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Review

The clinical success of tooth- and implant-supported zirconia-based fixed dental prostheses. A systematic review

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SUMMARY The aim was to make an inventory of the current literature on the clinical performance of tooth- or implant-supported zirconia-based FDPs and analyse and discuss any complications. Electronic databases, *PubMed.gov*, Cochrane Library and *Science Direct*, were searched for original studies reporting on the clinical performance of tooth- or implant-supported zirconia-based FDPs. The electronic search was complemented by manual searches of the bibliographies of all retrieved full-text articles and reviews, as well as a hand search of the following journals: *International Journal of Prosthodontics, Journal of Oral Rehabilitation, International Journal of Oral & Maxillofacial Implants* and *Clinical Oral Implants Research*. The search yielded 4253 titles. Sixty-eight potentially relevant full-text articles were retrieved. After applying pre-established criteria, 27 studies were included. Twenty-three studies reported on tooth-supported and 4 on implant-supported FDPs. Five of the studies were randomised, comparing Y-TZP-based restorations with metal–ceramic or other all-ceramic restorations. Most tooth-supported FDPs were FDPs of 3–5 units, whereas most implant-supported FDPs were full arch. The majority of the studies reported on 3- to 5-year follow-up. Life table analysis revealed cumulative 5-year survival rates of 93·5% for tooth-supported and 100% for implant-supported FDPs. For tooth-supported FDPs, the most common reasons for failure were veneering material fractures, framework fractures and caries. Cumulative 5-year complication rates were 27·6% and 30·5% for tooth- and implant-supported FDPs, respectively. The most common complications were veneering material fractures for tooth- as well as implant-supported FDPs. Loss of retention occurred more frequently in FDPs luted with zinc phosphate or glass–ionomer cement compared to those luted with resin cements. The results suggest that the 5-year survival rate is excellent for implant-supported zirconia-based FDPs, despite the incidence of complications, and acceptable for tooth-supported zirconia-based FDPs. These results are, however, based on a relatively small number of studies, especially for the implant-supported FDPs. The vast majority of the studies are not controlled clinical trials and have limited follow-up. Thus, interpretation of the results should be made with caution. Well-designed studies with large patient groups and long follow-up times are needed before general recommendations for the use of zirconia-based restorations can be provided.

KEYWORDS: ceramics, dental implants, denture, partial, fixed, dental restoration failure, systematic review, yttria-stabilised tetragonal zirconia

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Introduction

Fixed dental restorations can be made from many different materials. There is extensive evidence of the excellent long-term results for conventional high-noble-alloy-based porcelain-fused-to-metal (PFM) restorations (1–3). As some studies have reported on adverse reactions against gold, however (4), attention has been focused on even more biocompatible materials as alternatives.

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All-ceramic dental restorations are a popular alternative to the conventional metal–ceramic restorations thanks to excellent biocompatibility and favourable aesthetics. The use of non-oxide-based ceramic restorations, such as porcelain and glass ceramics, is, however, limited to anterior restorations of limited size due to the risk of complete fracture (5). Yttrium oxide-stabilised tetragonal zirconium dioxide polycrystal (Y-TZP) ceramics, sometimes referred to as zirconia, with its ability for phase transformation and crack propagation arrest, have provided us with new possibilities and treatment options. Laboratory tests of this material have proved its excellent mechanical properties and thus opened up for extended applications and increased use of this material (6).

Studies reporting on the clinical success of zirconia-based restorations have mainly focused on tooth-supported fixed dental prostheses (FDPs) (7). When teeth are lost, an implant-supported restoration may be used instead. Only a few studies report on all-ceramic restorations supported by implants (8).

As zirconia-based restorations are a topic of great current interest and the number of published studies has increased recently, a systematic review evaluating and comparing results is motivated.

The objective of this systematic review was to make an inventory of the current literature to summarise the information on the clinical performance of tooth- or implant-supported zirconia-based FDPs and analyse and discuss the complications to possibly provide helpful instruments in the decision-making process of when and where the use of zirconia-based restorations is appropriate.

Materials and methods

The following questions were addressed in the current literature search:

1. What is the clinical success and survival rate of tooth- or implant-supported FDPs with a framework made of Y-TZP?
2. Is there any difference in success and survival rate between tooth- or implant-supported FDPs?

Definitions

1. *Anterior FDPs* were defined as where the pontic is replacing a canine or incisor (9).
2. *Posterior FDPs* were defined as where the pontic is replacing a premolar or molar.
3. *Implant-supported* described a dental prosthesis that depends entirely on dental implants for support.
4. *Tooth-supported* describes a dental prosthesis that depends entirely on natural teeth for support (9).
5. *Biological complications* encompass caries, loss of pulp vitality and periodontal disease (10).
6. *Technical complications* included fracture of the framework, fracture or chipping of the veneering ceramic, marginal gap, discoloration and loss of retention (10) and abutment tooth fracture that did not lead to failure.
7. *Failure* was defined as restoration having been removed (11).
8. *Success* was defined as an FDP that remained unchanged and did not require any intervention over the observation period (12).
9. *Survival* was defined as the FDP remaining *in situ* at the examination visit with one or more modifications (10).

Selection criteria

The inclusion criteria for the addressed questions were original paper presenting clinical results on tooth- or implant-supported FDPs with a substructure made of Y-TZP. For studies reporting on the same patient cohorts, only the latest publications were included. Exclusion criteria for the addressed questions were case reports, review articles, *in vitro* studies, crown restorations, inlay-retained FDPs and combined tooth- or implant-supported FDPs.

Search strategy

A search of current literature was made using the PubMed (US National Library of Medicine), the Cochrane Library (The Cochrane Collaboration) and Science Direct (Elsevier) databases to identify clinical studies on tooth- or implant-supported FDPs with a substructure made of Y-TZP. The search was conducted in September 2013. 'Free-text words' and MeSH terms were used as search terms. Publications date was set from 1 January 2000 until 30 September 2013 and English set as language filter.

Search terms

(all-ceramic OR all-ceramics OR ceramic OR yttrium OR yttria OR ytzp OR y-tzp OR zirconium OR zirconia)

AND (dental restoration OR dental restorations OR fixed partial dentures OR fixed partial prosthesis OR fixed partial prostheses OR 'Denture, Partial, Fixed' [Mesh])

Two authors independently read the title and abstracts of all publications that matched the search terms. When at least one author considered a publication relevant, it was read in full text.

Furthermore, the literature searches were complemented with snowballing, that is the reference lists of included studies and identified reviews were hand-searched for additional relevant articles. A manual search of the following journals was performed as well:

1 *The International Journal of Prosthodontics*,
2 *Clinical Oral Implants Research*,
3 *The International Journal of Oral and Maxillofacial Implants*,
4 *Journal of Oral Rehabilitation*.

In the case of studies with incomplete information, the corresponding authors were contacted. If information was provided, the article was included. If not, the article was excluded from further analysis.

Results

Study search

The results of the search from the three databases are presented in a flow diagram (Fig. 1). A total of 4253 publications were identified in the database searches. Three hundred and forty-two of these titles were considered relevant and abstracts were retrieved. Based on reading of the abstracts, 68 potentially relevant full-text articles were identified. After applying the inclusion and exclusion criteria, the number of articles was reduced to 27. By snowballing, six potentially relevant full-text articles were retrieved for evaluation.

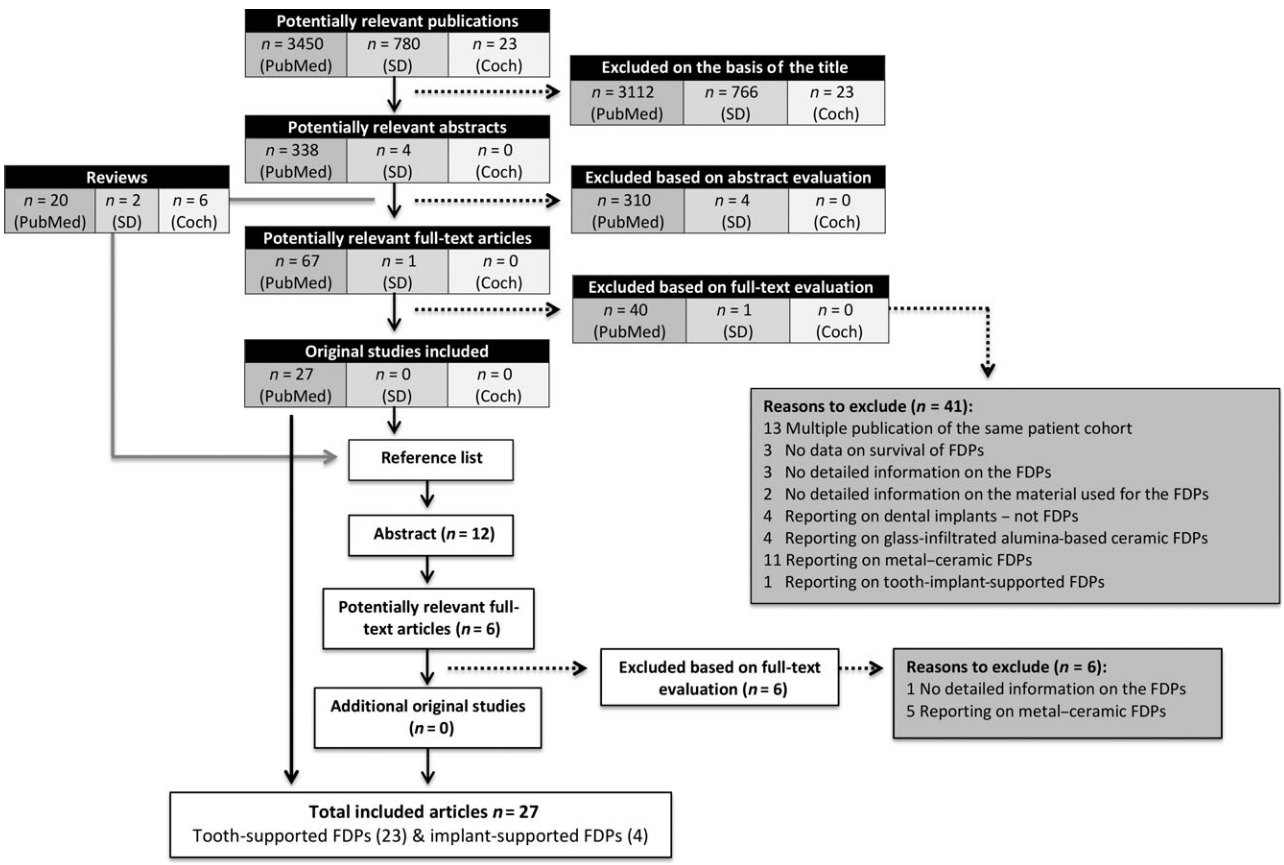

Fig. 1. Search strategy and results of the literature review for the PubMed, the Cochrane Library (Coch) and Science Direct (SD) databases.

Table 1. Characteristics of the included studies (a) tooth supported and (b) implant supported

Author	TS/IS	Core material	Veneer material	Cement	FDP baseline	FDP follow-ups
(a)						
Beuer *et al.* 2010 (13)	TS	IPS. e.max ZirCAD	Glass ceramic IPS e.max ZirLiner	GIC Ketac Cem	18 16 3 unit 2 4 unit	18 16 3 unit 2 4 unit
Beuer *et al.* 2009 (14)	TS	Cercon	Porcelain Cercon Ceram Express	GIC Ketac Cem	21 21 3 unit	21 21 3 unit
Burke *et al.* 2013 (15)	TS	LAVA Y-TZP	Porcelain LavaCeram	Resin Cem RelyX Unicem	41 38 3 unit 3 4 unit	33 30 3 unit 3 4 unit
Christensen *et al.* 2010 (16)	TS	Cercon	Ceramco PFZ	Resin-modified GIC RelyX Luting Plus cement	32 32 3 unit	24 24 3 unit
		IPS e.max ZirCad	IPS e.max ZirPress		33 33 3 unit	28 28 3 unit
		Everest Fully Sintered	Initial ZR		33 33 3 unit	31 31 3 unit
		Everest pre-sintered	CRZ Press		33 33 3 unit	31 31 3 unit
		LAVA	Lava Ceram		32 32 3 unit	28 28 3 unit
Edelhoff *et al.* 2008 (17)	TS	DigiZon	Glass ceramic Initial ZR-Keramik	GIC $n = 21$ Fuji Plus Capsule or Resin cem $n = 1$ Panavia 21 TC	22 14 3 unit 3 4 unit 2 5 unit 3 6 unit	21 13 3 unit (1 a-a-p) 3 4 unit 2 5 unit 3 6 unit
Gökcen-Röhlig *et al.* 2010 (18)	TS	Everest System	Feldspathic porcelain Vita Zahnfabrik	N/A	25 13 2 unit 8 3 unit 4 4 unit	25 13 2 unit 8 3 unit 4 4 unit
Lops *et al.* 2012 (19)	TS	LAVA	N/A	GIC N/A	28 12 2 unit 13 3 unit 4 4 unit 4 6 unit 2 10 unit	24 11 2 unit 10 3 unit 4 4 unit 4 6 unit 2 10 unit
Molin *et al.* 2008 (20)	TS	Denzir	Feldspar porcelain $n = 7$ Vita veneering ceramic D or Glass ceramics $n = 12$ IPS Empress	Zinc phosphate cement $n = 10$ De Trey zinc or Resin cem $n = 9$ Panavia F	19 19 3 unit	19 19 3 unit
Ohlmann *et al.* 2012 (21)	TS	LAVA	Porcelain LavaCeram	Resin Cem RelyX Unicem	10 10 3 unit (a-a-p)	10 10 3 unit
Pelaez *et al.* 2012 (22)	TS	LAVA	Porcelain LavaCeram	Resin Cem RelyX Unicem	20 20 3 unit	20 20 3 units
Perry *et al.* 2012 (23)	TS	LAVA	Porcelain LavaCeram gen 1	Resin Cem RelyX Unicem	16 3 unit or 4 unit	16 3 unit or 4 unit
Raigrodski *et al.* 2012 (24)	TS	LAVA	Porcelain LavaCeram	Resin Cem GIC Rely X Luting	20 20 3 unit	19 1 3 unit (48 months) 18 3 unit (60 months)

				Failures		Complications	
Placement: Ant/post	Mean observation time	Survival	Success	Technical	Biological	Technical	Biological
11% ant 89% post	3 years mean: 35 (±14) months	55·6%	N/A		1 endodontic	1 loss of retention 4 technical complications (N/A)	2 biological complications (N/A)
100% post	3 years mean: 40 months range: 37–44 months	90·5%	N/A	1 framework fracture 1 loss of retention			1 endodontic
30% ant 70% post	5 years ±3 months mean: 62 months	N/A	N/A	1 fracture of veneering material		7 fractures of veneering material 1 colour mismatch	3 endodontic
100%	3 years	81%	N/A	1 framework fracture 5 fractures of veneering material	1 caries	19 fractures of veneering material	N/A
	2 years	97%	N/A	1 fracture of veneering material		15 fractures of veneering material	N/A
	3 years	88%	N/A	1 framework fracture 3 fractures of veneering material		17 fractures of veneering material	N/A
	2 years	100%	N/A			9 fractures of veneering material	N/A
	3 years	87%	N/A	4 fractures of veneering material	1 caries	28 fractures of veneering material	N/A
19% ant 81% post	3 years mean: 39 (±5·4) months range: 26–45 months	90·5%	N/A			3 fractures of veneering material	1 endodontic
28% ant 72% post	3 years	N/A	N/A			1 loss of retention 2 fractures of veneering material	
72% ant 28% post	7 years mean: 6·5 years	88·9%	81·8%	1 framework fracture	1 abutment tooth fracture	1 fracture of veneering material 2 loss of retention	
5% ant 95% post	5 years	100%	N/A			1 loss of retention	
50% ant 50% post	2 years	N/A	N/A			2 fractures of veneering material	2 endodontic
100% post	4 years mean: 50 (±2·4) months	95%	N/A		1 abutment tooth fracture	2 fractures of veneering material	
N/A	2 years	N/A	N/A			2 fractures of veneering material	
100% post	5 years 1 FDP 48 months 18 FDPs 60 months	N/A	N/A	2 fractures of veneering material		2 minor veneering porcelain chippings	1 endodontic 1 abutment tooth fracture (FDP intact)

Table 1. (continued)

Author	TS/IS	Core material	Veneer material	Cement	FDP baseline	FDP follow-ups
Rinke *et al.* 2013 (25)	TS	Cercon	Porcelain $n = 48$ Cercon ceram or Porcelain $n = 51$ Experimental	Zinc phosphate cement Harvard cement	99 81 3 unit 18 4 unit	80 73 3 unit 17 4 unit
Sailer *et al.* 2009 (26)	TS	Cercon	Porcelain Cercon Ceram	Resin cem Panavia 21 TC	38 31 3 unit 6 4 unit 1 5 unit	36 29 3 unit 6 4 unit 1 5 unit
Salido *et al.* 2012 (27)	TS	LAVA	Porcelain LavaCeram	Resin Cem RelyX Unicem	17 17 4 unit	17 17 4 unit
Sax *et al.* 2011 (28)	TS	Cercon	Porcelain Prototype veneering ceramic	Resin cem Panavia F 2.0 or Variolink	57 47 3 unit 8 4 unit 2 5 unit	26 20 3 unit 5 4 unit 1 5 unit
Scmhitt *et al.* 2012 (29)	TS	LAVA	Porcelain LavaCeram	GIC Ketac Cem	30 22 3 unit 8 4 unit	25 21 3 unit 4 4 unit
Scmhitter *et al.* 2012 (30)	TS	Cercon Degudent	Porcelain Cercon ceram S	GIC Ketac Cem	30 1 4 unit 19 5 unit 8 6 unit 2 7 unit	22
Sorrentino *et al.* 2011 (31)	TS	Procera	Feldspathic porcelain Procera All Zircon	Resin Cem RelyX Unicem	48 48 3 unit	48 48 3 unit
Tinschert *et al.* 2008 (32)	TS	DC-Zirkon	Porcelain Vita D	Zinc phosphate cement $n = 50$ Harvard cement or Resin cem $n = 15$ Panavia 21	65 35 3 unit 15 4 unit 10 5 unit 3 6 unit 1 7 unit 1 10 unit	58 N/A
Tsumita *et al.* 2010 (33)	TS	Cercon	Porcelain Creation ZI	Resin cem Panavia 2.0	21 21 3 unit	21 21 3 unit
Wolfart *et al.* 2009 (34)	TS	Cercon *EAD = end abutment design* *CD = cantilever design*	Porcelain Cercon ceram S	GIC Ketac Cem	58 EAD: 24 3 unit (a-p-a) CD: 34 3 unit (a-a-p) 5 4 unit (a-p-a-p)	55 EAD: 24 3 unit (a-p-a) CD: 31 N/A 3 unit (a-a-p) N/A 4 unit (a-p-a-p)
Vult von Steyern *et al.* 2005 (35)	TS	DC-Zirkon	Feldspathic porcelain Vita D	Zinc phosphate cement De Trey	20 2 3 unit 12 4 unit 6 5 unit	20 2 3 unit 12 4 unit 6 5 unit

				Failures		Complications	
Placement: Ant/post	Mean observation time	Survival	Success	Technical	Biological	Technical	Biological
100% post	7 years mean: 84 months	83·4%	57·9%	4 framework fractures 4 loss of retention 4 fractures of veneering material	3 caries 2 periodontal lesion 1 abutment tooth fracture 1 unknown	20 fractures of veneering material 7 loss of retention	1 caries 4 endodontic
100% post	3 years mean: 40·3 (±2·8) months	94·7%	N/A	1 fracture of veneering material		12 fractures of veneering material	1 endodontic
100% post	4 years	76·5%	N/A	3 framework fractures	1 abutment tooth fracture	2 fractures of veneering material	
100% post	10·7 (±1·3) years	67%	N/A	3 framework fractures 1 fracture of veneering material 1 loss of retention	6 caries 2 abutment tooth fracture 2 endodontic	16 fractures of veneering material	11 caries 1 loss of vitality
100% post	5 years mean: 62·1 months	92%	N/A	1 framework fracture	1 endodontic	1 loss of retention 6 fractures of veneering material	1 endodontic
37% ant 63% post	5 years	82%	N/A	2 framework fractures 1 fracture of veneering material	1 fracture of abutment tooth	7 fractures of veneering material 4 loss of retention	1 endodontic
100% post	5 years	100%	91·9%			3 fractures of veneering material	
N/A	3 years Mean (ant): 38 ± (18) months Mean (post): 37 months ± 15·5 months	N/A	N/A			4 fractures of veneering material 2 loss of retention	3 endodontic
100% post	Mean: 28·1 (±3·4) months Range: 21–33 months	N/A	N/A			3 fractures of veneering material	
100% post	4 years mean: 48 months range (EAD): 34–59 months range (CD): 1–68 months	EAD: 96% CD: 91%	N/A			6 fractures of veneering material 1 loss of retention	3 endodontic 2 caries
25% ant 75% post	2 years	N/A	N/A			3 fractures of veneering material	1 endodontic

Table 1. (continued)

Author	TS/IS	Core material	Veneer material	Cement	FDP baseline	FDP follow-ups
(b)						
Larsson *et al.* 2013 (36)	IS	Cercon	Porcelain Cercon ceram S	Resin cem Panavia F 2.0	10 1 9 unit 9 10 unit	9 1 9 unit 8 10 unit
Larsson *et al.* 2010 (37)	IS	Denzir	Porcelain Espridient Triceram	Zinc phosphate cement De Trey zinc crown and bridge Fixodont Plus	13 9 2 unit 3 3 unit 1 4 unit	13 9 2 unit 3 3 unit 1 4 unit
Oliva *et al.* 2012 (38)	IS	Cera Crown Oral Iceberg	N/A	Screw retained	N/A	22 21 12 unit 1 14 unit
Pozzi *et al.* 2013 (39)	IS	Nobel Procera Zirconia Implant Bridge Nobel Biocare AG	Feldspathic porcelain Noritake Cerabien Zirconia, CZR	Screw retained	N/A	26

All of these were, however, excluded. The manual searches of the dental journals did not identify any additional articles (Fig. 1).

In total, 27 studies were included in the present review (Table 1a,b) (13–39). The majority were prospective studies performed in university settings. Five of the studies were randomised, comparing Y-TZP-based restorations with metal–ceramic, based on high-noble alloys, or other all-ceramic restorations. Twenty-three of the studies reported on tooth-supported and four on implant-supported FDPs. The majority of the restorations were posterior. Most tooth-supported FDPs were 3–5 units, whereas most implant-supported FDPs were full arch. Follow-up ranged from 2 to 11 years – but the majority of the studies reported on 3- to 5-year follow-up. Most studies evaluated a limited number of FDPs; 10 reported on 20 FDPs or less, 12 reported on 20–50 FDPs, and 5 reported on more than 50 FDPs.

Data extraction

Two authors (19, 30) were contacted to provide additional information. Sufficient data for the calculation of cumulative survival and complication rates were then available for all included studies. Analysis was thus based on 887 tooth-supported and 72 implant-supported FDPs. The cumulative 5-year survival rate of implant-supported zirconia-based FDPs was 100%. The cumulative 5-year survival rate of tooth-supported zirconia-based FDPs was 93·3%. The most common reasons for failure were veneering material fracture, framework fracture and caries (Table 2).

The cumulative 5-year complication rate of implant-supported zirconia-based FDPs was 30·5%. Only technical complications, predominantly veneering material fractures, were reported in this group. The cumulative 5-year complication rate of tooth-supported zirconia-based FDPs was 27·6%. Technical complications dominated this group as well with veneering material fractures and loss of retention being the most common (Table 3). Loss of retention occurred more often in restorations cemented with zinc phosphate or glass–ionomer cements compared to those cemented with resin cements. The majority of the complications occurred within the first two years (Fig. 2a–d).

Discussion

The literature search for the present review was performed systematically, following suggested guidelines concerning the definition of the research question, search plan, retrieval of publications and data extraction (40, 41).

However, the inclusion and exclusion criteria were not as strict as some authors suggest using, for example highly specific requirements for PICO elements (population, intervention, control and outcome) and/or systems for evaluation of quality of evidence (42). No limits concerning the minimum

				Failures		Complications	
Placement: Ant/post	Mean observation time	Survival	Success	Technical	Biological	Technical	Biological
Full arch Mandibular	8 years	100%	N/A			8 fractures of veneering material	
8% ant 92% posts	5 years	100%	31%			9 fractures of veneering material	
Full arch Maxilla $n = 12$ Mandible $n = 12$	5 years	N/A	N/A			1 screw loosening 1 fracture of veneering material	
Full arch Maxilla $n = 12$ Mandible $n = 14$	5 years mean: 42·3 months range: 36–60 months	100%	98·6%			3 fractures of veneering material	

number of included patients, presence of a control group, randomisation or minimum follow-up were set. This was carried out as studies on Y-TZP FDPs so far still predominantly evaluate relatively few enrolled patients, with no power analysis performed before initiating the study, no randomisation or control group and with mostly short-to-medium follow-up. Until well-designed studies with large patient groups and long-term follow-up are available, an analysis of the available data is motivated and valuable as zirconia-based restorations are widely used and a topic of great current interest. The conclusions drawn are, however, limited to preliminary short-term indications.

Only four of the included studies had a follow-up of more than 5 years (19, 25, 28, 36). Life table analyses of cumulative survival rates based on heterogeneous studies only provide estimates of survival. The analyses were limited to 5 years as the majority of the studies reported on 3- to 5-year follow-up, and complications and failures often appear during the first few years.

The 5-year survival rate of implant-supported FDPs was excellent at 100%. But the analysis is based on only four studies, and interpretation of the results should therefore be made cautiously (36–39). Previous studies on metal–ceramic implant-supported FDPs report slightly lower survival rates of approximately 96% (43, 44). These studies are based on groups of larger numbers of patients and with up to 10-year follow-up. No biological complications were noted, but 30·5% technical complications were registered, which is only slightly higher than the complication rate of the tooth-supported FDPs. In other reviews, a significant difference has been found between tooth- and implant-supported FDPs concluding that implant-supported prostheses have been more prone to technical complications (45, 46). The increased risk of complications for implant-supported FDPs has been explained by the fact that osseointegrated implants are characterised by direct contact between the bone and the loaded implant and a lack of shock absorption, sensory response and movement (44). The implant-supported restoration might therefore be subjected to excessive loads resulting in a higher risk of technical complications.

A similar 5-year survival rate for tooth-supported zirconia-based FDPs compared to what has been reported for tooth-supported metal–ceramic FDPs was found (10). The most common cause of failure as well as complications for the tooth-supported FDPs was veneering material fractures. This has been reported from the very beginning of evaluations of zirconia restorations and has caused concern. To avoid exposing zirconia frameworks to unfavourably high temperatures during veneer firing, creating undesirable phase transformation, veneering materials of low firing temperature are often used. Lowering the firing temperature also affects the mechanical properties, which creates an increased risk of veneer fractures (47).

Table 2. Reasons for failure of zirconia-based FDPs

Failures							
Technical failures				Biological failures			
Tooth-supported restorations		Implant-supported restorations		Tooth-supported restorations		Implant-supported restorations	
Veneer fracture	20			caries	8		
Framework fracture	13			abutment tooth fracture	7		
Loss of retention	5			endodontic treatment	3		
				periodontal lesion	1		
Total number:	38	Total number:	0	Total number:	19	Total number:	0
Total number of technical failures: 38				Total number of biological failures: 19			

Table 3. Type of complications of zirconia-based FDPs

Complications							
Technical complications				Biological complications			
Tooth-supported restorations		Implant-supported restorations		Tooth-supported restorations		Implant-supported restorations	
veneer fracture	175	veneer fracture	21	endodontic treatment	20		
loss of retention	18	loss of retention	1	caries	12		
technical complication	4			biological complication, not specified	2		
colour mismatch	1			abutment tooth fracture	1		
Total number:	198	Total number:	22	Total number:	35	Total number:	0
Total number of technical complications: 220				Total number of biological complications: 35			

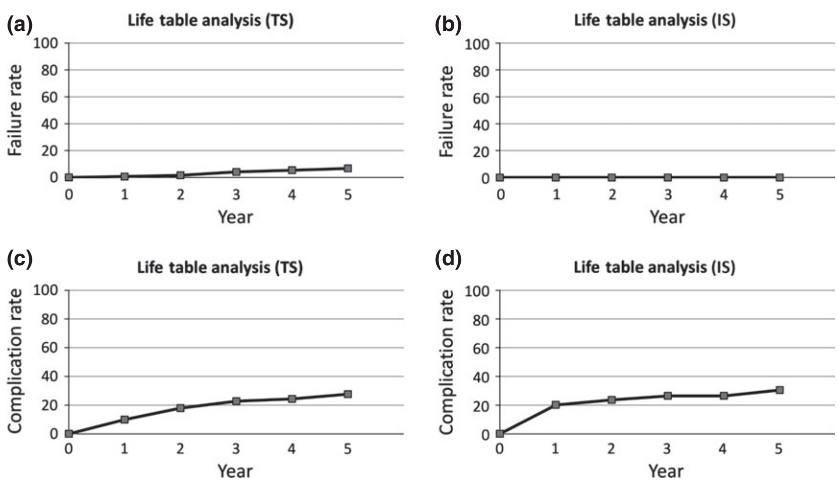

Fig. 2. Illustration of failure (a, b) and complication rates (c, d) of tooth- (TS) and implant-supported (IS) FDPs.

Recent publications, where zirconia-based FDPs are compared with metal–ceramic FDPs in randomised settings, have failed to show statistically significant differences between the two materials (16, 21, 26), and a randomised study comparing implant-supported FDPs based on zirconia and metal–ceramic, respectively, did not identify any fractures of the veneering material at all (48). A possible explanation for improved results in later publications could be the fact that the knowledge of how to design, handle and produce zirconia-based restorations has increased (6).

Recently, much attention has been focused on the design of the supporting substructure and the thickness of the veneering material (49). Veneering materials are brittle and of relatively low tensile strength. An anatomical design of the substructure will provide support for the veneer and create conditions for mainly compressive forces within the veneering material (50–52). An anatomical design also controls the thickness of the veneering material. Thick layers of porcelain veneered on frameworks with low thermal diffusivity such as zirconia may generate high residual tensile stresses which can contribute to fractures of the veneering material (49). Uncontrolled stresses will increase even further if the firing process and subsequent cooling are not performed appropriately (49). Many manufacturers have adapted the cooling process according to these findings.

Despite the veneering material fractures, the survival rate for zirconia-based restorations is still high, and their importance should therefore not be overemphasised. Few veneer fractures lead to a need for removal of the restoration. The majority do not affect function or aesthetics, they can be adjusted by polishing or repaired with composite or porcelain veneers, and the restorations remain *in situ*. The prognosis of repairs is, however, not known as few have been attempted and no follow-up is presented.

No framework fractures were reported for implant-supported FDPs, but for tooth-supported FDPs, 8 studies reported a total of 15 failures due to framework fracture (14, 16, 19, 25, 27–30). Should this be the cause for concern? Ceramics are brittle, and restorations should be designed with a safety factor approach (53). When analysing the reasons for failure mentioned in the individual reports, we find that more than half of the framework fractures occurred in cases where manufacturer's instructions concerning recommended dimensions and handling of the material were not observed (14, 16, 25, 27, 28, 30). To disregard manufacturer's recommendations concerning minimum requirements for dimensions of coping walls and connectors is obviously a risk that should be avoided. If these cases are excluded from the present analysis, the risk of framework fracture is <1%.

Apart from veneer fractures, the only other complication reported in the group of implant-supported FDPs was loss of retention which was seen in one case. Among the tooth-supported FDPs, loss of retention was responsible for nine per cent of the failures and eight per cent of the complications. Zinc phosphate and glass–ionomer cements were over-represented in cases of loss of retention. The indications for conventional cementation should be critically reviewed as resin cements with reactive phosphate monomer can form a chemical bond to zirconia-based ceramics after proper conditioning (54, 55). Few incidents of loss of retention have been reported in restorations using resin-based cements (7).

Among the biological complications that were noted for the tooth-supported FDPs, caries and endodontic problems were the most frequent. Caries has long been considered one of the more important factors leading to FDP failure (56). Whether zirconia-based restorations would be more prone to caries compared to metal–ceramic restorations is difficult to establish as caries is a disease with a complex multifactorial background where type of restorative material is probably not the most important factor. One factor that has been proposed to be of possible influence is the type of processing used to produce FDPs. Most Y-TZP restorations are manufactured from pre-sintered blocks. The final sintering involves a shrinkage that needs to be compensated for, and there has been some concern as to whether this affects marginal fit and risk of micro-leakage (57). When comparing metal casting versus CAD/CAM-produced Y-TZP, the results from different studies are conflicting with some showing as good or even superior accuracy for Y-TZP and others showing lower accuracy (57). Clinical implications have yet to be determined. One study was responsible for 75% of caries incidences leading to failure and 92% of caries incidences leading to complications (28). An unusually high occurrence of marginal gaps was noted as a prototype processing technology was used in that study, which was initiated more than 10 years ago (58). If this study is excluded from the present analysis, caries is a much less common event. The time factor must, however, also be mentioned as caries progresses over time. As the studies included in the present review were of limited follow-up times, future follow-up may show different caries incidence.

In the present study, no periodontal complications were noted for either treatment group. This is in contrast to what has been published for metal–ceramic implant-supported FDPs (43) and also in contrast to studies claiming a high risk of peri-implantitis (59). Ceramic materials have been found to accumulate less plaque and plaque with reduced vitality, compared to other restorative materials (60–62). The clinical significance is uncertain, however. A review comparing metal and ceramic abutments did not find significant differences (63). Another explanation for the lack of biological complications in the present study may be the fact that many aspects of periodontal disease develop over time and may not be noticeable in the limited short-term follow-up reports that make up the basis for the present review. This factor should be addressed again in future reports.

Conclusions

Most available studies on zirconia-based FDPs at present evaluate a limited number of FDPs with short-term follow-up. The vast majority of the studies are not controlled clinical trials. Interpretation of the findings in the present review should therefore be made with caution. Within the limitations of the studies forming the basis for the present review, the following conclusions, which have to be considered preliminary indications, suggest that:

1. The 5-year survival rate of implant-supported zirconia-based FDPs is excellent,
2. The 5-year survival rate of tooth-supported zirconia-based FDPs is acceptable and comparable to metal–ceramic FDPs,
3. Technical factors are the most common cause of failure and complications for implant-supported and tooth-supported zirconia-based FDPs and
4. Indications for conventional cementation should be critically reviewed as loss of retention occurred more frequently in FDPs luted with zinc phosphate cement or glass–ionomer cements compared to those luted with resin cements

Well-designed studies with large patient groups and long-term follow-up are needed before general recommendations for the use of zirconia-based restorations can be provided.

Ethical approval

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Conflict of interests

The authors declare no conflict of interests.

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