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Review article

Survival rates and complication behaviour of tooth implant–supported, fixed dental prostheses: A systematic review and meta-analysis

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ABSTRACT

Objective: To assess the survival and complication rates of tooth-implant supported fixed dental prostheses (T-I FDPs).

Sources: An electronic search in MEDLINE/PubMed, Cochrane Library, and Embase was conducted using MeSH terms to identify randomised controlled trials (RCTs) or prospective studies with an observation period of at least 3 years, including at least 10 participants.

Study selection: Included studies were qualitatively assessed. Survival rates of T-I FDPs and implants as well as technical and biological complications were obtained. Failure and complication rates were pooled by weighting each rate in inverse proportion to its variance.

Data: A total of eight studies were considered for qualitative analysis; seven studies with a minimum follow-up of five years were included for quantitative analysis. Estimated survival rates of T-I FDPs were 90.8% (95% CI: 86.4–93.8%) after five years and 82.5% (95% CI: 74.7–88.0%) after 10 years. Implant survival estimates were 94.8% (90.9–97.0%) and 89.8% (82.7–99.4%) after 5 and 10 years, respectively. From a total of 185 T-I FDPs, 21 (11.4%) minor and 23 (12.4%) major biological complications were observed, whereas 23 (12.4%) minor and three (1.6%) major technical complications occurred.

Conclusions: Due to the lack of well-designed studies exceeding a 10-year follow-up, prognosis for the long -term can hardly be given. Considering the inclusion criteria of this systematic review, T-I FDP–supported fixed dental prostheses show acceptable survival rates after five and 10 years. Rigidly constructed T-I FDPs should be preferred. With regard to the available data, these conclusions are valid only for three- to four-unit T-I FDPs.

Clinical significance: Tooth–implant supported fixed dental prostheses are a recommendable treatment option in partial dentition. Based on the current literature, they should be rigidly constructed with a maximum number of four units.

1. Introduction

Treatment of partially edentulous dentition presents a variety of restorative scenarios and is, in each case, the product of an individual decision-making process [1,2]. In the group of younger elderly (65–74 years of age), the number of remaining teeth increased by five teeth over the course of the past quarter-century [3,4]. Due to the increased number of residual teeth, possible treatment options with fixed restorations occur more frequently [5]. The restoration of missing teeth in partially edentulous dentition with fixed dental prostheses represents a prognostically superior treatment option compared to removable dentures, especially with regard to the periodontal condition of the remaining teeth [6,7]. Furthermore, a fixed dental prosthesis leads to better improvement of oral health–related quality of life [8].

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Table 1
Search strategy in Medline/PubMed.

Population	#1: Implants[All Fields] OR #2 Tooth-implant[All Fields]
Intervention	#3: #1 OR #2 AND ((fixed[All Fields] AND ("dental prosthesis"[MeSH Terms] OR ("dental"[All Fields] AND "prosthesis"[All Fields]) OR "dental prosthesis"[All Fields] OR ("dental"[All Fields] AND "prostheses"[All Fields]) OR "dental prostheses"[All Fields])) OR ("denture, partial, fixed"[MeSH Terms] OR ("denture"[All Fields] AND "partial"[All Fields] AND "fixed"[All Fields]) OR "fixed partial denture"[All Fields] OR ("fixed"[All Fields] AND "partial"[All Fields] AND "dentures"[All Fields]) OR "fixed partial dentures"[All Fields]))
Comparison	Included in population, intervention and outcome
Outcome	#4: #1 OR #2 AND outcome[All Fields]; #1 OR #2 AND ("mortality"[Subheading] OR "mortality"[All Fields] OR "survival"[All Fields] OR "survival"[MeSH Terms]); #1 OR #2 AND (failure[All Fields]); #1 OR #2 AND (complication[All Fields]);

The fifth German oral health study recently reported, that patients in Germany have implants 10 times more frequently than 20 years ago [3]. Replacing lost teeth with dental implants is part of the differential therapeutic planning process of fixed and removable dental prostheses [9,10]. The combination of teeth and implant abutments for fixed dental prostheses (FDPs) has been investigated since the early 1980s, and the tooth–implant connection was emphasised by studies that showed an eight-time higher threshold value for tactile perception of implants [11] and a maximum bite force of tooth–implant supported fixed dental prostheses (T-I FDPs) comparable to the bite force of natural teeth [12]. With regard to chewing coordination, the lack of periodontal mechanoreceptors leads to a delayed and less precise movement pattern, which can be shown by the example of splitting chocolate dragees [13]. During the past 10 years, several systematic reviews of T-I FDPs have been published. A meta-analysis conducted by Lang and coworkers focused on estimates of the long-term survival rates of T-I FDPs, and on the incidence of biological and technical complications [14]. The authors reported survival rates of 94.1% after five years, and 77.8% after 10 years of clinical service. Weber and collaborators reviewed the literature with regard to the impact of implant prostheses on outcomes in the partially edentulous arch [15]. The implant survival rates of T-I FDPs and I-I FDPs (FDPs supported only with an implant) after 72 months were 91.1% and 97.7%, respectively. No significant difference was found. Prosthesis success rates after 72 months were 87.5% for T-I FDPs and 89.7% for I-I FDPS, respectively. A further systematic review aimed to derive cumulative survival rates of different implant-supported prostheses and reported survival rates of 91.3% for T-I FDPs and 96.4% for I-I FDPs, respectively [16]. A recent systematic review assessed the effect of rigid and non-rigid connections between implants and teeth with an overall prosthesis survival rate of 85% and higher risk for tooth intrusion in non-rigid connections, considering observation periods of between 18 and 120 months [17]. The available systematic reviews included prospective and retrospective studies, and defined different observation periods.

The aim of this systematic review was to evaluate prospective clinical studies of T-I FDPs by addressing the following population, intervention, comparison and outcome (PICO) -question: What is the clinical performance of T-I FDPs with regard to survival rates and complication behaviour in partially edentulous patients with at least two adjacent missing teeth?

2. Methods

The systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocols [18].

2.1. Protocol

A protocol was defined by FB, MvS and AvS prior to the literature search.

2.2. Eligibility criteria

The PICO design was used to develop the focused question.

Patients:	Partially edentulous patients with at least two adjacent missing teeth
Intervention:	Restored with T-I FDPs
Comparison:	Not performed, prognosis as primary aim
Outcome:	Survival of FDPs and/or implants and complications after an observation period of at least three years

Inclusion criteria were:

- Randomised controlled trials (RCTs) or prospective clinical studies
- At least 10 patients included
- Observation period of at least 3 years
- Language of publication English or German
- Details of reconstruction (rigid, non-rigid connection), number of implants and teeth needed to be reported

Studies that did not meet the inclusion criteria were excluded.

2.3. Information sources and search

Three electronic databases (Medline/PubMed, Cochrane Library, and Embase) were searched for articles published between January 1988 and January 2018. A manual search through different German dental journals (*Deutsche Zahnärztliche Zeitschrift*, *Implantologie*, *Quintessenz*) was conducted. January 9, 2018, was the last date of search.

The search was performed using the terms (Implant* AND (outcome OR survival OR failure* OR complication) AND (fixed dental prostheses OR fixed partial dentures)), Tooth-implant AND (outcome OR survival OR failure* OR complication) AND (fixed dental prostheses OR fixed partial dentures), (tooth-implant) (Table 1).

The search was updated from 11 to 16 February 2019. In addition, a search for grey literature was performed using the online catalogue of the German National Library (5 to 7 February 2019). Furthermore, the abstract archive of the International Association for Dental Research (IADR) was screened for abstracts published during the past 10 years.

2.4. Study selection

Two reviewers (AvS and MvS) independently screened titles and abstracts for relevance. Potential full texts of articles were read and assessed according to inclusion criteria. Any disagreement was solved by discussion with a third reviewer (FB). Agreement strength among the reviewers was assessed using Cohen's kappa (K) statistic.

2.5. Data collection process and data items

For data collection, an extraction sheet was defined using MicrosoftExcel software (Microsoft Office Professional Plus 2016, CA, USA). The table included author, year, number and characteristics of patients, intervention, observation period, comparison, outcome, dropouts and results (survival, biological and technical complications).

Survival of a T-I FDP was defined as the restoration remaining *in situ* at follow-up examination, without a diagnostic finding showing a need to remove the restoration (*e.g.*, no need for removal of T-I FDP, implant or tooth, no need for endodontic treatment of abutment tooth). Biological and technical complications were recorded as reported in the publications.

2.6. Risk of bias in studies

A methodology checklist was used for assessment of potential risk of bias. These checklists were provided by the Scottish Intercollegiate Guidelines Network (SIGN 50, www.sign.ac.uk) [19]. According to this, an overall rating of the methodological quality of studies was carried out, resulting in distinguishing high-quality (+ +), acceptable (+) and low-quality (–) studies.

2.7. Summary measures and synthesis of results

The estimated failure rates of T-I FDP and implants per 100 T-I FDPs/implant years were calculated describing the risk of T-I FDP loss and implant loss per 100 T-I FDPs/implants in one year.

Failure rates were calculated by dividing the number of events by the corresponding total exposure time. The total exposure time was calculated by multiplying the mean follow-up time with the included reconstructions or implants, respectively.

Based on the failure rates, the inverse variance method was used to calculate pooled survival rates after five and 10 years. To test for heterogeneity, the DerSimonian-Laird estimator for τ^2 was calculated. Fixed- and random-effect models were used for calculating the pooled incidence of failure. All statistical analyses were performed using the statistical software R, version 3.4.3 [20]. Meta-analysis was carried out using the R package 'meta' [21].

3. Results

3.1. Study selection

After initially finding 2285 articles, 62 studies were included for full-text analysis. Eight publications were considered for qualitative analysis, and seven studies had a minimum follow-up of five years for quantitative analysis (Fig. 1). The inter-reviewer strength of agreement regarding final study selection was $\kappa = 0.838$.

An update of the literature search in PubMed (16 February 2019) yielded 435 titles. After the removal of duplicates, 249 titles were screened, of which 247 titles were excluded. Two publications were screened at the abstract level, but did not meet the inclusion criteria.

The search in three German journals yieldedtwo titles that were excluded during title screening.

The search in the German National Library revealed 84 titles, of which 80 were excluded during the title screening. Four full texts were screened but did not meet the inclusion criteria.

Abstract archives of the IADR showed one abstract of possible relevance out of 39 titles. The abstract did not meet the inclusion criteria, but gives an outlook for clinical five-year data to be published in the next three years [22].

3.2. Study characteristics

Studies published from 1988 to 2016 were included in this analysis (Table 2). All studies were prospective cohort studies. Observation periods from three to 10 years were reported. Seven studies reported on rigid T-I FDPs, and one study reported on both rigid and non-rigid T-I FDPs. All studies described metal-based frameworks veneered with ceramic or acrylic resin, except one study that investigated T-I FDPs made of zirconia frameworks [23]. The number of units per T-I FDP was predominantly three. Two studies reported on three- unit FDPs with additional four- to 10-unit restorations [24], and 3- unit FDPs with additional 2- to 14- unit restorations [25]. Another study did not explicitly describe the number of units [26], but according to described methods and pictures of the publication it was assumed, that T-I FDPs consisted of 3 units. In addition, this study reported an early prototype of Al_2O_3 implants. All other studies used titanium implants.

A total of 141 patients received 185 T-I FDPs, predominantly in the posterior region of the mandible. One study reported on T-I FDPs in both maxilla and mandible [25]. The reported inclusion criteria differed among the studies and differed in extent of reporting. In part, demographic data was not reported in detail, and mainly described the entire study cohort, including T-I FDPs and other interventions. Follow-up intervals and examinations were performed either clinically or in addition to combination with radiographs. During follow-up examinations, several indices were recorded, such as plaque indices, bleeding indices and pocket depth.

3.3. Risk of bias within studies

The included studies were evaluated as well-conducted cohort studies. One study was assessed as a high-quality cohort study (Table 3).

3.4. Results of individual studies

3.4.1. Outcome of survival – risk of bias across studies and synthesis of results

A funnel plot of the included studies showed no publication bias across the studies.

Because the test for heterogeneity between the studies was not significant ($p = 0.802$ for T-I FDPs and $p = 0.624$ for implant failure), we pooled failure rates, using fixed-effects models.

The test for heterogeneity I^2 resulted in 0% for synthesis of implant-related data, and data of T-I FDPs. Low values of I^2 represented a variability among studies that was based on random effects.

Eight studies provided data on the survival behaviour of T-I FDPs. One study reported three-year results, four studies reported five-year results, and three studies reported 10-year results. The study by Beuer and co-workers was not included for quantitative analysis, because the follow-up period was shorter than five years. Figs. 2 and 3 show forest plots for T-I FDP failure and implant failure.

The pooled incidence rate for T-I FDP failure event per year was 0.02 (95% confidence interval [CI]: 0.01–0.03) (Table 4). The incidence rate for implant failure was 0.01 (95% CI: 0.01–0.02) (Table 5). Assuming constant hazard over the five- and 10-year periods, the pooled failure rates corresponded to the following survival rates: For T-I FDPs the estimated survival rate was 90.8% (95% CI: 86.4–93.8%) after five years, and 82.5% (95% CI: 74.7–88.0%) after 10 years, respectively. Implant survival rates were 94.8% (95%CI: 90.9–97.0%) and 89.8% (95%CI: 82.7–99.4%) after five and 10 years, respectively.

3.4.2. Outcome of biological complications (Table 6)

The most recent study reported in 2016, showed one biological failure (secondary caries) during the three-year follow-up of 27 zirconia T-I FDPs [23].

Block and co-workers observed 40 rigidly constructed T-IFDPs and 40 non-rigidly constructed T-I FDPs over a period of five years [27]. All five tooth-related failures occurred in endodontically treated teeth presenting tooth fracture. Two teeth (rigid T-I FDP) in one patient were removed after 3.25 and 3.5 years. In the non-rigid group, one tooth was extracted after 3.5 years, and two teeth in one patient were extracted between 3.5 and four years of service. In the rigid group, one implant of a rigid T-I FDP failed during the third year of follow-up due to loss of osseointegration without inflammation resulting in implant-removal, and one implant presented crestal bone loss of more than 2 mm. In the non-rigid group, two implants presented crestal bone loss greater than 2 mm. Intrusion of teeth measured from a minimum of 0.5 mm occurred in 66% of non-rigid T-I FDPs and 44% of rigid T-I FDPs. Twenty-five percent of the non-rigid group had intrusion greater than 0.5 mm (12.5% in the rigid group). The five-year cohort study reported by

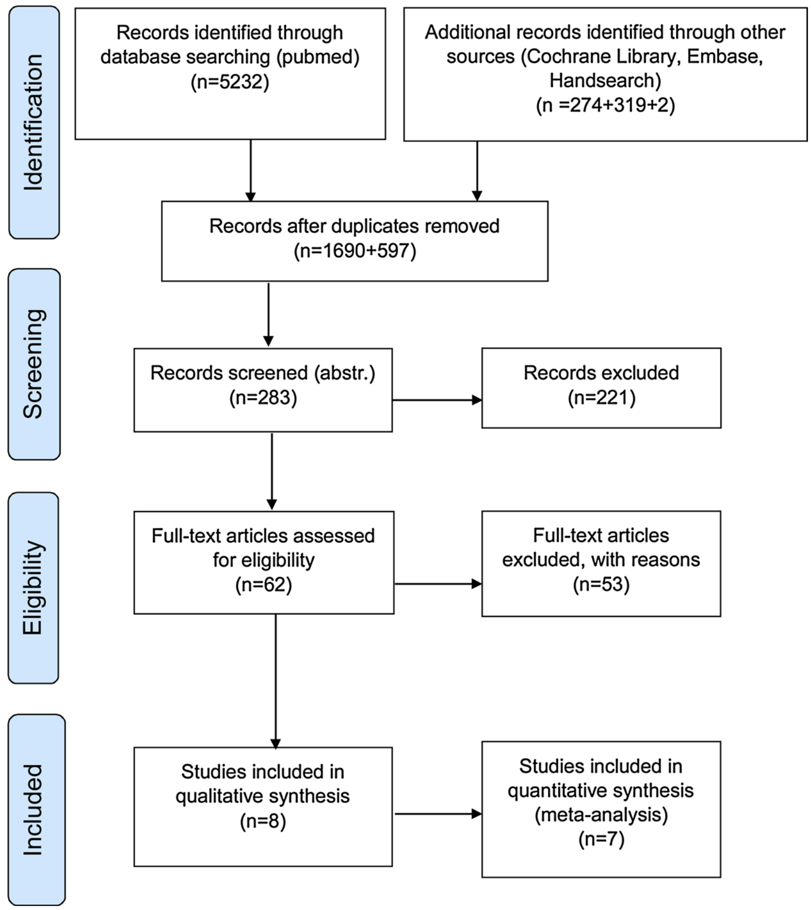

Fig. 1. Diagram of literature search and selection process.

Brägger and co-workers revealed three minor biological complications without specification, and one bone defect around an implant, subsequently followed by fracture of the implant [24]. The 10-year follow-up by Brägger and co-workers presented results of 22 rigidly constructed T-I FDPs, and reported one biological complication due to implant loss (4.5%). This resulted in one lost T-I FDP [25]. Gunne et al. reported one lost abutment tooth due to secondary caries and endodontic complications among 23 rigidly constructed T-I FDPs [28,29]. Results of the five-year follow-up by Koth and collaborators showed one implant loss due to inflammation and loss of osseointegration, resulting in loss of one T-I FDP [30]. The report on the same cohort after 10 years by Steflik and co-workers showed one implant loss after seven years, without known failure type; in that case, the study participant consulted a private dentist [26]. After nine and 10 years, two more implants were removed, without description of the concrete failure scenario.

3.4.3. Outcome of technical complications (Table 6)

One technical failure (chipping of ceramic veneer) occurred during the three-year follow-up of zirconia T-I FDPs [23]. Block and co-workers reported 18 prosthetic complications that occurred as abutment fractures (13 non-rigid T-I FDP, five rigid T-I FDP, nine patients) at the laser weld of the Omniloc abutment [27]. The five-year cohort study by Brägger and co-workers reported one implant fracture of an implant with a prior bone defect [24]. During 10 years of follow-up of 22 T-I FDPs, Brägger and co-workers observed four (16.7%) cases of loss of retention, resulting in biological failure (caries) [25]. Two additional T-I FDPs had to be remade because of technical complications without specification, and four T-I FDPs presented technical complications without need of replacement. Ten-year data obtained from Gunne and co-workers presented three loose horizontal gold screws of the precision attachment in the T-I FDP. Retightening of these screws was possible. Marginal implant bone loss during the 10-year follow-up was 0.5 mm [28]. Olsson and co-workers reported five-year summarised technical complications for the same cohort of 23 T-I FDPs in combination with I-I FDPs [29].

4. Discussion

4.1. Summary of evidence

The aim of this systematic review was to evaluate survival rates and complication behaviour of T-I FDPs. Prospective clinical studies were included to describe the currently available data based on that specific study type. From 63 full texts screened, only eight articles fulfilled the criteria for inclusion in qualitative analysis, and seven articles were included for meta-analysis. Seven articles were published between 1988 and 2005. In contrast to this, the treatment concept of T-I FDPs is underrepresented in the current literature; only one article, published in 2016, was found [23]. The level of evidence of the studies according to SIGN50 criteria was mostly 2+; that is, the studies were well-conducted cohort studies with a low risk of confounding or bias and a moderate probability that the relationship was causal. From the results it can be concluded that T-I FDPs show good to acceptable survival rates after five and 10 years. Rigidly constructed suprastructures should be preferred. Because of the high fracture rate shown in the literature special caution should be taken when including endodontically treated teeth.

Table 2
Characteristics of included studies.

Author (year)	Study design	No. of patients (gender)	Intervention	Type of FDP (rigid / non-rigid)	Comparison	Total no. of implants	Total no. of teeth	Total no. of T-I FDPs	Follow-up period (years)	Drop-out	Outcome measures	Comment
Beuer et al. (2016)	Prospective cohort study	27 (n.a.)	all-ceramic 3-unit T-I FDP; cemented (glasionomer cement); implant: Camlog, Screwline Promote	rigid	T-T FDP	27	27	27	3	0	Clinical and radiographic biological and technical complications	
Brägger et al. (2005)	Prospective cohort study	21 (n.a.)	metal-ceramic T-I FDP, 3-units: 10, 4-units: 6, 5-units: 4, 10-units: 2; cemented or screw-retained; implant: ITI Bonefit, Straumann	rigid	iSC and I-I FDP	22	24	22	10	n.a.	Loss of implants and teeth; biological and technical complications	
Block et al. (2002)	Prospective cohort study	40 (31f, 9 m)	cross-arch design; metal-ceramic 3-unit T-I FDP, rigid side: screw-retained on Implant, temporary cemented on telescopic crown on tooth; non-rigid side: screw-retained on implant and permanently cemented on tooth, Beyeler slot attachment*; Omniloc Implant;	Rigid and non-rigid	Rigid *vs.* non-rigid	80	80	80	5	10 (9f, 1 m)	Bone loss around implants; mobility (teeth, implants); probing depths; soft tissue indices; prosthetic complications; intrusion	*2-part matrix on tooth crown, patrix impl.retained FDP; maxillary complete denture;
Brägger et al. (2001)	Prospective cohort study	15 (n.a.)	metal-ceramic 3 unit (median) T-I FDP (2-14 units); screw-retained and cemented	rigid	I-I FDP T-T FDP	19	18	18	5	n.a.	Implant loss; tooth loss; technical and biological complications	
Gunne et al. (1999)	Prospective cohort study	23 (15f, 8 m)	Cross-arch design; metal(gold)-ceramic 3-unit T-I FDP, Mc Collum T-attachment, horizontal gold screw;	rigid	I-I FDP	23	23	23	10	3	as Gunne et al. (1992)	cohort from Gunne et al. (1992)
Olsson et al. (1995)	Prospective cohort study	23 (15f, 8 m)	Cross-arch design; metal(gold)-ceramic 3-unit T-I FDP, Mc Collum T-attachment, horizontal gold screw;	rigid	I-I FDP	23	23	23	5	1	as Gunne et al. (1992)	cohort from Gunne et al. (1992)
Gunne et al. (1992)	Prospective cohort study	23 (15f, 8 m)	Cross-arch design; metal(gold)-ceramic 3-unit T-I FDP, Mc Collum T-attachment, horizontal gold screw;	rigid	I-I FDP	23	23	23	3	0	Stability of FDP, implants; tooth mobility, BOP; crestal bone level, technical complications	Maxillary complete denture
Steflik et al. (1995)	Prospective cohort study	15 (n.r.)	Metal-based T-I FDP, zemented;	rigid	Control: unrestored tooth near the FDP	23	n.r.	15	10	1	as Koth et al. (1988)	cohort from Koth et al. (1988)
Koth et al. (1988)	Prospective cohort study	15 (n.r.)	Metal-based T-I FDP, zemented;	rigid	Control: unrestored tooth near the FDP	23	n.r.	15	5	1	Gingiva bleeding index, plaque accumulation, cervical fluid volume, mobility, radiographic assessment	

Table 3
Risk of bias within studies.

Author (year)	Study design	Overall assessment of the study (SIGN 50)[a]	Level of evidence[b]	Funding
Beuer et al. (2016)	Prospective cohort study	+	2+	Financial funding KaVo, Germany; materials: Camlog, Germany and GC Europe
Brägger et al. (2005)	Prospective cohort study	+	2+	Funding by University of Bern, Switzerland
Block et al. (2002)	Prospective cohort study	+ +	2+ +	Funding by National Institute for Dental and Craniofacial Research, US
Brägger et al. (2001)	Prospective cohort study	+	2+	Funding by University of Bern, Switzerland
Gunne et al. (1999)	Prospective cohort study	+	2+	Not reported
Olsson et al. (1995)	Prospective cohort study	+	2+	Not reported
Gunne et al. (1992)	Prospective cohort study	+	2+	Not reported
Steflik et al. (1995)	Prospective cohort study	+	2+	Funding by Kyocera International
Koth et al. (1988)	Prospective cohort study	+	2+	Not reported

1+ Well-conducted meta-analyses, systematic reviews, or RCTs with a low risk of bias; **2+ +** High quality systematic reviews of case control or cohort or studies High quality case control or cohort studies with a very low risk of confounding or bias and a high probability that the relationship is causal; **2+** Well-conducted case control or cohort studies with a low risk of confounding or bias and a moderate probability that the relationship is causal; **2-** Case control or cohort studies with a high risk of confounding or bias and a significant risk that the relationship is not causal; **3** Non-analytic studies, *e.g.* case reports, case series; **4** Expert opinion.

[a] How well was the study done to minimise the risk of bias or confounding? High quality (+ +), Acceptable (+), Low quality (-).

[b] Level of evidence (SIGN 50): **1+ +** High quality meta-analyses, systematic reviews of RCTs, or RCTs with a very low risk of bias.

4.1.1. Rigidly versus non-rigidly constructed T-I FDPs

Block and co-workers reported five-year observational data by comparing rigidly and non-rigidly constructed T-I FDPs in 40 patients [27]. A total of five T-I FDPs were lost for reasons of five tooth fractures in two rigid and in three non-rigid T-IFDPS, respectively. One additional rigid T-I FDP was lost due to a lost implant. The complication rate was higher in non-rigid T-I FDPs. Further intrusion of teeth measured from a minimum of 0.5 mm occurred in 66% of non-rigid T-I FDPs and 44% of rigid T-I FDPs. Twenty-five percent of the non-rigid group had intrusion greater than 0.5 mm (12.5% in the rigid group). From this data, it can be concluded that rigidly constructed suprastructures should be preferred. In addition to these findings from only one study, a systematic review from 2016 evaluated rigid and non-rigid connections between implants and teeth [17]. Although that review presented other inclusion criteria and included short-term data as well, it concluded that the major drawback of non-rigidly connected FDPs is tooth intrusion. Nevertheless, the authors rated the evidencelimited and emphasised an overall low quality of studies included.

4.1.2. Endodontically treated teeth

Brägger and co-workers performed a study assessing the survival of 18 T-I FDPs, 40 I-I FDPs, and 58 T-T FDPs with a follow-up period of five years [25]. The authors considered that most of the lost tooth abutments were root canal treated and had cast post and cores, but, information regarding concrete post-endodontic treatment conditions and procedures was not given. However, observations from other studies reporting that structurally compromised endodontically treated teeth have a greater vulnerability for failure than vital teeth with minor defect sizes can be confirmed [31–33]. In the same context, Block and co-workers observed 40 rigidly constructed T-IFDPs and 40 non-rigidly constructed T-I FDPs over a period of five years [27]. All five tooth-related failures occurred in endodontically treated teeth presenting tooth fracture. From this data, it can be concluded that it is important to observe all precautions strictlyfor the maintenance of root canal-–treated teeth. This includes, first and foremost, sufficient adherence to the ferrule-effect. In this context, the type of post material is of secondary importance [33].

4.1.3. All-ceramic materials

An interesting finding was two studies reporting on T-I FDPs constructed in part out of all-ceramic materials [23,26,30]. *Beuer and co-workers* reported suprastructures of hand veneered zirconia T-I FDPs. The objective of this study was to compare the performance of veneered zirconia T-I FDPs with T-T FDPs, and they reported three-year results with survival rates for technical complications of 96.3% (T-I FDP) and 95.5% (T-T FDP). Survival rates for biological complications were 100.0% (T-I FDP) and 95.5% (T-T FDP). The study was limited by the short-term character of the three-year observation period. Compared to these results, the estimated overall survival rates of all-ceramic implant-supported single crowns (iSCs) is 93.0% after five years, and the corresponding value for the implant survival rate is 95.3% [34]. The five-year survival estimate for implant-supported zirconia-based partial FDPs was 98.3%, and chipping of the veneering ceramic was frequently observed (22.8%) at the reconstruction level [35]. Thus, the short-term results of all-ceramic T-I FDPs are promising in comparison to the estimated five-year survival rates of implant-supported SCs and FDPs.

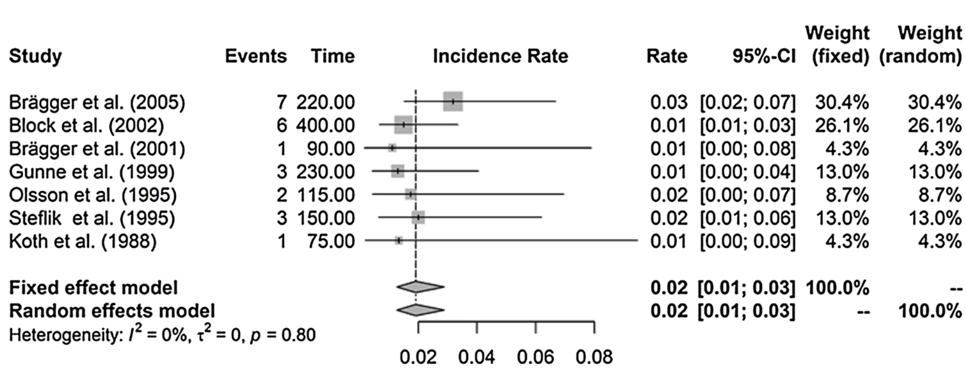

Fig. 2. Forest plot of failure rates of T-I FDPs.

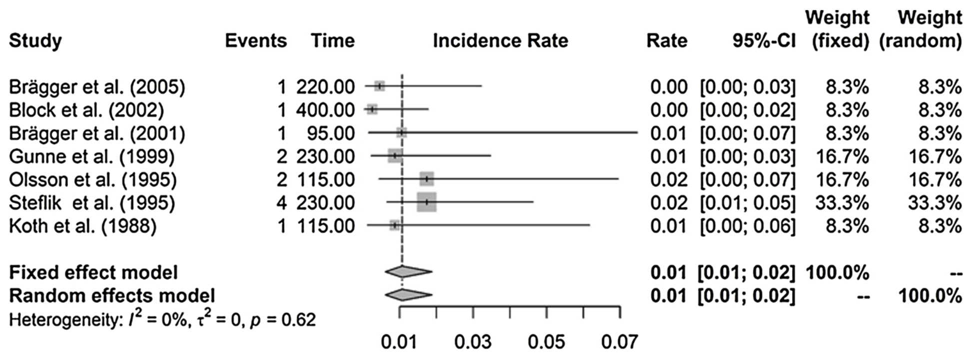

Fig. 3. Forest plot of failure rates of implants.

4.1.4. Multi-unit T-I FDPs

Brägger and co-workers published a 10-year study comparing 22 T-I FDPs with 33 I-I FDPs and 69 iSCs [24]. The study included different designs of T-I FDPs, ranging from three to 10 units. After an observation period of eight to 12 years, 31.8% of T-I FDPs, 10% of iSCs and 6.1% of I-I FDPs were lost, showing statistically significant lower survival rates of T-I FDPs than of other intervention groups. Because all other studies included in this review only investigated 3–4 -unit T-I FDPs, this study is an exception and therefore not directly comparable. Thus, the increased failure rate of 31.8% must be interpreted with caution. To what extent this is causally connected with the construction of multi-unit T-I FDPs cannot be conclusively clarified in this review. Due to these results and the fact that all other studies investigated mostly 3–4 -unit T-I FDPs, this current analysis can only give a clinical recommendation for short-span T-I FDPs at the moment.

4.1.5. Comparison of outcome with other reviews and meta-analyses

The present meta-analysis showed survival rates of T-I FDPs between 90.8% after five years, and 82.5% after 10 years. Survival was defined as T-I FDP *in situ* with no need of renewal. The five-year survival rates are slightly lower than reported by Lang and co-workers who performed a systematic review and meta-analysis including prospective and retrospective studies and an estimated five-year survival rate of 94.4% [14]. The 10-year survival rate was 77.8%, slightly lower than the present results. The meta-analysis by Weber and co-workers included prospective and retrospective studies with a follow-up period between one and six years [15]. The authors reported an 87.3% success rate of T-I FDPs (suprastructures), which allows limited comparison with the recent results, because success rates were defined differently to the present survival rates. Both publications included prospective and retrospective studies [14] or additional retrospective case studies [15]. Furthermore, the duration of follow-up was at least one year [15] or five years [14]. The present review included prospective studies with a minimum follow-up of three years. The novelty was to focus on the design of prospective clinical trials and to do a weighted analysis qualitatively and quantitatively. The qualitative evaluation level included a prospective cohort study with a short term follow-up of three years [23]. This study is the latest one published and includes a full-ceramic suprastructure. On the quantitative evaluation level, the present review included studies with at least five-year data. This is in accordance with the systematic review of *Lang* and collaborators and focuses on clinically relevant long-term data.

With regard to statistical analyses, the publication by *Lang* and collaborators, reported heterogeneity tests with Spearman goodness-of-fit statistics. In cases of heterogeneity, random-effects *Poisson* regression was used. The group of *Weber* and collaborators published a detailed description of their statistical approach in a separate paper [36]. For each meta-analysis point estimates of implant survival, implant success, and/or prosthetic success were used. To test the homogeneity of the reported success rates, chi-squared tests were performed. A further weighted analysis of the methodology of present reviews is recommended to be performed in a separate study, using an assessment tool for systematic reviews, for example the R-AMSTAR instrument [37].

The T-I FDP survival after five years is comparable to tooth-supported cantilever FDPs with a survival rate of 91.4% [38]. In addition, tooth-supported FDPs present a comparable five-year survival rates of 93.8% [39]. Regarding mainly metal–ceramic reconstructions, implant-supported FDPs show a higher survival rate of 95.6% after five years, as do implant-supported SCs with a survival rate of 96.3% [40]. After 10 years, T-I FDP survival rates decrease to 82.5%. For this observation period, tooth-supported conventional and cantilever FDPs present

Table 4
Survival and annual failure rates of T-I FDPs (5-year and 10-year data).

Author (year)	Total number of FDPs	Mean follow up time	Number of failures	Total FDPs exposure time	Estimated failure rate (per 100 FDP years)	Estimated survival after 5 years (%)	Estimated survival after 10 years (%)
5-year-follow up							
Block et al. (2002)	30	5	6	400	1,5	92.7	
Brägger et al. (2001)	18	5	1	90	1,1	94.6	
Olsson et al. (1995)	23	5	2	115	1,7	91.6	
Koth et al. (1988)	15	5	1	75	1,3	93.5	
Pooled estimate (95%CI)[*]						90,8 (86.4–93.8)	
10-year-follow up							
Brägger et al. (2005)	22	10	7	220	3.2		72.2
Gunne et al. (1999)	23	10	3	230	1.3		87.7
Steflik et al. (1995)	15	10	3	150	2,0		81.7
Pooled estimate (95%CI)[*]							82.5 (74.7–88.0)

[*] Based on inverse variance method (fixed effect model), DerSimonian-Laird estimator $\tau^2 = 0$ (test for heterogeneity p = 0.802). Survival defined as T-I FDP *in situ*.

Table 5
Survival and annual failure rates of implants (5-year and 10-year data).

Author (year)	Total number of Implants	Mean follow up time	Number of failures	Total FDPs exposure time	Estimated failure rate (per 100 FDP years)	Estimated survival after 5 years (%)	Estimated survival after 10 years (%)
5-year-follow up							
Block et al. (2002)	30	5	1	400	1.0	98.8	
Brägger et al. (2001)	19	5	1	95	1,1	94.8	
Olsson et al. (1995)	23	5	2	115	1,7	91.6	
Koth et al. (1988)	23	5	1	115	0.87	95.7	
Pooled estimate (95%CI)[*]						94.8 (90.9–97.0)	
10-year-follow up							
Brägger et al. (2005)	22	10	1	220	0,5		95.5
Gunne et al. (1999)	23	10	2	230	0,9		91.6
Steflik et al. (1995)	23	10	4	230	1,7		83.9
Pooled estimate (95%CI)[*]							89.8 (82.7–99.4)

Survival defined as T-I FDP *in situ*.
[*] Based on inverse variance method, DerSimonian-Laird estimator for $\tau^2 = 0$(test for heterogeneity p = 0.624).

survival rates of 89.2% and 80.3%, respectively [38,39]. Survival rates of I-I FDPs and iSCs were 80.1% and 89.4%, respectively [40,41].

Implant-supported FDPs and SCs show a better survival rate performance than do T-I FDPs, especially over a period of up to 10 years of observation. However, T-I FDPs are a recommendable treatment option in cases when I-I FDPs or iSCs are not feasible, when general health parameters do not allow augmentative procedures prior to implantation, as, for example, for patients treated with antiresorptive medication [42]. Other reasons are the patient deciding, during informed consent, to have as few implants as possible or when augmentative procedures are refused by the patient.

Implant survival was defined as implant *in situ* without need for removal. The survival rates of implants after five and 10 years of observation were 94.8% and 89.8%, respectively. These findings are slightly higher than those reported by Lang and co-workers [14]. However, this review included other studies in part. The estimated five-year survival rates of implants in T-I FDPs (94.8%) are comparable to those of implants in I-I FDPs, as reported in a meta-analysis by Pjetursson and co-workers [41]. Ten-year implant survival rates for I-I FDPs reported by the same authors were higher (94.8%), than the present findings. In general, follow-up data of implants was reported either with clinical examination parameters or in addition to radiographic measurements of bone level changes [23,27,28]. Some studies only noted the number and time of lost implants, without any specification of reasons [24,28,29]. On the other hand, some studies reported loss of osseointegration with or without inflammation followed by implant loss [26,27,30].

4.2. Limitations

The present review focused on prospective studies to synthesise and assess current data obtained from a specific study design. However, although the test for heterogeneity showed a low value, and from a statistical point of view, homogeneous data, the included studies differed in aspects of framework design and material of T-I FDPs and concrete number of FDP units. Furthermore, the examination protocols and reporting of specific outcomes show a certain variability among the studies. This can be because the studies showed more outcome parameters than only survival of implants and T-I FDPs. A detailed description of conditions of included teeth was mostly not reported in detail. In some cases, the authors referred to a former cohort [24,25,30] in the methods section, which made it difficult in part to transfer this information to the data extraction table. The primary endpoints were described in varying categories as bridge stability [28,29], peri-implant tissue indices [26,28,30], tooth loss and implant loss [25], and bone loss around teeth and implants [27], and terms of survival and success were not described consistently.

Some of the reported complications could not simply be attributed to technical and biological complications. The differences in these findings may cause a biased analysis regarding the number of complications in the pooled data.

A further limitation of the present review is, that data from mostly comparative studies was included for synthesis of the results. Data from Brägger et al. 2005 and 2010 may have an impact on the present results. The number of units ranged from three to ten, and data was compared with I-I FDPs and implant-supported single crowns. It can be assumed, that the patient collective was more heterogeneous. The comparisons in the other studies may have a minor impact on the present results, because these studies presented a clear, pre-defined classification of partial dentition. The present review focused on survival of T-I FDPs and implants. To analyse the survival of teeth would be important; however, it was not possible from the included data. Because the survival of implants and T-I FDPs was the aim of the present analysis, data extraction was performed regarding implants and suprastructures. A further point of discussion is the inclusion criteria of this review. If the review only included state-of-the-art T-I FDPs, such as rigid constructions and titanium implants, the available data for meta-analysis would decrease to a critical level. This aspect shows that clinical studies with T-I FDPs are underrepresented, especially up to 10 years of observation. Hence, a reliable evaluation of the clinical long-term performance of T-I FDPs is not possible. It can be argued that if more rigid inclusion criteria had been stated previously, it would have allowed meta-analysis. This review was not able to address patient-based outcome measures because only one study additionally assessed patient satisfaction [27]. Furthermore, the overall number of included T-I FDPs limited this review. For the five-year analysis, 86 T-I FDPs were pooled, whereas only 60 restorations could be included for the 10-year analysis.

5. Conclusions

Due to the lack of a sufficient number of well-designed, long-term studies, a statement on the long-term outcome of T-I FDPs can hardly be given.

Considering the inclusion criteria of this systematic review, T-I FDPs show acceptable survival rates after five and 10 years. Rigidly constructed superstructures should be preferred with a view to the currently available evidence. Because of the available data, these conclusions are valid only for three- to four- unit T-I FDPs.

Future research on tooth–implant supported fixed dental prostheses needs:

Table 6
Biological and technical complications extracted from included studies (3-year – 10-year data).

Author (year)	Mean follow-up [y]	T-I FDPs included	Loss of T-I FDPs [n]	Biological complications				Technical complications			
				Minor*	***[n]***	***Major*****	***[n]***	***Minor****	***[n]***	***Major*****	***[n}***
Beuer et al. (2016)	3	27	0			secondary caries	1	veneering porcelain fracture	1		
Brägger et al. (2005)	10	22	7	periimplantitis (treated)	3	1 Implant loss (not specified)	1	technical complication (no remake or loss associated)	4	loss of retention with renewal of FDP	2
						secondary caries (prior to this loss of retention)	4				
Block et al. (2002)	5	30	6	Implant bone-loss >2 mm	3	Implant loss of osseointegration without inflammation	1	abutment fracture (13 non-rigid, 5 rigid FDP);	18		
				intrusion >0.5 mm (8 non-rigid, 4 rigid)	12	tooth fracture (2x rigid, 3x non-rigid T-T FDP)	5				
Brägger et al. (2001)	5	18	1	biological complication (not specified)	3	implant with bone defect, followed by implant fracture (listed below)	1			implant fracture	1
Gunne et al. (1999)[a]	10	23	3			caries with endodontic complications	1	reported pooled with I-I FDP			
						implant loss (not specified)	2				
Olsson et al. (1995)[a]	5	23	2			implant loss (not specified)	2	reported pooled with I-I FDP			
Steflik et al. (1995)[b]	10	15	3			implant loss (inflammation, increased mobility)	1				
						implant loss (not specified)	3				
Koth et al. (1988)	5	15	1			implant loss (inflammation, increased mobility),	1				

* minor complication = FDP *in situ*.
** major complication = reported with loss of FDP.
[a] cohort from Gunne et al. (1992).
[b] cohort from Koth et al. (1988).

- The collection of long-term data obtained from:
- Well-designed study protocols with comparable intervention groups (design and material of T-I FDPs, number of units, location in the jaw)
- Valid measurements of standardised parameters during follow-up examinations
- Detailed reports of outcomes
- Evaluation of patient-reported outcome measures and aspects of cost-effectiveness

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