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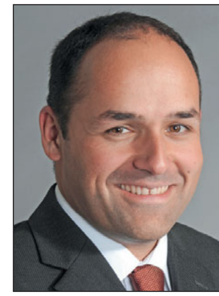
Outcome of bonded vs all-ceramic and metal-ceramic fixed prostheses for single tooth replacement



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Key words *all ceramic, fiber reinforced composite, fixed dental prosthesis, inlay-retained, metal ceramic, resin-bonded*

Aim: The conventional treatment of a single missing tooth is most frequently based on the provision of a fixed dental prosthesis (FDPs). A variety of designs and restorative materials are available which have an impact on the treatment outcome. Consequently, it was the aim of this review to compare resin-bonded, all-ceramic and metal-ceramic FDPs based on existing evidence.

Materials and methods: An electronic literature search using "metal-ceramic" AND "fixed dental prosthesis" AND "clinical, all-ceramic" AND "fixed dental prosthesis" AND "clinical, resin-bonded" AND "fixed dental prosthesis" AND "clinical, fiber reinforced composite" AND "clinical, monolithic" AND "zirconia" AND "clinical" was conducted and supplemented by the manual searching of bibliographies from articles already included.

Results: A total of 258 relevant articles were identified. Metal-ceramic FDPs still show the highest survival rates of all tooth-supported restorations. Depending on the ceramic system used, all-ceramic restorations may reach comparable survival rates while the technical complications, i.e. chipping fractures of veneering materials in particular, are more frequent. Resin-bonded FDPs can be seen as long-term provisional restorations with the survival rate being higher in anterior locations and when a cantilever design is applied. Inlay-retained FDPs and the use of fiber-reinforced composites overall results in a compromised long-term prognosis. Recently advocated monolithic zirconia restorations bear the risk of low temperature degradation.

Conclusions: Several variables affect treatment planning for a given patient situation, with survival and success rates of different restorative options representing only one factor. The broad variety of designs and materials available for conventional tooth-supported restorations should still be considered as a viable treatment option for single tooth replacement.

Conflict of interest statement: *The author declares that he has no conflict of interest.*

■ Introduction

The replacement of single missing teeth is of significant clinical importance and several treatment options exist, all having specific advantages and limitations[1-7]. Despite the purportedly advantageous rehabilitation of missing single teeth with oral implants, patients already perceive benefits in chewing ability, aesthetics and satisfaction with their oral situation, after receiving conventional dental prostheses[8]. A variety of restoration designs and materials exist for tooth-supported reconstructions spanning from fiber-reinforced composites to metal alloys and ceramic materials[9]. Numerous clinical

Table 1 Relevant clinical parameters for treatment planning.

Neighbouring teeth[2,10-13]	Caries free? Endodontically treated? Periodontally involved? Deformations / Discolorations? Trauma? Amount of tooth substance available for retention
Location and Occlusion[9,10,14,15]	Anterior vs. Posterior Mandible vs. Maxilla Occlusal relationship
Space and volume requirement[3,16-21]	Restorative space available Bone and soft tissue volume available
Patient status[10,19,20,22,23]	Skeletal growth completed Patient age and co-morbidities
Restoration design and material[15,24]	Metal alloys vs. Ceramics vs. Fiber-Reinforced Composite Cement type End-Abutments vs. Cantilever vs. Resin-bonded
Human factor[25,26]	Experience of treatment provider Patient education

parameters have to be taken into account during the process of treatment planning (Table 1).

An extensive survey amongst 200 patients who received different types of restorations to replace single missing teeth has revealed that restoring aesthetics and function was their main motivation for treatment. Damage of the neighboring teeth, pain, postoperative sensitivity and dental phobia were important factors in selecting a specific type of restoration or no treatment. Patient satisfaction decreased from implant-supported single crowns to conventional and resin-bonded fixed dental prostheses (FDPs). No treatment and removable partial denture treatment showed the lowest levels of satisfaction[26]. On the other hand, a survey amongst general practitioners in Belgium revealed that for 42% of all teeth extracted, no treatment was rendered, due to lack of treatment decision or because tooth replacement was deemed unnecessary. Removable restorations were chosen in 54%, fixed dental prostheses in 24%, single implants in 21% and resin-bonded fixed dental prostheses in 1% of all cases. The authors also pointed out that patient-related socioeconomic factors, as well as the clinician's experience with different treatment modalities had an effect on treatment planning[27].

Given the complexity of the decision-making process for both the clinician and the patient, it was the aim of this review to provide a comprehensive overview on treatment outcomes of resin-bonded versus all-ceramic and metal-ceramic fixed dental prostheses for single-tooth replacement.

Material and methods

An electronic MEDLINE (PubMed) search was conducted using the following combinations of search terms "metal-ceramic" AND "fixed dental prosthesis" AND "clinical (552), all-ceramic" AND "fixed dental prosthesis" AND "clinical (783), resin-bonded" AND "fixed dental prosthesis" AND "clinical (364), fiber reinforced composite" AND "clinical (280), monolithic" AND "zirconia" AND "clinical (45) ". Publications up to the year 1990 were considered. In addition, a manual search of bibliographies from relevant articles was carried out. From an initial yield of 1979 titles, 258 articles were considered as being relevant for this review with no restrictions being applied in terms of study design, patient selection and observation period. Given the availability of recent systematic reviews and meta-analyses for different types of conventional fixed restorations, the focus was a descriptive and critical overview.

Results

General aspects of FDPs

Conventional fixed reconstruction of missing teeth requires the preparation of abutment teeth and the subsequent placement of a fixed dental prosthesis. In addition to losing a significant amount of tooth substance[28,29], preparation of teeth bears the risk of irreversibly damaging pulpal tissue[30].

Besides utilising teeth mesially and distally adjacent to the edentulous site as abutments, cantilevered restorations based on at least two teeth mesially or distally to the edentulous site are an alternative option. Such cantilever FDPs require a more thorough treatment planning[31] and are biomechanically less favourable; furthermore, precautions have to be taken to avoid exaggerated moment loading on the abutment teeth[32]. Comparing different types of FDPs placed on teeth and implants as end abutments or with cantilevers, Brägger et al found after a mean observation period of 11.3 years, that the success rate was significantly higher in FDPs with end abutments, compared to cantilever FDP designs[33]. This was consistent with a former report[34].

Based on a retrospective chart review, Libby et al identified a list of complications limiting the longevity of FDPs from 4.1 up to 16.0 years. The reasons for failure were dental caries (38%), periapical involvement (15%), perforated occlusal surfaces (15%), a fractured post and cores (8%), defective margins (8%), fractured teeth (7%) and porcelain failures (8%)[35], which is consistent with other clinical reports[34,36].

As a general trend, it has been shown that short-span FDPs predominantly fail due to biological complications, whereas long-span FDPs are prone to technical complications. Overall, short- span restorations exhibit greater survival rates compared to long-span FDPs[37,38]. The performance of short-span FDPs is even better when vital teeth are being used as abutments. No relationship between gender and irreversible complications could be found. Failures occurred in patients who were older when initial treatment was rendered[39].

Heschl et al evaluated extensive FDPs placed in periodontally compromised patients, after a mean observation period of 75.7 months. While probing depths remained at a constant level, significant deteriorations were observed based on plaque index scores and bleeding on probing. The authors nevertheless concluded that treatment with tooth-supported extensive FDPs can be recommended even in patients with a history of periodontitis, given a favourable distribution of abutment teeth[40]. However, it has also been shown that ill-fitting crown margins and excess cement may have a negative impact on periodontal health of the abutment teeth[41]. Similarly, Suárez et al observed gingival bleeding more frequently around crowned teeth compared to contralateral teeth[42]. Robertsson found impaired periodontal health with accumulation of plaque and gingivitis following FDP treatment[43].

Connector dimensions are an important factor for the mechanical reliability of FDPs and material-specific minimal dimensions are recommended by the manufacturers. However, these guidelines are often not adhered to due to space limitations in specific situations[44].

Metal-ceramic FDPs

Aimed at improving aesthetics and survival rates of resin-veneered gold restorations, metal-ceramic systems were developed[45-47]. Based on different reports from that epoch, clinicians considered metal-ceramic restorations to be more aesthetic[48], while metal-resin restorations or metal-ceramic restorations with metal margins were believed to show better marginal adaptation[48-50].
Wear of the opposing dentition was initially described as a clinical problem in porcelain-fused-to-metal restorations, due to the comparatively high surface hardness of the veneering material[51,52]. The occurrence of veneer fractures has been a further problem associated with the composite structure of metal-ceramic restorations, which even warranted the development of special intraoral repair systems[53]. Furthermore, gingival bleeding and the deepening of gingival pockets[54] were described as negative side effects of metal-ceramic restorations, potentially due to insufficient preparation depth of the abutment teeth. Despite these initial shortcomings, resulting in compromised longevity[55], metal-ceramic restorations were in widespread use[56]. Acceptable clinical performance has been reported even for extreme clinical situations including multi-unit restorations, questionable abutment teeth and advanced periodontal involvement[57].

For porcelain-fused-to-metal restorations, allergic reactions[58] to high noble and noble metal alloy cores (palladium and gold) and to base metal alloys (nickel and cobalt) have been reported[59]. However, gingival health around metal-ceramic restorations were reported to be less compromised compared to resin-veneered silver-palladium restorations[60].

A broad range of survival rates for metal-ceramic FDPs has been determined by various authors, ranging from 92.8% to 98.0% after 60 months and from 84% to 87% after 120 months. A recent prospective study even reported a 94.4% survival rate of FDP retainer crowns after 132 months of function (Table 2).

Titanium has more recently been introduced as a core material with contradictory results on the clinical performance in the literature[36]. Substantial differences in the coefficient of thermal expansion between titanium and conventional noble and

Table 2 Clinical performance of metal-ceramic fixed dental prostheses. Note: shaded lines present follow-up studies of the same patient cohort.

Author	Restoration type	Materials	No. of restorations	Observation period [months]	Survival [%]	Remarks
Svanborg et al 2013[61]	FDPs (varying design and number of units)	CoCr	201	60	92.8	Success: 83.8%
Näpänkangas et al 2002[38]	FDPs (majority 3- to 5-unit)	Not specified	195	120	84.0	
Walton 2002[62] and Walton 2003[63]	FDPs (majority 3-unit)	High noble alloys	515	60	96.0	Tooth fractures (38%), caries (11%), loss of retention (13%), periodontal breakdown (27%)
				120	87.0	
				180	85.0	
Behr et al 2012[64]	FDPs (3- and 4-unit)	Precious alloys	654	60	94.0	Chipping fractures 4.3%
				120	87.0	
Reitemeier et al 2013[65]	Posterior metal ceramic FDP retainers	High noble / noble alloys	276*	132	94.4	* retainer crowns Success rate: 81.7% Bruxism as risk factor
Walter et al 1994[66]	Single crowns and FDPs	Ti	88	36	95.0	Success rate: 84%
Kaus et al 1996[67]	Single crowns and FDPs up to 6-units	Ti	84	30	59.0	Survival rate for crowns: 85%
Walter et al 1999[68]	FDPs (3- and 4-unit)	Ti	22	60	84.0	
		Gold alloy	25		98.0	
Boeckler et al 2010[69]	FDPs (majority 3-unit)	Ti	31	36	96.8	Success rate: 76.4%
Hey et al 2013[70]	FDPs (majority 3-unit)	Ti	31	72	88.0	Success rate: 58.6%

non-noble alloys necessitated the development of adequate veneering materials and an additional learning curve[71]. Two reports on a clinical study involving single crowns and a variety of FDP types, fabricated with the Procera system (Nobel Biocare, Zürich, Switzerland), showed favourable outcomes after 5 years of clinical service[72,73]. Similarly, a multicenter university-based study on single crowns and 3-unit FDPs, using the same system, showed that 95% of all restorations performed satisfactorily with respect to surface and colour, anatomic form and marginal integrity, both after insertion and after 1 year of service[74].

In general, the compromised performance of titanium-based metal-ceramic FDPs results in lower survival rates up to 96.8% after 36 months, decreasing to 84% and 88% after 60 and 72 months, respectively (Table 2).

All-ceramic FDPs

In order to overcome limitations of metal-ceramic restorations with respect to aesthetics, invasiveness[1] and biocompatibility[75-78], different all-ceramic systems have been considered for the fabrication of FDPs, ultimately aimed at replacing metal-ceramic restorations[79]. Despite the comparatively short availability of all-ceramic systems, a decrease in complication rates can already be noticed when comparing earlier and later publications. This may be indicative of a learning curve associated with new materials, manufacturing techniques and clinical procedures such as cementation protocols[80-82].

An early approach to all-ceramic restorations was a castable glass ceramic (Dicor; DeTrey-Dentsply, Konstanz, Germany), which was considered to show better aesthetic results, better wear characteristics and diminished oral plaque accumulation, but required a bonding protocol with etching prior to luting for achieving sufficient survival rates[83]. Other approaches in the field of silica-based ceramics included leucite-reinforced glass ceramics (Empress; Ivoclar Vivadent AG, Schaan, Liechtenstein) and lithium disilicate ceramics (Empress 2; Ivoclar Vivadent AG)[84]. Infiltration ceramics (In-Ceram; VITA Zahnfabrik, Bad Säckingen, Germany) constituted a first step towards the use of oxide ceramics as restorative materials[85,86]. The advent of sophisticated Computer aided design / Computer aided manufacturing (CAD/CAM) systems[87-90] facilitated the use of pure oxide ceramics, such as zirconia ceramic, which can be used in a variety of clinical indications[77,91,92]. Major advantages of zirconia ceramics include high flexural strength, allowing for conventional cementation[93], fracture toughness, biocompatibility, aesthetics[94] and ultimately a greater reliability compared to infiltration ceramics and silica-based ceramics[87]. Consequently, in a series of literature reviews, Raigrodski et al described Zirconia-based FDPs as an acceptable restorative option in both the anterior and posterior segments[88,95-98].

Several authors stressed the excellent biocompatibility of zirconia ceramics did not cause allergy symptoms in a group of patients showing allergic reactions to metal-ceramic restorations[99]. The use of zirconia ceramic also did not deteriorate periodontal parameters[100,101] and avoided marginal discolouration[101].

From a manufacturing point of view, early zirconia restorations were problematic, showing high levels of marginal discrepancy, resulting in secondary caries and consequently lower survival rates[102,103]. More recent reports, however, showed that after short observation periods, 93.75% of zirconia-ceramic FDPs had appropriate marginal matching[101]. Connector dimensions appear to be extremely critical for the performance of all-ceramic restorations, and various authors showed that manufacturer recommendations often cannot be met[104-107]. In a retrospective analysis of 120 zirconia-based FDPs, the incidence of framework fractures during the first year was limited to 1.7%[108].

Chipping of the veneer ceramic seems to be the major technical complication in restorations based on zirconia ceramic[102,103,109,110]. Risk factors which have been identified include FDP span[103], endosseous implants used as abutments[111,112], absence of a nightguard, presence of a ceramic antagonist restoration and parafunctional habits[111]. From a material point of view, a reduction in thermal mismatch between core and veneer[113], as well as anatomically contoured substructures supporting the veneer have been advocated[114,115].

For lithium-disilicate ceramics, the literature reports 10-year survival rates of 71.4% and 87.9% which, overall, seems to be comparable to different types of infiltration ceramics[106,107,117,118]. A good body of literature exists on the clinical performance of zirconia-based FDPs with high numbers of restorations placed and long observation periods. Despite a high incidence of chipping fractures, zirconia-based restorations appear to have good survival rates (Table 3).

Comparison of metal-ceramic FDPs vs all-ceramic FDPs

Different authors directly compared metal-ceramic and all-ceramic restorations with respect to clinical performance, patients' preference and periodontal aspects. In an older study on patients' perception of all-ceramic and metal-ceramic crowns and FDPs, it could be shown that the shade and colour of a restoration are the most discriminating factors for assessing overall treatment quality. Contradictory results were described with patients considering all-ceramic crowns as being more natural and metal-ceramic FDPs as being more natural compared to alternative materials[143].
Both metal-ceramic and all-ceramic FDPs seem to not affect periodontal health, as determined by the plaque index, the gingival index and the probing depth, compared to unaltered teeth[144-146]. This is supported by a study by Zenthöfer et al who could not find a difference in probing pocket depth, probing attachment level, plaque index, gingival index and aesthetic performance between cantilever FDPs, made from zirconia and metal frameworks, respectively[147].

On the other hand, there seems to be a difference between metal-ceramic and all-ceramic restorations, in terms of technical complications with metal-ceramic FDPs being more durable[146,148]. Despite showing a survival rate of 100% for both metal-ceramic and all-ceramic FDPs, Sailer et al reported chipping rates of the veneering ceramic being 25% for zirconia ceramic and 19.4% for metal-ceramic FDPs, with extended fractures of the veneer occurring only in zirconia-based restorations[149].

Based on the results from five clinical studies, it appears that lithium disilicate and alumina ceramic show lower long-term survival rates compared to metal-ceramic restorations. However, hardly any difference in clinical performance seems to exist between FDPs made from zirconia-ceramic and metal-ceramic FDPs (Table 4).

Table 3 Clinical performance of all-ceramic fixed dental prostheses. Note: shaded lines present follow-up studies of the same patient cohort.

Author	Restoration type	Materials	No. of restorations	Observation period [months]	Survival [%]	Remarks
Zimmer et al 2004[104]	3-unit anterior FDPs	IPS Empress 2	31	38	72.4	3 framework fractures (insufficient connector dimensions) 1 veneer fracture 2 biologic failures
Marquardt and Strub 2006[116]	3-unit anterior FDPs	IPS Empress 2	31	50	70.0	3 framework fractures (insufficient connector dimensions) 1 veneer fracture 2 biologic failures
Wolfart et al 2009[117]	3-unit anterior and posterior FDPs	Lithium disilicate	36	86	8 years: 93.0	6% fractures 6% chipping fractures 3% endodontic complication 6% debonding
Kern et al 2012[118]	3-unit anterior and posterior FDPs	Lithium disilicate	36	121	5 years: 100 10 years: 87.9	Success rate 5 years: 91.1% Success rate 10 years: 69.8%
Solá-Ruiz et al 2013[106]	3-unit FDPs	Lithium disilicate	21	120	71.4	Postoperative sensitivity: 14.3% Recession: 24% Marginal discoloration: 7.1%
Reich et al 2014[107]	Anterior and posterior FDPs	Lithium disilicate	32	46	93.0	Success rate: 83% 3 endodontic complications 2 chipping fractures 1 catastrophic fracture
Suárez et al 2004[42]	Posterior FDPs	InCeram zirconia	18	36	94.4	1 root fracture
Eschbach et al 2009[119]	3-unit posterior FDPs	InCeram zirconia	65	54.4	96.8	1 technical failure 1 biologic failure 2 debondings 4 veneer fractures 3 endodontic complications 2 secondary caries
Chaar et al 2015[120]	3-unit posterior FDPs	InCeram zirconia	65	116.4	93.6	
Vult von Steyern 2005[121]	Posterior 3-unit FDPs	InCeram alumina	20	60	5 years: 90.0 11 years: 65.0	Data also reported in Vult von Steyern et al. 2001[122]
	3-unit to 5-unit FDPs	Zirconia ceramic	20	24	100	
Kern et al 2012[105]	3-unit and 4-unit posterior FDPs	InCeram zirconia	20	74.6	85.0	
Philipp et al 2010[123]	3-unit posterior FDPs	Ce-TZP/A-nanocomposite	8	12.8	100	
Vult von Steyern et al 2005[124]	3-unit to 5-unit FDPs	Zirconia ceramic	23	24	100	3 chipping fractures
Sailer et al 2006[125]	3-unit to 5-unit posterior FDPs	Zirconia ceramic	57	36	84.8	Secondary caries in 10.9% of FDPs Chipping fractures in 13.0% of FDPs
Sailer et al 2007[102]	3-unit to 5-unit posterior FDPs	Zirconia ceramic	57	53.4	73.9	Success rate of zirconia frameworks: 97.8% Secondary caries in 21.7% of FDPs Chipping fractures in 15.2% of FDPs

Sax et al 2011[103]	3-unit to 5-unit posterior FDPs	Zirconia ceramic	57	128	67.0	3 framework fractures 16 chipping fractures (correlation with FDP span) Marginal discrepancy in 90.7% of FDPs
Raigrodski et al 2006[126]	3-unit posterior FDPs	Zirconia ceramic	20	31.2	100	5 chipping fractures
Raigrodski et al 2012[127]	3-unit posterior FDPs	Zirconia ceramic	20	60	90.0	Success rate: 79%
Edelhoff et al 2008[128]	3-unit to 6-unit FDPs	Zirconia ceramic	22	39	90.5	2 chipping fractures
Beuer et al 2009[129]	3-unit posterior FDPs	Zirconia ceramic	21	40	90.5	
Beuer et al 2010[130]	3-unit and 4-unit anterior and posterior FDPs	Zirconia ceramic	18	35	55.6	3 biologic failures 5 technical failures
Crisp et al 2008[131]	3-unit and 4-unit anterior and posterior FDPs	Zirconia ceramic	41	12	100	1 chipping fracture 2 endodontic treatments
Crisp et al 2012[132]	3-unit and 4-unit anterior and posterior FDPs	Zirconia ceramic	41	36	100	2 chipping fractures 3 endodontic treatments
Burke et al 2013[133]	3-unit and 4-unit anterior and posterior FDPs	Zirconia ceramic	41	60	97.0	8 chipping fractures
Sorrentino et al 2012[134]	3-unit posterior FDPs	Zirconia ceramic	48	60	100	3 chipping fractures
Roediger et al 2010[135]	3-unit and 4-unit posterior FDPs	Zirconia ceramic	99	48	94.0	13 chipping fractures 6 loss of retention 3 secondary caries 1 loss of vitality
Rinke et al 2013[110]	3-unit and 4-unit posterior FDPs	Zirconia ceramic	99	84	83.4	12 technical complications (framework fracture, veneer fracture, loss of retention) 6 biologic complications
Wolfart et al 2009[136]	3-unit and 4-unit posterior FDPs	Zirconia ceramic	end abutment: 24	48.7	96.0	
			cantilever: 34	50	92.0	
Schmitt et al 2009[100]	3-unit and 4-unit posterior FDPs	Zirconia ceramic	30	34.2	100	Success rate: 96.3%
Schmitt et al 2012[137]	3-unit and 4-unit posterior FDPs	Zirconia ceramic	30	62.1	92.0	
Lops et al 2012[138]	Anterior and posterior FDPs	Zirconia ceramic	28	78	88.9	Success rate: 81.8%
Tsumita et al 2010[139]	Posterior FDPs	Zirconia ceramic	21	28.1	100	
Molin and Karlsson 2008[140]	3-unit FDPs	Zirconia ceramic	19	60	100	1 debonding
Tinschert et al 2008[141]	Anterior and posterior FDPs	Zirconia ceramic	65	anterior: 38 posterior: 37	100	4 chipping fractures 2 decementations 3 endodontic complications
Sagirkaya et al 2012[142]	3-unit to 6-unit FDPs	Zirconia ceramic	160*	48	99.4	*Units

Table 4 Clinical performance of metal-ceramic vs. all-ceramic fixed dental prostheses.

Author	Restoration type	Materials	No. of restorations	Observation period [months]	Survival [%]	Remarks
Sailer et al 2009[149]	3-unit to 5-unit posterior FDPs	Zirconia-ceramic	38	40.3	100	25% minor veneer chipping
		Metal-ceramic	38		100	19.4% minor veneer chipping
Pelaez et al 2012[144]	3-unit posterior FDPs	Zirconia-ceramic	20	50	95.0	2 minor chippings 1 biologic complication Data also reported in Pelaez et al. 2012[145]
		Metal-ceramic	20		100	
Zenthöfer et al 2015[147]	3-unit cantilever FDPs	Zirconia-ceramic	11	36	100	6 complications (endodontic treatment, ceramic chipping)
		Metal-ceramic	10		100	
Makarouna et al 2011[150]	FDPs	Lithium disilicate	18	72	63.0	
		Metal ceramic	19		95.0	
Christensen and Ploeger 2010[148]	3-unit posterior FDPs	Metal-ceramic	293	36	84.0 – 100	Variety of material combinations
		Zirconia-ceramic			81.0 – 88.0	
		Alumina-ceramic			54.0 – 76.0	

Resin-bonded FDPs

In an attempt to reduce the amount of tooth substance which has to be removed for placing conventional restorations, and concomitant with the development of adhesive strategies, resin-bonded fixed dental restorations were introduced in the 1980's[151] and have since then been well-documented as a treatment modality[152-154]. Different authors advocated resin-bonded FDPs (RBFDPs) merely as long-term provisionals[19,155] although anecdotal case reports show long-term survival of RBFDPs up to 15 years[156].

Following minimal or even no preparation of oral or buccal tooth surfaces, RBFDPs are placed using adhesive cements which constitute their sole form of retention. The predominant indications for RBFDPs are congenitally missing teeth[157]. This treatment modality has been described as not affecting the periodontal condition of the abutment teeth, although higher levels of plaque accumulation and gingivitis have been reported[158,159]. To some extent this may be seen as a consequence of overcontouring, which occurs in minimally invasive preparation designs[160]. The most frequent complication in patients treated with RBFDPs is debonding of the restoration[11,161-165], which is in contrast to conventional FDPs where biological problems seem to be the most common cause for failure[34,35,166]. Rebonding of RBFDPs is possible but may lead to lower retention compared to originally bonded restorations[163,167,168]. Moreover, newer bonding systems show improved performance[169,170] compared to former materials[160,171], but have to be selected with respect to the material used for fabricating the restoration[172]. While metal substructures have predominantly been used in the past, causing discolouration of abutment teeth [20,173-175], the development of high-strength ceramics allows for the fabrication of metal-free RBFDPs[176]. Furthermore, the incidence of debondings seems to be affected by a variety of additional factors, including the location in the oral cavity, the preparation technique applied and the design of the restoration[177].

In this context, RBFDPs in anterior locations seem to perform better compared to those in posterior locations[14,178]. However, this is contradicted by a clinical study by Dündar et al, who reported that factors such as jaw type and adhesive protocol did not affect the short-term performance of RBFDPs[179]. While a variety of different minimally invasive preparation techniques have been described[180-182], including the creation of retentive features[164,172,183], novel developments in bonding technology may even allow for RBFDPs on unprepared teeth[184]. In a 6-year longitudinal study on 141 restorations, Rammelsberg et al found that retentive tooth preparation, as well as the use of silane-coating of retentive elements improved the longevity of the restorations, while the intraoral location did not affect survival time[162].

Besides the classic two-retainer design, single-retainer cantilever RBFDPs[23,185] have been reported to show better clinical performance[170,186]. The higher debonding rates observed in two-retainer designs, predominantly in the form of unilateral debondings[180], have been claimed to result from differences in tooth mobility of the abutment teeth[172]. Potentially negative side effects of cantilever RBFDPs such as permanent movement of the abutments has not been found[187].

High levels of patient satisfaction and oral health-related quality of life following treatment with RBFDPs has been described by several authors[157,174,188,189]. Although reporting only 1-year results on a limited number of patients, either treated with conventional or resin-bonded cantilever FDPs in posterior locations, Prasanna et al did not find a significant difference in the performance of both treatment modalities[190].

Cautiously interpreting the survival rates reported by different authors, it may be concluded that single-retainer, cantilever RBFDPs perform better compared to RBFDPs with two retainers. Also, anterior restorations have a better prognosis than posterior ones. The restorative material used for fabricating RBFDPs only has a minor effect on long-term outcome, particularly when current materials i.e. zirconia-ceramic and metal-ceramic are considered (Table 5).

Inlay-retained fixed dental prostheses

Inlay-retained fixed restorations have been introduced as a further option to conventional FDPs, with the primary goal of reducing the invasiveness of the treatment rendered[28,29,206-208] without jeopardising aesthetics, functional performance and periodontal parameters[208,209].

Similarly to RBFDPs, the development of proper bonding techniques was a prerequisite for achieving sufficient clinical stability[210-212]. Furthermore, the restorative material used, the size of the adhesive surface, as well as the connector size constitute the parameters governing clinical longevity[213].

Hence, in 1995 Quinn et al reported a 76.5% survival rate for partial coverage crown-retained FDPs after 10 years, with the main reason for failure being loss of retention and caries[214]. More recently, resin-bonded cast metal onlays used for the retention of FDPs, with other indications, showed an overall success rate of 94% and a high level of patient satisfaction after a mean observation period of 42 months[215].

When analysing the long-term success of inlay-retained fixed dental prostheses (IRFDPs), this restorative option appears to be regularly problematic as survival rates decreased to 80% after 12 months and even to 57% after 60 months. On the other hand, 100% survival has been reported after a service life of 20 months. One study directly comparing conventional and inlay-retained FDPs clearly showed lower survival rates for IRFDPs (Table 6). The use of different restorative materials may cause the deviations in survival time described.

Fiber reinforced composite

As an alternative and cost effective material, fiber reinforced composites have been introduced for a variety of indications including the chairside creation of RBFDPs[219]. In posterior locations, bonded inlay-retained fixed fiber reinforced composite (FRC) restorations have been described as an aesthetic alternative treatment entity[5,82,220-222], with reduced treatment costs[6,223].

In this context, Freilich et al evaluated the clinical performance of FRC restorations, with a variety of designs. Excluding patients with severe parafunctional habits, the survival rate was 95%, at a mean survival period of 3.75 years. The authors pointed out that survival was associated with substructure design volume whereas retainer configuration did not have a significant effect. Surface defects and a reduction in the luster of the restorations occurred frequently[224]. In a retrospective study, Bohlsen and Kern showed that the survival rate of both single crowns and fixed dental prostheses made from FRC was low. At a mean follow-up time of 4 to 6 years, survival rates ranged from 59.9% to 67.9%, depending on the type of cement used[225]. In contrast, a cumulative survival rate of 80% after 5 years was reported for FRC restorations replacing anterior teeth in periodontally compromised patients[226]. Cenci et al also found a 81.8% survival rate for FRC restorations after an observation period of 7 years, with fractures of the restorations constituting the most important technical complication[227]. Similarly, a multi-center

Table 5 Clinical performance of resin bonded fixed dental prostheses. Note: shaded lines present follow-up studies of the same patient cohort.

Author	Restoration type	Materials	No. of restorations	Observation period [months]	Survival [%]	Remarks
Sailer et al 2014[191]	Anterior single retainer RBFDP	Zirconia ceramic	15	53.3	100	2 debondings
Saker et al 2014[192]	Anterior cantilever RBFDP	Metal ceramic	20	34	100	
		InCeram Alumina	20		90.0	2 fractures 3 debondings
Sailer et al 2013[193]	Anterior / posterior single retainer RBFDP	Glass ceramic	35	72	100	No debondings Ceramic chipping 5.7%
Spinas et al 2013[22]	Anterior, double wing retention RBFDP	Fiber Reinforced Composite	32	60	93.7	
Izgi et al 2013[194]	Posterior slot-retained RBFDP	Cast metal	41	75.6	83.0	
Younes et al 2013[19]	3-unit RBFDP, double wing retention	Cast metal	42	> 192	5 years: 95.0 10 years: 88.0 20 years: 66.0	Success rates: 5 years: 75%; 10 years: 58%; 20 years: 45% Reasons for failure: debondings, caries, periodontal break-down
Sun et al 2013195	Anterior veneer retained cantilever RBFDP	IPS e-max Press	35	46.57	100	
Kern 2005[196]	Anterior two retainer RBFDP	In Ceram alumina	16	75.8	67.3 / 73.9	
	Anterior single retainer RBFDP		21	51.7	92.3	
Kern and Sasse 2011[197]	Anterior two retainer RBFDP	In Ceram alumina	16	120.2	67.3 / 73.9	
	Anterior single retainer RBFDP		22	111.1	94.4	
Sasse et al 2012[198]	Anterior cantilever RBFDP	Zirconia ceramic	30	41.7	100	2 debondings
Sasse and Kern 2013[199]	Anterior cantilever RBFDP	Zirconia ceramic	30	64.2	100	2 debondings
Sasse and Kern 2014[200]	Anterior cantilever RBFDP	Zirconia ceramic	42	61.8	100	2 debondings 1 carious lesion
Howard-Bowles et al 2011[25]	Anterior and posterior RBFDP	Metal-ceramic	222	41	Overall: 84.1 Anterior: 91.5 Posterior: 75.9 Cantilever: 90.3 Fixed-fixed: 75.7	Based on questionnaire
Boening and Ullmann 2012[155]	Anterior RBFDP	Metal-ceramic	56	76	84.0	5 debondings 1 chipping fracture 1 carious lesion
Dündar et al 2010[179]	Anterior and posterior two retainer RBFDP	Metal-ceramic	58	20.3	Maxilla: 93.2 Mandible: 92.9	4 debondings
Botelho et al 2000[187]	2-unit cantilever RBFDP	Metal ceramic	33	30	97.0	
Botelho et al 2002[201]	2-unit cantilever RBFDP	Metal ceramic	82	36.7	95.1	
Botelho et al 2006[189]	2-unit cantilever RBFDP	Metal ceramic	269	51.7	95.5	Success rate: 94.8%
Botelho et al 2014[14]	Cantilever RBFDP	Metal ceramic	211	113.2	90.0	28 debondings Success rate: 84.4
Hussey and Linden 1996[153]	2-unit cantilever RBFDP	Metal-ceramic	142	36.2	94.0	Success rate: 88%
Ketabi et al 2004[202]	Anterior and posterior RBFDP	Metal-ceramic	74	93.6	83.0	9 debondings 6 carious lesions 3 veneer fractures
Samama 1996[203]	RBFDP	Cast metal	145	68.4	83.0	
Corrente et al 2000[204]	RBFDP	Metal-ceramic; Metal-resin	150	80.4	76.2	
Zalkind et al 2003[205]	RBFDP	Metal-ceramic	51	60	67.0	Success rate: 48%
Chai et al 2005[166]	3-unit FDP	Metal-ceramic	61	48	82.0	
	2-unit cantilever FDP	Metal-ceramic	25		77.0	
	3-unit RBFDP	Metal-ceramic	77		63.0	
	2-unit cantilever RBFDP	Metal-ceramic	47		81.0	

Table 6 Clinical performance of inlay-retained fixed dental prostheses. Note: shaded lines present follow-up studies of the same patient cohort.

Author	Restoration type	Materials	No. of restorations	Observation period [months]	Survival [%]	Remarks
Abou Tara et al 2011[16]	3-unit posterior IRFDP	Zirconia ceramic veneered	23	20	100	2 veneer fractures 1 debonding
Wolfart et al 2005[217]	3-unit anterior and posterior FDP	Lithium disilicate ceramic (IPs e.max Press)	36	48	4 years: 100	
	3-unit anterior and posterior IRFDP		45	37	4 years: 89.0	Reasons for failure: debonding/fracture
Harder et al 2010[218]	Posterior IRFDP	Lithium disilicate ceramic (IPs e.max Press)	45	70	5 years: 57.0 8 years: 38.0	Survival of FDPs with crown and inlay retainer: 100% (5 years), 60% (8 years)
Ohlmann et al 2008[209]	Posterior IRFDP	Zirconia ceramic veneered	30	12	80.0	1 chipping fracture 3 veneer delaminations 6 decementations 3 framework fractures

clinical study using different restoration designs with respect to the retentive element, showed a 5-year success rate of 71.2% and a survival rate of 77.5% for FRC restorations. The retention type (wing vs inlay) did not show a significant effect[228].

Monolithic zirconia restorations

In response to the high incidence of veneer chipping fractures in all-ceramic restorations, the use of zirconia ceramics, without the addition of veneering material was introduced[229]. Nowadays various companies offer modified zirconia ceramics which are pre-stained[230], and which require higher sintering temperatures. These materials are frequently referred to as 'translucent' zirconia[231]. The characterisation of such restorations is based on the use of staining liquids prior to sintering[231,232], a process requiring the experience of a dental technician. From a materials perspective, the following three factors may be problematic. Depending on the staining technique applied, the material properties may deteriorate[233,234]. Additionally, masticatory loads acting on unveneered zirconia ceramic, as well as the conditions within the oral cavity, may cause low temperature degradation phenomena[235,236]. Also, the risk of antagonist wear is discussed[237]. From an aesthetics point of view, monolithic zirconia restorations seem to be of limited applicability in the aesthetic zone[231]. Despite some promising clinical results[238], the corrrect long-term documentation for this treatment modality is missing thus far[231].

Systematic reviews and meta-analyses

Several systematic literature reviews and meta-analyses can be found, addressing the clinical performance of various types of FDPs (Table 7). Ignoring different clinical situations and restoration types, the overall survival rate of FDPs after 5 years was reported in the range of 89.2% to 95.5% and 65.5% to 89.4% after 10 years[239,242,243].

For RBFDPs, survival rates in the range between 87.7% to 92.3% have been calculated after 5 years of service[248,249]. For cantilever FDPs, a survival rate of 91.4% after 5 years and 80.3% to 81.8% after 10 years was described[241,242]. All-ceramic restorations showed survival rates of 90% after 3 years[244], and a range between 88.6% to 94.3% after 5 years[240,246,247]. For metal-ceramic FDPs, survival rates of 97% after 3 years[244] and 94.4% after 5 years[240] were calculated (Table 7).

In a critical review on the performance of all-ceramic and metal-ceramic FDPs, also elaborating on the shortcomings of existing meta-analyses, Layton concluded that the survival rate of metal-ceramic FDPs would be significantly higher than that of all-ceramic FDPs, and that all-ceramic FDPs experienced a high incidence of technical failure[250]. A recent review by Pjetursson et al reporting 5-year survival rates for FDPs, based on different materials, showed the highest survival rate (94.4%) for metal-ceramic restorations, while different all-ceramic options were below 91%[245].

Table 7 Overview of existing systematic reviews.

Author	Restoration type	Observation period [years]	Survival [%]	Remarks
Tan et al 2004[239]	FDPs	10	89.1	Caries 2.6% Periodontitis 0.7% Loss of retention 6.4% Abutment fracture 2.1% Material fractures 3.2%.
Sailer et al 2007[240]	All-ceramic FDPs	5	88.6	Framework fractures 6.5% Veneering material fractures 13.6%
	Metal-ceramic FDPs		94.4	Framework fractures 1.6% Veneering material fractures 2.9%
Pjetursson et al 2004[241]	Cantilever FDPs	10	81.8	Loss of pulp vitality 32.6% Caries at abutment teeth 9.1% Loss of retention 16.1% Material fractures 5.9% Fractures of abutment teeth 2.9%
Pjetursson et al 2007[242]	FDPs	5	93.8	Biological complications after 5 years (caries, loss of pulp vitality) 15.7%
		10	89.2	
	Cantilever FDPs	5	91.4	Complications after 5 years 20.6%
		10	80.3	
Pjetursson et al 2012[243]	tooth-supported and implant-supported FDPs and single crowns	5	89.2 - 95.5	Annual failure rates FDPs 1.14% Cantilever FDPs 2.20% RBFDPs 4.31%
		10	65.0 - 89.4	
Heintze and Rousson 2010[244]	All-ceramic FDPs (Zirconia)	3	90.0	Core fractures < 1.00 % Veneer chipping 24.0 % - 54.0 %
	Metal-ceramic FDPs		97.0	Core fractures 0% Veneer chipping 34.0 %
Pjetursson et al 2015[245]	Metal-ceramic FDPs	5	94.4	
	Reinforced glass ceramic FDPs		89.1	
	Glass infiltrated alumina FDPs		86.2	
	Zirconia FDPs		90.4	
Le et al 2015[246]	All-ceramic FDPs (Zirconia)	5	93.5	Complication rate 27.6%
Schley et al 2010[247]	All-ceramic FDPs (Zirconia)	5	94.3	Technical complication free rate 76.41% (chipping fractures) Biological complication free rate 91.72%
Wassermann et al 2006[248]	Resin bonded FDPs (single retainer and InCeram Alumina)	5	92.3	
Pjetursson et al 2008[249]	Resin bonded FDPs	5	87.7	Debonding 19.2% Caries 1.5% Periodontitis 2.1%

Discussion

Every review publication relies on the quality of the original research reports and consequently has to be interpreted with caution. The publications considered were not limited to robust clinical studies thus a larger database was used. Unfortunately, reporting of clinical outcomes has not been standardised in the past and in some instances it appears that authors unconsciously intended to 'hide' unfavourable outcomes. The inclusion of cumulative survival and success rates should be a prerequisite for any publication. This is particularly problematic in all-ceramic and metal-ceramic restorations, where chipping fractures of veneer materials constitute a frequent complication. As these chipping fractures may vary with respect to their extent, studies reporting on such complications are hard to compare as a uniform classification system has not yet been universally adopted[241]. Furthermore, publications repeatedly reporting on the same patient cohort or even on subsets of cohorts are misleading[144,145]. Also, follow-up publications after longer observation periods should be clearly marked as such even if the authorship has changed. In the same context, it was noted that obvious facts such as greater removal of tooth structure for a crown, compared to a veneer, have been publishable in the past[28,29]. On the other hand, the rapid development of novel restorative materials such as ceramic systems[251-253] and bonding agents question the validity of older publications in general even if a proper study design had been applied.

Despite not reflecting the highest level of evidence, several clinical studies compared different treatment alternatives not only focusing on numerically measurable facts such as survival and chipping rates. In a retrospective study evaluating 50 patients with missing lateral incisors, following treatment with orthodontic space closure or conventional and resin-bonded FDPs, the authors found higher levels of satisfaction in orthodontically treated patients[43]. A case-control study comparing the longevity of implant-supported crowns and 2-unit cantilevered RBFDPs, proved that both treatment options had similar survival rates, but a greater number of biological complications were observed with implant-supported crowns[254]. Using a theoretical approach, the cost-effectiveness of various treatment modalities for missing maxillary lateral incisors was evaluated[10]. According to this report, cantilever and resin-bonded FDPs appeared to be more cost-efficient compared to single implant crowns, while conventional FDPs would be less cost-effective than latter ones.

Several studies have been conducted comparing the performance of conventional FDPs and implant-supported crowns, with partially contradictory results. In a clinical study comparing the cost-effectiveness of both treatment options, Zitzmann et al found satisfactory long-term results from the patient's perspective in both groups. The lower initial costs, however, were in favour of the implant-supported single crowns[255]. Similarly, Wolleb et al calculated a survival rate of 98.7% for tooth-supported FDPs, and a 100% survival rate for implant-supported single crowns. Biological complications including loss of vitality, endodontic complications, root fractures and caries dominated, while veneer fractures occurred in 3.8% of the FDPs[256]. Technical complications appeared in a systematic review by Pjetursson et al, demonstrating a higher incidence in implant-supported reconstructions compared to restorations on teeth. They included fractures of the veneer, screw loosening and loss of retention[242].

Comparing the economic aspects of 41 FDPs and 59 implant-supported single crowns over an observation period of 4 years, implant-supported restorations required more visits, while the overall treatment time was similar to FDP treatment. The implant solutions were less expensive while the costs for treating complications were comparable in both groups[257]. In a cohort of patients with congenital defects, which affected the formation of teeth, 58% of patients with reconstructions on teeth remained free from all failures or complications, while 47% of patients restored with implant-supported restorations needed retreatment or repair during a mean observation period of 8 years. Patients affected by amelogenesis/dentinogenesis imperfecta demonstrated the highest failure and complication rates whereas in patients with cleft lip, alveolar process and palate or hypodontia/oligodontia, 71% of the single crowns and 73% of the FDPs on teeth remained complication-free over a median observation period of about 16 years[12]. In the same patient cohort, initial treatment costs for implant-supported reconstructions were much higher compared to tooth-supported restorations, whereas the long-term cumulative treatment costs for both groups were not significantly different[258].

Conclusions

Not requiring surgical interventions, conventional tooth-supported restorations appear to be more predictable in achieving initial treatment success with fewer appointments and shorter treatment time. Despite substantial differences in the remuneration of medical services, a basic trend towards higher laboratory fees and lower honorariums for the dental practitioner may be seen for FDP treatment, compared to implant-supported single crowns. Biological complications seem to limit the survival time of FDPs while implant-supported single crowns show a higher incidence of technical problems. Taking maintenance expenditures into account, the short-term advantage of conventional restorations appears to diminish.

Given the high number of variables affecting treatment decisions, a universally effective solution does not exist; instead clinicians should establish a specific risk profile for each patient situation. Survival and success rates of any restorative option, as well as risk profiles, must not be seen in isolation, but in combination with the patient's wishes and the capabilities of the treatment provider.

■ Acknowledgements

This paper is dedicated to my clinical teacher and fatherly friend Dr. Peter Stadlbauer, Waldmünchen and to my highly respected scientific mentor Prof. Dr. Dr. Siegfried Heckmann, Erlangen.

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