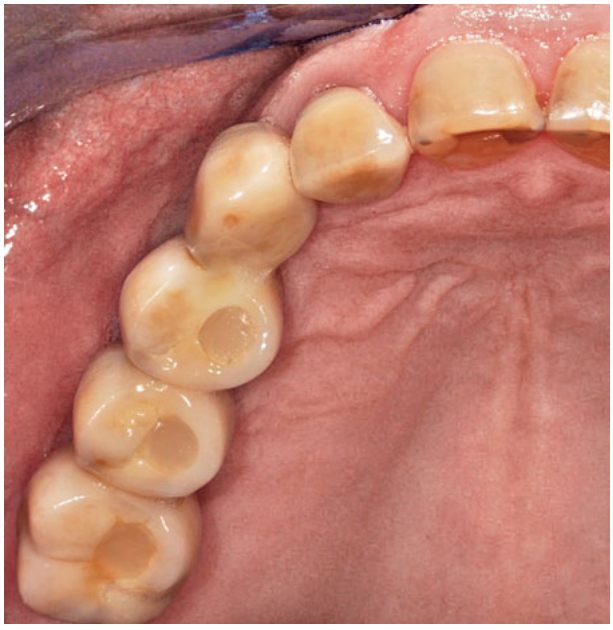

Fig 2 Occlusal view of an implant-supported zirconia reconstruction from the maxillary right first molar to canine (16-15-14-x).

Data collection

All patients were contacted by a letter and thereafter by a personal phone call to inform them about a thorough clinical assessment, which took place for all recruited patients within a time period of 3 months. The minimum observation period after delivery of the reconstructions was 12 months. The longest follow-up period was 36 months. Patients' demographics as well as data of teeth, implants, number of reconstructions, and failures were available from the patients' chart and were prospectively updated during the clinical examination. Photos were obtained, and technical and biologic complications were recorded.

The primary endpoint of the study was technical problems such as clinically visible cracks or fractures, debonding or screw loosening, fading of the staining, and complete loss of the reconstruction. Secondary endpoints were esthetic and morphologic aspects, ie color match, anatomical shape of the reconstructions, marginal adaptation, and caries as well as periodontal/peri-implant parameters. Outcome measures were: the modified United States Public Health Service (USPHS) criteria (Table 1), the Plaque Index (PI), probing depth (PD) ≥ 4 mm, and positive bleeding on probing (BOP+).

Two trained examiners performed the data collection for this study. They assessed all reconstructions

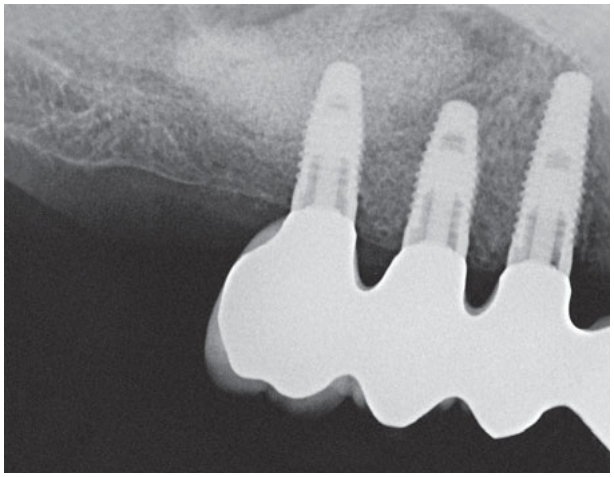

Fig 3 Radiograph of an implant-supported zirconia reconstruction from the maxillary right first molar to canine (16-15-14-x).

according to the USPHS criteria. The presence of caries and loss of vitality (verified with CO_2 test) were monitored for the abutment teeth. Thereafter, one examiner measured the periodontal parameters at four sites (mesial, buccal, distal, and lingual) around each tooth or implant supporting a SC or FDP by means of a periodontal click-probe (Kerr Click-probe, Kerr Hawe), and one examiner took photos of all reconstructions.

Statistical analysis

Descriptive statistics were used for patient demographics, the number of teeth or implants, the type of prostheses, and related clinical records. All data were collected in an Excel file and statistical analysis was performed with computerized software (STATA/SE version 13.1, Stata Corporation). With regard to the USPHS criteria, Wilcoxon signed rank test was used to assess differences between the two independent evaluators. Two-sided *P*-values of $< .05$ were considered to be statistically significant.

RESULTS

Forty patients (17 men, 23 women) with a mean age of 59.1 years (SD 14.7 years) were available for the clinical assessment. Six patients were lost to follow-up for the following reasons: one patient had passed away, three had moved away, and two refused to participate due to other illness.

Ninety-five teeth and 63 implants supported a total of 109 monolithic zirconia reconstructions consisting of a total of 238 units (including 62 pontics and 18 cantilevers). An overview of all included zirconia reconstructions is given in Table 2. Median follow-up time was 23.8 months (range 12 to 36 months). Sixty-six monolithic zirconia reconstructions (60%) were located in the maxilla and 43 reconstructions in the mandible (40%). Seven patients received both implant- and tooth-borne reconstructions. An occluding unit with both the maxillary and the mandibular reconstruction made from monolithic zirconia occurred in only one patient, with one reconstruction being tooth-supported and the other implant-supported.

No technical complications such as fractures or cracks and no debonding of tooth-borne reconstructions were recorded. For implant-borne reconstructions, no loosening or fracture of the abutment screws occurred and no instance of debonding from the hybrid titanium base was recorded. One patient lost a SC as a consequence of implant loss in the region of the maxillary right canine after 1 year. The total survival rate of the zirconia reconstructions after a median follow-up period of 33.8 months was 99.6% (teeth, 100%; implants, 98.4%).

The records obtained by the USPHS revealed good clinical outcomes (Table 3). While the scores for "color match" ($P < .001$) and "anatomical form" ($P = .005$) were different between the two examiners, no difference was found for marginal adaptation ($P = .71$). No secondary caries or loss of vitality of abutment teeth was recorded during the follow-up period. The biologic evaluation revealed healthy gingival conditions around tooth- and implant-borne reconstructions (Table 4). The PI was low, at 8.9%. A mean BOP-value of 10.6% (standard deviation [SD], 16.1%; range, 0% to 66.6%) was found. Most teeth and implants exhibited PD between 1 mm and 3 mm (93.0%). At two implants sites, PD ≥ 6 mm were observed without BOP+ or pus (1.3%) (Table 4).

Table 1 Modified USPHS criteria for classification of fully anatomical zirconia reconstructions

Characteristic	Rating	Criteria
Color match	Alpha	No mismatch in color, translucency, or opacity between the reconstruction and adjacent tooth
	Bravo	Slight mismatch between reconstruction and adjacent tooth (in normal range)
	Charlie	Major mismatch between reconstruction and adjacent tooth (outside of normal range)
Marginal adaptation	Alpha	No visible mismatch or gap that could be probed
	Bravo	Slight under- or over-contour could be probed
	Charlie	Visible crevice and under- or over-contour could be probed
Secondary caries	Alpha	No caries lesion in the region of the crown margin (only analyzed in tooth-borne reconstructions)
	Bravo	Caries lesion in the region of the crown margin (only analyzed in tooth-borne reconstructions)
Anatomical form	Alpha	Ideal anatomical shape, good proximal contact points
	Bravo	Reconstruction does not correspond to natural tooth anatomy (slightly under- or over-contoured and/or weak proximal contact points)
	Charlie	Reconstruction does not correspond to natural tooth anatomy (pronounced under- or over-contour and/or no contact points)

Table 2 Overview of examined zirconia reconstructions

Prosthetic indication	Region	No. of rec./units (63 implant-supported)	No. of rec./units (95 tooth-supported)	Total units
SC	Posterior	17/17	37/37	54
FDP	Posterior	11/55	5/36	91
SC	Anterior	1/1	19/19	20
FDP	Anterior	9/30	10/43	73
Total SC		18	56	74
Total FDP		20	15	35
Total units		103	135	238

FDP, fixed dental prosthesis; rec., reconstruction; SC, single crown.

DISCUSSION

The present case series demonstrates promising treatment outcomes for tooth- and implant-borne monolithic zirconia reconstructions without any important technical or biologic complications after an observation period of 12 to 36 months. There were no differences between tooth- and implant-borne reconstructions. The reason for the loss of one implant could not be explained. It was replaced by a new implant with a new monolithic zirconia crown. However, the short follow-up period needs to be considered in this context.

Today CAD/CAM technology enables the processing of a high variety of metal-free dental materials. So far, strength and stability of monolithic zirconia has been analyzed in several laboratory investigations.[23,28,29] It was shown in in-vitro investigations that precision of fit of wax or CAD/CAM-fabricated zirconia frameworks is clearly superior to PFMs with short- and long-span reconstructions.[30,31] Accordingly, high precision of fit may hinder loosening of screw-retained implant-borne reconstructions, an event that has not occurred in the present study. High precision of fit in combination with an adequate luting system may hinder caries development at the crown margin of tooth-borne reconstruc-

Table 3 Outcomes based on the USPHS classification criteria assessed by two examiners A and B (per prosthetic pillar)

Characteristic	Examiner	Alpha	Bravo	Charlie	*P**
Color match	A	138	19	0	< .001
	B	112	41	4	
Marginal adaptation	A	147	10	0	.71
	B	146	11	1	
Secondary caries	A	95	0	0	1.0
	B	95	0	0	
Anatomical form	A	144	13	0	.005
	B	152	5	0	

* Wilcoxon signed rank test.

Table 4 Periodontal/peri-implant parameters

Parameter	Number of occurences (63 implants/252 sites)	Number of occurences (95 teeth/380 sites)	Total
PD ≤ 3 mm	245	377	622
PD 4–5 mm	6	2	8
PD ≥ 6 mm	2	0	2
BOP+	9	43	52
PD > 4 mm/BOP+ combined	1	2	3

BOP, bleeding on probing; PD, pocket depth.

tions. Furthermore, in-vitro analyses and clinical studies pointed to the importance of the interproximal connector size, being 3 × 3 mm up to 4 × 4 mm for zirconia-based reconstructions. Accordingly, an adequate framework design is required for zirconia-based and monolithic prostheses.[8,9,31-33] Such minimum dimensions were strictly maintained in the present study for multi-unit FDPs. Due to the high fracture resistance, the occlusal space required for monolithic zirconia reconstructions could be limited to a minimum of 0.5 mm. Thus, the reduction of the abutment tooth during preparation is subsequently minimized.[34] This advantage is particularly helpful in cases of short abutment teeth and/or restricted maxillomandibular space.

Zirconia framework fractures may still occur as a consequence of the porosity present in the white-stage zirconia blank (pre-sintered or sintered), post-sintering damage, and/or low temperature degradation of the zirconia.[35,36] Therefore, it is of upmost importance that zirconia blocs of high quality are used. Since scan-bodies for implants were not yet available in the present study, the conventional analog method was applied.

One laboratory study identified a comparable passive fit for CAD/CAM and wax/CAM procedures with monolithic zirconia crowns and better passive fit than with veneered zirconia.[37] A prosthetic optimal mock-up/wax-up as applied in the present study allows for a try-in session and can even be used as a short time preliminary reconstruction. With special consideration to the individual occlusal pattern, particularly in presence of FDPs, it will minimize the need for adjustments after the milling and sintering process. If minor adjustments are necessary, the external surfaces of monolithic zirconia must be carefully polished to reduce any abrasive effects.[38] Considering the technical outcomes rated by means of the USPHS criteria, no significant differences

were found in the assessment of both trained and calibrated examiners. Ratings of examiner B were slightly less favorable. Assessing the color of monolithic zirconia appears to be difficult and is sensitive to the light conditions and colors of adjacent reconstructions or natural teeth respectively. Missing translucency and bright opacity may hinder a natural and neutral integration between healthy non-restored teeth in spite of individual coloring and staining. Adding a thin veneering layer on the buccal – not occlusal – surface of monolithic reconstructions (cut-back) might solve this problem.[25] This technology was not considered in the present study.

Coloring, staining, and glazing procedures are less time-consuming than veneering zirconia frameworks. However, esthetical aspects of monolithic zirconia reconstructions remain a challenge. Laboratory studies that applied the two body wear technique have shown that polished monolithic zirconia, although very hard, produces less contact wear than, for example, feldspathic ceramics to the opposing enamel.[39,40] The monolithic reconstructions exhibited no measurable wear.[40] Wear of opposing enamel appears to be less with monolithic zirconia as compared to contact wear with other ceramics.[39,40] This is probably due to its homogenous surface. In fact, it appears that wear might be slightly higher when using coloring and glazing liquids than with purely polished zirconia surfaces and may be similar to wear of a feldspathic veneer.[38-40]

It was also shown that the application of liquid stains was successful in reducing the lightness and opalescence of monolithic zirconia and made it more yellowish. However, the translucency of monolithic zirconia could not be altered by these coloring procedures.[38] Alterations in the techniques of fabrication and sintering monolithic zirconia may increase its translucency of zirconia.[41] Thus, modifications of monolithic zirconia material may evolve into new material characteristics and lead to more favorable esthetics.

A related effect is demonstrated by favorable biologic periodontal/peri-implant parameters. This positive outcome can also be attributed to the good biologic properties of zirconia and accurate work by a qualified and trained technician.[11] Furthermore, professional assistance was rendered to maintain good oral hygiene during the observation time. Pocket probing depths exceeding 4 mm were a rare biologic complication and mostly identified at the palatal implant site. This might be explained by the specific morphology of the palatal peri-implant mucosa, and they were identified as pseudo-pockets with the absence of BOP+ and/or pus. Similar favorable clinical results were also observed in other clinical studies using zirconia abutments.[21,42]

The present study is a preliminary contribution to the clinical use of full contour, monolithic zirconia. Comparable clinical studies on monolithic zirconia like the present report are not yet available. Hence, the comparison of other findings with those of the present study was not possible. Compared to the 5-year survival rates of veneered zirconia reconstructions of 92.1% for SCs and 90.4% for FDPs, the results of the present study (survival rate 99.6% after 12 to 36 months) seem to be promising.[15,16] Limitations of the present investigation were the rather inhomogenous patient sample and the short observation period. In addition, only one CAD/CAM system was used. However, the results indicated that, in general, the monolithic zirconia reconstructions exhibited high survival rates, and that no significant differences were observed between tooth-borne and implant-borne monolithic zirconia reconstructions.

CONCLUSION

These short-term results indicate that monolithic zirconia reconstructions for teeth and implants may be a possible treatment option in various indications, particularly in the posterior region. Further research and longer observation time is needed to assess its superiority compared to other monolithic or conventional restorative materials.

REFERENCES

1. Tordiglione L, De Franco M, Bosetti G. The prosthetic workflow in the digital era. Int J Dent 2016;2016:9823025.
2. Ortorp A, Kihl ML, Carlsson GE. A 3-year retrospective and clinical follow-up study of zirconia single crowns performed in a private practice. J Dent 2009;37:731–736.
3. Papaspyridakos P, Lal K. Computer-assisted design/computer-assisted manufacturing zirconia implant fixed complete prostheses: clinical results and technical complications up to 4 years of function. Clin Oral Implants Res 2013;24:659–665.
4. Pelaez J, Cogolludo PG, Serrano B, Lozano JF, Suarez MJ. A prospective evaluation of zirconia posterior fixed dental prostheses: three-year clinical results. J Prosthet Dent 2012;107:373–379.
5. Raigrodski AJ, Chiche GJ, Potiket N, et al. The efficacy of posterior three-unit zirconium-oxide-based ceramic fixed partial dental prostheses: a prospective clinical pilot study. J Prosthet Dent 2006;96:237–244.
6. Sailer I, Gottnerb J, Kanelb S, Hammerle CH. Randomized controlled clinical trial of zirconia-ceramic and metal-ceramic posterior fixed dental prostheses: a 3-year follow-up. Int J Prosthodont 2009;22:553–560.
7. Tinschert J, Schulze KA, Natt G, Latzke P, Heussen N, Spiekermann H. Clinical behavior of zirconia-based fixed partial dentures made of DC-Zirkon: 3-year results. Int J Prosthodont 2008;21:217–222.
8. Vult von Steyern P, Carlson P, Nilner K. All-ceramic fixed partial dentures designed according to the DC-Zirkon technique. A 2-year clinical study. J Oral Rehabil 2005;32:180–187.
9. Larsson C, Vult von Steyern P. 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 2010;23:555–561.
10. Larsson C, Vult von Steyern P, Nilner K. A prospective study of implant-supported full-arch yttria-stabilized tetragonal zirconia polycrystal mandibular fixed dental prostheses: three-year results. Int J Prosthodont 2010;23:364–369.
11. Nothdurft FP, Pospiech PR. Zirconium dioxide implant abutments for posterior single-tooth replacement: first results. J Periodontol 2009;80:2065–2072.
12. Della Bona A, Kelly JR. The clinical success of all-ceramic restorations. J Am Dent Assoc 2008;139(Suppl):8s–13s.
13. Sailer I, Feher A, Filser F, Gauckler LJ, Luthy H, Hammerle CH. Five-year clinical results of zirconia frameworks for posterior fixed partial dentures. Int J Prosthodont 2007;20:383–388.
14. Euan R, Figueras-Alvarez O, Cabratosa-Termes J, Oliver-Parra R. Marginal adaptation of zirconium dioxide copings: influence of the CAD/CAM system and the finish line design. J Prosthet Dent 2014;112:155–162.
15. Pjetursson BE, Sailer I, Makarov NA, Zwahlen M, Thoma DS. All-ceramic or metal-ceramic tooth-supported fixed dental prostheses (FDPs)? A systematic review of the survival and complication rates. Part II: Multiple-unit FDPs. Dent Mater 2015;31:624–639.
16. Sailer I, Makarov NA, Thoma DS, Zwahlen M, Pjetursson BE. 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 2015;31:603–623.
17. Takeichi T, Katsoulis J, Blatz MB. Clinical outcome of single porcelain-fused-to-zirconium dioxide crowns: a systematic review. J Prosthet Dent 2013;110:455–461.
18. Kolgeci L, Mericske E, Worni A, Walker P, Katsoulis J, Mericske-Stern R. Technical complications and failures of zirconia-based prostheses supported by implants followed up to 7 years: a case series. Int J Prosthodont 2014;27:544–552.
19. Worni A, Kolgeci L, Rentsch-Kollar A, Katsoulis J, Mericske-Stern R. Zirconia-based screw-retained prostheses supported by implants: a retrospective study on technical complications and failures. Clin Implant Dent Relat Res 2015;17:1073–1081.
20. Al-Amleh B, Lyons K, Swain M. Clinical trials in zirconia: a systematic review. J Oral Rehabil 2010;37:641–652.
21. Glauser R, Sailer I, Wohlwend A, Studer S, Schibli M, Scharer P. Experimental zirconia abutments for implant-supported single-tooth restorations in esthetically demanding regions: 4-year results of a prospective clinical study. Int J Prosthodont 2004;17:285–290.
22. Kollar A, Huber S, Mericske E, Mericske-Stern R. Zirconia for teeth and implants: a case series. Int J Periodontics Restorative Dent 2008;28:479–487.
23. Batson ER, Cooper LF, Duqum I, Mendonca G. Clinical outcomes of three different crown systems with CAD/CAM technology. J Prosthet Dent 2014;112:770–777.
24. Limmer B, Sanders AE, Reside G, Cooper LF. Complications and patient-centered outcomes with an implant-supported monolithic zirconia fixed dental prosthesis: 1 year results. J Prosthodont 2014;23:267–275.
25. Moscovitch M. Consecutive case series of monolithic and minimally veneered zirconia restorations on teeth and implants: up to 68 months. Int J Periodontics Restorative Dent 2015;35:315–323.
26. Stober T, Bermejo JL, Rammelsberg P, Schmitter M. Enamel wear caused by monolithic zirconia crowns after 6 months of clinical use. J Oral Rehabil 2014;41:314–322.
27. Goodacre CJ. Designing tooth preparations for optimal success. Dent Clin North Am 2004;48(v):359–385.
28. Rosentritt M, Preis V, Behr M, Hahnel S, Handel G, Kolbeck C. Two-body wear of dental porcelain and substructure oxide ceramics. Clin Oral Investig 2012;16:935–943.
29. Stawarczyk B, Ozcan M, Schmutz F, Trottmann A, Roos M, Hammerle CH. Two-body wear of monolithic, veneered and glazed zirconia and their corresponding enamel antagonists. Acta Odontol Scand 2013;71:102–112.
30. Katsoulis J, Mericske-Stern R, Yates DM, Izutani N, Enkling N, Blatz MB. In vitro precision of fit of computer-aided design and computer-aided manufacturing titanium and zirconium dioxide bars. Dent Mater 2013;29:945–953.
31. Katsoulis J, Muller P, Mericske-Stern R, Blatz MB. CAD/CAM fabrication accuracy of long- vs. short-span implant-supported FDPs. Clin Oral Implants Res 2015;26:245–249.
32. Beuer F, Stimmelmayr M, Gernet W, Edelhoff D, Guh JF, Naumann M. Prospective study of zirconia-based restorations: 3-year clinical results. Quintessence Int 2010;41:631–637.
33. Edelhoff D, Florian B, Florian W, Johnen C. HIP zirconia fixed partial dentures: clinical results after 3 years of clinical service. Quintessence Int 2008;39:459–471.
34. Jang GW, Kim HS, Choe HC, Son MK. Fracture strength and mechanism of dental ceramic crown with zirconia thickness. Procedia Eng 2011;10:1556–1560.
35. Lughi V, Sergo V. Low temperature degradation -aging- of zirconia: a critical review of the relevant aspects in dentistry. Dent Mater 2010;26:807–820.
36. Miyazaki T, Nakamura T, Matsumura H, Ban S, Kobayashi T. Current status of zirconia restoration. J Prosthodont Res 2013;57:236–261.
37. Karl M, Graef F, Wichmann M, Krafft T. Passivity of fit of CAD/CAM and copy-milled frameworks, veneered frameworks, and anatomically contoured, zirconia ceramic, implant-supported fixed prostheses. J Prosthet Dent 2012;107:232–238.
38. Beuer F, Stimmelmayr M, Gueth JF, Edelhoff D, Naumann M. In vitro performance of full-contour zirconia single crowns. Dent Mater 2012;28:449–456.
39. Kim MJ, Oh SH, Kim JH, et al. Wear evaluation of the human enamel opposing different Y-TZP dental ceramics and other porcelains. J Dent 2012;40:979–988.
40. Kontos L, Schille C, Schweizer E, Geis-Gerstorfer J. Influence of surface treatment on the wear of solid zirconia. Acta Odontol Scand 2013;71:482–487.
41. Jiang L, Liao Y, Wan Q, Li W. Effects of sintering temperature and particle size on the translucency of zirconium dioxide dental ceramic. J Mater Sci Mater Med 2011;22:2429–2435.
42. Sailer I, Philipp A, Zembic A, Pjetursson BE, Hammerle CH, Zwahlen M. A systematic review of the performance of ceramic and metal implant abutments supporting fixed implant reconstructions. Clin Oral Implants Res 2009;20(Suppl 4):4–31.