Clinical Evaluation of All-Ceramic Zirconia Framework Resin Bonded Bridges

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ABSTRACT

Objective: To evaluate the clinical longevity of 58 adhesively bonded single unit yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) ceramic Resin Bonded Bridges (RBB). Materials and Methods: Twenty six consecutive patients with at least one congenitally missing tooth in the maxilla or mandible were provided with 58 single unit Y-TZP RBBs. The cantilever RBBs were designed and milled using a CAD-CAM system to produce frameworks which were veneered using a glass-ceramic material and cemented with a self-etching dual-cure resin cement. Results: Following a mean follow up period of 36.2 months (maximum 62.3 months, minimum 25.4 months), 48 restorations remain in service with a survival rate of 82.7%. One anterior retainer fracture was encountered and no fractures of the posterior framework or ceramic were noted within the time frame reported. Conclusions: All ceramic Y-TZP RBBs replacing maxillary and mandibular teeth in the anterior and posterior areas demonstrated an 82.7% Kaplan Meier survival rate over 3 years, which was comparable to previously published survival rates for the non-perforated metal framework RBBs. Clinical implications: Replacement of anterior or posterior teeth using single unit cantilevered RBBs using Y-TZP ceramics should be considered a viable restorative option with a high survival rate.

INTRODUCTION

The replacement of a single tooth, either congenitally missing or through acquired loss can be achieved by multiple restorative alternatives, such as a conventional or resin-bonded fixed dental prosthesis, osseointegrated dental implants or a removable dental prosthesis.

A Resin Bonded Bridge (RBB) is considered the most conservative option for replacing teeth, particularly single tooth replacements. A systematic review of RBBs reported a 5-year survival rate of 87.7%[1] and 10-year estimated survival figures of 65%.[2] In contrast, a recent study reported no change between five- and ten-year follow-up period with 80.8% and 80.4% survival rates respectively.[3] These figures were lower than the reported 5-year and 10-year survival rates of 94.5%[4] and 89.4% respectively[2] for implant-retained single crowns; or the 93.8% and 89.1% respectively for conventional fixed dental prosthesis.[5] Nevertheless, RBBs are non-invasive and reversible, if no or minimal tooth preparation has been carried out, with reported high patient satisfaction.[6] RBBs are a treatment of choice in patients who are too young for dental implant therapy, given the likelihood of an interference with normal craniofacial growth and resultant relative submergence of implants.[7,8]

RBBs have evolved over the years. The original design relied on macro-mechanical retention and these 'Rochette' termed prostheses were fabricated with a perforated metal retainer wing, which was bonded with composite resin material.[9,10] Subsequent developments in retainer designs as well as cements, have resulted in a rise in the usage of non-perforated retainers. Different techniques have been used to create micro-mechanical retentive features through chemical means such as tin plating, acid etching, or air abrasion of the fitting surface.[11] Today a non-perforated, sandblasted, non-precious metal-framed prosthesis luted with a chemically active resin cement is the most widely used type.

The resin-retained, non-perforated metal retainer has been predictably used with reported retention rates of up to 95.5% (mean service life 51.7 months).[12] The use of multiple abutments for RBBs as a means of improving survival rates revealed that these were more likely to fail,[13] especially when three or more abutment teeth were employed.[14] Also given the higher propensity for caries at a debonded abutment[15] there has been a move towards the provision of single unit cantilever prosthesis. To date, there is less evidence to support superiority of one design over the other when utilising RBBs to replace posterior teeth.

Metal framework RBBs demonstrate adequate fracture resistance (541N)[16] and cost-effectiveness but have been criticised for their aesthetic limitations due to a greying effect of abutment teeth due to metal shine through[17] This can be minimised with the use of an opaque luting cement (Panavia 21 OP, Kuraray Co. Ltd, Osaka, Japan).[3] Despite these measures, the aesthetic outcome, in the author's opinion, is less than optimal, especially in the younger patient with teeth that display a higher degree of translucency.

Previous attempts at using tooth coloured frameworks, in order to address this shortcoming, have proven unsuccessful due to limited longevity and poor fracture strength.[18] Meanwhile, limited evidence seems to demonstrate improved success when using a glass-infiltrated alumina ceramic framework.[19]

In recent years, several computer aided design and computer aided machining technology (CAD-CAM) systems have been introduced for dental use allowing custom designing and milling of yttria-stabilised tetragonal zirconia polycrystalline (Y-TZP) ceramics. The framework was designed on a computer and subsequently milled, as this method has been shown to demonstrate proven accuracy and fit.[20] Materials, such as Y-TZP ceramics are used in implant and conventional restorations. Y-TZP ceramics have impressive physical properties with flexural strengths between 800-1000 MPa and fracture toughness between 6-8 MPa $m^{0.5}$,[21] and are utilised for aesthetic restorations. However, the role of Y-TZP ceramic RBBs is yet to be thoroughly evaluated and to date, one study reported a three-year survival rate of 100% with a mean follow up of 41.7 months (range 9.4 – 55.9 months).[22] This study investigated two different luting resins and only reported zirconia RBBs (n=30 total) in the maxillary and mandibular anterior region, and as such their application in posterior areas of the mouth remains to be investigated. The same authors subsequently reported a five-year survival rate of 100% in anterior RBB's with a mean observation time of 64.2 months.[23]

The aim of this paper is to report short-term follow up results of 58 consecutively placed all-ceramic Y-TZP cantilever RBBs for the replacement of single maxillary or mandibular anterior or posterior teeth.

MATERIALS AND METHODS

Fifty eight cantilever RBBs in 26 consecutive patients were provided. Patients had 1 to 4 RBBs replacing single teeth in different sites. Thirty six were placed in the maxilla (30 anterior, 6 posterior) and twenty two RBBs in the mandible (7 anterior, 15 posterior). All restorations replaced congenitally missing teeth. The mean follow-up period was 36.2 months (maximum 62.3 months, minimum 25.4 months).

The details of the prostheses are outlined in Table 1. The RBBs had been provided as part of the patient's routine clinical care. Ethics approval was applied for but was not deemed necessary by the Institutional Review Board for reporting outcome retrospectively in an anonymised manner.

All patients had congenitally missing teeth and fixed orthodontic treatment for space distribution was carried out as part of the multi-disciplinary management. After a period of at least six months post completion of orthodontic treatment, prosthetic treatment was commenced. Ovate pontic sites were developed by modifying the interim prosthesis where necessary. In some cases orthodontic retainers were used. The chosen abutment teeth underwent no tooth preparation. Impressions were made in heavy and light body addition-cured silicone impression material (Virtual®, Ivoclar-Vivadent AG, Schaan, Liechtenstein). The light body was injected around the abutment tooth and the occlusal surfaces of the remaining teeth to capture fine detail. The heavy body material was loaded in disposable, perforated impression trays and the material was allowed to set in the mouth. The opposing impression was recorded in irreversible hydrocolloid impression material.

Fuji Rock type 4 dental stone (GC Europe, Leven, Belgium) was mixed with water (100g powder/20mls water), vacuum mixed for 45 secs and poured into the impressions and left to set for 1 hour. Once based, the casts were articulated using low expansion articulation plaster (56 mls water /100g powder, Bracon, East Sussex, UK) and a semi-adjustable articulator (Denar Mark II, Whip Mix Corporation, Fort Collins, CO 80525, USA).

Stone casts were scanned using the CS1 scanner or the upgraded CS2 scanner and the Cares Visual software (Institut Straumann AG, Basel, Germany). Y-TZP ceramic frameworks were designed and milled using the Etkon CAD-CAM, Straumann CARES, Gräfelfing, Germany). Designs ensured a prosthesis retainer wing thickness of at least 0.6mm with no addition of porcelain to the retainer. The connector size was set according to the software design parameters for YTZP ceramic (Zerion®, Straumann, ≈4mm depth). The retainer design ensured maximum palatal coverage of the anterior abutment tooth. The posterior prostheses were designed to ensure the retainer covered at least the palatal/lingual cusps or the entire occlusal surfaces of the abutment teeth. No tooth preparation was carried out to create inter-occlusal space in the anterior or posterior region and occlusal surfaces were not fully covered on posterior teeth if occlusal interferences was judged as a problem. When an existing restoration was present, the framework was extended to fully cover the margins of the restoration. Prosthesis designs were outsourced to Straumann's milling facility and finished frameworks returned after manufacturing *(Figure 1 and 2)*. The YTZP frameworks (Zerion®, Straumann) were checked for accuracy of fit on the dental cast. If the connector width and thickness interfered with function or aesthetics, minor adjustments were made without compromising the manufacturers' recommendations for minimum thickness.

Figure 1: Anterior YTZP ceramic RBB framework following CAD-CAM manufacturing and before the addition of veneering material.

Figure 2: Posterior YTZP ceramic RBB frameworks after veneering with IPS e.max Ceram glass-ceramic.

Prior to ceramic veneering, the frameworks were steam cleaned (X3 steam, Amann Girrbach, Germany) and dried to cleanse the framework. IPS e.max Ceram ZirLiner was mixed with Zirliner build up liquid (Ivoclar-Vivadent, Schaan, Liechtenstein) and a thin layer was applied to the pontic part of the framework using a brush. The framework was then sintered in a porcelain furnace (Multimat MCII, Dentsply, Germany), at 960°C for one minute under partial vacuum according to the manufacturers firing schedule. IPS e.max Ceram layering ceramic was mixed with build-up liquid and the pontic was developed to full contour. The build-up was fired according to the manufacturers' dentine/enamel firing cycles (750°C for one minute under vacuum) in a porcelain furnace (Multimat MCII). Following adjustments using diamond burs, the restorations were stained and glazed according to the manufacturers' recommendations (725°C for one minute under vacuum). Occluding surfaces of the retainer wings were polished using a hand piece at a speed of 5,000 rpm, using a series of coarse, medium and fine diamond impregnated ceramic rubber wheels (Skillgloss green, blue and yellow HP surface finishers, Skillbond, UK) to achieve a highly glazed finish.

RESTORATION CEMENTATION

The abutment teeth were cleaned with pumice to ensure complete biofilm removal prior to trial placement of the restoration, which were adjusted if necessary. Any final adjustment was carried out in the laboratory and the fitting surface was steam cleaned and dried in preparation for cementation.

Prior to cementation, the fitting surface of the retainer was treated with zirconia primer (Monobond-S, Ivoclar-Vivadent) and the abutment primed with a solution of primer A-B (Multi-Link Automix, Ivoclar-Vivadent). The manufacturers' instructions were strictly followed for the cementation protocol. All restorations were cemented using a self-etching dual-cure resin cement (Multi-Link Automix, Ivoclar-Vivadent). Once seated the restorations were tack cured using a LED dental curing light (Bluephase®, Ivoclar-Vivadent, Intensity =1200 Mw/cm²) for 5 seconds followed by excess cement removal and definitive light curing for sixty seconds (20 seconds per segment).

Patients were reviewed 4-6 weeks post-cementation and later examined on an annual basis. They were asked to contact immediately if any of the restorations debonded or fractured. Failure was defined by fracture, loosening or debond of the restoration. Patients with failures were invited to attend the hospital for further clinical assessment and review.

STATISTICAL ANALYSIS

Data was analysed using IBM SPSS Statistics v22. Kaplan-Meier survival analysis was used to calculate survival until failure. A life table was generated including survival time, the cumulative proportion surviving and standard error at the time and number of cumulative failures. Censored observations were also included up to maximum length of follow up. A graphical representation of the survival curve was also generated. Survival times were compared using the Logrank test between RBBs placed posteriorly or anteriorly and RBBs placed in the maxilla or mandible.

RESULTS

The longest surviving restoration recorded was '*in situ*' for 62.3 months *(Table 1)*. The majority of failures occurred within the first 12 months after cementation *(Table 1)*. The last failure recorded at 20.8 months (restoration number 10), was a professional decision taken to replace a functioning restoration as the patient had two other prostheses that had failed and subsequently wanted all the teeth replaced with dental implants. In total, 10 RBBs (17.3%) failed in 7 patients *(Table 1)*.

Six restorations failed in the maxilla and 4 in the mandible; 8 failures occurred in the anterior and 2 in the posterior region *(Table 1)*.

Five debonded restorations were successfully recemented. Four restorations in two patients were not recemented as they preferred to have replacement with single tooth dental implant restorations and one surviving RBB in one of these patients was also replaced with an implant restoration following professional judgment.

Table 1. Life table for failure data from 58 adhesively bonded single unit yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) ceramic Resin Bonded Bridges

Restoration number	Patient number	Pontic	Retainer tooth	Survival time (months)	Cumulative Proportion Surviving at the Time		Number of cumulative failures
					Estimate	Standard error	
1	6	12	13	.5	.	.	1
2	24	12	11	.5	.966	.024	2
3	19	24	25	3.2	.948	.029	3
4	10	41	42	5.5	.	.	4
5	24	22	21	5.5	.914	.037	5
6	13	23	22	6.5	.897	.040	6
7	17	45	46	7.2	.879	.043	7
8	4	31	32	7.4	.862	.045	8
9	10	12	13	12.7	.845	.048	9
10^	10	31	32	20.8	.828	.050	10
11	25	22	23	25.4*	.	.	10
12	25	35	36	25.4*	.	.	10
13	25	45	46	25.4*	.	.	10
14	26	12	11	25.4*	.	.	10
15	19	35	36	30.5*	.	.	10
16	19	45	44	30.5*	.	.	10
17	21	22	23	32.3*	.	.	10
18	21	12	13	32.3*	.	.	10
19	21	31	32	32.3*	.	.	10
20	23	31	32	33.7*	.	.	10
21	23	41	42	33.7*	.	.	10
22	11	12	13	37.4*	.	.	10
23	11	22	23	37.4*	.	.	10
24	15	12	11	37.6*	.	.	10
25	15	22	21	37.6*	.	.	10
26	15	46	47	37.6*	.	.	10
27	15	45	44	37.6*	.	.	10
28	7	12	11	39.9*	.	.	10
29	9	12	11	40.4*	.	.	10
30	9	22	21	40.4*	.	.	10
31	20	12	11	40.4*	.	.	10
32	20	45	46	40.4*	.	.	10
33	13	23	24	42.0*	.	.	10
34	17	22	24	42.0*	.	.	10
35	17	12	14	42.7*	.	.	10
36	22	35	36	43.2*	.	.	10
37	22	45	46	43.2*	.	.	10
38	22	44	43	43.2*	.	.	10
39	2	12	13	46.4*	.	.	10
40	2	22	23	46.4*	.	.	10
41	2	45	46	46.4*	.	.	10
42	2	35	36	46.4*	.	.	10
43	4	41	42	46.4*	.	.	10
44	5	22	21	46.8*	.	.	10
45	18	12	13	46.8*	.	.	10
46	18	22	23	46.8*	.	.	10
47	18	35	36	46.8*	.	.	10
48	18	45	46	46.8*	.	.	10
49	16	12	13	48.0*	.	.	10
50	14	14	16	52.4*	.	.	10
51	14	24	26	52.4*	.	.	10
52	1	12	11	54.2*	.	.	10
53	1	22	23	54.2*	.	.	10
54	3	12	13	56.5*	.	.	10
55	3	22	23	56.5*	.	.	10
56	8	12	13	57.2*	.	.	10
57	12	14	16	62.3*	.	.	10
58	12	24	25	62.3*	.	.	10

^ - Restoration voluntarily removed and replaced with a dental implant

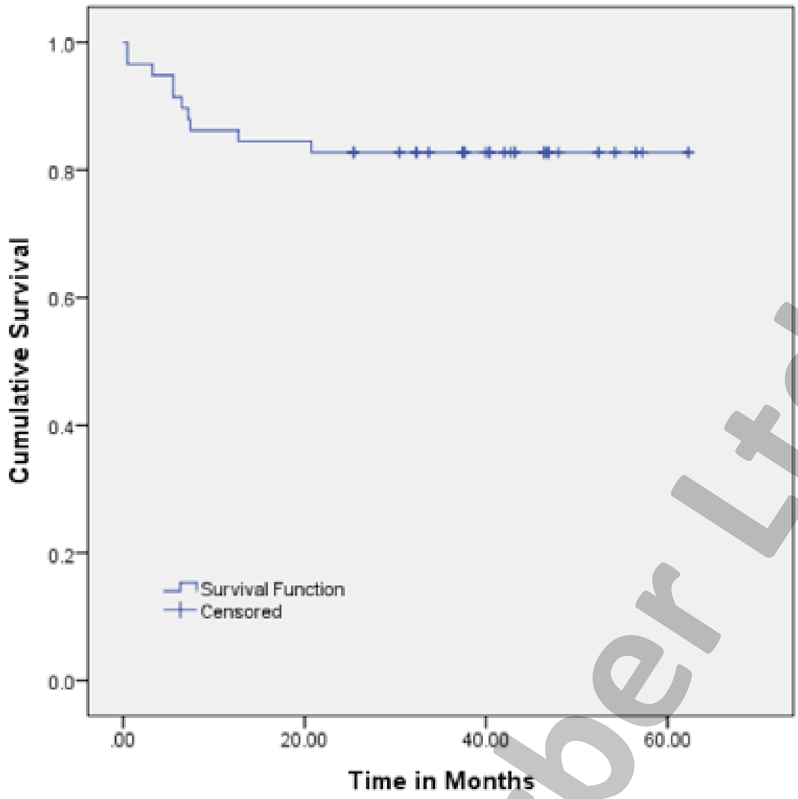

Figure 3: Kaplan-Meier survival curve for all 58 YTZP resin bonded bridges showing the time of failure or censoring (first debond, fracture or professional decision to replace).

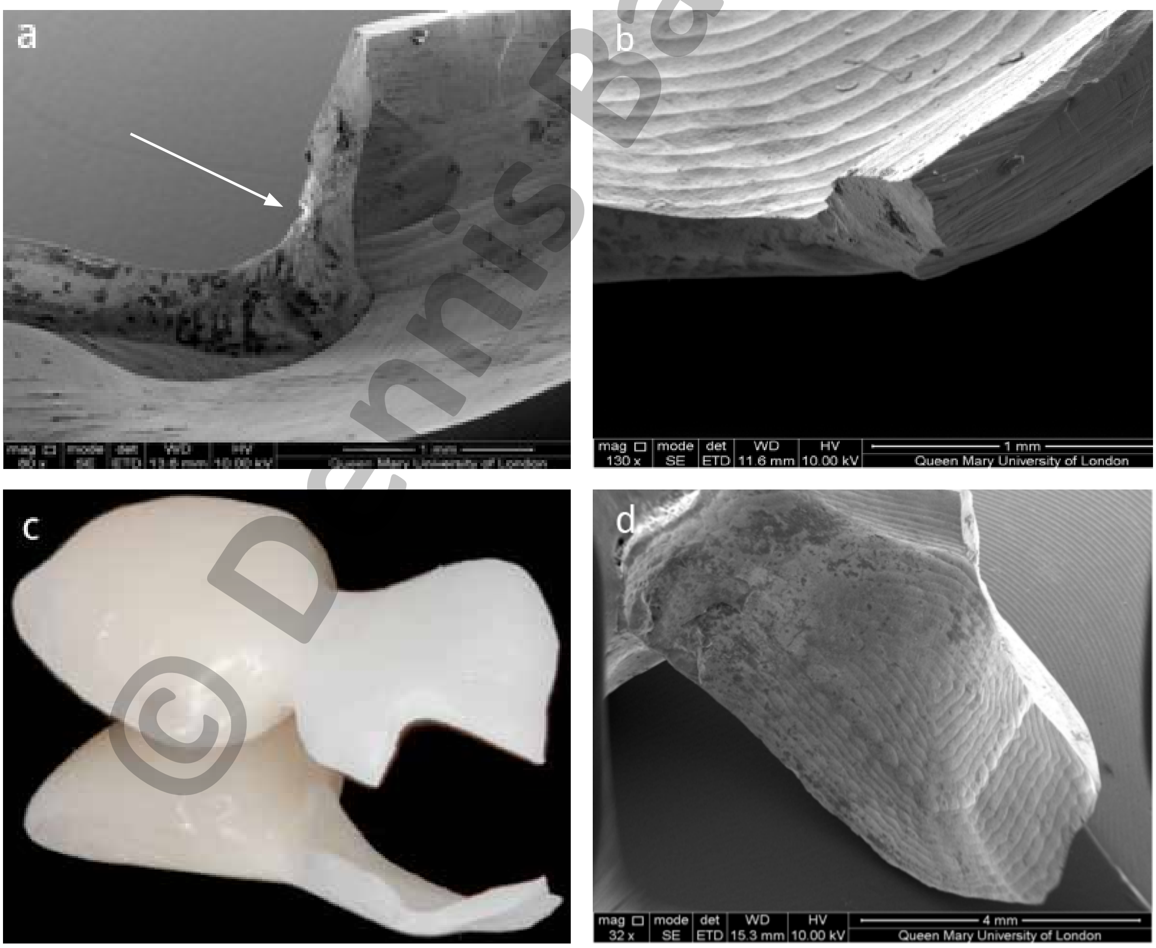

Figure 4: a-b) SEM photomicrographs; c) photo showing a failed YTZP ceramic RBB wing and fracture origins (indicated by arrow in a); d) SEM photomicrograph of the palatal surface of the failed YTZP ceramic RBB wing showing an adhesive debond failure.

Eighty-four percent of the restorations did not fail up to 12.7 months (*Figure 3*). There were no statistically significant differences (P>0.05) between RBBs placed posteriorly or anteriorly or RBBs placed in the maxilla or mandible.

The most common reason for restoration failure was debonding. One YTZP framework fracture occurred in a restoration after 35 months in function. A fracture to the retainer wing (*Figure 4a-d*) and an adhesive debond was noted. Adhesive failure at the YTZP ceramic wing interface was noted and no cement residue was present (*Figures 4b and d*). The fracture origin could be traced back from the fracture hackle to a defect on the inner wing surface indicated by the arrow (*Figure 4a*). No glass-ceramic veneering material fractures were found during the follow up period.

Figure 5a-b: Congenitally missing maxillary lateral incisor replaced with a cantilever all-ceramic YTZP ceramic bridge; (a) facial view, (b) palatal view.

Figure 6: Two congenitally missing premolars replaced with cantilever all ceramic YTZP ceramic bridges.

DISCUSSION

This clinical case series of 58 consecutively placed RBBs reported the replacement of missing teeth using a single-retainer cantilever RBBs fabricated out of YTZP ceramic. The data from this study, with a mean follow-up of 36.2 months demonstrated short-term stability and compared favourably with non-perforated metal framework RBBs after five and ten years, with reported survival rates of 80.4% and 80.8% respectively.[3] The findings were in contrast to the previously regarded opinion that all-ceramic RBBs have a lower survival rate at 10 years.[19] This study however evaluated only anterior RBBs which had differing retainer design (both one and two wings) and using a glass-infiltrated alumina ceramic (In-Ceram, VITA Zahnfabrik, Bad Säckingen, Germany). Some of these restorations were also silica coated and silanised followed by cementation using phosphate monomer containing luting cements. It is therefore not a comparable study with the current work which produced RBBs with different design/stress distribution, ceramic and adhesive chemistry (Y-TZP ceramic and Monobond-S /Multi-Link Automix) and bonding protocols. Nonetheless, the authors acknowledge that these results were based on short-term follow up and recommend a randomized controlled trial comparing the conventional metal framework design.

All failures occurred within the first twelve months of function. This finding was in agreement with a recently published study[3] with a ten-year follow-up, in which most of the failures occurred during the first four years. Analysis of the King *et al*'s Kaplan-Meier survival curve also seemed to indicate a steep fall during the first twelve months.[3]

As previously suggested by Hussey *et al*,[24] a RBB, which was functioning after a single episode of recementation, should be considered as successful. Based on this criterion, our success rate of 93.1%, compared favourably to that of non-perforated metal RBBs[12] and other studies on zirconia RBBs.[25] Therefore, they may be a viable restorative option for the replacement of a single tooth, in both the anterior and posterior region. This provided the first reported evidence of their usage in posterior areas of the mouth.[26] One of the main advantages of using this material is the superior aesthetics that could be achieved, especially when replacing teeth in relatively young adults with associated translucent teeth (*Figures 5 and 6*) and the relative biocompatibility in comparison to non-precious metals. However, the aesthetics were not validated in the current study and again calls for a comparative study with metal-based RBB's including subjective, patient-centered outcomes.

Although a total of 9 debonds were noted, these were primarily at the resin/YTZP interface, and no cement residue was noted on the frameworks as illustrated in Figures 4b and d. The debonded restorations were air abraded (with 50 micron alumina oxide) and recemented using the previously described technique in an attempt to increase adhesion between the cement and the retaining wing. Bonding to zirconia has been a challenge in the past and the resin luting agent used in this study was one of the first commercially available products with a specific zirconia primer, which may explain the improved success rate.[27] Although Sasse *et al*,[22] showed no difference between MultiLink and Panavia in a relatively small cohort of patients, the authors recommend the former given that there is no need for Oxyguard and may thus be less technique sensitive. With further developments in resin and coupling agent[28] technology, adhesion of YTZP ceramic to the resin and tooth structure is anticipated to be further enhanced.

The manufacturer's recommendations for preparation of the CAD-CAM YTZP frameworks (Zerion®, Straumann) notes that sandblasting the surface with Al_2O_3 can cause damage and deformation of the crystal lattice structure which might cause a phase change (from tetragonal to monoclinic), requiring a thermal heat treatment to reverse this (Straumann® CARES® Tooth-borne prosthetic procedures, Straumann). The authors therefore did not use a sandblasting regimen as it was thought that this might cause surface micro-cracking and phase changes effecting the survivability of the thin YTZP substrates used in this study. On the contrary, current studies indicate that sandblasting with 110-250 micron Al_2O_3 produces larger surface flaw sizes in the form of pitting, ploughing, sharp scratches and grain pull out.[29] Clinical studies appear to have modified sandblasting recommendations for YTZP to 50 micron Al_2O_3 (0.1 bar and now 0.25 bar pressure) to minimise these issues giving 10-year survival rates of 98.2%.[30] The survival rate in the current study was consistent with that for sandblasted (50 micron Al_2O_3) nickel-chromium RBB's, and particle air abrasion only used when bond failures occurred, minimising surface damage to successfully bonded YTZP substrates.

Another often quoted concern with all ceramic prostheses is with regards the abrasiveness of the material used and the potential for wear. Several '*in vitro*' studies in the literature however appear to show minimal enamel wear against monolithic YTZP when compared with feldspathic porcelain[31,32] The authors polished the YTZP ceramic retainer wing surfaces during the study rather than over glazing. Polished rather than glazed YTZP ceramic surfaces produced a reduced enamel wear according to '*in vitro*' wear studies.[32,33] Many of the YTZP ceramics have a fine (0.5 microns) and uniform grain size which can be correlated to their low wear behaviour.[33] The increased strength and toughness of the fine grain sized YTZP ceramics increases the resistance to crack propagation and consequently a smoother surface is maintained during wear and the more deleterious fracture/flaw controlled wear may be avoided. The polishing process and the subsequent stress generated during the wear process may also affect the tetragonal to monoclinic phase transformation, which can produce compressive stresses that can oppose crack propagation. The effect of this process during wear processes is however not well understood.[34] Differing chemistry, microstructure and processing of commercial YTZP products and any susceptibility to the long-term effects of low temperature degradation should however also be considered.

Tooth preparation was not carried out to provide resistance or retentive features nor to create interocclusal space for the retainer wing. Several restorations were cemented "high" in occlusion due to lack of interocclusal space. Despite this there was no noted differences in the survival of the restorations. In clinical situations where inter-occlusal space was limited the authors used the Dahl principal in order to create this space. This minimally invasive approach has been used in longer term (>7 years) resin bonded bridge clinical studies, where tooth preparation was not linked to increased restoration survival performance.[31] This less invasive approach to conserve tooth enamel was therefore adopted throughout the study and used in conjunction with YTZP ceramics. Preservation of enamel may have enhanced adhesion although an argument can be made that retention would be compromised given the lack of optimal resistance and retentive features. One anterior RBB was reported with a fracture to the retainer wing (*Figure 4a-d*) and an adhesive debond. Cement failure was adhesively at the YTZP ceramic wing interface and no cement residue was present (*Figures 4b and d*). This type of complete adhesive failure to YTZP ceramic substrates after aqueous aging and cyclic loading has been associated with a reduced bond strength of MDP containing resin[35] and associated with degradation of the filler-resin interfacial bond.[36] It was hypothesized by the authors that this failure was multifactorial. The fracture origin could be traced back from the fracture hackle to a defect on the inner wing surface indicated by the arrow (*Figure 4a*). This may be associated with the inability of the computer aided machining unit to deal with the internal angle required by the digital design. Thus the milling tools created an area of reduced thickness (*Figure 4b*), which may have reduced the mechanical properties of the substrate in contact with the opposing dentition and its susceptibility to low temperature degradation. CAD-CAM allowed the rapid and accurate manufacture of YTZP substrates however, it is important to carefully evaluate the three dimensional design before the manufacturing process because of the geometry of the milling burs and efficiency of the subsequent sintering process. Despite being used as a cantilever design in the posterior region, there were no fractures of the posterior YTZP ceramic frameworks or veneering ceramic.

The authors performed cementation of RBBs under strict moisture control but did not use rubber-dam for isolation prior to cementation and this could potentially have influenced success rates. The literature, however is inconclusive in relation to rubber-dam use. King *et al*. showed that use of rubber-dam was associated with 1.73 increased hazard ratio for debonding.[3] They have discussed that this could be related to operator factor. A previous study reported better success with the use of rubber dam.[10]

A longer term randomized clinical trial would be the ideal study design to compare the success and aesthetic outcomes with metal RBBs. However, requirement of a very large sample size can be a limitation.

CONCLUSIONS

Within the limitations of this prospective clinical case series, a survival rate of 82.7% (over 3 years) was found when using Y-TZP ceramics for the construction of single unit cantilevered RBBs in anterior or posterior areas, for replacement of missing teeth.

CLINICAL IMPLICATIONS

Replacement of anterior or posterior tooth using single unit cantilevered RBBs using Y-TZP ceramics should be considered a viable restorative option with a high survival rate.

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