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Five-year clinical evaluation of zirconia-based bridges in patients in UK general dental practices

F.J.T. Burke [a,*], R.J. Crisp [a], A.J. Cowan [b], J. Lamb [c], O. Thompson [d], N. Tulloch [e]

[a] Primary Dental Care Research Unit, University of Birmingham School of Dentistry, School of Medical and Dental Sciences, St. Chad's Queensway, Birmingham B4 6NN, UK
[b] General Dental Practice, Buxton, England, UK
[c] General Dental Practice, Liverpool, England, UK
[d] General Dental Practice, Coleraine, Northern Ireland, UK
[e] General Dental Practice, Alness, Scotland, UK

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ABSTRACT

Objectives: This study reported the results at 5 years of fixed-fixed all-ceramic bridges, constructed in a yttria oxide stabilized tetragonal zirconium oxide polycrystal (Y-TZP) substructure, placed in adult patients in UK general dental practices.

Materials and methods: Four UK general dental practitioners recruited patients who required fixed bridgework and, after obtaining informed written consent, appropriate clinical and radiographic assessments were completed. The teeth were prepared and bridges constructed in accordance with the manufacturer's instructions. Each bridge was reviewed annually within 3 months of the anniversary of its placement by a calibrated examiner, together with the clinician who had placed the restoration, using modified USPHS criteria.

Results: Of the 41 bridges originally placed, 33 bridges were examined at 5 years. All Y-TZP frameworks were intact and no bridge retainers had debonded. Eight chipping fractures in the veneering ceramic were noted over the 5-year period. In five cases the patients were unaware of these and these cases were polished. Of the remaining three cases, in one a repair was attempted but was unsuccessful, but the bridge remained in satisfactory service. However, in the case involving a chipping fracture of the mesial–incisal angle of a central incisor, it was considered that replacement of the bridge was necessary.

Conclusion: 97% ($n = 32$) of the 33 Lava Y-TZP fixed-fixed bridges, evaluated in patients attending UK general dental practices, were found to be performing satisfactorily.

Clinical relevance: The use of Y-TZP frameworks holds promise.

1. Introduction

While metal ceramic restorations have been regarded as the gold standard for crown and bridges,[1] demand by patients for metal-free and aesthetically excellent restorations has driven the development of high strength ceramic systems. In this regard, given its strength, zirconia (ZrO_2) has been considered to be a suitable substructure for restoration of posterior teeth.[2] Readers are directed to other texts for a complete exposition of zirconia in dentistry,[3,4] but, in brief, pure ZrO_2 has a monoclinic crystal structure at room temperature and transitions to tetragonal and cubic phases at increasing temperatures. The addition of 3% yttria oxide (Y_2O_3) stabilises the

* *Corresponding author*. Tel.: +44 121 466 5476; fax: +44 121 237 8815.
E-mail address: f.j.t.burke@bham.ac.uk (F.J.T. Burke).
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tetragonal phase ceramic, and the material is then known as *yttria oxide stabilized tetragonal zirconium oxide polycrystal*, or Y-TZP. This material has excellent fracture toughness due to transformation toughening,[3] since, when compressive stresses are applied, the tetragonal phase changes to monoclinic, with the associated volume expansion placing the crack tip in compression, retarding its growth. The first crowns and bridges constructed in Y-TZP were placed in patients a decade ago, and, since then, the expansion of the use of zirconia has been dramatic, with 24 systems being reported as being available in 2009.[5] In addition, factors such as the competition resulting from this expansion in zirconia systems and the rise in cost of precious metals such as gold and palladium in recent years (and the associated rise in the cost of metal-ceramic restorations) may be considered to have stabilised prices of Y-TZP substructure restorations, and improved their uptake by clinicians.

The aim of this practice-based multi-centre clinical observational study was therefore to evaluate the 5-year performance of all-ceramic fixed-fixed bridges, constructed with a Lava (3M ESPE, Seefeld, Germany) zirconia substructure, placed in adult patients in four UK general dental practices, whose dentists were members of the UK-wide practice based research group The Product Research and Evaluation by Practitioners (PREP) Panel (which currently comprises 33 members) and luted using a self-adhesive resin based cement (RelyX Unicem: 3M ESPE, Seefeld, Germany), with no additional surface treatment of the Y-TZP framework fitting surface. The papers reporting the 1-year and 3-year results of this evaluation of these bridges have been published.[6,7] In this, in order to overcome the opacity of (pure white) Y-TZP, the milled framework in is stained after the milling stage and prior to sintering with a dye available in seven different shades appropriate to the shade of the veneering ceramic.

The primary end points of this investigation were retention of the restoration, lack of fracture of the restoration, margin integrity, secondary caries status and post-operative sensitivity. Secondary end points were the health of gingival tissues surrounding the restored teeth, colour match, stain resistance and surface quality.

2. Materials and methods

2.1. Ethical standards

Ethics Committee approval was obtained prior to commencing the study (MREC/04/6/08 South West Multicentre Research Ethics Committee, Dartington, Devon TQ9 6JE, UK). Informed written consent was obtained from all patients prior to registration for participation in the evaluation, with patients having the right to withdraw from the study at any time.

2.2. Patient recruitment

Four general dental practitioner members of the PREP panel with practices in England ($n = 2$), Scotland and Northern Ireland agreed to recruit ten patients who required a fixed-fixed bridge, and complied with the criteria set out in Table 1. Having considered the Patient Information Sheet and having received satisfactory answers to any questions concerning the evaluation, each patient was asked to complete and sign a consent form.

Table 1 – Patient inclusion and exclusion criteria.

To be considered appropriate for inclusion in the study a patient was:
- Over 18 years of age
- Had a molar supported permanent dentition free of any clinically significant occlusal interferences
- Had well maintained dentitions free of any active, untreated periodontal disease
- Had a maximum of two three or four-unit fixed/fixed bridges requiring placement
- Was a regular dental attender who agreed to return for assessments.

Patients were excluded from participating in the study if:
- There is a history of any adverse reaction to clinical materials of the type to be used in the study
- There was evidence of occlusal parafunction and/or pathological tooth wear
- They were pregnant or had medical and/or dental histories which could possibly have complicated the provision of the proposed restoration and/or influenced the behaviour and performance of the restorations in clinical service
- They were irregular dental attenders.

The abutment teeth included were in occlusal function and there was a valid reason for the placement of a bridge to replace the missing unit(s). The abutment teeth were free of signs and symptoms of periapical pathology both clinically and radiographically

The pre-operative status of abutment teeth and their gingival tissues was assessed using codes and criteria set out in Table 2. Appropriate vitality and radiographic assessments were completed.

2.3. Operative and laboratory procedures

Preparation of the teeth was carried out to the manufacturer's specification, with rounded line and point angles, a shoulder of 1 mm at the gingival margin and a minimum of 2 mm occlusal clearance. Tooth shade(s) was/were selected using the Vitapan (Vita Zahnfabrik, Germany) Classical shade guide. The impression was taken in a vinyl polysiloxane material, with an opposing arch impression in alginate and a bite registration. A temporary bridge was constructed and placed and impressions were sent to the designated laboratory for the

Table 2 – Criteria for baseline evaluation.

Margin adaptation O = Optimal, 1 = slight deficiency
Colour match O = Optimal, 1 = Slight mismatch, 2 = Gross mismatch

Gingival health

Facial	1	2	3	4
Mesial	1	2	3	4
Distal	1	2	3	4

Gingival status codes:
1. Healthy gingivae
2. Mild inflammation – slight colour change, slight oedema, no bleeding on probing
3. Moderate inflammation – redness, oedema and glazing, bleeding on probing.
4. Severe inflammation – marked redness and oedema, tendency to spontaneous bleeding

study (Castle Ceramics, Tamworth, Staffs, UK). As described previously,[6] the Lava Y-TZP substructure was constructed at 3M ESPE, Seefeld, Germany using the digitised information obtained by the non-contact photo-optical scanning system of the casts, dies and bite registration wafers. The bridge frameworks were designed and fabricated using the custom CAD–CAM system with the parameters of the system setting the minimum thickness of the framework (0.5 mm) and the square area of the bridge connectors (9 mm^2). The completed frameworks were returned to the UK laboratory for the addition to full contour of appropriate overlaying veneering ceramic, LavaCeram (3M ESPE, Seefeld, Germany) and the completed bridges delivered to the clinicians for placement using a self-adhesive resin-based luting system (RelyX Unicem, 3M ESPE, Seefeld, Germany). Once the luting material was polymerised, the occlusion was checked, maintenance instructions given to the patient, and baseline assessment forms were completed (Table 2). Patients paid the standard fee for their bridges less an adjustment because the laboratory fees were funded from the project grant.

2.4. Annual review of the restorations

The bridges were reviewed at 5 years ± 3 months of their placement by a trained and calibrated examiner, together with the clinician who had placed the restoration, using criteria which were suggested by Ryge8 (1980) (Table 3). Before the patient was dismissed a consensus opinion was agreed if the examiners ratings had differed. Photographs of the restorations were also taken at the annual reviews. If any restoration was found to be defective, an adverse event form was completed and the necessary remedial work completed.

2.5. Statistical analysis

The data were analyzed using Kaplan Meier methodology at two levels:

(1) Survival until replacement was deemed necessary, disregarding any interventions such as endodontic therapy or chipping fracture, and (2) where any intervention on the bridges (such as chipping fracture, need for endodontic therapy, *etc.*) was classified as a failure, but the bridges remained in clinical function.

Table 3 – Criteria modified from Ryge.[8]

Anatomical form
0 = Restoration continuous with tooth anatomy
1 = Slightly under- or over-contoured restoration

Secondary caries
0 = No visible evidence of caries contiguous with the margin of the restoration
1[a] = Caries is evident contiguous with the margin of the restoration

Marginal adaptation
0 = Restoration is contiguous with existing anatomic form, sharp explorer does not catch
1 = Explorer catches, no crevice is visible into which the explorer will penetrate
2[a] = Obvious crevice at margin, dentine or lute exposed

Surface roughness
0 = Smooth surface
1 = Slightly rough or pitted
2 = Rough, cannot be refinished

Colour match
0 = Very good/good colour match, restoration almost invisible
1 = Slight mismatch in colour, shade or translucency
2[a] = Obvious/gross mismatch, outside the normal range

Gingival health: To be assessed adjacent to the restoration
1 = Healthy gingivae
2 = Mild inflammation – slight colour change, slight oedema, no bleeding on probing
3 = Moderate inflammation – redness, oedema and glazing, bleeding on probing.
4 = Severe inflammation – marked redness and oedema, tendency to spontaneous bleeding

[a] Unacceptable.

3. Results

At baseline, a total of 41 fixed-fixed Lava Y-TZP bridges were placed in 36 patients (24 Female and 12 Male). Thirty-eight of the bridges (93%) were of three-units, with the remaining three being four-units. The distribution of the bridges at baseline and those reviewed at years one, two, three and five are as shown in Table 4.

Table 4 – Distribution of the bridges reviewed at 1–3 and 5 years.

Tooth replaced (3-unit)		Baseline	Year 1	Year 2	Year 3	Year 5
	Central Incisor	6	5	3	4	4
	Lateral Incisor	7	7	6	7	5
	Canine	1	1	1	1	1
	1st Premolar	8	6	7	8	6
	2nd Premolar	4	4	2	3	5
	1st Molar	7	7	5	5	5
	2nd Premolar	1	1	1	1	1
	1st Molar	4	4	3	3	3
Teeth replaced (4-unit)						
Upper	1st and 2nd premolars	3	3	2	2	3
Total		41	38	30	34	33

Table 5 – Classification of chipping fractures according to criteria suggested by Crisp et al.[7]

A. A minor chip <1 mm in diameter – may be left alone or polished.
B. A larger chip >1 mm but still within the veneering porcelain
C. A repairable chip involving the framework interface
D. A catastrophic loss of veneering porcelain requiring restoration replacement.

At the 5-year review, 33 bridges (of mean age 62 months) in 28 patients (17 female, 11 male) were examined, a recall rate of 80%. The distribution of the bridges was as follows:

- Anterior (incisor and canine pontics) = 11 (33%).
- Posterior (molar and premolar pontics) = 22 (67%).

All of the anterior bridges were in the maxillary arch, as were 82% ($n = 18$) of the posterior bridges.

If chipping fractures (detailed below) are disregarded, all of the bridges were present and intact, examples being presented in Figs. 1 and 2, *i.e.* the zirconia frameworks performed well. However, in addition to the two chipping fractures reported at years one and three,[6,7] six further chipping fractures of the veneering porcelain were noted. Five had not been noticed by the patient and were considered readily reparable by re-contouring and polishing. One of these cases caused the exposure of a small area of the zirconia sub-structure: it was distal to the lower first molar pontic and was readily polished to the clinician's and the patient's satisfaction. However, in one case the fracture involved the mesial–incisal angle of a central incisor (Fig. 3), and this was considered to be aesthetically unacceptable and, accordingly, this bridge was replaced. The chipping fractures were classified according to criteria suggested by Crisp et al.[7] (Table 5) and were as follows:

Fig. 1 – Lava (3M ESPE) bridge replacing LR5 at 5-year review.

Of the 33 bridges examined at 5 years, two (3% of the total of 66) of the abutment teeth had been endodontically treated: no further endodontic treatments had been deemed necessary in addition to those reported at the 3-year assessment ($n = 3$). These bridges were otherwise intact and performing satisfactorily. The final composite restorations placed in the access cavities were optimal when examined using the same criteria as the Lava bridges.

At 5 years, with regard to marginal integrity, thirty (91%) of the Lava bridges were scored as optimal for marginal adaptation, with no unacceptable scores recorded. No secondary caries was detected and no post-operative sensitivity was reported. Regarding the gingival tissues, a high proportion

Notation of chip	Review year detected	Category	Comments
22 (pontic)	Year 1	A	Palatal surface of lateral incisor
14 (pontic)	Year 2	C	Repair attempted but failed. Surface polished and patient content.
24 (abutment)	Year 5	A	Very small polishable chip on occlusal surface.
26 (abutment)	Year 5	A	Small polishable chip distal marginal ridge.
24 (abutment)	Year 5	A	Small occlusal chip – looked like small loss of glaze.
46 (pontic)	Year 5	C	3–4 mm^2 loss of veneering porcelain exposing distal connector 46 – not visible and polishable
11 (abutment)	Year 5	B	Mesial incisal angle fracture - Bridge replaced.
13 (abutment)	Year 5	B	Polishable chip, buccal surface.

Table 6 – Comparison of gingival health at baseline, 1–3 and 5 years.

	Baseline		One-year		Two years		Three years		Five years	
Facial	1	85%	1	95%	1	92%	1	94	1	94%
	2	15%	2	5%	2	4%	2	6%	2	6%
					3	4%				
Mesial	1	82%	2	100%	1	100%	1	100%	1	97%
	2	18%							2	3%
Distal	1	85%	1	95%	1	96%	1	100%	1	97%
	2	15%	2	5%	2	4%			2	3%

Fig. 2 – Two Lava (3M ESPE) bridges replacing UR2, UL2 at 5-year review.

Fig. 3 – The three-unit bridge which was replaced due to unaesthetic fracture of the mesio-incisal corner of UR1.

(94%) of optimal scores, similar to those reported at previous reviews,[6,7] were recorded (Table 6). One (3%) of the bridges examined showed a slight shade mismatch, as reported previously[6,7] but this was of no concern to the patient. In a case of a patient with generalised heavy nicotine staining, the bridge under investigation exhibited some accumulation of stain on the veneering porcelain.

At the 5-year review, the anatomic form of all of the bridges was scored as optimal.

Fig. 4 a and b presents the Kaplan Meier statistical analysis of the bridges in the study at the two levels which were described in Section 2.

4. Discussion

This paper has described a practice-based cohort study in which 33 bridges, with Y-TZP cores, were evaluated at 5 years. In this regard, there is a dearth of medium/long term evaluations of zirconia-based bridges, particularly those placed in the general dental practice environment. This paper therefore seeks to address this situation and is the first to describe their performance of zirconia-based bridges at 5 years placed in patients from general dental practice, this having been described as the ''real world, with real dentists and real patients'',[9] although results from a practice-based study of zirconia single crowns fitted in a private clinical setting have been published.[10] The recall rate of 33, from the original 41, may be considered satisfactory and similar to that achieved in many similar studies in dentistry. Reasons for non-attendance of the eight patients were, principally, change of location, with three patients in the N.Ireland cohort being unexpectedly transferred away because of military duties.

The results indicate that the zirconia-based bridges performed satisfactorily over the evaluation period, with no fractures of the Y-TZP framework. However, the incidence of chipping fractures increased from year 3 to year 5, and this necessitated the replacement of one (anterior) bridge (Fig. 3). This is a phenomenon which is also seen in metal-ceramic crowns and bridges, both clinically[11,12] and in the laboratory[13] and may, in part, be as a result of the physical properties of the core which have been considered predictors of the reliability of crown veneered systems.[14] It may also be as a result of the thickness of the veneering ceramic, with too much unsupported ceramic potentially predisposing to fracture. In the bridges placed in the present study, the Y-TZP core was designed to be 0.6 mm thick by the early Lava software (3M ESPE). More recently, however, a process termed ''Digital Wax Knife'' has been introduced by 3M ESPE, which gives the technician the ability to design the Y-TZP core to provide greater support for the veneering ceramic. It could be considered that, if this software had been available when the examined bridges were constructed, the cores would have been thicker and the potential for chipping fracture might have been reduced. In this regard, results of a laboratory study, in which a Y-TZP core was modified (from a standard core thickness of 0.5 mm) by a 1 mm increased thickness in the proximal area and 2.5 mm height cervical margin on the lingual, indicated significantly higher reliability for the modified core design group, where the fatigue fracture modes were veneer chipping not exposing the core.[15] This was commented upon in the systematic review by Heintze and Rousson,[16] who concluded that veneer chipping frequency was higher in zirconia Fixed Partial Dentures (FPDs) compared with PFM FDPs. These workers further considered that the veneer needed to be supported by the core and that, if the thickness of the veneer exceeds that of the core by twofold, the risk of veneer chipping is increased considerably. This is likely to be the case in the bridges placed in the present study which pre-dated the introduction of the ''Digital Wax knife''. Nevertheless, it is considered that further study is necessary to more fully elucidate this and to confirm (or otherwise) this effect clinically. In this regard, since chipping fractures have been considered to result from high contact force on one cusp after the restoration has been *in situ* for some time (*i.e.* ageing has taken place[17]), the clinician has the ultimate responsibility to ensure that the occlusion on the restoration is not likely to result in chipping fracture. In the present work, although impossible to confirm after the event, the examiners considered that three of the chipping fractures may have resulted from traumatic lateral occlusal forces. However, when writing on the subject of chipping fractures, Anusavice[18] concluded that their aetiology was unknown.

It may also be considered that the employment of a laboratory with experience in using Y-TZP frameworks and the associated veneering ceramic is important, with full adherence to the manufacturer's protocol with regard to cooling times and materials' handling being of importance. In this regard, results of a study on the effect of firing protocols indicated that a modified firing protocol with an additional 6 min cooling time enhanced the resistance of the veneered

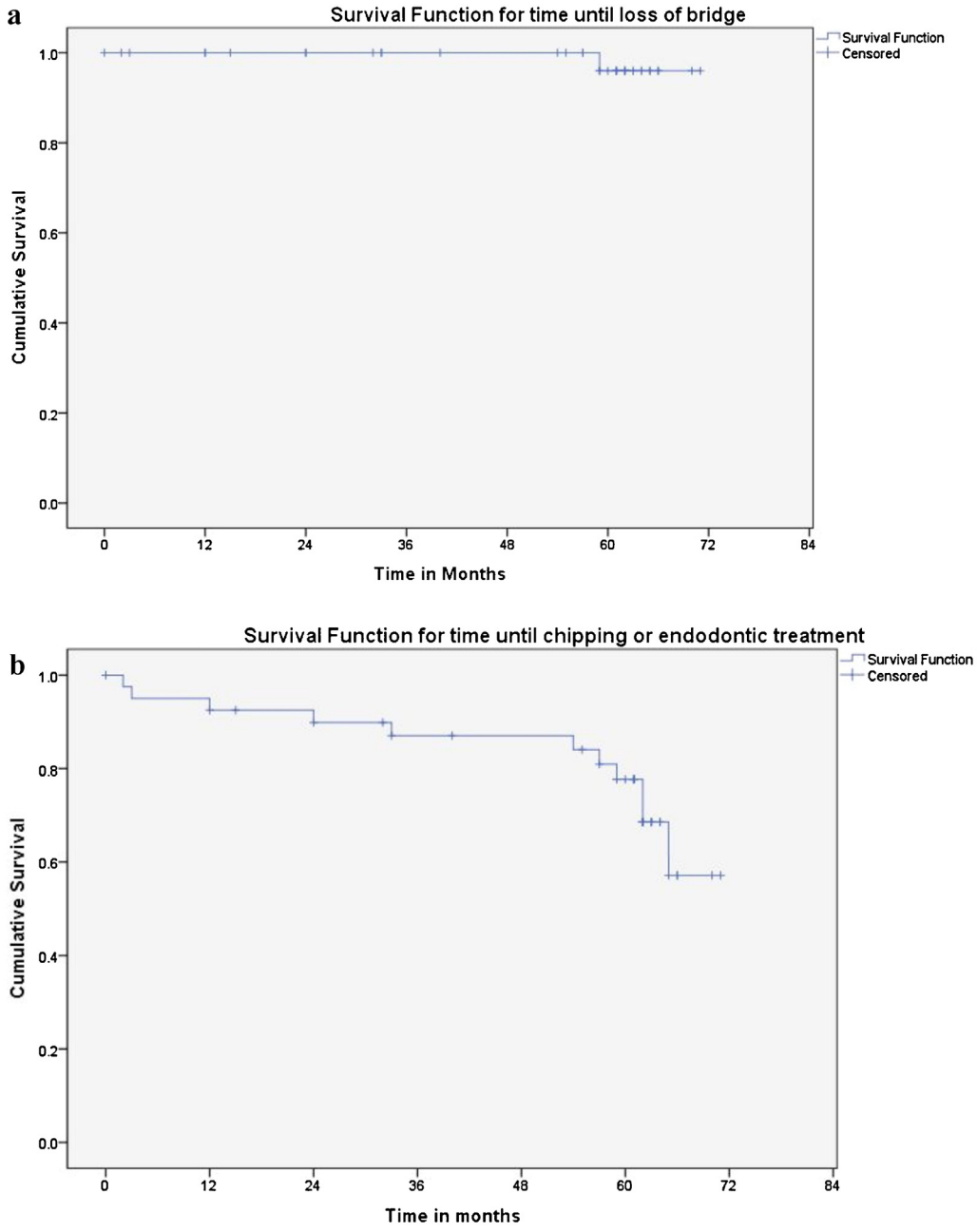

Fig. 4 – (a and b) Kaplan Meier analysis of the data at two levels: (a) survival of the bridges until replacement was deemed necessary. (b) Survival of the bridges, expressing all interventions (such as chipping fracture, and need for endodontic therapy) which were carried out as failures, but where the bridges remained in clinical function.

zirconia restorations.[17] In this regard, it is not always clearly stated in publications that the veneering porcelain is a material recommended by the manufacturer of the framework in terms of matching co-efficient of thermal expansion, this being critical,[19] as is the minimalizing of stress, both in the zirconia framework and the veneering porcelain, by following the prescribed sintering and firing regime specified for the specific material.[20]

Another approach to minimize the risk of chipping fractures is the construction of zirconia restorations to full contour, as described in the *in vitro* study by Beuer et al.[21] In the clinical situation, restorations could be constructed in full thickness zirconia, with the veneering ceramic only applied where it is desirable for aesthetics.

With regard to the Lava Y-TZP bridges described in the present study, their overall performance is as good as, or better than, the performance of the Y-TZP bridges reported by others[22–24] and in the systematic review by Al-Amleh and colleagues.[25] Of the 17 clinical trials which these researchers included in their work, they reported Y-TZP framework

fractures in five studies (seven bridges from a total of 109), this not being a problem noted in the present study. They also quantified chipping fractures as having occurred in all eight of the investigated Y-TZP brands and further reported that these chipping fractures occurred in areas which were not loadbearing, that finding being only partly in agreement with the results of the present work. However, Al-Amleh and colleagues[25] reported that a large proportion of chipping fractures were undetected by patients but that some restorations required total replacement because of major chipping fractures which could not be polished or which posed aesthetic problems. Those findings are similar to those reported in the present study.

One paper which had not been published at the time of Al-Amleh's systematic review[25] was that by Sax and co-workers,[26] following up the work previously reported by Sailer et al.[12]. They reported the survival of 26 zirconia-based fixed partial dentures (FPDs) at 10.7 ± 1.3 years, with 16 FPDs being lost to follow up, with the results indicating three framework fractures, a 10-year survival rate of 91.5% and chipping fractures in 16 FPDs over 10 years, a complication rate of 32%. These workers further observed a correlation between the span of the FPDs and incidence of chipping, with 4- and 5-unit FPDs having a 4.9 times higher probability for chipping fractures than 3-unit FPDs. However, the authors remarked that "these problems may be associated with the prototype status of the system".

Metal–ceramic materials have provided the framework for bridges for the past 40 years and the benchmark for fixed-fixed bridgework survival must therefore be the survival rate for bridges constructed in metal-ceramic materials. These have a reported survival rate of at least 84% at 10 years by Napangas et al.[27] and a reported 79% survival at 18–23 years by Palmqvist and Schwartz.[28] Of particular relevance to the present work is the survival of metal-ceramic bridges placed within general dental practice in England and Wales which has been reported, by Burke and Lucarotti,[29] on a database of *circa* 4000 bridges, to be 72% at 10 years, with factors such as type of bridge, patient payment exemption status, patient attendance pattern and position of the bridge in the patient's mouth being found to influence survival. Since metal-ceramic has, for 40 years, been the "gold standard" it is important, if all-ceramic bridges are to be adopted by dentists and their patients, that their survival is as good as or better than, metal-ceramic. The results of the present study, with one failure from 33 bridges at 5 years, compare favourably with the 5-year data included in the Burke and Lucarotti[29] study and may be considered to be within the parameters set in the other studies mentioned above, although the criteria for evaluation of the bridges in the various studies are not entirely similar.

Periodontal health is an important aspect of any restoration, so it may be considered of interest to note the satisfactory gingival tissue health scores adjacent to the Lava bridges in the present study and to note the trend of improving scores already reported,[6,7] confirming that the Y-TZP-based material is well tolerated by the soft-tissues.

Finally, it has been considered, by Schmitter and co-workers[30] that "the initial euphoric attitude towards zirconia has been relativized by the number of adhesive (delamination) and cohesive (chipping) fractures compared with metal ceramic restorations". The results of the present study, from the real world of general dental practice (where the vast majority of dental treatments are carried out, worldwide) indicate that there is no need for anxieties concerning delamination and only modest need for anxiety with regard to chipping fractures, since the discussion (*vide supra*) may be considered to point future clinicians and framework designers in a direction which will facilitate optimization of the Y-TZP core.

Within the limitations of the present study, therefore, it may be surmised that the use of Y-TZP frameworks holds promise and that its burgeoning impact over the past decade will continue, as costs of Y-TZP frameworks become more similar to those of metal and as technicians become more adept at handling what was, to them, a novel concept less than a decade ago.

5. Conclusion

At 5 years, 97% of the Y-TZP-based (Lava) bridges, placed in patients attending four UK dental practices, were continuing to perform satisfactorily.

Disclosures

None of the authors have a financial interest in any of the companies whose products are used in this study. Dr Burke is a member of the Scientific Advisory Board of 3M ESPE.

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