Efficacy of tooth-supported compared to implant-supported full-arch removable prostheses in patients with terminal dentition. A systematic review

Efficacy of tooth-supported compared to implant-supported full-arch removable prostheses in patients with terminal dentition. A systematic review

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Running title: tooth vs. implant-supported overdentures

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Conflict of interest: The authors declare they do not have any conflict of interest in relation to this publication.

Sources of funding: This systematic review did not receive external funding.

Abstract

Aims To compare tooth- (TSRP) and implant-supported (ISRP) removable prostheses in terms of abutment and prosthesis survival (PICO 1) and estimated cumulative survival of teeth/implants and prostheses (PICO 2) at ≥12 months post prosthesis delivery in patients with stage IV periodontitis.

Materials and Methods Five databases were searched to identify RCTs, CCTs, single arms, prospective cohort studies, case series and retrospective studies. Duplicate screening was performed and ranges for abutment and prosthesis survival were calculated.

Results Twenty-six studies were included in the qualitative assessment. Only one study with critical risk of bias comparing the 2 treatment modalities reported similar survival rates at 2 years. Overall, prospective studies on ISRPs indicated an implant survival rate ranging from 96.4% to 100% and a prosthesis survival rate of 100% with a follow-up from 12 to 54 months. Prospective studies on TSRPs indicated a tooth survival ranging from 85.71% to 100% at 1 to 10 years follow-up.

Conclusions The available evidence is of poor quality and it does not allow to make robust conclusions on the efficacy of these rehabilitations in stage IV periodontitis patients. Particularly for TSRPs, careful patient selection is crucial and a certain number of complications should be expected.

Keywords: removable denture, overdenture, periodontitis, terminal dentition, edentulism

Clinical relevance

Scientific rationale for study In patients with terminal dentition due to periodontitis, a tooth- or implant-supported removable denture may potentially offer advantages (namely oral hygiene and cost). Currently, we lack evidence-based indications on the efficacy of these rehabilitations.

Principal findings There is low-quality evidence (no RCT/CCT) that documents tooth and implant-supported removable dentures as viable options in periodontitis patients. A higher number of complications is likely to be expected for abutment teeth.

Practical implications

A careful patient selection, particularly in case of tooth-supported dentures (patient's compliance, position and number of remaining teeth), is recommended to improve abutment and prosthesis survival.

Introduction

The rehabilitation of patients with terminal dentition due to stage IV periodontitis is a challenging task, which requires a multidisciplinary approach and a close collaboration between the periodontist and the prosthodontist in order to restore health, function and aesthetics (Nyman and Lindhe, 1976, Nyman and Lindhe, 1977). The clinician often faces the dilemma whether to maintain few residual teeth/roots and use them to support full-arch rehabilitations, or extract the remaining teeth and deliver a conventional removable complete denture or an implant-supported prosthesis.

Considering that the maintenance of a high level of oral hygiene in periodontal patients is of outmost importance in order to avoid disease relapse (on residual teeth) (Axelsson and Lindhe, 1981) or the development of peri-implantitis (in case of implant-supported restorations) (Sousa et al., 2016, Donos et al., 2012), the manufacturing of removable prostheses could offer important advantages, such as easier access to oral hygiene (Weaver, 1989).

Removable prostheses such as overdentures (OVDs) retained by roots, were initially introduced as a transition from a terminal dentition to full edentulism (Miller 1958; Morrow et al. 1969), whilst OVDs retained by titanium implants were introduced at a later time (Mericske-Stern and Zarb, 1993, Naert et al., 2004), and are considered as a valid treatment option for mandibular edentulism (McGill Consensus, Feine et al. 2002).

At the same time, these types of restorations present with several limitations. In particular, tooth-supported full-arch removable prostheses, such as double crown reconstructions, require extensive tooth preparation to prevent excessive over-contouring of the abutment teeth and a high level of precision as well as considerable technical and clinical skills (Verma et al., 2013). Furthermore, a high incidence of root caries/ fractures, endodontic complications and the need for frequent prosthetic maintenance measures for this type of rehabilitations has been reported (Chhabra et al., 2019, Ettinger and Qian, 2004, Ettinger and Krell, 1988). On the other hand, it has been suggested that implant-supported full-arch

removable prostheses could lead to an increased risk of marginal bone loss around implants (Tandlich et al., 2007).

A systematic review on the available evidence on the efficacy of tooth-supported compared to implant-supported full-arch removable prostheses is warranted to clarify the current applicability and indications of these prosthetic rehabilitations and offer clinicians an evidence-based approach when dealing with patients with terminal dentition due to periodontitis stage IV.

Materials and methods

The aim of this review was to evaluate the efficacy of tooth-supported compared to implant-supported full-arch removable prostheses in terms of survival rate of the abutments (teeth/implants) and of the prosthesis.

The study protocol was registered in Prospero (N. CRD42020184322) and it is in line with the Cochrane Handbook (Higgins and Green, 2011). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was adopted (Moher et al., 2009).

Focused question 1

In patients with terminal dentition and/or stage IV periodontitis, what is the efficacy of tooth-supported (TSRP) compared with implant-supported (ISRP) full-arch removable prostheses in terms of survival rate of the implants/teeth and survival of the prosthesis, as reported in studies with at least 1 year of follow-up post prosthesis delivery?

In case an insufficient number of studies was identified to answer focused question 1 (<4), an additional focused question (2) would be considered.

Focused question 2

In patients with terminal dentition due to stage IV periodontitis, what is the estimated cumulative survival of teeth/implants and prostheses in case of tooth-supported (TSRP) and in case of implant-supported (ISRP) full-arch removable prostheses, as reported in studies with at least 1 year of follow-up post prosthesis delivery?

Inclusion/exclusion criteria

In order to answer focused question 1, the following inclusion criteria (based on the PICO) were considered:

- Population: adult (≥18 years old), systemically healthy patients with terminal dentition preferably due to periodontitis (stage IV) or already edentulous. Only studies considering at least 10 patients per intervention were included.
- Intervention: full-arch implant-supported removable prostheses (ISRP). No zygomatic implants, pterygoid implants and subperiosteal implants were considered. Only implants placed in pristine bone or where minor bone regeneration procedures were performed to treat fenestration/dehiscence were considered, whereas large bone reconstructions were excluded.
- Comparison: full-arch tooth-supported removable prostheses (TSRP).
- Outcomes:

- Primary outcomes:
  - Implant and tooth survival at ≥1 year of follow-up post prosthesis delivery
  - Prosthesis survival at ≥1 year of follow-up post-delivery, which would be defined as the reconstruction remaining in situ at the follow-up examination visit irrespective of its condition (Verma et al., 2013), but with prosthesis replacement not deemed necessary.

- Secondary outcomes:
  - Biological complications (for teeth they included but were not be limited to endodontic complications, periodontal attachment loss ≥2 mm, suppuration, increased tooth mobility, caries, fracture, abscess; for implants they included but were not be limited to peri-implant marginal bone loss, peri-implantitis, suppuration, abscess, implant fracture).
  - Technical complications, which were divided into *minor (chair side approach), major, aesthetic and functional* complications (Papaspyridakos et al., 2012). Moreover, data on denture hygiene were collected.
  - Patient-reported outcome measurements (PROMs). These included, but were not be limited to discomfort, satisfaction with appearance, ability to chew, ability to taste and general satisfaction (Papaspyridakos et al., 2012)

- Type of study: randomized controlled trials (RCTs) and parallel-arms prospective controlled studies
with a follow-up of at least 12 months post- prosthesis delivery.

For focused question 2, the same inclusion criteria were applied in terms of intervention, comparison and outcomes, while we considered a broader spectrum of study designs, namely: RCTs, parallel-arms prospective controlled studies, single arms (from RCTs and parallel-arm controlled studies) (at least 10 patients per arm), prospective cohort studies, case series (at least 10 patients) and retrospective studies (at least 10 patients) with a follow-up of at least 12 months post prosthesis delivery. Only studies that reported information on the periodontal conditions of the population, so that it could be reasonably expected/extrapolated that tooth loss (or at least a number of the extractions) was due to periodontitis stage IV, were considered.

Search strategy

A sensitive strategy was developed that included terms related to the Population, Intervention/Comparison and Outcomes combined with Boolean operator "and". Five databases were searched: MEDLINE via OVID, EMBASE, Web of Science, Scopus and The Cochrane Database (including the Central Register of Controlled Trials (CENTER)), updated to 11th April 2020. Details on the search strategy and on the additional databases and the fourteen journals searched to identify both published and unpublished (grey literature) data are provided in the Supplementary material (Appendix 1).

Any ambiguous or incomplete data was investigated further by contacting the researchers responsible for the work. In particular, an attempt was done to obtain periodontal data whenever the periodontal condition of the population was mentioned but clear details were not provided. Only papers written in English were considered, due to time constraints.

Methods for study selection and data extraction

A two-stage screening was carried out in duplicate and independently by two experienced reviewers using Ryyan web application. During the first-stage (titles and abstracts), studies that did not clearly mention in the abstract that the population of interest had a terminal dentition or was already edentulous were discarded. During the full-text articles screening

(second-stage), data screening and abstraction form was devised to verify study eligibility, carry out the methodological quality assessment and abstract data on study characteristics and outcomes for the included studies. In case of missing or incomplete data and absence of further clarification by study authors, the manuscript was excluded.

Any disagreement was resolved by discussion and, whenever necessary, a third reviewer was consulted. Calculation and presentation of level of agreement was carried out using Kappa statistics.

Data extraction was performed independently and in duplicate by two reviewers for the primary outcomes, while for the secondary outcomes 40% of the data were cross-checked for quality control.

Risk of bias assessment

Quality assessment of the included studies was conducted by two reviewers in duplicate. For non-randomized studies, RoB 1 tool was employed, while for randomized trials Rob2 was employed. The original study design guided the choice of the tool and when more than one study referred to the same population, only one risk of bias assessment was carried out. We accepted the definition of study design reported in the papers unless there was clear evidence that a different approach was applied. As per Cochrane guidance, Rob1 can be applied to all "follow-up" studies, term that identifies a category of studies in which "participants are followed up from the start of intervention up to a later time for ascertainment of outcomes of interest" (Sterne et al., 2016).

Quantitative analysis

Owing to the heterogeneity of the studies and the fact the majority of them did not report data on error measurements for the primary outcomes, no meta-analysis could be performed. Ranges of survival rates were summarised according to the different study designs.

Results

A total of 5,823 unique records were identified and screened for title and abstract, which led to 528 articles eligible for full-text screening and 17 additional studies identified through manual search (Figure 1). Twenty-six studies met the inclusion criteria and were included in

the qualitative analysis (reasons for exclusion are reported in the Supplementary material, Appendix 9). A high level of agreement was found between the reviewers during the screening stage (K > 0.9). No data could be obtained from ongoing studies.

Focused question 1

No RCTs or prospective controlled studies were identified to answer this question.

Focused question 2

- Primary outcomes and characteristics of the included studies

Twenty-six articles were identified to answer focused question 2. In particular, only 1 study directly compared tooth-supported vs. implant-supported removable dentures (and a third group of combined tooth/implant-supported removable prosthesis). The study design was unclearly defined and we classified it as "mixed" retrospective-prospective case series, with possibly one group treated and follow-up longitudinally and the others selected amongst already treated patients and followed up as a cohort study (Hug et al., 2006). This study involved 17 patients receiving a TSRP (n=21) and 15 patients receiving an ISRP (n=20). Treatment allocation was not done at random. The abutment survival rate was 100% for TSRP and 98% (1 implant failed) for ISRP at 2 years of follow-up. The prosthesis survival rate was 100% in both cases.

The other studies that were identified included 12 prospective studies (Eccellente et al., 2011, Glibert et al., 2018, Budtz-Jorgensen and Thylstrup, 1988, Budtz-Jorgensen, 1991, Budtz-Jorgensen, 1995, Keltjens et al., 1999, Toolson and Taylor, 1989, Toolson et al., 1982, Toolson and Smith, 1978, Toolson and Smith, 1983, Van Waas et al., 1993, Van Assche et al., 2012) reporting the data from 7 different original clinical studies (5 articles related to different follow-ups of the same 2 studies) (Budtz-Jorgensen, 1991, Budtz-Jorgensen, 1995, Toolson and Taylor, 1989, Toolson et al., 1982, Toolson and Smith, 1983) and 13 retrospective studies (Chhabra et al., 2019, Keltjens et al., 1994, Rinke et al., 2019, Shaw, 1984, Widbom et al., 2004, Yoshino et al., 2020, Yao et al., 2013, Zou et al., 2013, Eisenburger et al., 2000, Gonda et al., 2013, Ericson et al., 1990, Coca et al., 2002, Coca et al., 2000), some of which included also a cross-sectional component (Coca et al., 2000, Widbom et al., 2004, Chhabra et al., 2019, Keltjens et al., 1994, Coca et al., 2002, Shaw, 1984) (Table 2). None of these studies included a direct comparison between the two treatment strategies.

The majority of the studies were conducted in a University/Hospital setting, although two studies took place in private practice (Eccellente et al., 2011, Yoshino et al., 2020). Fourteen studies were published ≥ 20 years ago (before or in 2000) and only 4 within the past 5 years.

Implant-supported removable prostheses (ISRPs)

Only 5 out of the 26 studies dealt with ISRPs, for a total of 629 implants and 142 prostheses. The 4 prospective studies (Eccellente et al., 2011, Glibert et al., 2018, Van Assche et al., 2012, Hug et al., 2006) showed an implant survival rate (implant level) ranging from 96.4% to 100% and a prosthesis survival rate of 100% at a follow-up between 12 to 54 months (Table 2). In particular, in one study, 3 implants failed within the first 3 months after placement (Glibert et al., 2018). Another study reported one short implant lost 2 weeks after insertion probably due to mobilization by the provisional prosthesis (Van Assche et al., 2012) and in another study with a mean follow-up of 26.7 months one implant was lost due to peri-implantitis, one due to fracture and 2 due to the lack of osseointegration (Eccellente et al., 2011).

Details on the prosthesis and abutment characteristics can be found in Supplementary material (Appendix 2).

The retrospective study (Zou et al., 2013) compared maxillary implant-retained telescopic crowns (connected to 4-8 implants in 20 patients - total 106 implants) versus bar overdentures (supported on 2, 3 or 5 implants in 21 patients - total 95 implants-). At a follow-up of 5 to 8 years no implants or prostheses were lost (100% survival rate).

Tooth-supported removable prostheses (TSRPs)

Twenty-two studies (10 prospective studies reporting the data of 5 trials – 1 is a single arm of an RCT - and 12 retrospective studies) dealt with TSRPs, for a total of 4,579 abutment teeth and 1,660 prostheses.

The prospective studies showed a tooth survival rate (tooth level) ranging from 85.71% to 100% at a follow-up ranging from 1 to 10 years. In particular, while 3 studies did not report any tooth loss up to 36 months of follow-up (100% survival rate) (Toolson and Smith, 1978, Hug et al., 2006, Van Waas et al., 1993), one study showed that 2 teeth were lost already at 12 months of follow-up (97.82% survival rate)(Budtz-Jorgensen and Thylstrup, 1988), with the highest incidence of tooth loss (85.71% survival rate) reported at 10-years follow-up (Toolson and Taylor, 1989).

Only few prospective studies informed on prosthesis survival, one reporting a survival rate at prosthesis level of 100% at 2 years (Hug et al., 2006), and two reporting a survival rate at patient level of 87.1% at 5 years (Budtz-Jorgensen, 1995) and of 78.57% at 10 years (Toolson and Taylor, 1989) (Table 2).

The main reasons for tooth extraction after prosthesis delivery were periodontal disease and caries (Keltjens et al., 1999, Budtz-Jorgensen, 1995, Toolson and Taylor, 1989), while no study clarified the causes for prosthesis failure.

The retrospective studies showed a larger and more heterogeneous range of survival rates, ranging from 34% to 93.85% at tooth level and from 38% to 100% at prosthesis level with a follow-up of 5 to 20.5 years (Table 2). While in some studies reasons for abutment extractions after prosthesis delivery were not provided, other studies indicated that periodontitis was the main reason for extractions, followed by root fractures and caries (Yoshino et al., 2020, Shaw, 1984, Keltjens et al., 1994, Eisenburger et al., 2000, Ericson et al., 1990). When the reasons for prosthesis failure were reviewed, the loss of abutment teeth was the main cause in 4 studies (Yoshino et al., 2020, Keltjens et al., 1994, Widbom et al., 2004, Eisenburger et al., 2000), but other causes included incompatibility of mucosal surface (unable to undergo further repair), material failure, wear of the artificial teeth and denture base fracture.

Details on the prosthesis and abutment characteristics can be found in Supplementary material (Appendix 2). The number of abutment teeth per prosthesis was not always specified, but canines tended to be most often retained for supporting the prosthesis in both prospective and retrospective studies. A significant correlation between abutment and prosthesis survival and the number of initial abutments was reported by three retrospective studies (Rinke et al., 2019, Yoshino et al., 2020, Eisenburger et al., 2000). It was also suggested that mandibular incisors may be the least suitable teeth as abutments, since they are the ones that most frequently fail and require extractions overtime (Eisenburger et al., 2000, Keltjens et al., 1994).

The level of residual periodontal support and of the residual tooth tissue (caries-free) of the abutment teeth at the time of prosthesis delivery was heterogeneously described and mainly reported in longitudinal studies (Table 1).

Likewise, the level of supportive care and patient's compliance was also not consistently reported (Table 1 and Supplementary material, Appendix 6).

Other factors such as age, gender, the vitality of the abutment teeth and type of dentition in the opposite jaw were heterogeneously reported as factors that may potentially play a role in the long-term survival of abutments and prostheses.

- Secondary outcomes

Details on secondary outcomes are reported in Supplementary material (Appendices 3, 4 and 5).

Biological complications

No biological complications were reported by the only study that assessed both TSRP and ISRP (Hug et al., 2006), although the reason for the failure of one implant was not specified.

Moderate horizontal marginal bone loss was observed around implants (0.8 ± 1.1. mm) and around roots (0.3±0.9 mm) at 2 years of follow-up (Hug et al., 2006).

ISRPs: Apart from biological complications that led to explantation (e.g. fracture, peri-implantitis and lack of osseointegration), only few studies reported on biological complications, which mainly related to the presence of localized inflammation (bleeding on probing), plaque and mucosal hyperplasia in a limited number of patients (see Supplementary material, Appendix 3).

The longitudinal studies that radiographically assessed peri-implant bone showed rather stable bone levels and a "physiological" bone resorption (Glibert et al., 2018, Hug et al., 2006, Van Assche et al., 2012) at up to 2 years of follow-up.

TSRPs: Overall, the most frequent biological complications in both prospective and retrospective studies were caries (which in some cases led to extractions) and replacement of existing restorations, whose prevalence was however directly related to the level of oral hygiene of the patients.

Another frequently reported biological complication was the deterioration of the periodontal status of abutment teeth, which sometimes led to extractions. In the prospective study by Budtz-Jorgensen et al. (Budtz-Jorgensen, 1991, Budtz-Jorgensen, 1995), where patients had severe periodontal bone loss from the beginning, an attachment loss of 1-4 mm was observed adjacent to 12.5% of the abutment tooth surfaces at 3 years and of 20.5% at 5 years. The

reduction of pockets >5 mm observed at 5 years in this study was partly due to the fact that seven abutments had to be extracted due to progressive periodontitis. Detailed periodontal information was provided by another longitudinal study, which indicated that out of 77 initially present abutment teeth, at 10-year follow-up, 4 were extracted because of periodontal disease (and 7 because of caries) and the remaining teeth had suboptimal plaque and gingival indices, but only one had pocketing (mean PPD 7.5 mm) (Toolson and Taylor, 1989).

Likewise, retrospective studies confirmed that an increase in periodontal pockets is a frequent long-term complication (Gonda et al., 2013, Coca et al., 2000, Coca et al., 2002). Other common complications included root fractures, loss of tooth vitality and endodontic problems (details in Supplementary Material, Appendix 3).

Technical complications

The only study that assessed both TSRP and ISRP (Hug et al., 2006) indicated that the incidence of prosthetic complications was higher in case of TSRP, particularly during the first year (49 vs. 21) (Supplementary material, Appendix 4).

Remarkably, periodontal and peri-implant parameters showed mostly healthy soft tissues at the re-examinations in both groups, with good levels of oral hygiene, and no caries developed in the abutment teeth.

ISRPs: Overall, in the prospective studies assessing ISRPs, *functional* complications were rarely reported, with only 1 study indicating that a patient needed denture relining and adaptation of the occlusion (Van Assche et al., 2012) and another indicating that 7 patients needed occlusal adjustments (Hug et al., 2006). This might be due to the relatively short follow-up of the studies. The most frequent *minor* complication observed in the prospective studies was screw/abutment loosening, while the most frequent *major* complication was denture fracture, although it happened only in 4 OVDs in one study and 1 OVD in another study (Hug et al., 2006, Eccellente et al., 2011). In a 5 to 8 year retrospective study, the most frequent maintenance procedures performed were prosthesis margin adaptation and OVD rebasing (n=84) and the most frequent *minor* complications included gingival hyperplasia, screw/abutment loosening, wear/repair of the denture teeth and need to reactivate or replace the attachments (Zou et al., 2013).

TSRPs: A wider and more detailed range of technical complications was described by the studies assessing TSRPs. *Functional* complications were frequently reported, particularly in retrospective studies and prospective studies with >5 years follow-up, and they included loss of stability, loss of retention, re-linement and occlusal problems (Supplementary material, Appendix 4). Prospective studies indicated that frequently occurring *minor* and *functional* complications included the need for attachment reactivation/replacement, fracture/wearing of denture teeth, re-linement and loss of stability and retention, while the most common *major* complication was need to redesign the denture (Toolson and Taylor, 1989, Hug et al., 2006). Other reported complications particularly in retrospective studies were de-cementation of copings, mucosal trauma, prosthesis fractures, abutment fractures (particularly in OVDs supported by 1 abutment tooth) and conversion to complete denture.

Hygiene of abutments and dentures

No information on denture hygiene could be identified for ISRPs.

Three studies reported on oral hygiene associated with TSRPs. In a prospective study the percentage of the fitting denture surface covered by plaque at 5 years of follow-up was suboptimal (≥30%) in 40% of the patients but only 2.9% had a score >50%. Moreover, they showed that 91.4% of the patients maintained a denture plaque index ≤1 (Budtz-Jorgensen and Thylstrup, 1988, Budtz-Jorgensen, 1991, Budtz-Jorgensen, 1995).

A retrospective study indicated that more than 40% of OVD patients showed poor maintenance and hygiene of their OVDs after an observation of up to 5 years(Chhabra et al., 2019). Another retrospective study where patients received reinforcement of oral hygiene and debridement at the follow-up examinations showed that both plaque and bleeding index improved overtime, from 34.7%±5.01% to 31.0%±5.90% and from 40.7%±6.28% to 22.9%±4.03%, respectively (Ericson et al., 1990).

Patient-reported outcome measures (PROMs)

In the only study that directly compared TSRPs and ISRPs, PROMS were assessed via a 9-item questionnaire evaluating ease of hygiene, general satisfaction with overdenture, ability to speak, comfort of wearing OVD, aesthetic appearance, stability of OVD during function, ability to chew, handling of the OVD when placing or removing it and general problems with OVD.

Overall patients receiving implant OVDs scored better, with median values ranging between 94 and 96 compared to median values between 82 and 95 for patients receiving tooth-retained OVDs (Hug et al., 2006).

Few other studies assessed PROMs in patients receiving full-arch removable dentures (for further details see Supplementary material, Appendix 5), but no validated tools such as the OHIP-20E (Allen and Locker, 2002) was used in the included studies.

Risk of bias

The only RCT (for the purpose of the review only one of the arms was eligible) (Van Waas et al., 1993) identified had a high risk of bias in 1 out of 5 domains and raised some concerns in the remaining domains and was therefore considered at high risk of bias (RoB 2 tool) (Supplementary material, Appendix 8).

The 25 "follow-up" studies had all a serious or critical risk of bias related to confounding factors and >50% of them presented also a serious or critical risk of bias in terms of selection of participant, classification of interventions and missing data (RoB 1) (Figure 2 and Supplementary material, Appendix 7). The domain "deviation from intended intervention" was the one with the lowest level of bias. Overall, the risk of bias was considered critical in 75% of the follow-up studies, while the rest were considered at serious risk of bias.

Discussion

This review demonstrated that there is low-quality evidence available to compare full-arch TSRPs versus ISRPs, as no RCT or CCT was identified to answer focused question 1.

Only one study (Hug et al., 2006) directly compared the two types of rehabilitations and indicated similar abutment and prosthesis survival rates at 2 years of follow-up, but with an increased incidence of complications when dealing with abutment teeth. However, since the aforementioned study was at critical risk of bias, this means that significant caution needs to be applied before its data could be considered as useful evidence and its results should not be considered when discussing evidence-based guidelines (Sterne et al., 2016). One of the main challenges faced by the authors of this systematic review was that, despite the great majority of the screened papers was on ISRPs, which appears to be a well- documented restorative option for edentulism, only a minority of them (<5%) provided data on the

periodontal status of the patients and/or the reasons for teeth extraction. This resulted in only 5 studies on ISRPs selected to answer focused question 2, out of which the 4 prospective studies had a short follow-up (12 to 54 months). Hence, no robust indications can be drawn on the use of this type of rehabilitation in stage IV periodontitis patients. Whilst it is more than plausible to suggest that in most of the other studies on ISRPs, periodontitis could have been one of main reasons for edentulism, this cannot be taken for granted and if no information was provided in this respect, studies were excluded to comply with our PICO.

On the other hand, despite a minority of the screened papers focused on TSRPs, a significant number (22) provided information (initial periodontal status and/or development of pockets and periodontally-related problems during the follow-up visits) from which it could be reasonably speculated that tooth loss had been caused by periodontitis. However, in this case we faced another challenge, i.e. the fact that the studies were not recent and performed according to potentially outdated prosthetic/restorative principles, hence with the risk of providing outdated information. Overall, the majority of studies (75%) had a critical risk of bias and the remaining ones had a serious/high risk of bias, thus a significant level of caution should be applied to interpret the findings, especially if the outcomes of this review are used to provide guidelines for the every-day clinical practice.

It is important to note that the majority of the studies were performed before the new classification of periodontal diseases was introduced (2018). Hence, assumptions were made based on the limited data provided by the studies on the periodontal status of the patients indicating that the reported partial/total edentulism could be related with stage IV periodontitis. This important limitation makes the strength of the conclusions of this review on the use of these types of prosthesis rehabilitations in stage IV periodontitis limited (and potentially biased).

The 4 prospective studies included in this review that dealt with ISRPs showed an implant survival rate ranging from 96.4% to 100% and a prosthesis survival rate of 100% at a follow-up from 12 to 54 months (Eccellente et al., 2011, Glibert et al., 2018, Van Assche et al., 2012, Hug et al., 2006), while the only retrospective study reported an implant and prosthesis survival rate of 100% at up to 8 years of follow-up (Zou et al., 2013).

Due to the limited number of included studies, it was not possible to draw any conclusion in relation to the effect that implant location, type of restoration, opposing jaw and implant

number might have on the estimated implant loss rate of OVDs in periodontitis patients. Nevertheless, recent systematic reviews (Dantas Ide et al., 2014, Kern et al., 2016) that did not limit the search to periodontitis patients showed that these factors may play an important role. In particular, Kern et al. (Kern et al., 2016) indicated higher implant loss rates when compared 1 vs. 2 implants or 2 vs. 4 implants supporting a mandibular OVD and when 4 compared to >4 implants supported a maxillary OVD. Different retention systems were employed by the studies included in the present review, but they did not seem to influence the survival rates, and this confirms the outcome from a recent systematic review (Goncalves et al., 2020).

The 5 included studies showed that biological complications were not common, with only one study with a follow-up between 12 to 54 months reporting one case of peri-implantitis (Eccellente et al., 2011), although no clear disease definition was provided. However, ISRPs do require maintenance, which may range from simple repair or re-tightening of retainers, to relining of the prosthesis or even remaking. A mean complication rate could not be estimated due to the multiplicity of the involved factors, which included prosthesis design, type of connection, denture quality and manufacturing, materials used, presence of parafunction (bruxism) and type of opposing dentition. It is important to highlight that, apart from the retrospective study that considered a time span of up to 8 years (Zou et al., 2013), the other prospective studies had short follow-ups (one study only reached 54 months) (Eccellente et al., 2011), which can be considered insufficient to provide clinically relevant information on complications rates and implant survival. It is recommended that longer-term follow-ups (at least 5 years) should be considered for future studies (Berglundh et al., 2002).

When evaluating TSRPs, prospective studies suggested a survival rate (tooth level) between 85.71% and 100% at a follow-up ranging from 1 to 10 years, with only 2 studies reporting data also on the prosthesis survival rate, which was 87.1% at 5 years (Budtz-Jorgensen, 1995) and 78.57% at 10 years (patient level). The retrospective studies showed a wider and more heterogeneous range of survival rates, going from 34% to 93.48% at tooth level and from 38% to 100% at prosthesis level at a follow-up between 5 to 20.5 years. Although retrospective studies hold intrinsic limitations due to the nature of study design and therefore no robust conclusions can be drawn from them, they may provide valuable information in relation to the occurrence of biological and technical complications and on the long-term survival of

prosthetic rehabilitations. Several factors may account for the heterogeneous results reported by retrospective studies. Firstly, the follow-up ranged from 1 to more than 20 years. Moreover, the number of abutments, their periodontal health and the amount of caries-free tissue at baseline were different between the studies, as well as the type of maintenance care provided.

Our outcomes indicate that the number and the anatomical distribution of abutment teeth significantly influenced the survival rate of TSRPs and of the abutments themselves. Fewer and unfavourably distributed abutment teeth may, in fact, experience greater load pressure by the antagonist teeth, and this may affect abutment tooth loss and, as a consequence, prosthesis failure (Koller et al., 2011). It is suggested that a missing polygonal support and less than four abutment teeth represent an increased risk for abutment loss (Rinke et al., 2019, Yoshino et al., 2020, Eisenburger et al., 2000).

Another crucial point in the long-term maintenance of this type of rehabilitation is the compliance of the patients and the level of supportive care provided (Supplementary material, Appendix 6). Few studies showed that when the abutments presented with severe periodontal disease at baseline, following treatment and periodontal maintenance, a good (teeth) survival overtime was maintained (90.27% of teeth at 5 years)(Budtz-Jorgensen and Thylstrup, 1988, Budtz-Jorgensen, 1991, Budtz-Jorgensen, 1995). The level of oral hygiene is also of outmost importance to reduce the risk of secondary caries, which are one of the main biological complications associated with tooth-supported prostheses.

Amongst the other factors that may influence the survival of abutment teeth, the nature of opposing dentition and tooth vitality might play a role, but the heterogeneity of data reporting did not allow us to draw definitive conclusions on the impact of these factors.

Although only one study with critical risk of bias (Hug et al., 2006) directly compared implant- and tooth-supported prosthesis, it appears that the latter is associated with a higher number of both biological and technical complications. Amongst the biological complications, caries and loss of periodontal support are the most recurrent ones, but root fractures, loss of tooth vitality and endodontic problems were also reported. Particularly with regards to caries, the patient's dietary intake should be addressed beforehand (Hujoel and Lingstrom, 2017).

Reported technical complications included loss of stability, loss of retention, need for re-linement and occlusal problems, but also need for attachment reactivation/replacement, wearing and fracture of the dentures. It is suggested that the risk of detachments, de-

cementation and abutment fractures increases for dentures supported by a reduced number of abutments, with the highest risk for 1-tooth-supported dentures (Rinke et al., 2019). It is not possible to draw any conclusion on the role that the different retention/attachment system might have on the incidence of complications in TSRPs, as none of the included studies made direct comparisons or was powered to assess this outcome. Nevertheless, in partial removable dentures Behr et al (Behr et al., 2000) showed that technical problems occurred more frequently in patients with a conical design denture (48.8%, n = 21) compared to patients with a parallel retention design (34.2%, n = 25), although the difference was not statistically significant.

It is noteworthy that, whereas overdentures retained by stud and bar-clip attachments require a minimum of 8-mm and 12-mm of prosthetic space (Sadowsky and Zitzmann, 2016), respectively, from the gingival level to the occlusal plan, telescopic crowns over abutment teeth do require a minimum of 15-mm (Hakkoum and Wazir, 2018). With this in mind, the necessary space to accommodate a tooth-supported overdenture on telescopic crowns might not always be sufficient, and an additional space gain towards the alveolar bone, with osteotomies, may be necessary (Faeghi Nejad et al., 2016, Atwood, 1971). The clinician needs therefore to balance different factors when choosing a tooth-supported overdenture, including prognosis, periodontal support and number of remaining teeth and inter-arch space. In this review, no data on the patient's inter-arches-distance could be retrieved from the original papers. Hence, an association between insufficient prosthetic space and abutments' prosthetic and biological complications could not be drawn.

The preservation of abutment teeth might offer a psychological advantage for patients that can retain their own teeth and avoid or at least cross a smoother pathway towards conventional complete dentures or implant supported treatment, but it also requires a high level of precision and significant technical and clinical skills (Verma et al., 2013), with the need of combined periodontal, restorative and prosthetic treatment. Whilst both implant- and (up to a certain level) tooth- supported OVDs may usually be a cheaper option than fixed full-arch rehabilitations, the related prosthesis maintenance and technical complications (especially for teeth-supported dentures) are associated with additional costs that need to be considered by the clinician and explained to the patients.

Furthermore, when implant surgery is not a viable option, maintaining few teeth for a removable overdenture instead of delivering a complete removable denture allows to reduce the collapse of the alveolar process and provides potentially better stability and masticatory functions to the patients (Van Waas et al., 1993).

Finally, when interpreting the results of the present systematic review it is important to consider some additional limitations. Besides the lack of publications on ISRPs reporting on periodontal parameters, the restriction of the study selection to English language might have led to the exclusion of relevant papers. As a matter of fact, TSRPs, particularly double-crown retained dentures are mainly used in Germany, Sweden and Japan. Relevant studies might have been published in national journals in their mother languages, which were not captured by this review.

Moreover, as per inclusion criteria, studies that involved patients affected by systemic diseases were excluded. While this allowed to remove the effect of potential confounding factors, it is also true that stage IV periodontitis and edentulism are often identified in elderly patients, which are more likely to present with systemic diseases. In this particular situation, since life expectation is increasing worldwide and more frailty elderly patients are candidates for prosthetic treatment, a careful evaluation of the patient cognitive ability and manual skills should be performed prior to the treatment initiation, considering the fact that this patient may no longer be able to perform proper oral hygiene by him/herself in the future, thus needing assistance from a caretaker. Hence, future studies should also take into account the role that systemic diseases and medications might have on the survival rate of these types of rehabilitation.

Finally, we did not take into consideration that, in case of terminal dentition due to periodontitis, the clinician has also the possibility to provide a full-arch removable rehabilitation combining teeth and implants. While it is widely accepted that it may not be ideal to connect a rigid ankylosed implant to relatively mobile dentition (Hoffmann and Zafiropoulos, 2012), there are specific situations (for instance due to anatomical limitations, economic reasons or implant/tooth failure) in which this option might be a viable one (Lian et al., 2018). One of the studies included in this review assessed this option and reported similar 2-year survival rates compared to prostheses supported by only teeth or only implants (Hug et al., 2006).

Conclusion

- Given the lack of RCTs and CCTs comparing full-arch ISRPs and TSRPs and the serious/critical risk of bias of the retrieved papers, direct comparisons between these two types of rehabilitations in stage IV periodontitis patients cannot be made.
- The average short follow-up particularly for studies reporting on ISRPs might be insufficient to assess the incidence of implant loss and the development of biological/prosthetic complications; hence no robust conclusions can be drawn in this respect
- Both ISRPs and TSRPs present the advantage of being relatively in-expensive (especially when compared to fixed solutions), well-accepted by the patients and the retrievability may allow periodontal patients to perform better oral hygiene manoeuvres.
- A careful patient selection should be performed, particularly in case of TSRPs. More specifically, this option should be selected only after carefully reviewing the number of abutment teeth left, their position and distribution within the mouth, periodontal support, inter-arch space, and after assessing the level of compliance of the patients and their ability to clean prostheses and abutments. While the importance of oral hygiene is also crucial for ISRPs, it becomes of even more relevance when dealing with abutment teeth, as they present the risk of deteriorating the periodontal status and developing secondary caries. Diet instructions in association with oral hygiene instructions are crucial for the long-term success of this restorative option.
- When proposing these types of rehabilitations to the patients, they should be informed of the need for regular supportive care appointments and that a certain number of minor to major complications should be expected overtime.
- It is anticipated that TSRPs might be associated with a higher number of complications, which may require additional costs for the patients (need for endodontic treatments, adjustments/remake of dentures, fillings, etc.), but they might be a conservative option to rehabilitate patients that for different reasons cannot receive implants or are not willing to receive a conventional complete denture.

Indications for future studies:

- Well-designed RCTs and CCTs with a minimum follow-up of 5 years that directly compare full-arch TSRP and ISRP in stage IV periodontitis patients are needed to compare the efficacy of these two types of rehabilitations in terms of biological, technical complications and PROMs. Details on the economic costs are also warranted.
- It is recommended that future studies (particularly those on ISRPs) clearly provide a description of the reasons for tooth extraction and history of periodontitis of the patients, as well as, clear details on the supportive care programme provided and compliance of the patients.
- Future studies should assess the vertical dimension of the patient's occlusion, as this plays a crucial role in the identification of the available inter-arches distance and in the choice of the retention system.

Table legend

Table 1 Demographics and general characteristics of the included studies. OH, oral hygiene; NSPT, non-surgical periodontal therapy; BOP, bleeding on probing; PPD, probing pocket depth; TCRD< telescopic crown-retained denture. In dark grey is the only study comparing tooth- and implant-supported prostheses, while in light grey are the studies reporting only on tooth-supported prostheses. Additional details on supportive care are provided in Supplementary Material (Appendix 6).

Table 2 Primary Outcomes of the included studies. Studies were grouped according to the follow-up (in case one study contributed to more than 1 follow-up it was presented more than one time). In dark grey is the only study comparing tooth- and implant-supported prostheses, while in light grey are the studies reporting only on tooth-supported prostheses. CI, confidence interval.

Figure legend

Figure 1: Flow chart of the selection process (modified from PRISMA flow-diagram). Despite the efforts to contact the authors and Editors of the Journals and to search the papers in multiple university libraries in Europe and US, 3 papers could not be retrieved (Supplementary material, appendix 1).

Figure 2: Risk of bias according to the RoB1 risk of bias tool for all follow-up studies (n=25).

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Author and Year	Follow-up period in months: Mean (range)	Setting and Country	Funding	N of Pts	Pts Drop-out	Jaw	N of Implants	N of Teeth	Patient Age (Mean± SD (range)	Gender (Female/ Male)	Smoking Status	Periodontal Status	Maintenance Care provided
PROSPECTIVE STUDIES													
Budtz-Jørgensen et al. 1988, 1991 and 1995	12, 36 and 60	University; Denmark	Not Reported	40	9	Maxilla and mandible	-	72-92	68.5 (53-81)	15F, 25M	Unclear	Reduced dentition and poor dental or periodontal conditions. Most of the patients were affected by progressive periodontal disease and received NSPT	2-4 recalls yearly
Eccellente et al 2011	26.7 (12 to 54)	Private practice; Italy	Not reported	45	0	Maxilla	180	-	60 (range 43-76)	18F, 27M	36 smokers	Already edentulous patients had a history of periodontitis. In partially edentulous patients, 58 teeth extracted due to periodontitis*	Unclear, OH instructions provided
Glibert et al. 2018	12	University/Hospital; Belgium	Not reported	21	0	Maxilla	83	-	65 (44–86)	9F, 12M	Smokers were not excluded, but limited to patients smoking less than 10 cigarettes per day.	All patients received periodontal treatment of the mandible when required and OH measures were optimized during the preoperative planning.	OH reinforced & professional maintenance adapted to the patients' need.
Hug et al. 2006	24	Unclear; Switzerland	Not reported	32 (Group 2: 17 and Group 3: 15)	0	Maxilla and mandible	77	56	Group 2: median 69 Group 3: median 69.	16F, 16M	Not reported	Preparatory periodontal treatment of the roots performed	Regular maintenance twice a year

Keltjens et al 1999	48	University; Netherlands	University of Nijmegen and The Netherlands Institute for Dental Sciences	49	Unclear	Maxilla and mandible	-	155	56±9	18F, 31M	Not reported	Unclear initial periodontal status but during the 4 years, 1 tooth was extracted due to periodontitis	Regular check-ups every 6 months where OH and periodontal condition were checked
Toolson et al. 1978, 1982, 1983, 1989	12, 24, 60 and 120	University; USA	Unclear	89	79 at 1 year, 74 at 2 years, 35 at 5 years and 61 at 10 years	Maxilla and mandible	-	233 (210 at 1 yrs, 190 at 2 yrs, 133 at 5 yrs)	31 to 83	45F, 44M	Unclear	Prior to the insertion of the overdenture, an attempt was made to bring the periodontal status of the retained teeth to a healthy state and this included eliminating sulcular depth >3mm.	Recalls at 1, 2, 5 and 10 years where OH instructions were given
Van Assche et al. 2012	24	University; Belgium	Institut Straumann AG	12	0	Maxilla	72	-	58.6; (47.7 to 71.3)	5F, 7M	Smokers included (n = 6)	Periodontal treatment of the remaining teeth in the mandible was performed. 10 out of 12 patients had their teeth extracted due to periodontitis. Bone loss >50% at mandibular teeth was present in 5 out of 10 patients.	Unclear, recall visits performed at 6, 12 and 24 months and 5 patients needed additional OH instructions.
Van Waas et al. 1993	24	University; Netherlands	TRIKON: Institute for Dental Clinical Research, and the 'Praeventie fonds'	52	0	Mandible	-	148	53 ± 11	33F, 19M	Unclear	All patients had severe decayed and/or periodontally involved teeth; Bad periodontal condition: n = 31 patients; Fair periodontal condition: n = 21 patients.	Not reported
RETROSPECTIVE STUDIES													
Chhabra et al. 2019	12-60	University/Hospital; India	Not reported	80	0	Maxilla and mandible	-	270	62 (45 to 79)	48F, 32M	Unclear	21 abutments: mobility degree III 97 abutments: mobility degree I/II; 186 abutments: gingival inflammation and 50 had BOP. All patients instructed and motivated for OH care and received periodontal treatment,	Patients were maintained on continuous OH recall (every 6 months) over the observation period up to 5 years.

												including scaling and polishing.	
Coca et al. 2000	24 to 132 (84% had follow-up >3 yrs; 47% had follow-up >5 yrs)	Not specified, probably University/Germany	Not reported	188	96	Maxilla and mandible	-	236	30-39 yrs: n=1; 40-49yrs: n=2; 50-59yrs: n=16; 60-69yrs: n=36; 70-79yrs: n=31; >80yrs: n=6	Not reported	Not reported	Unclear initial periodontal status, but during the follow-up the maximal PPD increased in 72% of cases, 39 teeth required deep scaling and periodontitis was the main reason for extractions (68.8% in the maxilla and 47.1% in the mandible)	Not reported. An improvement of OH was necessary in >53% of the cases
Coca et al. 2002	48 to 144 months	University/Germany	Not reported	83	17	Maxilla and mandible	-	99	41-50 yrs: n=4; 51-60: n=11; 61-70 yrs: n=27; 71-80 yrs: n=19; >80 yrs: n=5	28 (42%) M, 38 (58%) W	Not reported	Unclear initial periodontal status, but during the follow-up, 53% of teeth had pocket formation and 68% had gingival inflammation	Not reported. OH was insufficient in 76% of the cases
Eisenburger et al. 2000	Up to 246	University/Hospital; Germany	Not reported	175	Unclear (when a patient did not attend the last date examination was used for analysis)	Maxilla and mandible	-	559	60.2M; 58.7F	80F, 95M	Not reported	Unclear initial periodontal status, but the majority of abutment teeth during the observation period (34%) were extracted due to periodontal disease	No regular long-term recall programme but patients were advised to have 1/2 appointments yearly for denture maintenance

Ericson et al. 1990	9 to 28 (median 20) at re-exam 1 and 24 to 43 (median 35) at re-exam 2	University; Sweden	Not reported	25	2 (at re-exam 2)	Maxilla and mandible	-	104	62.7 (35 to 74)	8F, 17M	Not reported	1patient had very advanced periodontitis. All patients received pre-treatment with special regard to periodontal care and at re-exam 1 and 2 the patients underwent debridement. Marginal bone level was 53.51% at re-exam 1 and 51.88% at re-exam 2	Unclear, but at re-exams patients received reinforcement of OH and debridement
Gonda et al. 2013	60	University/Hospital; Japan	Not reported	Unclear	Unclear	Maxilla and mandible	-	65	Unclear	Unclear	Not reported	Unclear initial periodontal status, but most frequent complication of abutments was the increase of periodontal pocket (52%)	Not reported
Keltjens 1994	Up to 72 months (3.7±1.9 yrs for maxilla prostheses, 3.9±2.4 yrs for mandible prostheses)	University; Netherlands	Not reported	148	0	Maxilla and mandible	-	512	59±10 (range 29-83)	61F, 87M	Not reported	Unclear initial periodontal status but during the 6 years, 44 abutment teeth were extracted due to caries or periodontitis	Yearly recall-system, but no special preventive regimen applied
Rinke et al.2019	64.5 ± 34.8 (24-179)	University/Hospital; Germany	Unclear	221	0	Not specified	-	538	62.3	100F, 121M	Not reported	At the follow-up, most of the abutment teeth were periodontally compromised and had reduced valence. For some of the patients it is documented that some of the missing teeth were lost due to periodontal problems, but this documentation is not consistent through all the patient's files*	A systematic recall system was not in place.

Shaw 1984	84	University/Hospital; United Kingdom	Unclear	23	5 (for the cross-sectional part)	Maxilla and mandible	-	53 (35 + 4 reduced at gingival height present for the cross-sectional part)	62 (36 to 74)	Not reported	Not reported	Periodontal disease was prevalent. During the follow-up, the most common reason for tooth extraction was the periodontal status	Recall frequency varied between 6 and 9 months, when OH was required to be reinforced
Widbom et al. 2004	45.6 (9-111.6)¶	University; Sweden	Skaraborg Institute and the Scientific Committee of the Skaraborg County Council	72	0	Maxilla and mandible	-	368	67.1 (44 to 85)	27F, 45M	Unclear	Unclear initial periodontal status but at follow-up, 20% of abutment teeth had pockets >4mm (20 teeth in the maxilla and 23 in the mandible)	Not reported
Yao et al. 2013	26 (10-36)	Hospital; China	Unclear	30	0	Mandible	-	60¶	68 (61 to 78)	Unclear	Unclear	Unclear initial periodontal status, but NSPT was performed. Abutment teeth selected when loosening ≤ I degree, periodontal pocket ≤ 3 mm (even after periodontal treatment), alveolar bone resorption ≤ 1/3 of root length.	Not reported
Yoshino et al 2020	145.2 ± 79.2 (36-432)¶	Private Practices; Japan	Unclear	174	0	Maxilla and mandible	-	1,030	63.6 ± 9.1 (41 to 87)	58F, 116M	Unclear	Unclear initial periodontal status but at follow-up the main reasons for abutment teeth loss (n = 235) was periodontitis (53.6%)	Maintenance visits at least once per year for a duration of at least 3 years
Zou et al. 2013	60-96	Hospital; China	Combined Engineering and Medical Project of Shanghai Jiao Tong University, National Natural Science Foundation of China, and Key Project of	44	3	Maxilla	217	-	57.6	24F, 20M	Unclear	The enrolled patients were all edentulous patients or patients with terminal nature dentition suffering from periodontal disease*	Unclear, yearly follow-up examinations

			Chinese Ministry of Education										

Table 1

Author and Year	Study Design	Number of Patients with Outcomes	Number of Implants	Implant Survival Rate	Number of Implant-Supported Prosthesis	Number of implants per prosthesis	Implant-Supported Prosthesis Survival Rate	Number of Teeth/Roots	Number of teeth per prosthesis	Tooth Survival Rate	Number of Tooth-Supported Prosthesis	Tooth-Supported Prosthesis Survival Rate
12 months												
Budtz-Jørgensen et al. 1988	Prospective Cohort	40						92	1-4	97.82%	44	unclear
Glibert et al. 2018	Case Series¶	21	83	96.4%	21	4	100%					
Toolson et al. 1978	Prospective Cohort	79						210	unclear	100%	Unclear (104 at baseline but not specified after drop-outs)	Not reported (possibly 100%)
24 months												
Eccellente et al. 2011	Prospective Case Series	45	180	97.77%	45	4	100%					
Ericson et al. 1990	Retrospective	25						104	Mandible: 2-6 Maxilla: 1 - 6	100%	26	100%
Hug et al. 2006	Mixed (Prospective/Retrospective case series)	32 (15: tooth-supported prosthesis & 17: implant-supported prosthesis	57	98.24%£	20	Unclear, but usually 2	95%£	56	unclear, but usually 2	100%£	21	95.23%£

Toolson et al. 1982	Prospective Cohort	74						190	unclear	97.89%[£]	Unclear (104 at baseline but not specified after drop-outs)	Not reported
Van Assche et al. 2011	Case Series	12	72 (36 long & 36 short implants)	Short Implants: 97.22% Long Implants: 100%	12	6	100%					
Van Waas et al. 1993	Case Series[¶]	52						148	2	100%	52	Not reported (possibly 100%)
Yao et al. 2013	Retrospective	30						60	2	unclear	30	100%[£]
36 months												
Budtz-Jørgensen et al. 1991	Prospective Cohort	35						80	1-4	94.12%%[£]	38	Unclear
Ericson et al. 1990	Retrospective	23						99	Mandible: 2 - 6 Maxilla: 1 - 6	98.99%[£]	24	100%
48 – 60 months												
Coca et al. 2000	Retrospective/ Cross-Sectional	92						236	1: n=24; 2: n=48; 3: n=24; 4: n=6;	86% for maxillary teeth & 92% for	106	100%[£]

									5: n=4	mandibular teeth		
Keltjens et al. 1999	Prospective Case Series	49						155	unclear	98.71%[£]	56	Unclear
Widbom et al. 2004	Retrospective/ Cross-Sectional	72						368	unclear	93.48%[£]	75	96%
Budtz-Jørgensen et al. 1995	Prospective Cohort	31						65	1-4	90.27%[£]	unclear	87.1%[£] [patient-level]
Chhabra et al. 2019	Retrospective/ Cross-Sectional	80						270	1: n=1 (1%); 2: n=7 (9%); 3: n=33 (41%); 4: n=39 (49%)	Unclear	97	100%
Gonda et al. 2013	Retrospective	Unclear						65[£]	unclear	93.85%[£]	49	Unclear
Rinke et al. 2019	Retrospective	221						538	1: n=75; 2: n=101; 3: n=87	55% (CI 0.48 to 0.62)	263	62% (CI 0.55 to 0.69)
Toolson et al. 1983	Prospective Cohort	54						133	unclear	89.26%[£]	Unclear	Not reported
72-144 months (6-12 years)												
Keltjens et al. 1994	Retrospective/Cross-sectional	148						512	unclear	91.40%[£]	181	89%
Coca et al. 2000	Retrospective/ Cross-Sectional	92						236	1: n=24; 2: n=48; 3: n=24; 4: n=6; 5: n=4	86%[£]	106	100%[£]
Coca et al. 2002	Retrospective/ Cross-Sectional	66						99	1: n=36 (54.5%); 2: n=27 (40.9%); 3: n=3 (4.5%)	79%	68	Unclear
Rinke et al. 2019	Retrospective	221						538	1: n=75; 2: n=101; 3: n=87	34% (CI 0.27 to 0.42)	263	38% (CI 0.30 to 0.45)
Shaw 1984	Retrospective/	23						53	1: n=1; 2: n=22;	75.47%[£]	25	40%[£]

	Cross-Sectional								4: n=1 5: n=1			
Toolson et al. 1989	Prospective Cohort	28						66	unclear	85.71%[£]	33[€]	78.57%[£] (patient-level: 6 patients had the prosthesis remade)
Yoshino et al. 2020	Retrospective	174						1,030	≤10	83.8%	213	94.7%
Zou et al. 2013	Retrospective	41	201	100%	41	Telescopic crowns: 4-8: n=21 Dolder bar: 2, 3, or 5 implants: n=109	100%					
240 months (≥20 years)												
Eisenburger et al. 2000	Retrospective	175						559	1: n=48; 2: n=97; 3: n=60; ≥4: n=45	89.4%	250	86.4%
Yoshino et al. 2020	Retrospective	174						1,030	≤10	66.3%	213	70.8%

Table 2

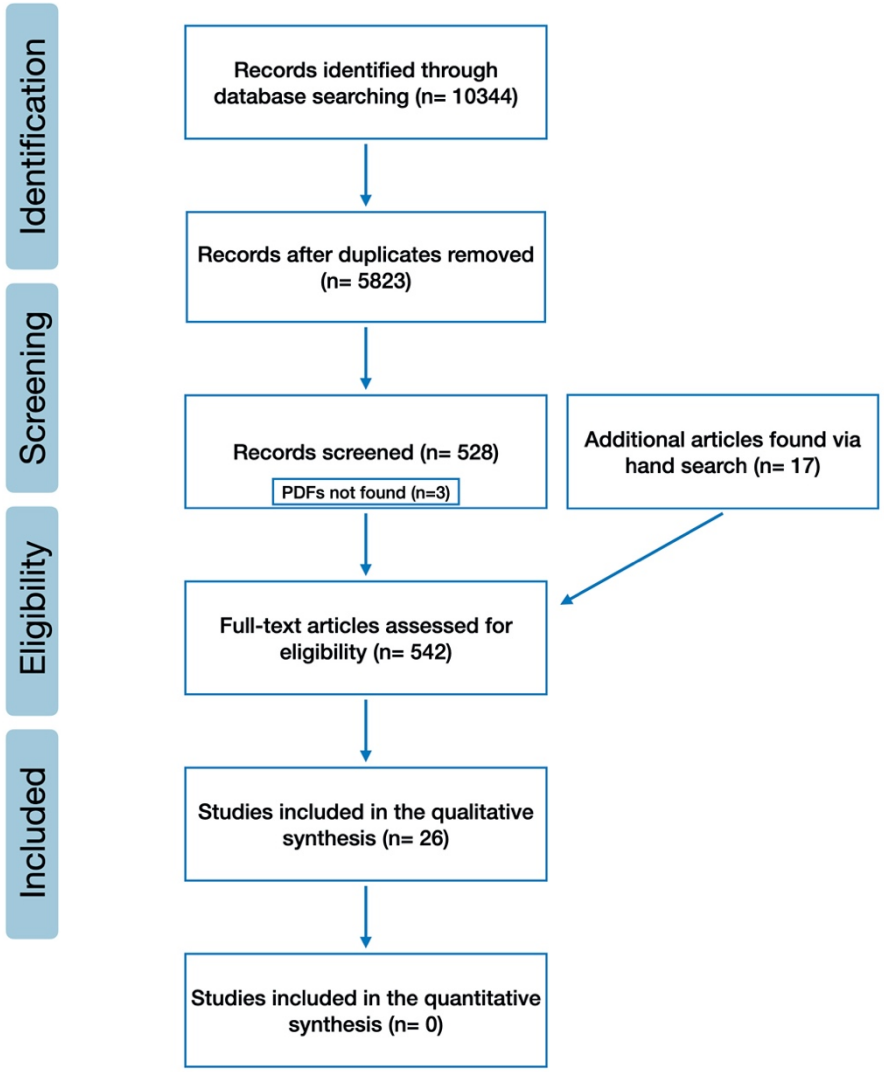
Identification
Screening
Eligibility
Included
Records identified through database searching (n= 10344)
Records after duplicates removed (n= 5823)
Records screened (n= 528)
PDFs not found (n=3)
Additional articles found via hand search (n= 17)
Full-text articles assessed for eligibility (n= 542)
Studies included in the qualitative synthesis (n= 26)
Studies included in the quantitative synthesis (n= 0)

Figure 1

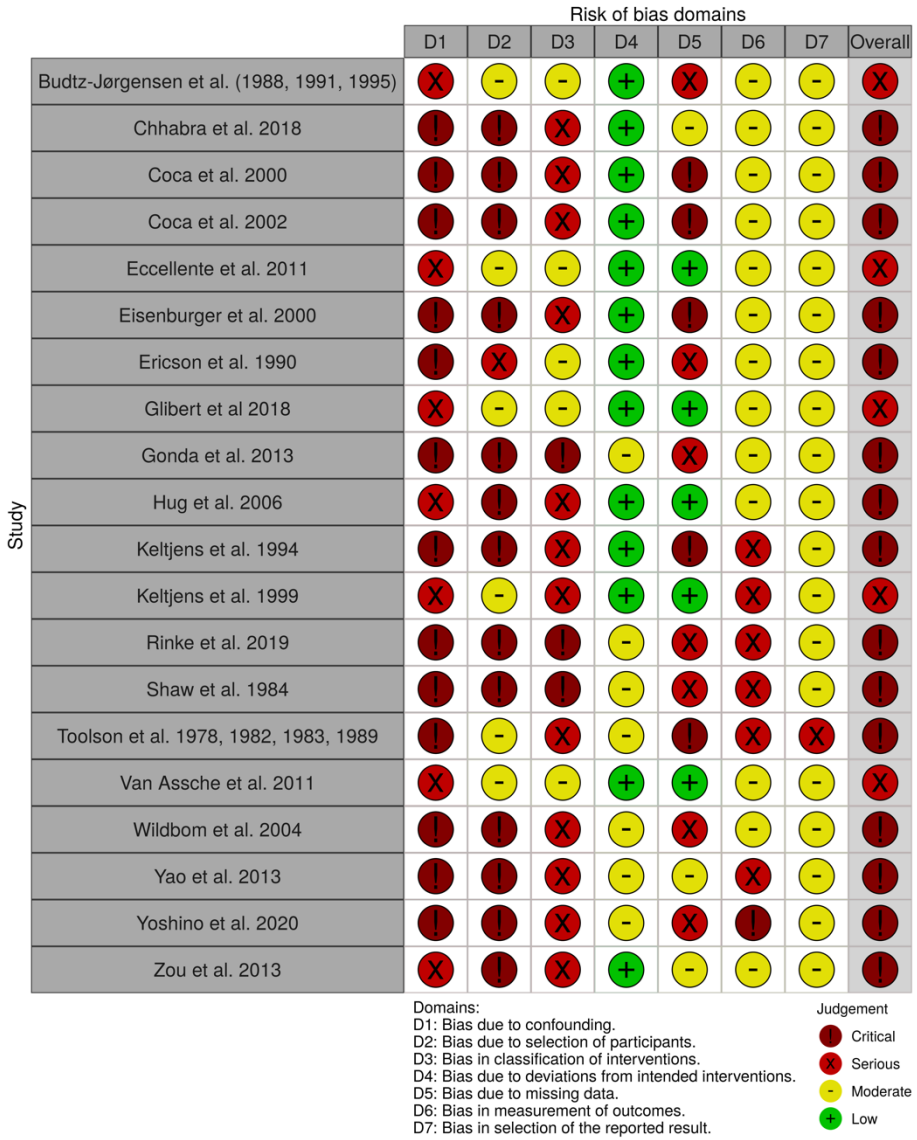
Risk of bias domains
D1
D2
D3
D4
D5
D6
D7
Overall
Study
Budtz-Jørgensen et al. (1988, 1991, 1995)
Chhabra et al. 2018
Coca et al. 2000
Coca et al. 2002
Eccellente et al. 2011
Eisenburger et al. 2000
Ericson et al. 1990
Glibert et al 2018
Gonda et al. 2013
Hug et al. 2006
Keltjens et al. 1994
Keltjens et al. 1999
Rinke et al. 2019
Shaw et al. 1984
Toolson et al. 1978, 1982, 1983, 1989
Van Assche et al. 2011
Wildbom et al. 2004
Yao et al. 2013
Yoshino et al. 2020
Zou et al. 2013
Domains:
D1: Bias due to confounding.
D2: Bias due to selection of participants.
D3: Bias in classification of interventions.
D4: Bias due to deviations from intended interventions.
D5: Bias due to missing data.
D6: Bias in measurement of outcomes.
D7: Bias in selection of the reported result.
Judgement
Critical
Serious
Moderate
Low

Figure 2