CLINICAL ORAL IMPLANTS RESEARCH

Review

A systematic review of the survival and complication rates of resin-bonded fixed dental prostheses after a mean observation period of at least 5 years

Daniel S. Thoma
Irena Sailer
Alexis Ioannidis
Marcel Zwahlen
Nikolay Makarov
Bjarni E. Pjetursson

Authors' affiliations:
Daniel S. Thoma, Alexis Ioannidis, Clinic of Fixed and Removable Prosthodontics and Dental Material Science, University of Zurich, Zurich, Switzerland
Irena Sailer, Nikolay Makarov, Bjarni E. Pjetursson, Division of Fixed Prosthodontics and Biomaterials, University Clinics for Dental Medicine, University of Geneva, Geneva, Switzerland
Marcel Zwahlen, Institute of Social and Preventive Medicine, University of Bern, Bern, Switzerland
Nikolay Makarov, Private Practice, Moscow, Russia
Bjarni E. Pjetursson, Division of Reconstructive Dentistry, Faculty of Odontology, University of Iceland, Reykjavik, Iceland

Corresponding author:
Prof. Dr. med. dent. *Bjarni E. Pjetursson*, DDS, MAS Perio, PhD.
Department of Reconstructive Dentistry
Faculty of Odontology
University of Iceland
Vatnsmyrarvegi 16
101 Reykjavik, Iceland
Tel.: +354 525 4871
Fax: +354 525 48 74
e-mail: bep@hi.is

Key words: biological complications, complication rates, de-bonding, failures, fiber-reinforced composite, fixed dental prostheses, longitudinal, Resin-bonded bridges, success, survival, systematic review, technical complications

Abstract

Objectives: The objective of this systematic review was to assess the 5-year and 10-year survival of resin-bonded fixed dental prostheses (RBBs) and to describe the incidence of technical and biological complications.

Materials and Methods: An electronic MEDLINE search complemented by manual searching was conducted to identify prospective and retrospective cohort studies and case series on RBBs with a mean follow-up time of at least 5 years. Patients had to have been examined clinically at the follow-up visit. Assessment of the identified studies and data extraction were performed independently by two reviewers. Failure and complication rates were analyzed using robust *Poisson* regression models to obtain summary estimates of 5- and 10-year proportions.

Results: The search provided 367 titles and 87 abstracts. Full-text analysis was performed for 22 articles resulting in seven studies that met the inclusion criteria. Five articles were found through manual search, and 17 studies were provided from (Pjetursson et al. 2008, *Clinical Oral Implants Research,* **19**, 131), resulting in an overall number of included studies of 29. Meta-analysis of these studies reporting on 2300 RBBs indicated an estimated survival of resin-bonded bridges of 91.4% (95 percent confidence interval [95% CI]: 86.7–94.4%) after 5 years and 82.9% (95% CI: 73.2–89.3%) after 10 years. A significantly higher survival rate was reported for RBBs with zirconia framework compared with RBBs from other materials. RBBs with one retainer had a significantly higher survival rate ($P < 0.0001$) and a lower de-bonding rate ($P = 0.001$) compared with RBBs retained by two or more retainers. Moreover, the survival rate was higher for RBBs inserted in the anterior area of the oral cavity compared with posterior RBBs. The most frequent complications were de-bonding (loss of retention), which occurred in 15% (95% CI: 10.9–20.6%) and chipping of the veneering material that was reported for 4.1% (95% CI: 1.8–9.5%) of the RBBs over an observation period of 5 years.

Conclusion: Despite the high survival rate of RBBs after 5 and 10 years, technical complications like de-bonding and minor chipping were frequent. RBBs with zirconia framework and RBBs with one retainer tooth showed the highest survival rate.

Date:
Accepted 30 December 2016

To cite this article:
Thoma DS, Sailer I, Ioannidis A, Zwahlen M, Makarov N, Pjetursson BE. A systematic review of the survival and complication rates of resin-bonded fixed dental prostheses after a mean observation period of at least 5 years.
Clin. Oral Impl. Res. **00**, 2017, 1–10
doi: 10.1111/clr.13007

The recognized replacement of single missing teeth presents one of the greatest challenges in reconstructive dentistry, predominantly in the esthetic zone. Various therapeutic options exist to replace single missing teeth using fixed tooth- or implant-borne reconstructions. This includes the use of traditional fixed dental prostheses (FDPs), implant-supported single crowns (SCI), and resin-bonded FDPs (RBB). To provide a basis for prosthetic treatment planning, systematic reviews were performed summarizing the existing dental literature on clinical studies with a medium- and long-term follow-up (Jung et al. 2012; Pjetursson et al. 2015, 2008). Obtained data for metal–ceramic FDPs demonstrated 5-year survival rates of 94.4% (95% confidence interval [CI]: 91.2–96.5%), for SCIs of 96.3% (95% CI: 94.2–97.6%) and for RBB of 87.7% (95% CI: 81.6–91.9%).

Apart from survival rates, patients and clinicians need to be aware of the frequency and type of complications occurring during the maintenance phase following the insertion of a reconstruction. Technical, biological, and esthetic complication rates for FDPs, SCIs, and RBBs range between 1.5 and 12.9 during a 5-year observation period (Jung et al. 2012; Pjetursson et al. 2015, 2008). These outcomes, however, do not take into account the entire extent of the treatment, which further includes the overall status of the dentition, occlusion, age, treatment time, invasiveness, and the cost-effectiveness (Antonarakis et al. 2014). Disadvantages associated with SCI predominantly include a relatively long treatment time and at least one surgical procedure and relatively high initial costs. In contrast, FDPs do usually not require any surgical procedure, shorter treatment time, and lower initial costs, but require neighboring teeth to be prepared for full crowns. Neither one, SCI nor FDP, have a reported superior cost-effectiveness over time (Beikler & Flemmig 2015). From a patient's perspective, alternative treatment options, mainly in a caries-free dentition, are requested. This should include a minimal-invasive therapeutic approach with lower costs and a shorter treatment time. RBBs have long been considered as mid-term provisional reconstructions with approximately 2 years of service (Howe & Denehy 1977; Rochette 1973). Moreover, RBBs were predominantly used in the anterior area and only later expanded to posterior regions (Livaditis 1980). Clinical data, however, indicated that this type of reconstruction does indeed offer high long-term survival rates (Sailer et al. 2013; Saker et al. 2014; Sasse & Kern 2013). Apart from these, minimal-invasiveness, lower costs, and treatment time offer further advantages over traditional FDPs and SCIs. Moreover, newer development in terms of materials (ceramics) and the use of single-retainer RBB offer further benefits and demonstrate promising clinical long-term results (Sasse & Kern 2013). Data from available studies have, however, not been combined in the past years using a systematic approach. To provide the dental community with the most recent evidence-based clinical data, the present systematic review was performed as an update of a previously published systematic review (Pjetursson et al. 2008).

The objectives of the present systematic review were to obtain the long-term survival rate of RBBs and to evaluate the incidence of technical, biological, and esthetic complications over a mean observation period of at least 5 years.

Materials and methods

Focused questions

"What are the survival and complication rates of RBBs after a mean observation period of 5 years?" "What is the influence of the framework material, the location (maxilla, mandible, anterior, posterior), and the number of retainers on the survival and complications rates of RBBs after a mean observation period of 5 years?"

Search strategy and study selection

This systematic review was designed as an update to a previous publication with the same objectives (Pjetursson et al. 2008). A MEDLINE (PubMed) search was performed for clinical studies, including articles published from February 1, 2007 up to October 28, 2015 in the Dental literature. The search was limited to the English and German languages. In addition, full-text articles of reviews on the same topic published between February 2007 and October 2015 were obtained and screened for relevant articles (reference list "list of reviews"). This was complimented by a hand search of the reference list of all included full-text publications.

The following search was applied:

((Denture, Partial, Fixed, Resin-Bonded [Mesh]) OR (RBB[all fields] OR fixed partial denture*[all fields] OR FPD[all fields] OR FPDs[all fields] OR fixed dental prosthesis[all fields] OR FDPs [all fields] OR FDP[all fields] OR FDPs[all fields] OR bridge*[all fields] OR adhesive bridge*[all fields] OR Maryland bridge*[all fields])) AND (Survival[Mesh] OR survival rate[Mesh] OR survival analysis [Mesh] OR dental restoration failure[Mesh] OR prosthesis failure[Mesh] OR treatment failure[Mesh]).

Inclusion criteria

This systematic review was based on specific inclusion criteria:

- Human trials
- Mean follow-up of 5 years or more
- Prospective and retrospective cohort studies and case series
- Published in dental journals
- Patient needed to be examined clinically at the follow-up visit
- Reported details of suprastructure
- Included at least 10 patients
- Language: English; German

Exclusion criteria

Studies not meeting all inclusion criteria were excluded from the review. Moreover, publications were excluded if they were based on patient records (i.e., questionnaires, interviews). Studies were also excluded if extensive tooth preparations were performed (e.g., inlay-retained FDPs).

Selection of studies

Two authors (DTH, AIO) independently screened the titles and abstracts derived from this broad search for possible inclusion in the review. Disagreements were resolved by discussion. If no abstract was available in the database, the abstract of the printed article was used. Based on the selection of abstracts, articles were then obtained in full text. If title and abstract did not provide sufficient information regarding the inclusion criteria, the full report was obtained as well. Again, disagreements were resolved by discussion and Cohen's Kappa coefficient was calculated as a measure of agreement between the two readers. The final selection based on inclusion/exclusion criteria was made for the full-text articles. For that purpose, Materials and Methods, Results and Discussion of these studies were screened. This step was carried out again by two readers (DTH, AIO) and double-checked. Any questions that came up during the screening were discussed within the group to aim for consensus. In addition, all 17 studies from the previous systematic review (Pjetursson et al. 2008) were included in the analyses.

Data extraction and method of analysis

Four reviewers (DTH, AIO, ISA, and BEP) independently screened the full-text articles. Any disagreements were discussed to aim for consensus and to standardize the subsequent analyses. The four reviewers then independently extracted the data of all included studies using data extraction tables. In addition, data of the included publications of the previously published review (Pjetursson et al. 2008) were extracted as well. All extracted data were double-checked, and any questions that came up during the screening and the data extraction were discussed within the group to aim for consensus.

Of the 29 studies included, information on the survival of the reconstructions and on biological and technical complications was retrieved. RBB survival was defined as the RBB remaining in situ with or without modification for the entire observation period. Failure was defined as the RBBs that were lost and required re-fabrication, or multiple re-cementations representing reconstructions that had been re-cemented more than once. Biological complications included caries on abutment teeth and periodontal disease progression. Technical complications analyzed included the loss of retention, with or without loss of the reconstruction, and fractures of the veneering ceramic, with or without loss of the reconstruction. From the studies included, the number of events for all these categories was extracted and the corresponding total exposure time of the reconstruction was calculated.

Statistical analysis

Failure and complication rates were calculated by dividing the number of events (failures or complications) in the numerator by the total exposure time (RBB time or abutment time) in the denominator. The numerator could usually be extracted directly from the publication. Not reported was never interpreted as not occurring. Hence, no failures or complications had to be clearly stated by the authors. In these cases, the studies were not included in the meta-analysis for this specific outcome. The total exposure time was calculated by taking the sum of:

- Exposure time of RBBs/abutments that could be followed for the whole observation time.
- Exposure time up to a failure of the RBBs/abutments that were lost due to failure during the observation time.
- Exposure time up to the end of observation time for RBBs/abutments that did not complete the observation period due to reasons such as death of the patient, change of address, refusal to participate, non-response, chronic illnesses, missed appointments, and work commitments.

For each study, event rates for RBBs and/or abutments were calculated by dividing the total number of events by the total RBBs or abutments' exposure time in years. For further analysis, the total number of events was considered to be Poisson-distributed for a given sum of RBBs exposure years, and Poisson regression with a logarithmic link function and total exposure time per study as an offset variable was used (Kirkwood & Sterne 2003a).

Robust standard errors were calculated to obtain 95% CIs of the summary estimates of the event rates. To assess the heterogeneity of the study-specific event rates, the Spearman goodness-of-fit statistics and associated *P*-value were calculated. Five- and 10-year survival proportions were calculated via the relationship between event rate and survival function S, $S(T) = \exp(-T \times \text{event rate})$, by assuming constant event rates (Kirkwood & Sterne 2003b). The 95% CIs for the survival proportions were calculated using the 95% confidence limits of the event rates.

Multivariable Poisson regression was used to investigate formally whether event rates varied by material utilized, number of retainers (one vs. multiple), position of the reconstruction (maxilla vs. mandible or anterior vs. posterior), and study design (prospective vs. retrospective). For the present systematic review, the literature review and evidence synthesis was conducted following the PRISMA guidelines from 2009 with the exception of a formal quality assessment of the included studies as all the included studies were case series for which no appropriate tools have been developed, and the main issue is completeness of follow-up. All analyses were performed using STATA, version 12.1 (Stata Corp., College Station, TX, USA).

Results

Included studies

A total of 29 studies on RBBs were included in the analysis (Fig. 1). Seventeen of the included studies originated from the previous systematic review (Pjetursson et al. 2008) with the same clinical question. The remaining 12 studies were identified by the present literature search. The characteristics of the selected studies are shown in Table 1. These studies reported on 27 different patient cohorts. The oldest study was published in 1990, and the median year of publication was 2003. Fifteen of the studies were prospective, 13 were retrospective studies, and one multicenter study was described as a mixture of a pro- and retrospective design (van Heumen et al. 2009). The studies included more than 2366 patients aging between 13 and 87 years. The proportion of patients with RBBs who were lost to follow-up during the study period was available for 22 of the 29 studies and ranged from 0% to 63%, with an average dropout rate of 16%. The studies were conducted under different environmental settings: 22 university settings, 2 private practices, and 4 specialists' clinics. Twenty-six studies reported on anterior, and 21 on posterior RBBs. Four of the studies (Creugers & Kayser 1992; Creugers et al. 1990; Kern 2005; Kern & Sasse 2011) were classified as multiple publications on the same patient cohort. The two incidences older studies (Creugers et al. 1990; Kern 2005) were

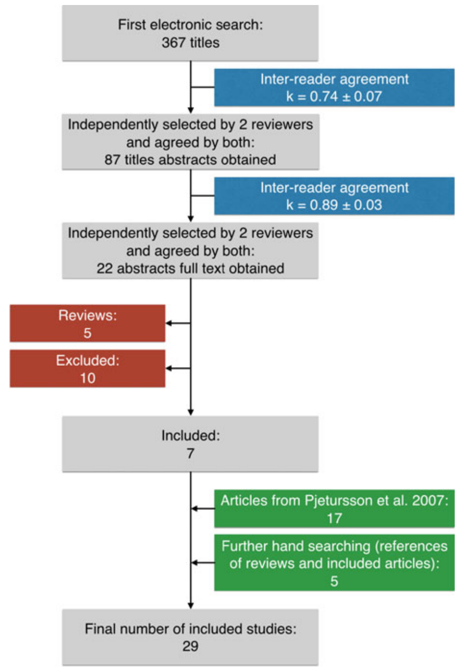

Fig. 1. Search strategy.

included because they gave additional information on technical complications that were not included in the more recent studies on the same patient cohort. Those studies, however, were not included in the survival analysis.

The preparation designs ranged from very conservative preparations or no preparation to extensive preparations with grooves, guide planes, and wrap-around design to improve the prostheses' mechanical retention. The materials used for the fabrication of the RBBs consisted of veneered (ceramic or resin) and non-veneered metal and all-ceramic (veneered densely sintered zirconia or glass-reinforced ceramic) frameworks or composite frameworks veneered with composite. Different surface treatments to the bonding area of the RBBs were performed prior to cementation with various resin cements. All descriptive data are presented in Table 1.

Survival

Twenty-three of the 29 included studies reported on the survival of the reconstructions (Table 2). Meta-analysis revealed that of the originally 2300 RBBs placed, 251 RBBs were known to be totally lost or had debonded more than once. In the meta-analysis, the annual failure rate was estimated at 1.8 (95% CI: 1.30–2.56%; Fig. 2), translating into a 5-year overall survival rate for RBBs of 91.3% (95% CI: 88–93.7%; Table 2). The included studies were also divided according to the mean observation time. A group of 18 studies reported on 1755 RBBs with a follow-

Table 1. **Study and patient characteristics and manufacturing procedures of the reviewed studies for resin-bonded bridges (RBBs)**

Study	Year of publication	Study design	No. of patients	Age range	Mean age	Setting	Drop out	Location	Material	Preparation in detail	Surface treatment	Cementation
Kumbuloglu & Özcan	2015	Prospective	134	16–68	42	University	0%	Anterior	Composite	No preparation	Resin monomer corresponding to cement	Rely X ARC Bifix DC Variolink II Multilink
Sailer & Hämmerle	2014	Retrospective	15	13–75	27.5	University	0%	Anterior	Densely sintered zirconia, veneered with ceramic	Vertical grooves, centric stop	Silanated	Panavia 21
Botehlho et al.	2014	Retrospective	153	23–83	55.4	University	n.r.	Anterior posterior	Metal, veneered with ceramic	A: axial preparation, occlusal clearance P: axial preparation, occlusal clearance	Air-abrasion	Panavia EX Panavia 21
Sasse & Kern	2014	Prospective	37	n.r.	32.7	University	0%	Anterior	Densely sintered zirconia, veneered with ceramic	Oral veneer with a notch & a proximal box	Air-abrasion	Panavia 21
Spinas et al.	2013	Prospective	30	13–17	n.r.	University	0%	Anterior	Composite	n.r.	n.r.	Permamix Smartix Dual
Sasse & Kern	2013	Prospective	27	n.r.	33.3	University	7%	Anterior	Densely sintered zirconia, veneered with ceramic	Oral veneer, groove & proximal box	Air-abrasion	Panavia 21 Multilink Automix
Younes et al.	2013	Retrospective	37	15–64	32.2	University	32%	Anterior posterior	Metal, veneered with ceramic	A: occlusal plane, approximal grooves, vertical rest P: guiding plane, occlusal rest, approximal grooves	Silicoating	Panavia Panavia EX
Sailer et al.	2013	Retrospective	40	10–61	n.r.	Private practice	30%	Anterior posterior	Glass reinforced ceramic, veneered with ceramic	A: no preparation P: minimal inlay preparation	Etching silanisation	Tetric Flow Tetric Ceram Rely X Panavia F HFO Variolink
Boening et al.	2012	Retrospective	44	14–68	22	University	21%	Anterior posterior	Metal, veneered with ceramic	A: horizontal groove P: occlusal rest	Air-abrasion	Panavia EX Panavia 21
Kern & Sasse	2011	Prospective	30	n.r.	n.r.	University	0%	Anterior	Glass infiltrated ceramic, veneered with ceramic	Oral veneer, a groove on the cingulum and a small proximal box	Silicoating silanisation	Panavia TC
van Heumen et al.	2009	Prospective, retrospective (multicenter)	13–64	13–64	35	University	22%	Posterior	Composite	Various techniques (inlay or minimal preparation)	Air-abrasion	Compolute Variolink Twinlook Panavia F
Agstaller et al.	2008	Prospective	184	17–87	49	University	63%	Anterior posterior	Metal, veneered with ceramic	A: nearly prallel opposing walls with a flat cingulum rest, at least one proximal seating groove P: nearly parallel opposing walls with flat occlusal rests, box-shaped lungually and proximally retentive supports	Electrochemically etching silicoating silanisation	Microfill Pontic
Garnett et al.	2006	Retrospective	45	13–44	17.6	University	47%	Anterior	Metal, veneered with ceramic	Various techniques	Air-abrasion	Panavia EX Panavia 21
Kern	2005	Prospective	30	n.r.	n.r.	University	0%	Anterior	Glass infiltrated ceramic	Oral veneer, groove	Silicoating silanisation	Panavia TC
Zalkind et al.	2003	Retrospective	51	15–55	n.r.	Specialist	0%	Anterior posterior	Metal, veneered with ceramic	A: oral veneer, vertical grooves, interproximal guiding planes P: wrap-around design with occlusal rests	Air-abrasion	Panavia

Table 1. *(continued)*

Study	Year of publication	Study design	No. of patients	Age range	Mean age	Setting	Drop out	Location	Material	Preparation in detail	Surface treatment	Cementation
Hikage et al.	2003	Prospective	24	n.r.	n.r.	University	n.r.	Posterior	Metal	Deep occlusal rests & inlays	Oxidation air-abrasion	Superbond C&B
Corrente et al.	2000	Retrospective	67	32–58	42.1	n.r.	n.r.	Anterior posterior	Metal, veneered with ceramic OR Metal veneered with resin	Extended guide planes	Electroetching	Panavia EX
de Kanter et al.	1998	Prospective	175	16–72	39	University	n.r.	Posterior	Metal, veneered with ceramic	Approximal grooves, guide planes & occlusal stops	Electroetching air-abrasion silicoating	Clearfil FII Panavia EX Microfill Pontic C
Pröbster & Henrich	1997	Prospective	264	n.r.	29	University	17%	Anterior posterior	Metal, veneered with ceramic	Various techniques	Silicoating air-abrasion etched	Concise Microfill Pontic Comspan
Hansson & Bergström	1996	Retrospective	32	18–70	34.4	University	9%	Anterior posterior	Metal, veneered with ceramic	Wrap-around design with vertical grooves	Air-abrasion	Compspan Opaque
Bergbreiter et al.	1996	Prospective	32	n.r.	n.r.	University	48%	Anterior posterior	Metal, veneered with ceramic	Grooves & rests	Silicoating silanisation	Microfill Pontic
Samama	1996	Retrospective	121	n.r.	n.r.	Private practice	n.r.	Anterior posterior	Metal, veneered with ceramic	n.r.	Electroetching	Superbond
de Rijk et al.	1996	Retrospective	146	n.r.	n.r.	University	5%	Anterior posterior	n.r.	Various techniques	n.r.	n.r.
Priest	1995	Prospective	83	n.r.	n.r.	Specialist	20%	Anterior posterior	Metal, veneered with ceramic	Wrap-around design with guide planes & rests	Perforation electroetching chemically etched	Various
Hosseini	1994	Retrospective	90	20–59	37.3	Specialist	n.r.	Anterior posterior	Metal, veneered with ceramic	Extended guide planes	Perforation	n.r.
Barrack & Bretz	1993	Prospective	109	14–69	45	Specialist	22%	Anterior posterior	Metal, veneered with ceramic	Wrap-around design with grooves & rests	Electroetching air-abrasion	Conclude Compspan Panavia EX Panavia Opaque
Thayer et al.	1993	Retrospective	n.r.	n.r.	n.r.	University	n.r.	Anterior posterior	Metal, veneered with ceramic	n.r.	Perforation etched	Various
Creugers & Käyser	1992	Prospective	183	13–78	30	University	8%	Anterior posterior	Metal, veneered with resin	Various techniques	Perforation electroetching	Clearfil F Silar Conclude Panavia EX
Creugers et al.	1990	Prospective	183	13–78	30	University	0%	Anterior posterior	Metal, veneered with ceramic	Various techniques	Perforation electroetching	Clearfil F Silar Conclude Panavia EX

n.r., not reported; n.a., not analyzed.

Table 2. **Annual failure rates and survival of resin bonded bridges**

Study	Year of publication	Total no. of RBBs	Mean follow-up time	No. of failure	Total RBB exposure time	Estimated failure rate (per 100 RBB years)	Estimated survival rate (in percent)
5-years follow-up							
Kumbuloglu & Özcan	2015	175	5	1	875	0.11	99.4
Sailer & Hämmerle	2014	12	5.1	0	61	0	100
Sasse & Kern	2014	42	5.2	0	216	0	100
Spinas et al.	2013	32	5	0	160	0	100
Sasse & Kern	2013	14	5.4	0	75	0	100
Sailer et al.	2013	49	6	2	210	0.95	95.3
Boening et al.	2012	56	6.3	4	355	1.13	94.5
van Heumen et al.	2009	60	5	19	300	6.33	72.9
Agstaller et al.	2008	232	6.3	7	529	1.32	93.6
Corrente et al.	2000	61	6.1	1	422	0.24	98.8
de Kanter et al.	1998	201	5	42	1005	4.18	81.1
Pröbster & Henrich	1997	325	5	29	1625	1.78	91.5
Hansson & Bergström	1996	34	6.1	6	207	2.90	86.5
Bergbreiter et al.	1996	74	6.5	8	481	1.66	92.0
Samama	1996	145	5.8	4	835	0.48	97.6
Priest	1995	31	5.3	15	164	9.15	63.3
Barrack & Bretz	1993	127	5.8	9	737	1.22	94.1
Thayer et al.	1993	85	7.3	13	621	2.09	90.1
Total		**1755**	**5.1**	**160**	**8878**		
Summary estimate (95% CI) *						1.80 (1.13–2.87)	91.4 (86.7–94.4)
10-years follow-up							
Botehlho et al.	2014	211	9.4	21	1990	1.06	90.0
Younes et al.	2013	42	13	10	546	1.83	83.3
Kern & Sasse	2011	38	9.6	5	364	1.37	87.2
Zalkind et al.	2003	51	9.1	20	464	4.31	65.0
Creugers & Käyser	1992	203	7.5	35	1488	2.35	79.0
Total		**545**	**8.9**	**91**	**4852**		
Summary estimate (95% CI) *						**1.88 (1.13–3.12)**	**82.9 (73.2–89.3)**
Overall total		**2300**	**6.0**	**251**	**13730**		
Overall summary estimate (95% CI) *						**1.83 (1.30–2.56)**	**91.3 (88.0–93.7)**

*Based on robust Poisson regression.

up ranging from 5 to 7.3 years (mean 5.1 years), and a group of five studies reported on 545 RBBs with a follow-up time exceeding 7.4 years (mean 8.9 years). An annual failure rate of 1.80 (95% CI: 1.13–2.87%) and 1.88 (95% CI: 1.13–3.12%) was estimated for the former and the latter group, respectively. The difference did not reach statistical significance ($P = 0.905$). Hence, the failure rate of RBBs seems to be relatively linear over the first 10 years. Based on the group with the shorter follow-up time, the estimated 5-year survival rate was 91.4% (95% CI: 86.7–94.4%) and from the group with the longer follow-up time, the 10-year survival rate was estimated to be 82.9% (95% CI: 73.2–89.3%; Table 2). The reported survival was also analyzed according to study design. Twelve of the included studies that reported on survival rates were prospective cohort or case series, one study had a retro- and prospective design, and the remaining ten studies that reported on survival rates were retrospective case series. The 5-year survival rate of the prospective studies was 91.4% (95% CI: 86.8–94.5%) compared to a 5-year survival rate of 92.2% (95% CI: 87.2–95.3%) in the retrospective studies. The difference between the groups did not reach statistical significance ($P = 0.779$).

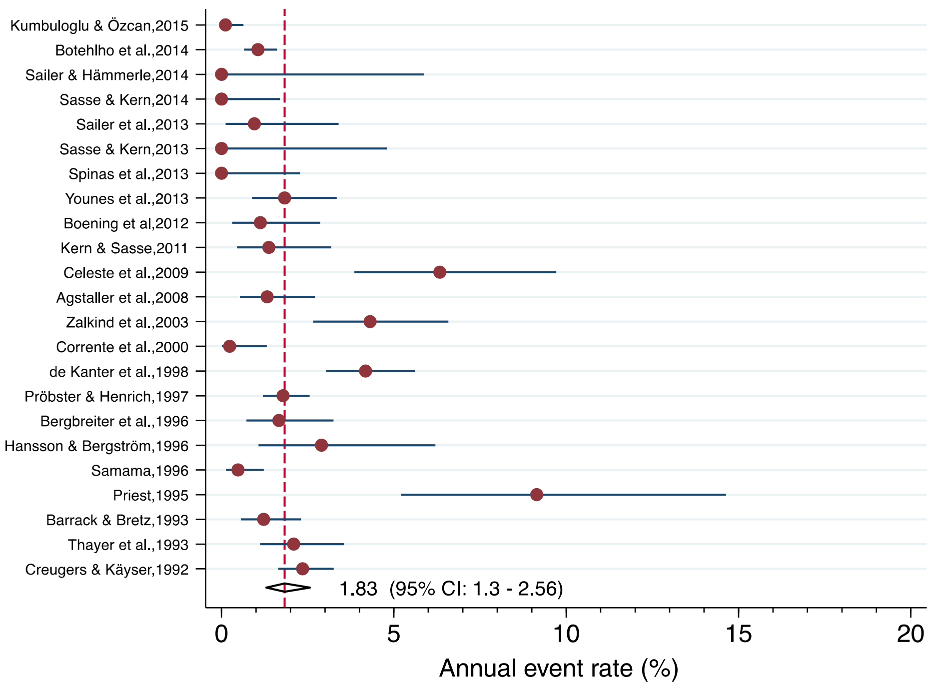

Fig. 2. Annual failure rates (per 100 years) of RBBs.

The studies were also divided according to the material utilized (Table 3). For metal–ceramic RBBs, eight studies provided data on 977 RBBs resulting in an estimated 5-year

Table 3. **Annual failure rates and survival of RBBs divided according to material utilized**

Study	Year of publication	Total no. of RBBs	Mean follow-up time	No. of failure	Total RBBs exposure time	Estimated annual failure rate* (per 100 RBB years)	Estimated survival after 5 years* (in percent)
Metal ceramic							
Botehlho et al.	2014	211	9.4	21	1990	1.06	94.9
Younes et al.	2013	42	13	10	546	1.83	91.2
Boening et al	2012	56	6.3	4	355	1.13	94.5
Agstaller et al.	2008	232	6.3	7	529	1.32	93.6
de Kanter et al.	1998	201	5	42	1005	4.18	81.1
Hansson & Bergström	1996	34	6.1	6	207	2.90	86.5
Bergbreiter et al.	1996	74	6.5	8	481	1.66	92.0
Barrack & Bretz	1993	127	5.8	9	737	1.22	94.1
Total		**977**	**6.0**	**107**	**5850**		
Summary estimate (95% CI) *						**1.83 (1.04–3.22)**	**91.3 (85.1–94.9)**
Metal resin							
Creugers & Käyser	1992	203	7.5	35	1488	2.35	88.9
Total		**203**	**7.5**	**35**	**1488**		
Summary estimate (95% CI) *						**2.35 (1.64–3.26)**	**88.9 (85.0–92.1)**
Glass infiltrated ceramic							
Kern & Sasse	2011	38	9.6	5	364	1.37	93.4
Total		**38**	**9.6**	**5**	**364**		
Summary estimate (95% CI) *						**1.37 (0.45–3.18)**	**93.4 (85.3–97.8)**
Glass reinforced ceramic							
Sailer et al.	2013	49	6	2	210	0.95	95.3
Total		**49**	**6**	**2**	**210**		
Summary estimate (95% CI) *						**0.95 (0.12–3.40)**	**95.3 (84.4–99.4)**
Densely sintered zirconia							
Sailer & Hämmerle	2014	12	5.1	0	61	0	100
Sasse & Kern	2014	42	5.2	0	216	0	100
Sasse & Kern	2013	14	5.4	0	75	0	100
Total		**68**	**5.2**	**0**	**352**		
Summary estimate (95% CI) *						**0 (0–1.04)**	**100 (94.5–100)**
Composite							
Kumbuloglu & Özcan	2015	175	5	1	875	0.11	99.4
van Heumen et al.	2009	60	5	19	300	6.33	72.9
Spinas et al.	2013	32	5	0	160	0	100
Total		**267**	**5**	**20**	**1335**		
Summary estimate (95% CI) *						**1.50 (0.15–14.7)**	**92.8 (47.9–99.2)**
Overall results		**1602**	**6.0**	**169**	**9599**		

*Based on robust Poisson regression.

survival rate of 91.3% (95% CI: 85.1–94.9%). One study with 203 reconstructions reported an estimated 5-year survival rate of 88.9% (95% CI: 85.0–92.1%) for metal–resin RBBs. One study reporting on 38 RBBs with glass-infiltrated ceramic as framework material and another study reporting on 49 RBBs with reinforced glass ceramic framework were analyzed. The estimated 5-year survival rate in these studies was 93.4% (95% CI: 85.3–97.8%) and 95.3% (95% CI: 84.4–99.4%), respectively. Three studies with 68 RBBs with zirconia as framework material estimated a 5-year survival rate of 100% (95% CI: 94.5–100%), and three studies reporting on 267 RBBs with fiber-reinforced composite as framework material estimated the 5-year survival rate to be 92.8% (95% CI: 47.9–99.2%). For fiber-reinforced composite RBBs, the results from the three included studies varied significantly. Two of the studies reported a 5-year survival rate of 99.4% and 100%, respectively. The third study, however, reported a 5-year survival rate of only 72.9% (Table 3). The analysis by type of material showed that RBBs with zirconia frameworks had a significantly ($P < 0.0001$) higher 5-year survival than metal–ceramic RBBs. The difference between metal–ceramic RBBs and other material groups did not reach statistical significance. The survival rate of RBBs was also analyzed by the number of retainers utilized. A group of 350 RBBs with one retainer was compared with a group of 1376 RBBs with two or more retainers using multivariable *Poisson* regression. The one-retainer group had significantly ($P < 0.0001$) lower annual failure rate of 0.87 (95% CI: 0.59–1.28%) compared with an annual failure rate of 2.17 (95% CI: 1.44–3.27%) for the two-retainer group. Moreover, the survival rate of RBBs was analyzed regarding the RBB location in the oral cavity. The position of the pontic (missing tooth) was used for the classification. The annual failure rate of RBBs inserted in the anterior area was 1.20 (95% CI: 0.39–3.69%) compared with an annual failure rate of 3.65 (95% CI: 2.72–4.89%) for RBBs placed in the posterior part of the mouth, this difference was at the margin of statistical significance ($P = 0.056$). The annual failure rate of RBBs placed in the maxilla was 1.03 (95% CI: 0.55–1.96%) compared with a failure rate of 2.71 (95% CI: 0.92–7.97%) for RBBs placed in the mandible. This difference, however, did not reach statistical significance ($P = 0.119$; Table 4).

Biological complications

Dental caries

Eleven studies with a total of 2030 abutment teeth reported on the incidence of caries on the abutment level. In robust Poisson model analysis, the overall annual complication rate was 0.34 (95% CI: 0.14–0.82%) translating into a 5-year complication rate of 1.7% (95% CI: 0.7–4.0%; Table 5).

Loss of vitality of abutment teeth

Two studies (Kumbuloglu & Ozcan 2015; Sailer et al. 2013) reported that none of the

***Table 4.* Annual failure and de-bonding rates and estimated 5-year survival and complications rates of RBBs according to position in the mouth and number of retainers**

	Total number of RBBs	Estimated annual rate	5-year summary estimate (95% CI)	Total number of RBBs	Estimated annual rate	5-year summary estimate (95% CI)	*P*-value**
		Maxilla			**Mandible**		
Survival	399	1.03* (0.55–1.96)	95.0%* (90.7–97.3)	243	2.71* (0.92–7.97)	87.3%* (67.1–95.5)	0.119
Debonding	795	2.64* (1.57–4.43)	12.4%* (7.6–19.9)	763	4.01* (2.38–6.74)	18.2%* (11.2–28.6)	0.255
		Anterior			**Posterior**		
Survival	479	1.20* (0.39–3.69)	94.2%* (83.1–98.1)	242	3.65* (2.72–4.89)	83.3%* (78.3–87.3)	0.056
Debonding	1227	2.37* (1.50–3.77)	11.2%* (7.2–17.2)	602	4.94* (2.58–9.40)	21.8%* (12.1–37.5)	0.056
		1-retainer			**2-retainers**		
Survival	350	0.87* (0.59–1.28)	95.7%* (93.8–97.1)	1376	2.17* (1.44–3.27)	89.7%* (84.9–93.1)	<0.0001
Debonding	383	1.47* (0.95–2.29)	7.1%* (4.6–10.8)	1433	4.17* (2.73–6.36)	18.8%* (12.8–27.2)	0.001

*Based on robust Poisson regression.

abutment teeth lost vitality during the observation period. However, as the studies did not report the number of vital abutment teeth at the beginning of the study, hence, statistical analysis was not possible.

Recurrent periodontitis

The incidence of RBBs lost due to recurrent periodontal disease was reported in 15 studies evaluating 1156 FDPs, of which 12 were lost. In robust Poisson model analysis, the overall annual complication rate was 0.17 (95% CI: 0.08–0.36%), translating into a 5-year complication rate of 0.8% (95% CI: 0.4–1.8%; Table 5).

Abutment tooth fracture

Eighteen studies reported on the incidence of RBBs lost due to abutment tooth fractures, evaluating 1518 RBBs of which three were lost. In robust Poisson model analysis, the overall annual complication rate was 0.03 (95% CI: 0.01–0.10%), translating into a 5-year failure rate of 0.2% (95% CI: 0.05–0.5%; Table 5).

Technical complications

De-bonding (Loss of retention)

De-bonding was the most frequent technical complication of RBBs. It was addressed in all included studies, and affected 519 of the 2619 RBBs. The annual RBB complication rate ranged between 0 and 12.8. In robust Poisson model analysis, the estimated annual rate was 3.3 (95% CI: 2.3–4.6%), translating into a 5-year complication rate of 15% (95% CI: 10.9–20.6%; Table 5). The included studies were also divided according to the mean observation time. A group of 21 studies reported on 1910 RBBs with a follow-up ranging from 5 to 7.4 years (mean 5.1 years), and a group of six studies reported on 709 RBBs with a follow-up time exceeding 7.4 years (mean 8.8 years). An annual failure rate of 3.48 (95% CI: 2.20–5.51%) and 2.92 (95% CI: 1.81–4.73%) was estimated for the former and the latter group, respectively. The difference did not reach statistical significance ($P = 0.594$). Hence, the de-bonding rate seems to be relatively linear over the first 10 years.

The incidence of de-bonding was significantly dependent of the framework material utilized. For metal–ceramic RBBs, the annual de-bonding rate was 2.89 (95% CI: 1.24–6.71%), for metal–acrylic it was 4.17 (95% CI: 3.21–5.31%), for fiber-reinforced composite RBBs it was 1.72 (95% CI: 0.47–6.30%), and for zirconia framework RBBs it was 1.42 (95% CI: 0.67–3.00%). However, for RBBs with glass-infiltrated and glass-reinforced ceramic frameworks no de-bonding occurred. Investigating formally the relative de-bonding rates of different material types of RBBs, using metal–ceramic RBBs as reference, RBBs with glass-infiltrated and glass-reinforced ceramic frameworks showed significantly ($P < 0.0001$) lower de-bonding rates. The difference between the de-bonding rates of metal–ceramic RBBs and other material groups did not reach statistical significance.

The incidence of de-bonding was also analyzed according to the jaw position: A group of 14 studies with a total of 795 RBBs reported on the outcomes in the maxilla, and a group of 12 studies with a total of 763 RBBs reported on the outcomes in the mandible. For the group of RBBs placed in maxilla, the annual de-bonding rate was estimated at 2.64 (95% CI: 1.57–4.43%), translating into a 5-year rate of de-bonding of 12.4% (95% CI: 7.6–19.9%). Similar results were obtained for the group of RBBs placed in the mandible. The annual de-bonding rate in the mandible was estimated at 4.01 (95% CI: 2.38–6.74%), resulting in a 5-year rate of de-bonding of 18.2% (95% CI: 11.2–28.6%). The difference between maxilla and mandible did not reach statistical significance ($P = 0.255$; Table 4).

The studies were also divided according to the position in the mouth. A group of 18 studies with a total of 1227 RBBs inserted on anterior teeth, and a group of 11 studies with a total of 602 RBBs inserted on posterior teeth. The group with posterior RBBs demonstrated a higher (21.8% (95% CI: 12.1–37.5%)) 5-year rate of de-bonding compared to the de-bonding rate of 11.2% (95% CI: 7.2–17.2%) for the anterior RBBs. This difference also did not reach statistical significance ($P = 0.\ 065$; Table 4).

Material complications: framework and veneer fractures

The incidence of RBBs lost due to material fractures was reported in 16 studies evaluating 1345 FDPs, of which 27 were lost. In robust Poisson model analysis, the overall annual failure rate was 0.34 (95% CI: 0.13–0.90%), translating into a 5-year complication rate of 1.7% (95% CI: 0.6–4.4%; Table 5).

Material fractures that might cause the loss of the entire reconstruction are severe fractures of the veneering material or fractures of the RBBs framework. The incidence of RBBs lost due to material fractures was material dependent. None of the RBBs made of metal–ceramic, zirconia, and reinforced glass ceramic was lost due to material fractures. Studies on RBBs made of metal–resin, glass-infiltrated ceramic, and fiber-reinforced composite, however, reported that significantly ($P < 0.0001$) more RBBs were lost due to material fractures.

Fourteen studies evaluating 1344 RBBs reported on the rate of minor veneer fractures (ceramic, acrylic, or composite chipping) that could be repaired without losing the reconstruction. In these studies, of the 1344 RBBs placed, 64 fractured.

For chipping, the annual complication rate was estimated at 0.84 (95% CI: 0.36–2.00%) translating into a 5-year complication rate of 4.1% (95% CI: 1.8–9.5%; Table 5). The chipping rates were also dependent on the material used. The lowest annual chipping rate of zero was reported material for zirconia RBBs, for metal–ceramic RBBs it was 0.29, for reinforced glass ceramic RBBs it was 0.95, for

Table 5. **Biological and technical complications**

Study	Year of publication	Total no. of abut-ments	Estimated rate of caries on abutments (per 100 abutment years)	Total no. of RBBs	Estimated rate of RBBs lost due to periodontitis (per 100 RBB years)	Estimated rate of RBBs lost due to abutment tooth fracture (per 100 RBB years)	Estimated rate of debonding (per 100 RBB years)	Estimated rate of RBBs lost due to veneer or framework fractures (per 100 RBB years)	Estimated rate of minor veneer fractures (per 100 RBB years)	Estimated rate of RBBs lost due to esthetic failures (per 100 RBB years)
Kumbuloglu & Özcan	2015	350	0	175	0	0	0.91	0.11	0.46	0
Sailer & Hämmerle	2014	12	0	12	0	0	3.28	0	0	0
Botehlho et al.	2014	211	0.14	211	0.15	0.10	1.41	0	0.10	n.r.
Sasse & Kern	2014	42	0.46	42	0	0	0.93	0	n.r.	n.r.
Spinas et al.	2013	64	n.r.	32	0	0	0	0	1.25	n.r.
Sasse & Kern	2013	14	0	14	0	0	1.33	0	n.r.	0
Younes et al.	2013	84	n.r.	42	0.18	0	3.30	0	0.55	n.r.
Sailer et al.	2013	35	0	49	0.48	0	0	0	0.95	0
Boening et al	2012	112	0.45	56	0	0	1.41	0	0.28	0.28
Kern & Sasse	2011	54	n.r.	38	0	0	0	2.20	n.r.	n.r.
van Heumen et al.	2009	120	n.r.	60	n.r.	n.r.	5.00	3.00	4.33	n.r.
Agstaller et al.	2008	n.r.	n.r.	232	0	0.19	0.76	0	0.19	0.19
Garnett et al.	2006	45	n.r.	39	n.r.	0	6.15	n.r.	n.r.	n.r.
Kern	2005	53	n.r.	37	n.r.	n.a.	n.a.	n.a.	1.04	n.r.
Zalkind et al.	2003	n.r.	n.r.	51	n.r.	0	7.71	n.r.	n.r.	n.r.
Hikage et al.	2003	n.r.	n.r.	26	n.r.	0	3.59	n.r.	n.r.	n.r.
Corrente et al.	2000	327	0	61	0	0	2.84	0.24	n.r.	n.r.
de Kanter et al.	1998	402	n.r.	201	n.r.	0	9.35	n.r.	n.r.	n.r.
Pröbster & Henrich	1997	650	0.80	325	n.r.	n.r	4.80	n.r.	n.r.	n.r.
Hansson & Bergström	1996	68	0	34	0.48	0	2.42	0	0.48	0
Bergbreiter et al.	1996	n.r.	n.r.	74	n.r.	n.r	2.29	n.r.	0.62	n.r.
Samama	1996	n.r.	n.r.	145	n.r.	n.r	1.32	n.r.	n.r.	n.r.
de Rijk et al.	1996	n.r.	n.r.	164	n.r.	n.r	3.16	n.r.	n.r.	n.r.
Priest	1995	n.r.	n.r.	31	0.31	n.r	12.8	0.31	n.r.	n.r.
Hosseini	1994	n.r.	n.r.	90	n.r.	n.r	1.71	n.r.	n.r.	n.r.
Barrack & Bretz	1993	n.r.	n.r.	127	0.68	n.r	1.22	n.r.	0.41	n.r.
Thayer et al.	1993	209	0.33	85	n.r.	n.r	5.31	0.64	n.r.	0.
Creugers & Käyser	1992	n.r.	n.r.	203	n.r.	0	4.17	n.r.	n.r.	n.r.
Creugers et al.	1990	n.r.	n.r.	203	n.r.	n.r	n.r.	0.32	2.89	n.r.
Summary estimate event rates (95% CI)			0.34* (0.14–0.82)		0.17* (0.08–0.36)	0.03* (0.01–0.10)	3.3* (2.3–4.6)	0.34* (0.13–0.90)	0.84* (0.36–2.00)	0.07* (0.02–0.25)
Cumulative 5 year complication rates (95% CI)			1.7%* (0.7–4.0)		0.8%* (0.4–1.8)	0.2%* (0.05–0.5)	15.0%* (10.9–20.6)	1.7%* (0.6–4.4)	4.1%* (1.8–9.5)	0.3%* (0.1–1.2)

CI, confidence interval; n.r., not reported; n.a., not analysed; RBB, resin bonded bridge.
*Based on robust Poisson regression.

glass-infiltrated ceramic RBBs it was 1.04, for fiber-reinforced composite RBBs it was 1.42, and for metal–acrylic RBBs it was 2.89. Formally investigating the relative chipping rates of different material types of RBBs, using metal–ceramic RBBs as reference, zirconia RBBs had significantly ($P < 0.0001$) lower chipping rates, but all the other material types had significantly ($P < 0.0001$) higher chipping rates than metal–ceramic RRBs.

Esthetic failures

Eight studies gave information on the number of RBBs removed or remade due to unacceptable esthetic appearance. Only two of 673 RBBs were removed due to esthetic reasons. In robust Poisson model analysis, the overall annual complication rate was 0.07 (95% CI: 0.02–0.25%), translating into a 5-year failure rate of 0.3 (95% CI: 0.1–1.2%; Table 5).

Discussion

The present review showed that RBBs may be considered as well established minimally-invasive prosthetic treatment option for the replacement of missing anterior teeth today. Specific criteria, however, were crucial for good outcomes. The factors influencing the outcomes of the RBBs were the selection of framework material, the design of the RBB, and the location in the jaws. The RBBs exhibited the best outcomes in anterior regions, with a single-retainer design and when made of zirconia-ceramic. Still today, RBBs cannot be recommended for posterior regions of the jaws. The predominant reason for problems was repeated de-bonding. Fracture of the RBB was a rare complication irrespective of the materials used.

The present systematic review is an update of a previous systematic review on the same topic (Pjetursson et al. 2008). The review is a part of a series of systematic reviews based on the same methodology addressing the survival and complication rates of different types of FDPs. A significant amount of information on RBBs has been published in the recent 8 years that could be included in this update. The results of the present systematic review are based on 29 studies reporting on more than 2300 RBBs made of six different material combinations. In the absence of RCTs comparing RBBs with FDPs of different design, a lower level of evidence with prospective and retrospective cohort studies and case report was included in these systematic reviews. To formally investigate whether study design influenced the outcome, 12 included prospective studies were compared with ten included retrospective studies. The difference in the 5-year survival rates between the different study designs was only 0.8% and did not reach statistical significance ($P = 0.779$). Hence, the authors felt confident including both study designs in the present systematic review.

The survival of the reconstruction in the present review was defined as RBBs remaining in situ and functioning without multiple de-bonding. Even though RBBs can be re-bonded several times, multiple de-bonding (two or more) was considered a failure because the failure rate has been shown to increase with each re-bonding. Creugers & Kayser (1992), for example, reported a significantly lower survival rate for RBBs that were re-bonded when compared with the original RBBs (Creugers & Kayser 1992). Similar observations on RBBs with multiple de-bonding have also been reported by other authors (Marinello et al. 1990).

The 5-year survival rate of RBBs in the present systematic review was 91.4% (95% CI: 86.7–94.4%) based on the 18 included studies reporting on 1755 RBBs, compared with a 5-year survival rate of 87.7% (95% CI: 81.6–91.9%) based on 12 studies with 1374 RBBs in the previous review (Pjetursson et al. 2008). Hence, the 5-year survival rate has increased by 3.7% and the CI has narrowed by including more recent studies. This might represent a positive learning curve with RBBs. Moreover, in the present systematic review, eight studies report on RBBs made with other framework materials than metal compared with only one study with ceramic framework in previous systematic review.

The outcome of the present systematic review clearly shows that different material combinations experience different complications. The main problem with metal–ceramic RBBs is de-bonding. But, relatively few metal–ceramic RBBs are lost due to framework or material fractures. Metal–acrylic RBBs have like metal–ceramic RBBs high incidence of de-bonding and in addition frequent fractures of the veneering material. RBBs made with ceramic framework also behave in a different way depending on the material utilized. Studies using densely sintered zirconia, for example, do not report any framework or material fractures, but have rather high incidence of de-bonding. Hence, even though densely sintered zirconia RBBs showed significantly higher 5-year survival rate than the other material combinations, there is still the issue of de-bonding. On the other hand, a study (Kern & Sasse 2011) using glass-infiltrated ceramic as framework material reported no de-bonding but a high incidence of RBBs is lost due to material fracture. Another study (Sailer et al. 2013) reporting on glass-reinforced ceramic as framework material also reported no de-bonding but a relatively high rate of veneer fractures. The results for composite RBBs are controversial. Two of the included studies report excellent outcomes with 5-year survival rate of 99.4% and 100%. The third included study (van Heumen et al. 2009), however, reported a 5-year survival rate of only 64%. All included studies on composite RBBs report incidences of chipping of the veneering material. Celeste and co-workers also report exceptionally high rates of fractures of the framework and de-bonding.

The outcome with RBBs was also tested regarding the position in the oral cavity. The survival rate in the maxilla was higher than in the mandible, and the survival rate was also higher in the anterior area compared with posterior position. The difference between the jaws did, however, not reach statistical significance, but the difference between the positions anterior vs. posterior was at the margin of significance ($P = 0.056$). The de-bonding rate showed the same trend as it was higher in mandible compared with the maxilla, and it was also higher in the posterior position compared with the anterior area.

In recent years, RBBs are more frequently designed with one retainer bonded to one abutment tooth, instead of bonding them in the traditional way with two or more retainers to multiple teeth. The idea behind this is to reduce the risk of fracture of the adhesive cement (de-bonding), induced by un-synchronized movement of the abutment teeth in different directions under functional load. The material of the present systematic review allowed formal comparison of RBBs retained with one retainer to RBBs retained with two retainers. The one-retainer design showed significantly higher survival rate and significantly lower de-bonding rate than the two-retainer design.

Combining the information and knowledge from the present systematic review, RBBs seems to function best and long lasting in the anterior area. The framework material of choice appears to be densely sintered zirconia, esthetically modified with buccal veneering ceramic. The need for improvement today is to decrease the de-bonding rate with surface treatment of the ceramic, new cementation protocols, or new abutment tooth preparation designs.

In the present systematic review, an estimated 10-year survival rate of 82.9% (95% CI: 73.2–89.3%) was reported based on five studies reporting on 545 RBBs with a mean follow-up period around 9 years. Compared with the previous systematic review on RBBs (Pjetursson et al. 2008) that reported 10-year survival rate of RBBs of 65.0% based on one study (Zalkind et al. 2003) reporting on 51 RBBs.

Comparing these results with the results for implant-supported SCs from a recent systematic review based on the same methodology (Jung et al. 2012), the 5-year survival rate of RBBs is only 4.9% lower and the 10-year survival rate 6.5% lower than the survival rate reported for implant-supported SCs. Furthermore, it is interesting to see that the annual failure rate of studies with 5- and 10-year follow-up is similar, 1.80% and 1.88%, respectively. Hence, RBBs seem to be stable reconstructions as the failure rate is relatively linear and not suddenly decreasing after between 5- to 10-year follow-up time. It has to be considered, however, that RBBs cannot be applied as treatment option in all clinical situations. Deep bite conditions, low or no overjet or the lack of enamel at the abutment teeth are strong limitations and sometimes even contraindications for the RBBs (Kern 2005).

In the present systematic review, a positive learning curve can be noticed regarding the way authors report on the clinical outcome. In the older studies, the authors frequently concentrated on the issue of de-bonding that was the main problem without reporting the entire picture. More recent studies give a more comprehensive report on everything that happened to the reconstruction over the observation period. The incidence of biological complications was relatively low in the present systematic review. Caries at abutment level was 1.7%, and incidence of RBBs lost due to periodontal diseases was 0.8% over and 5-year observation period. For traditional tooth-supported end abutment FDPs, the respective figures are 4.8% and 0.4%. The incidence of RBBs lost due to esthetic failures was only 0.3%. For implant-supported SCs, 7.1% of the cases were reported to have unacceptable esthetic outcome. However, these figures cannot be compared as it was not reported whether the implant restorations had to be remade or not. The incidence of technical complications was well reported in the included studies, and as previously mentioned the incidence was very dependent on the material combination utilized.

The studies included were mainly conducted in an institutional environment, such as universities or specialists' clinics. Therefore, for a technique-sensitive procedure like making a RBBs, the long-term outcomes observed here could not be generalized to dental services provided in private practice.

A possible limitation of the present systematic review is that only literature in English and German language was included. Although, both the English and the German dental literature were searched for the review, all the included papers were in the English language. Most probably, the language limitation is not a major factor influencing the outcome. This would be in concurrence with an empirical study, which found little effect on the combined effect estimates in meta-analyses of RCTs, with the inclusion or exclusion of studies published in languages other than English (Egger et al. 2003).

Instead of performing a formal quality assessment of the included studies and sensitivity analysis, this review used stringent inclusion criteria. For example, only studies with clinical follow-up examinations were included to avoid the potential inaccuracies in event description in studies that based their analysis on patient self-reports.

The original idea behind RBBs was to enable fixed reconstruction with minimal or no tooth preparation, hence, to conserve tooth structure. For anterior RBBs, the use of a minimally invasive preparation design is considered sufficient by most authors. The extension of the tooth preparations with wrap-around design, grooves, and rests that has been recommended (De Kanter et al. 1998) in recent years to increase retention for RBBs placed on posterior teeth cannot qualify as a conservative method.

Literature-based systematic reviews of prognosis and survival outcomes are hampered by a variety of problems (Altman & Cates 2001). The present systematic review revealed several shortcomings in the previous clinical studies. Hence, it appears appropriate to make the following recommendations: Long-term cohort studies on RBBs should have complete follow-up information for all patients. This means that data on well-defined time periods should be reported for the entire cohort, especially for the different years after insertion. Moreover, future research should look into taking advantage of the best properties from different materials to make RBBs even more predictable.

Conclusions

In specific and clearly defined patient situations, RBBs may be considered as valid minimally invasive treatment alternative to conventional FDPs or single implant crowns. Anterior RBBs made with zirconia frameworks and single-retainer design appear to perform best, yet, other all-ceramic RBBs as well as composite RBBs are very promising as well. Despite the high survival rate of RBBs after 5 years, technical complications such as de-bonding still are frequent.

For their application in the posterior region of the jaws, new treatment concepts and possibly also material options need to be developed for improved outcomes. There is a need for comparative studies with a long follow-up time, to fully assess the long-term outcomes of the RBBs.

Conflict of interest

The authors report no conflict of interest.

References

Altman, D.G. & Cates, C. (2001) Authors should make their data available. *BMJ* **323**: 1069–1070.

Antonarakis, G.S., Prevezanos, P., Gavric, J. & Christou, P. (2014) Agenesis of maxillary lateral incisor and tooth replacement: cost-effectiveness of different treatment alternatives. *International Journal of Prosthodontics* **27**: 257–263.

Beikler, T. & Flemmig, T.F. (2015) Eao consensus conference: economic evaluation of implant-supported prostheses. *Clinical Oral Implants Research* **26**(Suppl 11): 57–63.

Creugers, N.H. & Kayser, A.F. (1992) An analysis of multiple failures of resin-bonded bridges. *Journal of Dentistry* **20**: 348–351.

Creugers, N.H., Snoek, P.A., Van 't Hof, M.A. & Kayser, A.F. (1990) Clinical performance of resin-bonded bridges: a 5-year prospective study. Part iii: failure characteristics and survival after rebonding. *Journal of Oral Rehabilitation* **17**: 179–186.

De Kanter, R.J., Creugers, N.H., Verzijden, C.W. & Van't Hof, M.A. (1998) A five-year multi-practice clinical study on posterior resin-bonded bridges. *Journal of Dental Research* **77**: 609–614.

Egger, M., Juni, P., Bartlett, C., Holenstein, F. & Sterne, J. (2003) How important are comprehensive literature searches and the assessment of

trial quality in systematic reviews? Empirical study. *Health Technology Assessment* **7**: 1–76.
van Heumen, C.C., van Dijken, J.W., Tanner, J., Pikaar, R., Lassila, L.V., Creugers, N.H., Vallittu, P.K. & Kreulen, C.M. (2009) Five-year survival of 3-unit fiber-reinforced composite fixed partial dentures in the anterior area. *Dental Materials* **25**: 820–827.
Howe, D.F. & Denehy, G.E. (1977) Anterior fixed partial dentures utilizing the acid-etch technique and a cast metal framework. *Journal of Prosthetic Dentistry* **37**: 28–31.
Jung, R.E., Zembic, A., Pjetursson, B.E., Zwahlen, M. & Thoma, D.S. (2012) Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. *Clinical Oral Implants Research* **23**(Suppl 6): 2–21.
Kern, M. (2005) Clinical long-term survival of two-retainer and single-retainer all-ceramic resin-bonded fixed partial dentures. *Quintessence International* **36**: 141–147.
Kern, M. & Sasse, M. (2011) Ten-year survival of anterior all-ceramic resin-bonded fixed dental prostheses. *Journal of Adhesive Dentistry* **13**: 407–410.
Kirkwood, B.R. & Sterne, J.A.C. (2003a) Poisson regression. Essential Medical Statistics, 249–262. Oxford: Blackwell Science Ltd.
Kirkwood, B.R. & Sterne, J.A.C. (2003b) Survival analysis: displaying and comparing survival patterns. In: *Essential Medical Statistics*, Chapter 26. Oxford: Blackwell Science Ltd.
Kumbuloglu, O. & Ozcan, M. (2015) Clinical survival of indirect, anterior 3-unit surface-retained fibre-reinforced composite fixed dental prosthesis: up to 7.5-years follow-up. *Journal of Dentistry* **43**: 656–663.
Livaditis, G.J. (1980) Cast metal resin-bonded retainers for posterior teeth. *Journal of the American Dental Association* **101**: 926–929.
Marinello, C.P., Kerschbaum, T., Pfeiffer, P. & Reppel, P.D. (1990) Success rate experience after rebonding and renewal of resin-bonded fixed partial dentures. *Journal of Prosthetic Dentistry* **63**: 8–11.
Pjetursson, B.E., Sailer, I., Makarov, N.A., Zwahlen, M. & Thoma, D.S. (2015) All-ceramic or metal-ceramic tooth-supported fixed dental prostheses (fdps)? A systematic review of the survival and complication rates. Part ii: Multiple-unit fdps. *Dental Materials* **31**: 624–639.
Pjetursson, B.E., Tan, W.C., Tan, K., Bragger, U., Zwahlen, M. & Lang, N.P. (2008) A systematic review of the survival and complication rates of resin-bonded bridges after an observation period of at least 5 years. *Clinical Oral Implants Research* **19**: 131–141.
Rochette, A.L. (1973) Attachment of a splint to enamel of lower anterior teeth. *Journal of Prosthetic Dentistry* **30**: 418–423.
Sailer, I., Bonani, T., Brodbeck, U. & Hammerle, C.H. (2013) Retrospective clinical study of single-retainer cantilever anterior and posterior glass-ceramic resin-bonded fixed dental prostheses at a mean follow-up of 6 years. *International Journal of Prosthodontics* **26**: 443–450.
Saker, S., El-Fallal, A., Abo-Madina, M., Ghazy, M. & Ozcan, M. (2014) Clinical survival of anterior metal-ceramic and all-ceramic cantilever resin-bonded fixed dental prostheses over a period of 60 months. *International Journal of Prosthodontics* **27**: 422–424.
Sasse, M. & Kern, M. (2013) Cad/cam single retainer zirconia-ceramic resin-bonded fixed dental prostheses: clinical outcome after 5 years. *International Journal of Computerized Dentistry* **16**: 109–118.
Zalkind, M., Ever-Hadani, P. & Hochman, N. (2003) Resin-bonded fixed partial denture retention: a retrospective 13-year follow-up. *Journal of Oral Rehabilitation* **30**: 971–977.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. PRISMA 2009 checklist.

