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Review Article

Survival and complication rates of tooth-implant versus freestanding implant supporting fixed partial prosthesis: a systematic review and meta-analysis

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Abstract

Purpose: This systematic review was performed to compare tooth, implant and prosthesis failures and biological and technical complications in tooth-implant vs freestanding implant supported fixed partial prostheses, in order to evaluate the effectiveness and predictability in combining teeth and implants in the same fixed partial prosthesis.

Study selection: A comprehensive and systematic literature research was conducted, according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement, to identify human trials, with a minimum sample size of 10 patients, comparing tooth-implant to freestanding implant supported fixed partial prostheses. Four groups of meta-analyses were performed based on the patients treated with tooth-implant vs freestanding implant-supported fixed partial prostheses: abutment failures, biological and mechanical complications, prosthesis failures, and prosthetic (technical) complications.

Results: The search yielded 749 records, after removal of duplicates. Based on the title assessment, the abstracts reading and the full-texts evaluation, 8 articles, published between 1999 and 2013, fulfilled the inclusion criteria and were included in the meta-analysis. The studies included were: 4 controlled clinical trials, 2 prospective and 2 retrospective cohort studies. The meta-analysis revealed no significant difference between tooth-implant and implant-implant supported fixed in the number of abutment (implant or tooth) failures, biological complications, prosthesis lost, and prosthetic complications.

Conclusions: Within the limitations of the present systematic review, although the freestanding implant supported fixed partial prosthesis remains the first choice, joining teeth and implants to support fixed prosthesis in partially edentulous patients becomes a valid alternative with an acceptable success rate.

Keywords: *Dental implants, Fixed partial prosthesis, Tooth-implant connection, Failure, Complications*

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1. Introduction

In the last decades technological and biomaterial development has led to dramatic advances in implant dentistry, allowing practitioners to perform prosthetic rehabilitations in most cases of partial or full edentulism. However, in recent years new trends are emerging in the field of implantology aimed at minimally invasive surgery and economic sustainability to satisfy the needs of an always increasing number of patients. From this point of view, joining teeth and implants to support fixed partial prostheses (FPPs) might be a feasible and predictable treatment option in some clinical situations. Clinical and statistical analyses of fixed prosthesis supported by tooth and implants have been reported in the literature since the mid-1980s by Ericsson et al. [1] and Koth et al. [2], despite recommendations by the Swedish National Health Council for the use of freestanding implant prostheses, due to the anatomical differences between implants and natural teeth and thus their biomechanical behavior [3]. Since then, several studies have showed favorable results when teeth were connected to implants, reporting longitudinal clinical data on treatment outcomes similar to freestanding implant rehabilitations. On the other hand, other studies have demonstrated more complications and lower survival rates when tooth-implant supported fixed prostheses were compared with tooth-tooth or implant-implant supported restorations [4]. Indeed, there are two conflicting opinions. Some authors advocate

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that implants and teeth should not be connected. Others believe that joining teeth and implants is a feasible and predictable treatment option in some clinical situations, such as the insufficient number of natural or implant abutments or their unfavorable distribution; remaining teeth with reduced periodontal support and increased mobility, long pontic spans and/or cantilever segments; alveolar bone deficiency requiring augmentation procedures, which are contraindicated or refused by the patient; anatomic limitations (e.g. maxillary sinus); implant failure; and economic reasons [5-12]. Nevertheless, after more than three decades of controversial results, tooth-implant connection supporting fixed prosthesis even today remains an unresolved issue. The aim of this systematic review was to identify studies comparing tooth-implant vs freestanding implant supported FPPs for assessing tooth, implant, and prosthesis failures and biological and technical complications of both prosthetic rehabilitations, in order to evaluate effectiveness and predictability in combining teeth and implants in the same FPP.

2. Materials and methods

In the present systematic review, the adopted protocol followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [13].

2.1 PICOS question

The following question was developed according to the population, intervention, comparison, outcome and study design (PICOS).
Population: Partially edentulous patients free from active periodontal disease rehabilitated with tooth-implant or freestanding implant supported FPPs with at least 1-year follow-up after implant loading.
Interventions: any type of implants or tooth-implant supported FPPs regardless of connection, cementation, fixation, and framework or veneering material.
Comparison: tooth-implant–supported fixed partial prosthesis (T-IFPPs) versus freestanding implant supported fixed partial prosthesis (I-IFPPs).
Outcomes:
Primary outcomes:

- Abutment (tooth or implant) failures defined as removal due to any biological or mechanical complication which did not allow implant or tooth to be used;
- Prosthesis failures defined as removal due to any biological or technical complication.

Secondary outcomes:

- Biologic complications at implant abutments not leading to loss, such as mucositis, peri- implantitis;
- Biologic and mechanical complications at tooth abutments not leading to extraction, such as intrusion, decay, periapical pathology, periodontitis, mobility, fracture;
- Prosthetic complications which did not require loss or replacement of the reconstruction, such as veneer or framework fracture, prosthesis screw fracture or loosening, abutment screw fracture or loosening, titanium abutment fracture, loss of retention, cement breakage, excessive occlusal wear.

Study design: Randomized clinical trials (RCTs), controlled clinical trials (CCTs) or prospective/retrospective cohort studies comparing T-IFPPs to I-IFPPs, with a minimum sample size of 10 patients (5 per group) and at least 1-year follow-up after implant loading were included. Case series, case reports, studies involving animals or in vitro models, letters to editors, narrative or systematic reviews and articles published in a different language than English were excluded.

2.2 Focused question

The focus question was formulated according to the PICOS criteria. “In partially edentulous patients, are there significant statistical differences in survival and complication rates of T-IFPPs in comparison with I-IFPPs?”

2.3 Search strategy

Detailed search strategies were developed to identify the studies eligible for inclusion in this systematic review.

2.3. 1 Electronic Search

A comprehensive and systematic electronic search was conducted in the Cochrane Central Register of Controlled Trials (CENTRAL; 2018, Issue 8), MEDLINE via OVID (from January 1966 to November 2018) and EMBASE via OVID (from 1980 to November 2018) databases. The search strategy employed combinations of keywords and was linked with the Cochrane Highly Sensitive Search Strategy (CHSSS) for identifying RCTs in MEDLINE: sensitivity maximising version (2008 revision) as referenced in Chapter 6.4.11.1 and detailed in box 6.4.c of the Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 [13]. Electronic searching was performed using the following MeSH terms: [Dental Implants OR Dental Implants, Single-Tooth OR Dental Abutments OR Dental Implantation, Endosseous OR Dental Prosthesis OR Dental Prosthesis, Implant-Supported] AND [Tooth OR Tooth Mobility OR Alveolar Bone Loss OR Dental Restoration Failure OR Prosthesis Failure OR Denture Design OR Dental Prosthesis Design OR Denture, Partial, Fixed OR Treatment outcome OR Survival Rate].

2.3. 2 Hand search

A hand search limited to articles published between January 2000 and November 2018 was conducted in the following peer-reviewed journals: Clinical Oral Implants Research, Clinical Implant Dentistry and Related Research, European Journal of Oral Implantology, Implant Dentistry, International Journal of Oral and Maxillofacial Implants, International Journal of Oral and Maxillofacial Surgery, International Journal of Periodontics and Restorative Dentistry, Journal of Prosthetic Dentistry, Journal of Clinical Periodontology, Journal of Dental Research, Journal of Oral Implantology, Journal of Periodontal Research, and Journal of Periodontology.

Unpublished literature search

An unpublished literature search was performed in the register of clinical studies of the US National Institutes of Health (www.clinicaltrials.gov) and in the multidisciplinary European database (www.opengrey.eu) in order to identify ongoing trials and grey literature. The references of all retrieved papers and review articles were also checked to select potentially relevant additional studies and to improve the sensitivity of the search.

2.4 Study selection

Based on the inclusion criteria, titles and abstracts of the identified publications were initially screened by two independent review authors for possible inclusion in the review. Full-text versions were obtained for titles and abstracts appearing to meet the inclusion criteria or reporting insufficient data to make a clear decision. The full-test analysis was performed independently and in duplicate by two review authors to establish whether or not the studies met the inclusion criteria. Any disagreement during the selection process was resolved through discussion and when resolution was not possible an experienced senior review author was consulted. Cohen’s kappa coefficient (k) was used to calculate the agreement between the reviewers. The level of agreement is regarded as excellent when $k > 0.75$, fair to good when it is 0.40 to 0.75, and poor when it is <0.40. All of the articles meeting the inclusion criteria underwent data extraction and quality assessment. All irrelevant articles were excluded and the reasons for their exclusion are outlined.

Table 2. Characteristics of excluded studies.

Study	Reason for exclusion
Ästrand et al 1991[15]	Redundant publication (Gunne et al. 1999[24])
Gunne et al 1992[16]	Redundant publication (Gunne et al. 1999[24])
Olsson et al 1995[17]	Redundant publication (Gunne et al. 1999[24])
Brägger et al 2001[18]	Redundant publication (Brägger et al 2005[26])
Naert et al 2001[19]	Lack of control group
Nedir et al 2006[20]	No pertinent study
Nickenig et al 2006[21]	Lack of control group
Nickenig et al 2008[22]	Lack of control group
Noda et al 2013[23]	Insufficient information for data extraction

2.5 Data extraction

The available data were extracted using specially designed data-extraction forms (Table 2). Any disagreement was discussed until consensus and where necessary a third review author was consulted. In case of redundant publications, only the most recent and with longest follow-up was included.

2.*6 Quality assessment*

The risk of bias in the included studies was assessed independently and in duplicate by two review authors as part of the data-extraction process. This evaluation was conducted using the Cochrane recommended approach for assessing risk of bias in randomized controlled clinical studies including four quality parameters: sequence generation, address of incomplete outcome data, free of selective outcome reporting, and other sources of bias [14]. Disagreements were discussed in order to aim for consensus.

2.*7 Assessment of heterogeneity*

Heterogeneity was assessed using Review Manager 5 (RevMan current version: 5.3.5). The significance of any discrepancies in the estimates of the treatment effects from the different trials was assessed using Cochran's test for heterogeneity and the I^2 statistic. The chi-square test was used to evaluate the percentage of total variation across studies that was due to heterogeneity rather than chance. Heterogeneity would have been considered to be significant if the probability value was less than 0.1. I^2 statistic was used to quantify inconsistency across studies. The importance of inconsistency would have been considered relevant with an I^2 value over 50%, indicating moderate to high heterogeneity.

2.8 Data analysis

A meta-analysis was performed only if there were studies with similar comparisons that reported the same outcome measures. Risk ratios were combined for dichotomous data, using either fixed-effects models or, in the presence of heterogeneity between the studies, random-effects models. However, if there was a high degree of heterogeneity, the data were explored further to determine if they should be excluded from the meta-analysis [14]. Four groups of meta-analyses were performed based on the patients treated with T-IFPPs versus I-IFPPs:

- Number of abutment (implant or tooth) failures in the two groups;
- Number of biological and mechanical complications at implant or tooth abutments in the two groups;
- Number of prosthesis failures in the two groups;
- Number of prosthetic complications in the two groups.

A forest plot was created to illustrate the effects in the meta-analysis of the different studies and the global estimation. Review Manager 5 was used to perform all analyses. The significance cut-off was set at $p < 0.05$.

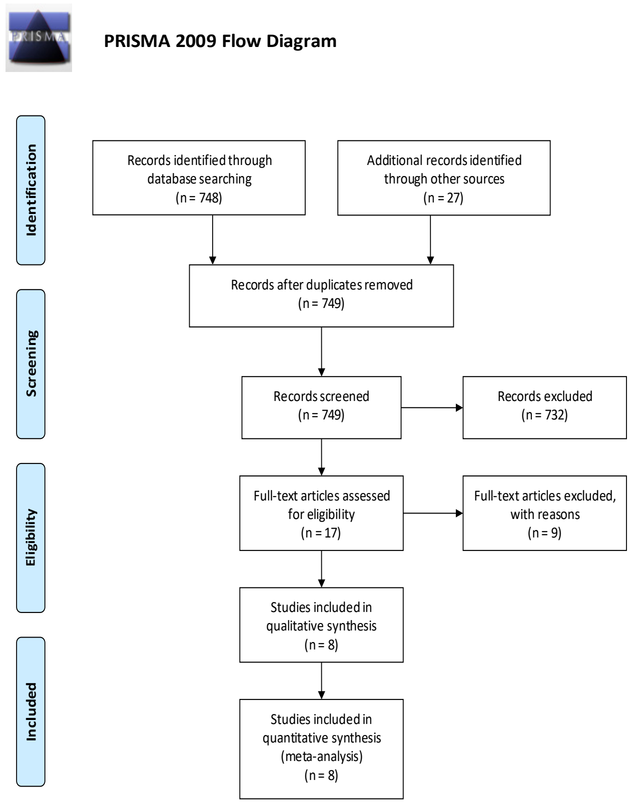

Fig. 1. Flowchart of the selection of the studies for the review.

3. Results

3.1 Study selection

Flow-chart of the search strategy and studies selection is depicted in Figure 1. A total 775 articles were identified, 748 through the electronic search and 27 from the hand search and through bibliographies of relevant papers and review articles. Out of 749 studies resulting after removal of duplicates, 732 were excluded, 620 based on the title assessment (inter-reader agreement k = 0.81 ± 0.33) and 112 based on the abstracts reading (inter-reader agreement k = 0.71 ± 0.22). Finally, of the 17 articles remaining for full-text evaluation, 8 fulfilled the inclusion criteria and 9 were excluded (Table 1) from the meta-analysis. The year of publication for the included studies ranged from 1999 up to 2013, with median year of publication being 2004.

3.2 Study characteristics

Characteristics of the included studies are summarized in Tables 3 and 4. The studies comparing T-IFPPs with I-IFPPs included in this systematic review were: 4 CCTs, 3 with a split-mouth design [8,16,28] and 1 with a parallel design [24]; 2 prospective cohort studies [26,30] and 2 retrospective cohort studies [27,29]. No RCTs were available. All eight studies were conducted in an institutional environment. Out of 8 studies, 4 compared two arms [8,24,25,28], whereas 2 studies evaluated three different approaches to support FPPs [26,29] and 2 studies evaluated six different approaches [27,30], so data from each experimental group was analyzed independently.

Table 1. Data extraction form.

Methods
·Study design
·Follow-up period
Partecipants
·Country of origin and study setting
·Sample size
·Age
·Gender
Interventions
·Restoration type (T-IFPP, I-IFPP)
·Site (upper, lower)
· Prosthesis length (units)
·Implant abutments (brand, diameter, length)
·Loading protocol (1-stage, 2-stage)
·Number of implants in each prosthesis
·Tooth abutments
·Tooth-implant connection type (rigid connection, no-rigid connection)
·Tooth fixation (permanent or temporary cementation)
·Prosthesis fixation (screw, cemented)
·Prosthesis construction (metal-ceramic, metal-acrylic)
·Opposing dentition (natural dentition, T-IFPP, I-IFPP, denture)
Outcomes
·Number of implant/tooth failures
·Number of prosthesis failures
·Tooth complications (intrusion, mobility, decay, periapical pathology, bone loss, fracture, extraction)
·Implant complications (bone loss, loss of integration, fracture, mucositis, periimplantitis)
·Prosthetic complications (veneer or framework fracture, prosthesis screw fracture, abutment screw fracture, fracture of titanium abutment, loss of retention, cement breakage, screw loosening, loosening of titanium abutment, excessive occlusal wear)
Notes
·Findings and conclusions of the study

3.3 Assessment of risk of bias

The bias risks are summarized in Figure 2. The evaluation was conducted using the checklist of Cochrane Collaboration's tool for assessing the risk of bias excluding domains 2, 3 and 4. The methodologic quality of the included studies was high for 3 [8,24,28], moderate for 3 others [25-27] and low for the last 2 [29,30]. The shortcomings mostly concerned domains such as "random sequence generation and other bias."

3.4 Effects of interventions

3.4. 1 Abutment (tooth or implant) failures and biological and mechanical complications

Abutment (tooth or implant) failures and biological and mechanical complications were assessed in 5 investigations [8,24-26,28]. In T-IFPPs abutment failures were 14 (8 out of 128 implants and 6 out of 130 teeth) and complications were 9 (3 out of 128 implants and 6 out of 130 teeth). In I-IFPPs abutment failures were 8 out of 231 implants and complications were 11 out of 231 implants. The meta-analysis revealed no significant difference in the number of abutment failures between T-IFPPs and I-IFPPs (risk ratio (RR) 1.82; 95% CI 0.28 to 11.98, $p = 0.53$, heterogeneity: Tau^2 1.96; $Chi^2 = 6.90$, $df = 2$ ($p = 0.03$); $I^2 = 71\%$) (Fig. 3); and no significant difference in the number of biological complications between T-IFPPs and I-IFPPs (RR 0.81; 95% CI 0.32 to 2.08, $p = 0.67$, heterogeneity: Tau^2 0.00; $Chi^2 = 3.64$, $df = 4$ ($p = 0.46$); $I^2 = 0\%$) (Fig. 4). No failures of tooth or implant abutments in both 15 I-IFPPs and 34 T-IFPPs were observed by Akça and Çehreli [25]. The 34 teeth used as abutments were permanently cemented to the rigid bridges and 4 of them were root-canal filled.

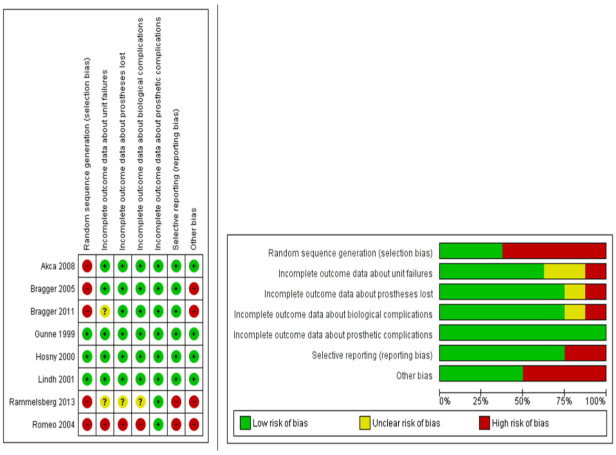

Fig. 2. Risk of bias summary: review authors' judgments about each risk of bias item for each included study and risks of bias in all included studies presented as percentages.

Only one abutment tooth required root canal treatment without any periapical pathology and the subsequent prosthesis replacement. In the Brägger et al. [26] study, at the 10-year observation period 2 hollow body implants (1/69 in the I-IFPPs and 1/22 in the T-IFPPs) were lost due to fracture after development of a bony defect. A further 4 implants were lost because of biological failure in 4 patients rehabilitated with T-IFPPs. The same 4 patients experienced also the loss of the 4 abutment teeth (4 out of total of 24 teeth supporting T-IFPPs) for caries following loss of retention, despite being rigidly connected and permanently cemented. Last, 11 implants (8 in the I-IFPPs and 3 in the T-IFPPs) affected by peri-implantitis, defined as a probing pocket depth of 5mm and bleeding on probing or pus secretion, were treated in 9 cases using antiseptics/antibiotics and in 2 cases using additional resective surgery. Gunne et al. [24], in a longitudinal study with intra-individual comparison between T-IFPPs and I-IFPPs in 23 patients, reported a total of 7/69 implants (5 in I-IFPPs and 2 in T- IFPPs) lost at the 5-year follow-up, without further losses at 10-year follow-up, with a cumulative success rate of 88.4%. Four and three implants were lost respectively within 6 months and between 18 and 24 months after loading. After 10 years one tooth was lost due to caries and endodontic problems, and only one tooth had more than physiological mobility. Furthermore, soft tissue inflammation with bleeding on probing was found around 3 implants, all belonging to I-IFPPs, and 1 abutment tooth. In the Hosny et al. [28] study, no failures were observed up to a 14-year follow-up (mean observation period of 6.5 years) regarding 30 implants and 30 teeth in T-IFPPs and 48 implants supporting I-IFPPs. Likewise, no biological or mechanical complications at abutments level were reported, except for the periapical lesion of one tooth at 6-month follow-up. In Lindh et al. [8], out of 57 implants valid for intra-individual comparisons (19 of the original 26 patients) 2 supporting an I-IFPP and in 1 a T-IFPP failed within 100 days of loading. At the end of 24-month follow-up referring to 54 implants still valid for intra-individual comparisons (18 of the original 26 patients), no further failure occurred. Regarding the 26 initial abutment teeth (15 root-treated, 11 vital), only 1 was lost because of fracture more than two years after prosthetic insertion. Instead, 3 root canal treatments were required, due in two cases probably to the initial preparation trauma and in one case to dentin demineralization caused by the washout of temporary cement.

3.4. 2 Prosthesis failures and prosthetic (technical) complications

Prosthesis failures were reported in six included studies [8,24-28]. Out of a total of 247 FPPs, 114 supported by implants and 133

Table 3. Characteristics of the included studies.

Authors Year	Study setting	Study design	No. patients (gender)	Age (mean)	Study aim	Follow-up (mean)	Implant brand diameter lenght	Comments	Conclusions
Akça K and Çehreli MC (2008)[25]	Hacettepe University Faculty of Dentistry Ankara, Turkey	P	29 (13 M- 16 F)	31-73 (48.3)	To compare prosthetic outcomes of rigidly connected short-span T-IFPPs and I-IFPPs.	24-30 months (26 months)	ITI/ Straumann 4.1 mm 10 mm		Similar outcomes for T-IFPP and I-I FPP in the early stages of function.
Brägger U et al. (2005)[26]	University of Berne, School of Dental Medicine Switzerland	P	127 38-drop-outs at 10 years follow-up (34M -55F) T-IFPPs=21 I-IFPPs=29 SCs=48)	19-78 (49.3)	To assess prospectively over 10 years the incidences of both technical and biological complications as well as failures occurring in a cohort of consecutive patients with fixed reconstructions on implants.	8-12 years (10 years)	ITI/ Straumann NR NR		Statistically significantly fewer biological failures occurred with T-I FPPs compared with the I-IFPPs ; T-IFPPs experienced statistically significantly more frequent technical failures compared with the other two groups of suprastructures.
Brägger U et al. (2011)[27]	University of Berne, School of Dental Medicine Switzerland	R	84 (51 F–33 M) (for 6 groups)	36.2-83.4 (62)	To evaluate retrospectively the biological and technical failure and complication rates with I-IFPPs, I-CFPPs, T-TFPPs, T-CFPPs, T-IFPPs and T-ICFPPs in partially edentulous patients treated for chronic periodontitis by graduate students.	7.43-10.04 years (NR) Range 2.29–26.42 years) (11.31 years)	NR NR NR		T-IFPPs did not result in increased failure and complication rates compared with I-IFPP.
Gunne F et al. (1999)[24]	Umeå University Maxillofacial Unit Sweden	P SM	23 (8 M - 15 F) 3 drop-outs	41-70 (57.7)	To compare T-IFPPs with I-IFPPs after 10 years of function.	10 years	Nobel Biocare NR 7-13mm	In T-IFPPs, an anterior unconnected "sleeping" implant was planned in in order to remade lost prosthesis	After 10 years of function no differences could be demonstrated between implant supported FPPss and tooth-implant supported FPPs regarding failure rates or marginal bone level changes.
Hosny M et al. (2000)[28]	University Hospitals of Catholic University of Leuven Belgium	R SM	18 (6 M-12 F) 4 drop-outs at more 18-month follow-up from the completion of the study	37-65 (49.5)	To compare the outcome of T-IFPPs and I-IFPPs up to 14-year follow-up.	14 years (6.5 years)	Brånemark NR 7 -18 mm		T-IFPPs did not affect the long-term outcome in comparison to I-IFPPs
Lindh T et al. (2001)[8]	Umeå University Department of Prosthetic Dentistry Sweden	P SM	26 (11 M - 5 F) 2 drop-outs	49-84 (67)	To compare the biological and mechanical consequences when implants placed in the posterior maxilla were connected to teeth, or when used standing free from the remaining natural dentition.	2 years	Nobel Biocare MarkII selftapping 3.75 mm 10-18 mm	In 13 TIFPPs one further anterior implant was planned as non-loaded reserve.	There was no difference in failure rate for the implants in the two different prosthesis designs (T-IFPPS and I-IFPPs).
Rammelsberg P et al. (2013)[29]	Heidelberg University Hospital Department of Prosthodontics Germany	R	132 (NR)	21-83 (61.2)	To investigate the complications of metal-ceramic and all-ceramic T-IFPPs, I-IFPPs and I-CFPPs.	6-79 months (28 months)	NR NR NR	Only data on prosthetic complications in T-IFPPs and I-IFPPs were retrievable.	The incidence of short-term failure for all groups of prosthesis was minimal (1.8%) and the incidence of short-term complications for T-IFPPs was no higher than for I-IFPPs.
Romeo E et al. (2004)[30]	University of Milan Dental Clinic, Department of Medicine Surgery and Medicine Italy	P	250 (106 M – 144 F) 49 drop-outs at 7 years follow-up (for 6 groups)	20-67	To evaluate the medium to long-term survival and success of different ITI implant-supported prosthesis (SCs, I-IFPPs, I-CFPPs, FCPs, T-IFPPs, ODs).	16–84 months (mean 46.2 months)	ITI/ Straumann 3.3-4.8 mm 8-16 mm	Only data on prosthetic complications in T-IFPPs and I-IFPPs were retrievable.	Seven-year survival rates were similar for implants supporting SC, I-IFPP, I-CFPP, FCP and T-IFPP.

Legend: P=prospective; R=retrospective; SM= split-mouth; Ra= randomized; M=male; F= female; T-IFPP= tooth-implant supported fixed partial prosthesis; I- IFPP= implants supported fixed partial prosthesis; SC= Single Crown ; T-TFPP= teeth supported fixed partial prosthesis; T-ICFPP= tooth-implant supported cantilever fixed partial prosthesis;, I-CFPP= implants supported cantilever fixed partial prosthesis; T-CFPP= teeth supported cantilever fixed partial; FCP= fixed complete prosthesis, OD= overdenture.

Table 4. Additional characteristics of the included studies.

Authors Year	Prosthesis	Site (lower/upper)	Prosthesis lengh (units)	Implant abutments	Loading protocol	Implants in each prosthesis	Tooth abutments	Tooth-implant connec-tion	Tooth fixation	Prosthesis fixation	Prosthesis construction	Opposing dentition
Akça K andÇehreli MC.(2008)[25]	49 T-IFPPs=34 I-IFPPs=15	T-IFPPs= 30L; 4UI-IFPPs= 10L; 5U	3	T-IFPP=34 I-IFPP=30	2-stage	T-IFPP=2 I-IFPP=1	34	Rigid	PC	Cement-retained	Metal-ceramic	NR
Brägger U et al.(2005)[26]	124 T-IFPPs=22 I-I-FPPs=33 SC=69	NR	2-10	T-IFPPs=22 I-IFPPS=69	2-stage	T-IFPPs=1 I-IFPPs=NR	24	NR	NR	T-IFPPs Screw = 12 Cemented =10I-IFPPs Screw = 8 Cemented = 25	NR	Natural dentition, SC or FPP.
Brägger U et al. (2011)[27]	T-IFPPs=20 T-ICFPPs=10 I-IFPPs= 9 I-CFPPs=15 T-TFPPs=82 T-CFPPs=39	NR	2-14 (for all groups)	86 (for all groups)	NR	NR	356 (for all groups)	NR	PC	Cement-retained	Metal-ceramic	NR
Gunne F et al.(1999)[24]	T-IFPPs=20 I-IFPPs=20	L/ posterior	3	T-IFPPs=23 I-IFPPs=46	2-stage	T-IFPPs=1 I-IFPPs=2	1	Rigid	PC	Screw-retained	Gold-acrylic	Complete denture
Hosny M et al.(2000)[28]	T-IFPPs=18 I-IFPPs=18	T-IFPPs 5L;13U I-IFPPs 5L;13U	T-IFPP3 -8I-IFPP 2-5	T-IFPPs=30 I-IFPPs=48	2-stage	T-IFPPs=1-3 I-IFPPs=2-4	1-4	Rigid=11 Non-rigid=7	TC=16 PC=14	Screw-retained	Metal-eramic=14 Metal-acrylic=4	NR
Lindh T et al.(2001)[8]	T-IFPPs=26 I-IFPPs=26	U	3	88	2-stage	T-IFPPs=2 I-IFPPs=1	1	Rigid	TC	Screw-retained	Titanium-ceramic	Natural teeth or implants
Rammelsberg P et al.(2013)[29]	T-IFPPs=48 I-IFPPs=91 I-CFPPs =27	93 U; 73 L	3-6	NR	2-stage	NR	NR	Rigid	PC or SPC	Cement-retained	Metal-ceramic=140 Zirconia=26	NR
Romeo E et al. (2004)[30]	T-IFPPs=13 I-IFPPs=137 SCs=106 I-CFPPs=42 FCPs=5 OD = 37	T-IFPPs 5 L;8 U I-IFPP 84L;53U	NR	T-IFPPs=31I-IFPPs=295	2-stage	NR	NR	NR	NR	NR	NR	NR

Legend: NR= not reported; U= upper; L=lower; T-IFPP= tooth-implant supported fixed partial prosthesis; I- IFPP= implants supported fixed partial prosthesis; SC= Single Crown ; T-TFPP= teeth supported fixed partial prosthesis; T-ICFPP= tooth-implant supported cantilever fixed partial prosthesis;, I-CFPP= implants supported cantilever fixed partial prosthesis; T-CFPP= teeth supported cantilever fixed partial; FCP= fixed complete prosthesis, FPP= fixed partial prosthesis; OD= overdenture, PC= permanent cementation; TC= temporary cementation; SPC=semi-permanent cementation.

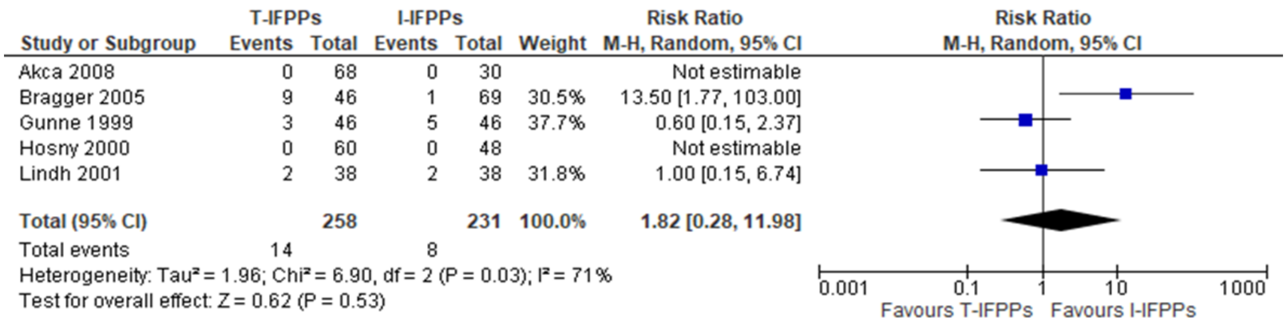

Fig. 3. Forest plot of comparison T-IFPPs vs I-IFPPs: abutment (tooth or implant) failures.

supported by teeth and implants, failures were 7 and 14, respectively. Information about prosthetic complications were reported in all 8 included studies [8,24-30]. Out of a total of 550 FPPs, 349 supported by implants and 201 supported by teeth and implants, prosthetic complications were 78 and 32, respectively. The most common prosthetic complications were veneer fractures (acrylic, ceramicbetween T-IFPPs and I-IFPPs (RR 0.76; 95% CI 0.44 to 1.33, p = 0.34, heterogeneity: Tau^2 0.18; Chi^2 = 9.70, df = 6 (p =0.14); I2=38%) (Fig. 6). In Akça and Çehreli [25] the only prosthesis replacement and composite), screw loosening, losses of retention, abutment or abutment-screw fractures. The meta-analysis showed no significant difference in the number of prostheses lost between T-IFPPs and I-IFPPs (RR 1.78; 95% CI 0.76 to 4.17, p = 0.18, heterogeneity: Tau^2 0.00; Chi^2 = 3.69, df = 4 (p = 0.45); I2 = 0%) (Fig. 5); and no significant difference in the reduction of prostheses complications was warranted by the root canal treatment of one tooth abutment,

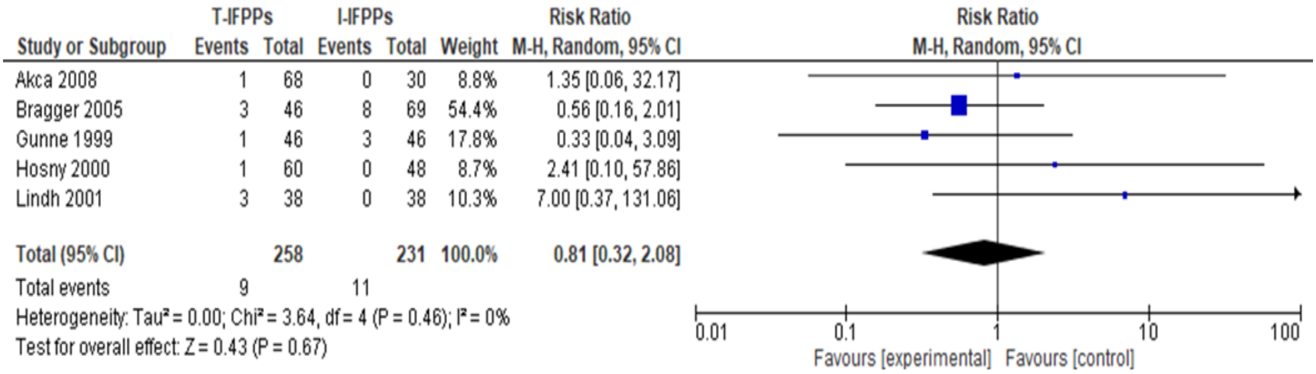

Fig. 4. Forest plot of comparison: T-IFPPs vs I-IFPPs: biological and mechanical complications at tooth or implant abutments.

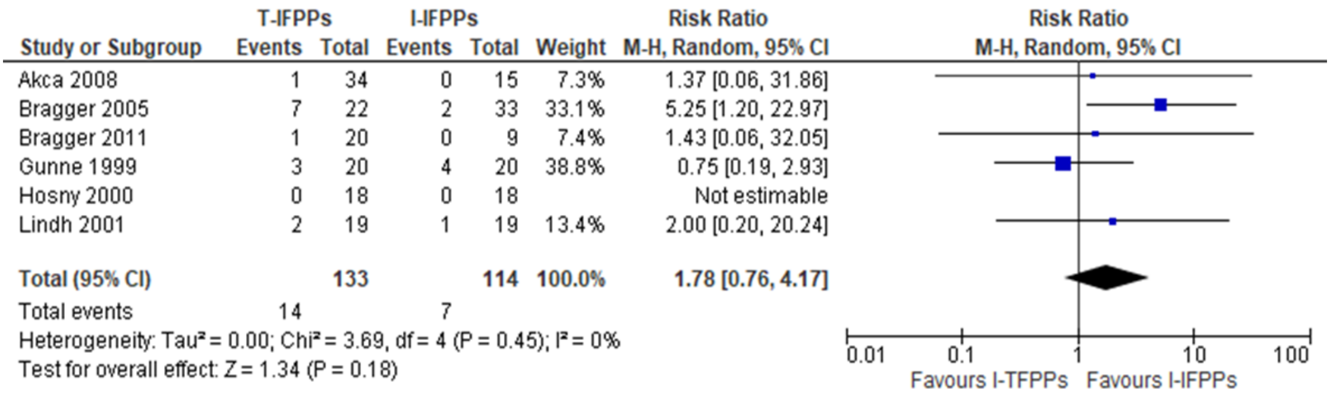

Fig. 5. Forest plot of comparison T-IFPPs vs I-IFPPs: abutment (tooth or implant) failures.

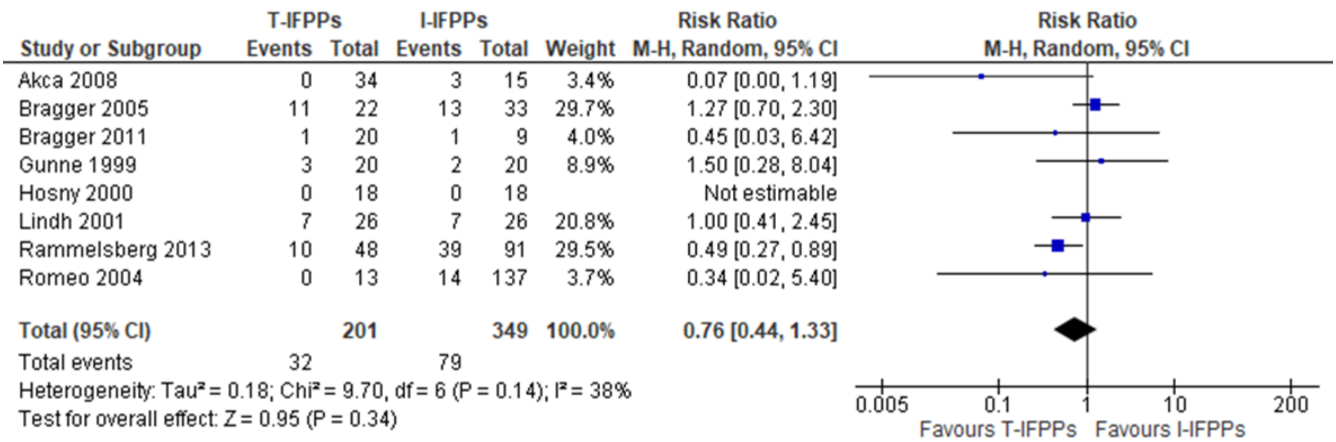

Fig. 6. Forest plot of comparison T-IFPPs vs I-IFPPs: abutment (tooth or implant) failures.

whereas technical complications occurred only in I-IFPPs, with 3 cases of chipping of porcelain veneering material. All prostheses were cemented. In the Brägger et al. [26] study, the total number of prostheses failed because of biological and technical complications after an average time in function of 10 years was 2 out of 33 (6.1%) I-I FPPs and 7 out of 22 (31.8%) T-IFPPs, without any information about the correlation with prosthesis fixation. Furthermore, technical complications not leading to prosthesis loss or remake were experienced only in the cemented prostheses (10 out of 25 I-IFPPs and 4 out of 10 T-IFPPs). Conversely, no complications affected screw-retained prostheses of the two groups (12 I-IFPPs and 8 T-IFPPs). Over the 10 years of maintenance, 18 out of 33 I-IFPPs (54.5%) and 11 out of 22 T-IFPPs (50%) remained completely free of any technical or biological complication/failure. Statistically significant differences were found in the loosening of occlusal screw (6/25 I-IFPPs vs 4/10 T-IFPPs) and loss of retention (4/25 I-IFPPs vs 5/10 T-IFPP), whereas 1 abutment loosening in I-IFPPs and 2 fractures of porcelain for each group of prosthesis showed no difference of the frequency. In 2011 Bragger et al. [27] evaluated retrospectively six different groups of ceramic-metal FPPs, all fixed by zinc phosphate or glass ionomer cement, in patients treated for chronic periodontitis by graduate students. In the first 10 years of follow-up, no failure and one technical complication in the 9 I-IFPPs and one failure and one technical complication in the 20 T-IFPPs were found. The authors reached the conclusion that T-IFPPs did not result in increased failure and complication rates compared with the I-IFPPs. In Gunne et al. [24] 4/23 I-IFPPs and 2/23 T-IFPPs were lost due to implant loss at the 5-year examination. At the 10-year follow-up (20 out of the initial 23 patients), after a further one T-IFPP lost, due to caries and endodontic complications of the abutment tooth, the cumulative success rate of 80% and of 85% were reported respectively for I-IFPPs and T-IFPPs. In this study, the only technical complications observed were 5 loose gold abutment screws, 3 belonged to T-IFPPs and 2 to I-IFPPs. It is worth noting that the implant prostheses were fixed to the titanium abutments with gold screws, whereas the gold crowns with acrylic veneer were cemented with zinc-phosphate cement on teeth and rigidly connected with the frameworks by a precision attachment. No complications were observed by Hosny et al. [28] No complications were observed by Hosny et al. [28] in all 36 screw-retained prostheses, regardless of the distribution of implants, teeth, and pontics and their sequence in the arch or the type and mode of connection. Lindh et al. [8] reported a cumulative survival rate of 96% for T-IFPPs and 95% for the I-IFPPs in patients with Kennedy Class I residual dentitions in the maxilla. All prosthetic frameworks were fabricated in titanium according to the Procera® method and coated with porcelain. All crowns on implant abutments were screw-retained. The T-IFPPs were fitted with custom-made rigid titanium attachments, except for the prostheses with limited vertical height, in which the crown on the natural abutment was cemented with temporary cement. Prosthetic complications detected in the interval between 12 and 24 months were 3 fractures of implant abutment screws in I-IFPPs and 1 prosthesis screw fracture and 2 instances of temporary cement breakage in T-IFPPs. Furthermore, one fistula at abutment level, healed upon retightening of the abutment screws, 2 prosthesis screws loosing, and 1 excessive occlusal wear, equally allocated in both types of prosthesis, were reported. Rammelsberg et al. [29], investigating the complications of 118 I-IFPPs (91 conventional and 27 with cantilever) and 48 T-IFPPs, reported a cumulative low incidence of prosthetic failure (1.8%), after a mean observation period of 2 years and 4 months (maximum: 6 years and 7 months). One-hundred and forty FPPs had a metal framework with ceramic veneer, and 26 FPPs were made with zirconia frameworks. All FPPs were made in one piece without using connectors and fixed with permanent (82) or semi-permanent (84) cementation. The failures were due to 2 implant losses and 1 replacement caused by extended chipping of the veneer, without any indication of allocation between the three different groups of prostheses. In contrast with the low incidence of failure was a high incidence of complications, including loss of retention (22/91for I-IFPPs and 3/48 for T-IFPPs) and chipping of ceramic veneers (17/91for I-IFPPs and 7/48 for T-IFPPs). Therefore, the incidence of complications tended to be lower for T-IFPPs (10/48) compared with I-IFPPs (39/91). Romeo et al. [30], analyzing different types of prosthesis supported by ITI implants, including I-IFPPs and T-IFPPs, found prosthetic complications (5 decementions, 3 abutment-framework connection screw loosening, 1 abutment screw fractured and 1 prosthetic pontic fractured, 4 aesthetic veneer fractures) only in 137 I-IFPP. No prosthetic complication was observed in 13 T-IFPPs. In this study all FPPS were made of gold alloy and porcelain, some were fixed by zinc-oxyphosphate or zin-eugenol oxide cement, some were screw-retained using a15- Ncm torque.

4. Discussion

This systematic review was performed to compare tooth, implant, and prosthesis failures and biological and technical complications in tooth-implant– vs freestanding implant supported FPPs in order to evaluate the effectiveness and predictability of combining teeth and implants in the same FPP. Over the last decades a certain number of papers have been published about T-IFPPs, ranging from CCTs, prospective or retrospective cohort studies, case series, case reports, studies involving animals or in vitro models, narrative or systematic review, with contrasting results and opposite opinions. In the authors' knowledge, the present was the only systematic review and meta-analysis comparing T-IFPPs with I-IFPPs and performed according to the PRISMA statement. However, despite the complete and rigorous screening process, no RCTs were available and only 8 prospective and retrospective studies, published between 1999 and 2013, were included. This made it impossible to strictly compare the present findings with those reported previously in the literature, due to extreme heterogeneity of aims, sample sizes, implant systems, follow-up periods, connection types, prosthesis design, and data collection. However, some comparisons may be retrieved from several studies.

4.1 Abutment (implant or tooth) failures

The results of the present review on the failure of tooth and implant abutments in T-IFPP were consistent with those reported by Lang et al. [31] in a systematic review with meta-analysis conducted on 13 prospective and retrospective cohort studies relating to FPPs supported by teeth and implants. After an observation period of 5 years (6 studies), 15 out of 529 abutment teeth and 20 out of 583 functionally loaded implants were lost. After an observation period of 10 years (2 studies) 5 teeth were lost on a total of 47 (10.6%, range 3.5% to 23.1%) and 7 implants on a total of 45 implants (15.6%, range 6.5% to 29.5%). Low failure rates for implant and tooth abutments after follow-up periods with a mean range of 18 to 120 months were also found by Tsaousoglou et al. [32]. Summarizing the 10 studies' data (481 patients, 526 FPPs supported by 981 abutment teeth connected with 1072 implants), the overall failure rate was 1.7% and 3.64% and the overall survival rate ranged between 90% and 100% and between 94.1% and 100%, respectively for implants and teeth. A similar summary estimate for the survival rate for teeth (2.72%) and for implants (2.53%) after an observation period of 5 years was reported by Mamalis et al. [33] in a systematic review on splinting implants and natural teeth in partially edentulous patients. By assessing data reported in 11 studies on tooth and implant abutment survival in T-IFPPs, 18/661 abutment teeth (2.76%) and 20/789 functionally loaded implants (2.53%) were lost. After 10-year follow-up, a statistically significant difference in the summary for the survival for teeth (5.65%) and implants (1.98%) was found, with 28/496 abutment teeth and 10/504 implants lost. Although the meta-analysis in the present review showed no significant difference ($p \leq 0.53$) between T-IFPPs and I-IFPPs in the abutment (tooth/implant) failures, the number of implants failed was higher in T-IFPPs (8/128) than in I-IFPPs (8/231). These data were in agreement with the results of a series of systematic reviews of the survival and complication rates of fixed partial dentures after an observation period of at least 5 years [31,34]. Comparing implants connected to teeth to freestanding implants, a significantly higher annual failure rate during the first 5 years after loading (1.33% vs 0.51%) was reported for implants combined with teeth. Furthermore, the implant survival rates were lower in T-IFPPs than I-IFPPs (90.1% vs 95.4%) at 5 years and much lower at 10 years (82.1% vs 92.8%) [31,34]. Slight different implant survival estimates (94.8% and 89.8% after 5 and 10 years, respectively) were detected in a recent systematic review and meta-analysis on survival rates and complication behaviour of T-IFPPs in partially edentulous patients with at least two adjacent missing teeth [35].

4.2 Biological and mechanical complications

Biological and mechanical complications retrieved in the selected studies were low both for tooth and implant for implant abutments. The meta-analysis revealed no significant difference in the number of biological and mechanical complications between T-IFPPs and I-IFPPs ($p = 0.88$). Similar results were reported by Tsaousoglou et al. [32], which found an occurrence up to 11.53% for periapical lesions, 5% for caries and 3.84% for root fractures out of 981 abutment teeth, and an occurrence up to 2.7% for loss of osseointegration and 2.32% for periodontal pathology out of 1072 implants. Comparing survival and complication rates of different designs of tooth and implant-supported fixed reconstructions in a systematic review, Pjetursson et al. [36] estimated, after an observation period of 5 years, soft tissue complications of 8.6% and 7% for fixed dental prostheses supported by solely implant and combined tooth-implant, respectively. Surprisingly, no tooth intrusion was detected in the selected studies of the present review and this might be affected by the small number of the evaluated tooth abutments and the prevalence of rigid connections. In the literature the most reported incidence in the occurrence of intrusion of abutment teeth was 3.5% to 5%, with a high discrepancy (range 3% to 37%) due to the difference in study designs, sample sizes, types of connector, implants, and prosthesis [37]. Nevertheless, intrusion is almost exclusively detected for nonrigid connections or subsequent to fracture or loosening of the rigid connection;

it is estimated at 5.2% (26/ 526 teeth) after 5 year follow-up by Lang et al. [31], and at 8.19% in presence of nonrigid connections in the meta-analysis performed by Tsaousoglou et al. [32]. Similar results were also found by Fugazzotto et al [10], which, examining 3096 sites of teeth connected to implants after an observation period ranging between 3 and 14 years, detected 9 cases of intrusion, all associated with fractures or loosening of the rigid connection.

4.3 Prosthesis failures

In the present study, the number of prostheses lost was higher for T-IFFPs (14/133) compared to I-IFPPs (7/114), but no significant difference between the two groups of reconstructions (p = 0.18) was shown by the meta-analysis. Although interesting and worthy, it was not possible to correlate prosthesis failures to prosthetic fixation methods (cementation or screw-retention), because included studies did not report clear information about this issue. Mamalis et al. [33] reported a number of failures of T-IFPPs (9 out of 534) at 5-year follow- up, with the summary estimate of 1.08% for failure and of 94.73% for the survival rate. Instead, prosthesis failures at 10-year follow-up were 33, with the summary estimate of 2.51% for failure and of 77.77% for survival rate. In the authors' opinion, the survival rate lower for an observation period of 10 years compared with 5 years was probably due to the higher failure rates of the abutment teeth rather than of the implants. Instead, in a more recent systematic review and meta-analysis of von Stein-Lausnitz et al.[35], failures of T-IFFPs were 10 out of 86 (estimated survival rate of 90.8%) after five years and 13 out of 60 (estimated survival rate of 82.5%) after 10 years. Lang et al. [31], after an observation period of 5 years (5 studies), found 7 failures out of 115 T-IFPPs, with the study-specific estimated survival ranging between 90.5% and 100% and an estimated survival rate of 94.1% (90.2% to 96.5%). After an observation period of 10 years (4 studies) failures were 14 out of 72 T-IFPPs, with the study-specific survival ranging between 70.2% and 85.1% and a summary estimated survival rate of 77.8% (66.4% to 85.7%). According to the authors' knowledge, the relatively low survival rate of T-IFPPs could not be attributed to the failure rates of teeth abutments and implant abutments, which were not significantly different from each other. Comparing data deriving from the same series of systematic reviews above mentioned [31,34], the failure rates of T-IFPPs and I-IFPPs were similar at 5- year follow-up (5.9% vs 5%) but significantly different at 10-year follow-up, with 22.2% failures in the tooth-implant group and 13.3% in the solely-implant group. The respective FPP survival rates were 94.1% at 5 years and 77.8% at 10 years for T-IFPPs and 95% at 5 years and 86.7% at 10 for I-IFPPs. A survival rate lower of T-IFPPs (91.27%) than for I-IFPPs (94.52%) in a mean follow-up period ranging between 5 to 10 years was reported more recently by Muddugangadhar et al. [37] in a comparative analysis. The authors retrieved 23 failures out of 294 T-IFPPs (14 studies) for a survival rate of 91.27%, 145 failures out of 2340 I-IFPPs (26 studies) for a survival rate of 94.525%. In the meta-analysis, the annual failure rate of T-IFPPs (1.514) was statistically significantly higher than the 0.881 seen for I-IFPPs. These results differed from those reported by Pjetursson et al. [36]; the reason for this was, the authors believed, the better designs and treatment protocol introduced in recent years.

4.4 Prosthetic complications

The meta-analysis showed no significant difference in the number of prostheses complications between T-IFPPs and I-IFPPs (p = 0.14). Nevertheless, the number of prosthetic complications was lower in the T-IFPPs (32/201) compared to I-IFPPs (79/349). Also for this topic, it was not possible to make any correlation to prosthetic fixation methods for the lack of information in the selected studies. The most common prosthetic complications detected in the selected studies were the same as those reported by Lang et al. [31]. Out of 60 T-IFPPs, an incidence of technical complications was estimated ranging from 0.7% (abutment and screw fractures) to 9.8% (fractures of veneer material) after a follow-up time of 5 years. At 10-year follow-up, loss of retention was present in 24.9% of prostheses and abutments/ screw loosening occurred at rates up to 26.4% [31]. Similarly, in the systematic review of Tsaousoglou et al. [32], the most frequent complication was the porcelain occlusal fracture, with an occurrence of up to 16.6%, followed by screw loosening with 15% and cement failure and screw fractures with 7.98%. The number of prosthetic complications of T-IFPPs, smaller than in other studies, might be explained by the extension and the type of connections and fixations of the evaluated prostheses, which were mostly short-span, rigidly connected, and cemented to natural teeth. This interpretation is in agreement with data reported by Nickenig et al. [38] and Borg et al [11]. In reviewing card files and documentation regarding 84 T-IFPPs (132 abutment teeth, 142 implant abutments), Nickenig et al. [38] found that technical complications (10% after 5 years and approximately 13% after 8 years) were more frequent in nonrigid (8/28) than in rigid connections (3/56) and in screw-retained (8/47) than in cemented (3/26) prostheses. In a literature review performed on 20 studies (812 T-IFPPs followed from 12 to 180 months), Borg et al. [12] advocated rigid one-piece castings permanently cemented to natural abutments, to avoid technical complications, such as failure of temporary cement, fracture of attachments, loosening or fracture of attachment screws, and fracture of veneering material. Last, the lower number of prosthetic complications in T-IFPPs than in I-IFPPs found in the present review was consistent to the results of Pjetursson et al. [36]. In the systematic review comparing complication rates of fixed dental prostheses supported by solely-implants and combined teeth-implants, the cumulative 5-year rates were, respectively, 11.9% vs 7.2% for veneer fractures, 1.5% vs 0.6% for abutment and screw fracture, 5.6% vs 6.9% for abutment or occlusal screw loosening, and 5.7% vs 7.3% for loss of retention [36].

5. Limitations

Despite an accurate screening process, the present systematic review has some limitations, which might affect the outcomes. The main limitations are the lack of RCTs and the limited number of selected studies, even if the paired design of intra-individual comparisons of four investigations may be considered to be highly powerful in detecting differences in smaller samples. Other limitations are some heterogeneity in sample size, follow-up duration, clinical situations, and prosthesis designs (connection, fixations), and the literature search restricted to the English language, although the chance of missing significant information seems to be very limited. Furthermore, results from the meta-analysis should be interpreted with caution, also considering that they were based on studies conducted in institutional environments (university) and therefore outcomes reported may not be generalized to private dental practice.

6. Conclusion

Within the limitations of the present systematic review and meta-analysis, no significant difference in abutments (tooth or implant) failures, prosthesis failures, biological and prosthetic complications were observed between T-IFPPs and I-IFPPs. Joining teeth and implants to support fixed prostheses in partially edentulous patients was shown to be a feasible and predictable treatment option in some clinical situations or to meet patient-centered preferences, or if financial issues hinder other types of rehabilitations. Therefore, although the I-IFPP remains the first choice, T-IFPP, whenever appropriate and justified, becomes a valid alternative with an acceptable success rate, mainly in order to reduce the complexity of the treatment and costs, and to improve the patient's acceptance.

Conflict of interest and source of funding statement

The authors have stated explicitly that there are no conflicts of interest in connection with this article. The authors received no specific funding from any agency in the public, commercial, or not-for-profit sectors for this research.

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