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REVIEW ARTICLE

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Systematic review evaluating the influence of the prosthetic material and prosthetic design on the clinical outcomes of implant-supported multi-unit fixed dental prosthesis in the posterior area

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Abstract

Objective: The objectives of the study were to assess the survival, failure, and technical complication rates of implant-supported fixed dental prosthesis (iFDPs) with pontic or splinted crown (iS_pC) designs in the posterior area and compare the influence of prosthetic materials and prosthetic design on the outcomes.

Methods: Electronic and manual searches were performed to identify randomized-, prospective-, and retrospective clinical trials with follow-up time of ≥12 months, evaluating the clinical outcomes of posterior iFDPs with pontic or iS_pCs. Survival and complication rates were analyzed using robust Poisson's regression models.

Results: Thirty-two studies reporting on 42 study arms were included in the present systematic review. The meta-analysis of the included studies indicated estimated 3-year survival rates of 98.3% (95%CI: 95.6–99.3%) for porcelain-fused-to-metal (PFM) iFDPs, 97.5% (95%CI: 95.5–98.7%) for veneered zirconia (Zr) iFDPs with pontic, 98.9% (95%CI: 96.8–99.6%) for monolithic or micro-veneered zirconia iFDPs with pontic, and 97.0% (95%CI: 84.8–99.9%) for lithium disilicate iFDPs with pontics. The survival rates for different material combination showed no statistically significant differences. Veneered restorations, overall, showed significantly ($p < .01$) higher ceramic fracture and chipping rates compared with monolithic restorations. Furthermore, there was no significant difference in survival rates (98.3% [95%CI: 95.6–99.3%] vs. 99.1% [95%CI: 97.6–99.7%]) and overall complication rates between PFM iFDPs with pontic and PFM iS_pCs.

Conclusions: Based on the data identified by this systematic review, PFM, veneered Zr, and monolithic Zr iFDPs with pontic and iS_pCs showed similarly high short-term survival rates in the posterior area. Veneered restorations exhibit ceramic chipping more often than monolithic restorations, with the highest fracture rate reported for veneered Zr iFDPs.

KEYWORDS
ceramics, dental crown, dental implants, fixed bridge, implant-supported dental prosthesis, meta-analysis, systematic review, zirconia

1 | INTRODUCTION

Computer-aided design and computer-aided manufacturing (CAD/CAM) procedures are well established today and have replaced conventional manual fabrication of fixed tooth- and implant-supported restorations to a large extent. While in the past, manually fabricated porcelain-fused-to-metal (PFM) restorations were mainly considered, a recent change of fabrication technology was accompanied by the introduction of new or improved restorative materials suitable for CAD/CAM technology (Alghazzawi, 2016; Davidowitz & Kotick, 2011; Miyazaki et al., 2009). These new material options range from highly esthetic dental ceramics like reinforced glass–ceramics (e.g., lithium disilicate glass ceramic) to high strength dental ceramics like different zirconia (Zr) generations varying both in translucency but also in fracture resistance (Silva et al., 2017; Spitznagel et al., 2018). In addition, hybrid materials were developed representing a combination of ceramics and resins, fundamentally differing in which part represents the matrix or the filler component (Silva et al., 2017; Spitznagel et al., 2018).

The clinical indications of these CAD/CAM materials for rehabilitation of partial edentulous areas with implant-supported restorations are determined by considering the compatibility of material properties, namely strength and the esthetics, with restoration characteristics such as restoration location (anterior/posterior) and restoration design. An implant-supported fixed restoration can be a single crown (iSC) or a multi-unit fixed dental prosthesis (iFDP). The latter one can be designed as splinted crowns (iS_pCs) and iFDPs with pontic units. In anterior regions, and for single-unit restorations, ceramics like reinforced glass ceramics were recommended, while first generations of Zr ceramics were considered the second choice to treat these indications due to reduced esthetics by means of high opacity. However, for iFDPs, especially located in load-bearing posterior areas, solely Zr was to be recommended for clinical application in case of requesting an all-ceramic solution as it offered sufficient strength (Sailer et al., 2018). Prior to the introduction of Zr generations with increased translucency by modification of the lattice composition toward an increased portion of the cubic phase, poor esthetics of early generation Zr materials had to be improved by the application of veneering ceramics, even in posterior areas. Systematic reviews focusing on veneered Zr (v-Zr) implant-supported restorations have shown, however, that chipping of veneering ceramic was the predominant technical problem. In contrast to the rather low annual occurrence of this complication that was analyzed to be 0.6% for v-Zr iSCs (Pjetursson et al., 2018), the respective annual complication rate when focusing on iFDPs made from the same material complex has been reported to be up to 13.9%. Finally, this means that every second iFDP (50%) made from v-Zr experienced this complication over a 5-year observation period (Sailer et al., 2018).

To overcome this limitation of v-Zr restorations, major improvements of the esthetic appearance of Zr were made in the last years (Ghodsi & Jafarian, 2018). With the increase of stabilizer content, mainly yttria, and the addition of coloring agents the developers have accomplished to significantly improve the translucency and the esthetics of Zr ceramics (Ghodsi & Jafarian, 2018; Zhang & Lawn, 2018). Unfortunately, this increase in translucency is necessarily accompanied with a decrease in fracture strength of new-generation Zr ceramics (Schönhoff et al., 2021). For this reason, most manufacturers offer a variety of Zr materials significantly differing regarding their optical properties, that is, translucency and mechanical properties (Schönhoff et al., 2021).

These material developments and esthetic improvements resulted in a shift toward new treatment and material concepts for iSCs and iFDPs. Nowadays, in most clinical situations, such restorations can be fabricated without use of any veneering ceramic, that is, in a monolithic approach, or applying a rather thin (<0.5 mm) facially layer of a veneering ceramic (i.e., micro-veneered zirconia; micro-v-Zr) (Pjetursson et al., 2021) to improve the esthetic appearance or, in most cases, to exactly match given coloration of adjacent natural or reconstructed teeth. For the connection of these restorations to the implant, prefabricated standardized abutments like titanium-base (ti-base) abutments are predominantly used today. In this concept, subtractively manufactured and finalized restorations are adhesively cemented to the ti-base abutments outside the oral cavity before being screw-retained to the supporting implants.

Monolithic or micro-v-Zr restorations can be applied in both, anterior and posterior regions and as an alternative to reinforced glass–ceramic materials for single-unit restorations. However, in order to provide sufficient fracture resistance in cases revealing multiple adjacent missing teeth, Zr remains to be the ceramic material of choice without any non-metallic material alternative. Depending on the anterior or posterior location of a restoration, different types of Zr according to the afore-mentioned material modification and available generations need to be carefully selected by the dentist or the dental technician. This, however, can be considered a challenging task since both naming of products (mostly containing superlatives of the term "translucency" such as high-, extra-, or super-translucent) and description of material properties and composition are mostly not particularly transparent.

First clinical studies demonstrated very promising outcomes of monolithic/micro-veneered implant restorations out of glass–ceramic or Zr used in combination with ti-base abutments. A previous systematic review (Pjetursson et al., 2021) has focused on failure and complication rates of veneered and monolithic all-ceramic iSCs. In this work, lower rates for ceramic chipping were found when the outcome of monolithic iSCs analyzed (Pjetursson et al., 2021). According to the findings of this review, new concepts for iSCs could be defined and validated, while the outcomes of iFDPs still need to be addressed in further investigations prior to define consistent conclusions and solution approaches. Comparisons of materials, designs and concepts should be made in order to define the most appropriate material according to the design of the iFDPs. Furthermore, a clear distinction between iS_pC and iFDP with pontic designs of iFDPs should be established in order to provide substantiated clinical implications.

Therefore, the primary aim of the present systematic review was to evaluate the survival rates as well as the incidence of technical complications of iFDPs inserted in the posterior area exploring the influence of different prosthetic materials. Furthermore, the secondary aim was to analyze the influence of the design of implant-supported multi-unit reconstructions, differentiating iFDPs with pontics from splinted crown (iSpCs) designs.

2 | MATERIALS AND METHODS

2.1 | Study design

The study protocol of this systematic review was designed according to the Cochrane guidelines (Cumpston et al., 2019) and reported following the guidelines for Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009). This report followed the appropriate EQUATOR (http://www.equator-network.org) guidelines. Furthermore, to improve searching databases for clinical questions, the PICO framework was applied (Schardt et al., 2007). PICO stands for patient/population (P), intervention (I), comparison (C), and outcome (O). For this systematic review, the "PICO" question was defined as follows:

- Population: Patients with multiple adjacent missing teeth in the posterior maxilla and/or mandible.
- Intervention: Reconstruction with implant-supported multi-unit fixed restorations.
- Comparison: Different restoration materials and prosthetic designs (iFDPs with pontics and iSpCs).
- Outcome: Survival, failure, and complication rates of the restorations.

The focus question was: "In patients that have multiple adjacent missing teeth in the posterior area what is the influence of the prosthetic material selection and restoration design (iFDPs with pontics vs. iS_pCs, veneered vs. monolithic) on the survival and complication rates of implant-support restorations?"

As this study is a literature-based systematic review, ethical committee approval is not required.

2.2 | Information sources and search strategy

Detailed and database-specific search strategies were developed to systematically access MEDLINE via PubMed (http://www.ncbi.nlm.nih.gov/pubmed), EMBASE (https://www.embase.com), and the Cochrane Central Register of Controlled Trials (CENTRAL) (http://www.thecochranelibrary.com). The search strategy was conducted to identify papers published until October 10, 2022, and it was primarily designed for the MEDLINE database, and subsequently modified appropriately to consider the syntax of the remaining included databases. Some free-text terms were additionally tagged with an asterisk as truncation symbol to improve the search sensitivity. No filters were applied for date of publication, journal, or language. The search results were downloaded and imported to a bibliographic database software (EndNote X9, Thomson Reuter) to facilitate duplicate removal and cross-reference checks. Details regarding the search strategy and the key word structures are displayed in Figure 1.

2.3 | Eligibility criteria

The inclusion criteria for the clinical investigations were as follow:

- Human studies
- Randomized controlled clinical trials (RCTs), controlled clinical trials, prospective cohort studies, or retrospective case series including at least 10 patients.
- A minimum follow-up time of 12 months after loading the final reconstructions.
- Restoration design (iFDPs with pontic or iS_pCs) and location (anterior or posterior) clearly described and data from iFDPs reported separately from other types of restorations.
- Detailed information on the restoration material used.
- If multiple publications on the same patient cohort were available, only the publication with the longest follow-up time and/or the most comprehensive data was included.
- Posterior iFDPs made of PFM, high-performance polymer materials, monolithic, or veneered all-ceramic materials.
- Sufficient reporting on the clinical outcomes (survival and technical complications) of the restorations.
- Reconstructions supported by titanium dental implants.

The studies not fulfilling the above listed criteria were excluded.

2.4 | Selection of studies

Two reviewers (E.M. and F.B.) screened the titles and abstracts of the entries identified in the literature search independently. Thereafter, the full-text version of all studies that potentially met the eligibility criteria or for which there was insufficient information in the title and abstract were obtained. Any publication considered potentially relevant by at least one of the reviewers was included in the next screening phase. Subsequently, the full-text publications were also evaluated in duplicate and independently by the same review examiners. Conflicts between their decisions were resolved by an open discussion in the presence of a third reviewer (D.K.). In case of no consensus established,

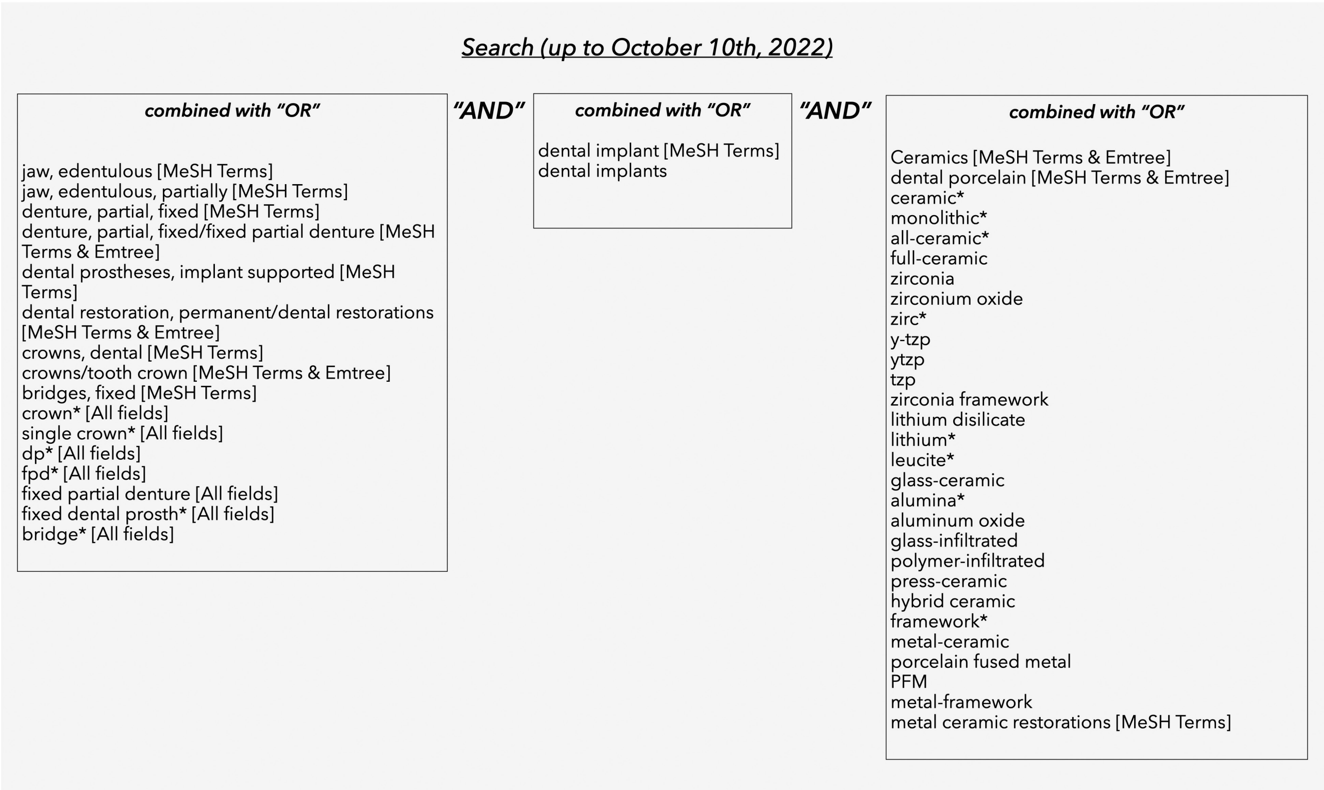

FIGURE 1 Summary of the search terms that were used for the electronic literature searches. The blocks are addressing the restoration type, the restoration support, and the restoration material.

a fourth reviewer (B.E.P.) was consulted. All evaluated full-text publications that did not meet the eligibility criteria were excluded, and the reasons for exclusion were noted. In the case of multiple publications reporting on the same patient cohort, only the publication with the longest follow-up time and/or the most comprehensive data was included in the qualitative and quantitative analyses.

2.5 | Data extraction

Two examiners (B.E.P. and D.K.) independently extracted all relevant information from the included articles using a data extraction sheet specifically designed for this review. Aside from the outcomes of interest, the following study characteristics were retrieved: name of first author, publication year, study setting, study design, mean follow-up time, total exposure time, total number of included patients, number of patients at the end of the follow-up period, number of patients that dropped out of the study, number of implants, abutments, and restorations at the baseline and at the end of the follow-up period were recorded. The restoration characteristics and the number of iFDPs based on restoration design (iFDPs with pontic or iS_pCs), retention type (screw retention or cement), and region (anterior or posterior) was extracted. The material characteristics namely the restoration material (veneered, micro-veneered or monolithic), abutment, framework, and veneering ceramic materials specifications, brands, and fabrication methods were recorded.

2.6 | Outcome measures

The clinical outcome measures for implants were as follow:

- Implant survival was defined as implants survived with or without complications. Implants lost were grouped according to time of failure, before or after loading.

The clinical outcome measures for restorations were as follow:

- Overall survival rate defined the number of restorations that were in-situ at the final follow-up visit with or without complications occurring.
- Overall failure and complication rate was defined as the overall rate of failures and biological and technical complications occurring. Giving the number of restorations free of all complications over the entire observation period.
- Overall failure due to ceramic fractures was defined as restorations failing due to ceramic fractures, such as framework fractures or catastrophic veneer fractures, leading to the remake of the restoration.

- Total number of ceramic fractures or chippings was defined as the incidence of ceramic fractures and chippings irrelevant of the extension of the fracture.
- Major ceramic chipping—repair, was defined as ceramic chippings that needed more treatment than polishing but remake was not required.
- Minor ceramic chipping was defined as surface roughness and polishable ceramic fractures.
- Loss of retention was defined as de-cementation or fracture of the luting cement of cement-retained restorations.
- Screw loosening or screw fracture was defined as screw-related complications yet not leading to the failure of the restoration.

2.7 | Risk of bias assessment of the included studies

The quality of the included studies was assessed by two reviewers (E.M. and F.B.) applying the Cochrane Collaboration's tool for assessing risk of bias. The Cochrane tool for assessing risk of bias in non-randomized studies of interventions (ROBINS-I) was implemented to evaluate the risk of bias of all included studies (prospective and retrospective) in seven different domains: (D1) bias due to confounding; (D2) bias in the selection of participants into the study; (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.

2.8 | Statistics

In the present systematic review, failure and complication rates were calculated dividing the number of events (failures or complications; numerator) by the total restoration exposure time (denominator).

In most cases, the numerator can be directly extracted from the publication data. The total exposure time was calculated by summarizing:

- Exposure time of restorations that could be followed for the whole observation time.
- Exposure time up to a failure of the restorations that were lost during the observation time.
- Exposure time up to the end of observation time for restorations in patients that were lost to follow-up due to reasons such as death, change of address, refusal to participate, non-response, chronic illnesses, missed appointments, and work commitments.

For each study, event rates for the restorations were calculated dividing the total number of events by the total restorations exposure time in years. For further analysis, the total number of events was considered to be Poisson distributed for a given sum of restoration exposure, and Poisson regression were used with a logarithmic link-function and total exposure time per study as an offset variable (Kirkwood & Sterne, 2003). To assess heterogeneity of the study specific event rates, the Spearman goodness-of-fit statistics and associated *p*-value were calculated. To reduce the effect of heterogeneity robust standard errors were calculated to obtain 95% confidence intervals of the summary estimates of the event rates.

The 3-year survival proportions were calculated via the relationship between event rate and survival function *S*, $S(T)=\exp(-T\,{*}\text{event rate})$, by assuming constant event rates (Kirkwood & Sterne, 2003). The 95% confidence intervals for the survival proportions were calculated by using the 95% confidence limits of the event rates. Multivariable Poisson regression was used to investigate formally whether event rates varied by material utilized, the design of the restoration (iFDPs with pontic/iS_pCs). All analyses were performed using Stata®, version 15.1 (Stata Corp).

3 | RESULTS

3.1 | Screening process

Literature search resulted in a total of 4.424 records (Figure 2). After duplicate removal, 3470 references were screened by title. Out of these, 157 full-text articles were assessed for eligibility and subsequently 32 studies were identified to be eligible for inclusion (Figure 2). The detailed reasons for exclusion of the full-text articles were provided in Table S1.

3.2 | Included studies

The present systematic review included 32 studies reporting on 42 study arms or cohorts with implant-supported restorations in the posterior area. 22 of the included cohorts reported on iFDPs with pontic (Table 1). The remaining 20 cohorts, however, reported on iS_pCs (Table 2). Eight of the included cohorts reported on PFM iFDPs with pontic ($n=449$), seven cohorts reported on v-Zr iFDPs with pontic ($n=353$), six cohorts reported on monolithic or micro-v-Zr iFDPs with pontic ($n=210$) and one cohort reported on lithium disilicate iFDPs with pontic ($n=50$; Table 1). Of the 20 included cohorts reporting on iS_pCs, 13 evaluated PFM iS_pCs ($n=527$), two cohorts v-Zr iS_pCs ($n=33$), two cohorts monolithic Zr iS_pCs ($n=34$), and the remaining three cohorts reported on reinforced glass–ceramic (lithium disilicate) iS_pCs ($n=100$; Table 2).

Nine of the included studies were RCTs, 15 were prospective cohort studies and the remaining eight studies were retrospective case series (Tables 1 and 2). Only one of the included RCTs made comparison directly related to the aim of the present systematic review comparing PFM iFDPs with pontic to v-Zr iFDPs with pontic (Esquivel-Upshaw et al., 2020). However, this study provided important information regarding chipping of the veneering ceramic, without reporting on survival and other technical complications. The remaining eight RCTs' research questions were not directly

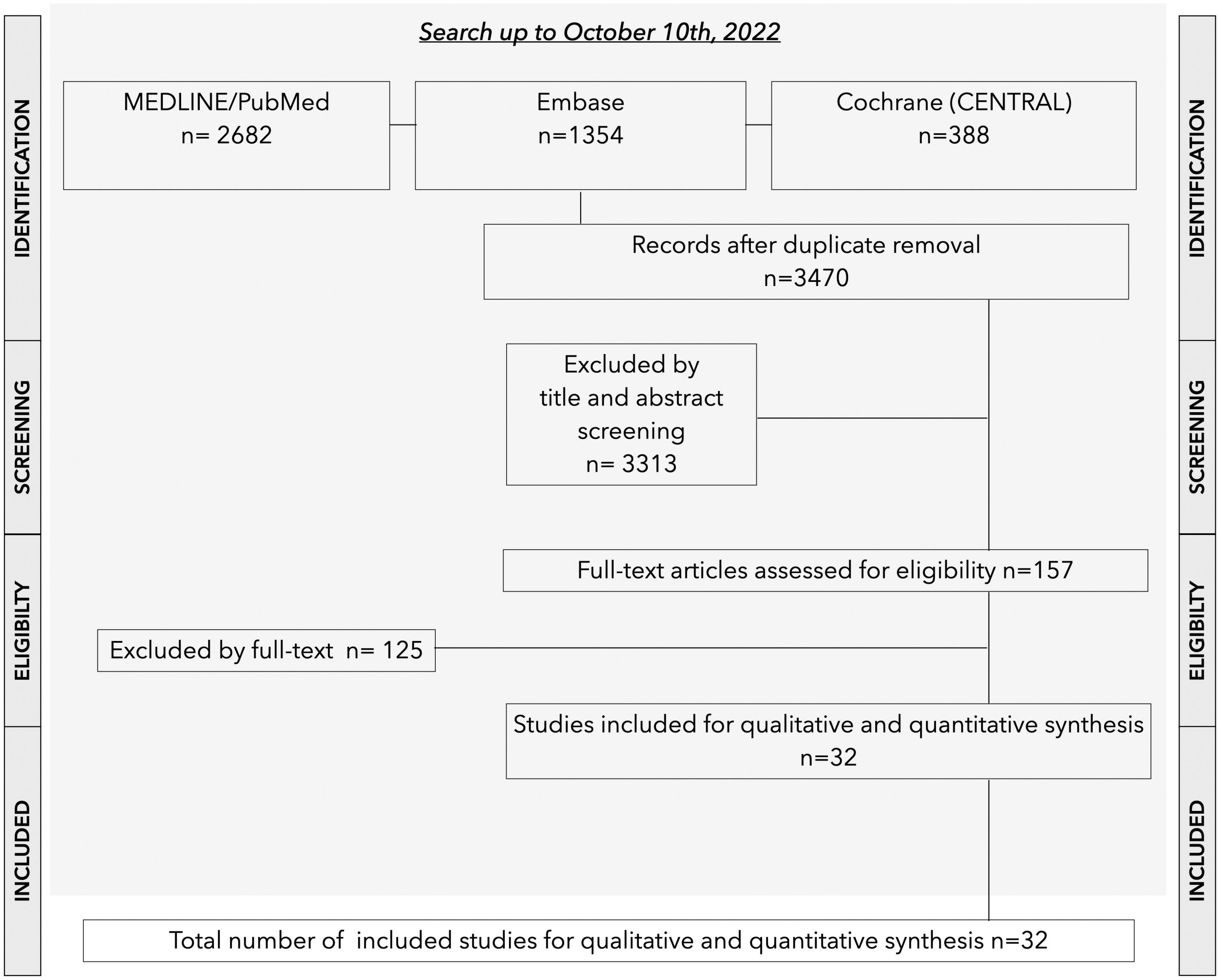

FIGURE 2 PRISMA flowchart.

comparable to the focused question of the present systematic review, such as comparing different Zr systems (Larsson & Vult von Steyern, 2016) different implant lengths (Fonseca et al., 2022; Guljé et al., 2019; Romeo et al., 2014), digital vs. conventional impression techniques (Derksen et al., 2021), splinted vs. non-splinted crowns (Al-Sawaf et al., 2020; Clelland et al., 2016) and the time point of implant loading (Cesaretti et al., 2016). As none of the included RCTs exactly addressed the focused question of the present systematic review, they were addressed as prospective studies and analyzed as such.

The studies reporting on PFM P-FDPs were published between 2001 and 2022 (median 2016). The studies on v-Zr iFDPs were published between 2012 and 2020 (median 2017), monolithic and micro-v-Zr iFDPs studies were published between 2018 and 2021 (median 2020) and reinforced glass–ceramic iFDP studies were published between 2018 and 2021 (median 2020; Tables 1 and 2).

The reporting on the proportion of patients followed for the observation period of the study (drop-out rate) was available in 28 included studies out of 32. The drop-out rate ranged between 0% and 25% with a mean of 5% (median 1%). None of the 28 studies reported a dropout rate of more than 25% (Tables 1 and 2).

From the overall included restorations, 69% were cement-retained and 31% screw-retained. The respected ratio for PFM iFDPs was 62% cemented and 38% screw-retained, for v-Zr iFDPs, 93% were cement-retained and only 7% screw-retained, for monolithic Zr iFDPs, 48% were cement-retained, and 52% screw-retained and all of the reinforced glass–ceramic iFDPs were cemented (Tables 1 and 2).

Twenty-two of the included studies were conducted in an institutional environment, such as university, 8 in private practice setting and the remaining 2 studies did not report the study setting (Tables 1 and 2).

3.3 | Survival and failure rates for implant-supported iFDPs with pontics

Six studies including 332 implant-supported PFM iFDPs with pontics with a mean follow-up period of 4.7 years provided data on the

TABLE 1 Study, patient, and restoration characteristics of the included studies on implant-supported iFDPs with pontics.

Study			Patient					Implants		FDPs				
Author, Year	Design	Setting	Initial [n]	End of follow-up [n]	Drop-out [n]	Drop-out [%]	Mean age [years]	Initial [n]	Failed [n]	Initial [n]	Drop-out [n]	Screw-retained [n]	Cemented [n]	Number of units per iFDPs with pontics
PFM Zr iFDPs with pontics														
Esquivel-Upshaw et al. (2020)	Pro [RCT]	U	96	96	0	0	Nr	128	Nr	64	Nr	0	64	3
Nejatidanesh et al. (2020)	Pro [RCT]	U	114	104	10	9	59	127	Nr	62	4	0	62	3 or 4
Ravidà et al. (2019)	Retro	U	53	Nr	Nr	Nr	63.4	106	0	53	Nr	41	12	3
Shi et al. (2017)	Pro	U	125	118	7	6	60.7	328	1BF & 3 AF	152	8	0	152	3
Vanlioglu et al. (2012)	Retro	U	95	95	0	0	41.2	70	Nr	34	0	0	34	3
Ozkan et al. (2007)	Pro	U	63	63	0	0	46.9	114	0	56	Nr	Nr	Nr	3 or 4
Duncan et al. (2003)	Pro	U	32	32	0	0	43.2	13	0	6	0	Nr	Nr	3 or 4
Aparicio et al. (2001)	Retro	U	25	25	0	0	54	38	2BF	22	0	22	0	Nr
Veneered Zr iFDPs with pontics														
Esquivel-Upshaw et al. (2020)	Pro [RCT]	U	96	96	0	0	Nr	130	Nr	65	Nr	0	65	3
Nejatidanesh et al. (2020)	Pro [RCT]	U	114	104	10	9	59	95	Nr	52	6	0	52	3 or 4
Ferrini et al. (2018)	Pro	U	24	24	0	0	63.6	48	0	24	0	24	0	3 or 4
Shi et al. (2017)	Pro	U	125	118	7	6	60.7	288	2AF	127	6	0	127	3
Larsson and Vult von Steyern (2016)	Pro [RCT]	U	3	3	0	0	Nr	10	Nr	4	Nr	0	4	3 to 5
Monaco et al. (2015)	Pro	U	131	Nr	Nr	Nr	53	Nr	Nr	44	Nr	Nr	Nr	Nr
Pozzi et al. (2012)	Pro	U	27	27	0	0	54.2	81	3BF	37	0	0	37	3 or 4
Monolithic Zr iFDPs with pontics														
De Angelis et al. (2021)	Pro [RCT]	U	32	25	7	22	56.9	Nr	Nr	25	Nr	25	0	Nr
Derksen et al. (2021)	Pro [RCT]	U	38	38	0	0	Nr	48	0	24	0	24	0	3
Pol et al. (2020)	Pro [RCT]	U	54	51	3	6	60.5	120	1BF	59	4	0	59	3
Koenig et al. (2019)	Pro	U	47	46	1	2	54.3	28	0	14	Nr	13	1	3
Cheng et al. (2018)	Pro	U	27	Nr	Nr	Nr	50.7	24	0	12	0	5	7	3
Degidi, Nardi, Gianluca, and Piattelli (2018)	Pro	U	76	72	4	5	45.3	156	0	76	4	Na	Na	3
Monolithic LiSi2 iFDPs with pontics														
Degidi et al. (2021)	Pro	U	50	49	1	2	45.5	100	0	50	1	0	50	3

Abbreviations: AF, failed implant after loading; BF, failed implant before loading; iFDP, implant-supported fixed dental prostheses with pontics; iFDP, implant-supported fixed dental prostheses with pontics; LiDi2, lithium disilicate; Na, not applicable; Nr, not reported; PFM, porcelain-fused-to-metal; PP, private practice setting; Pro [RCT], RCTs that were considered as prospective study for data analysis; Pro, prospective clinical study; RCT, randomized controlled trial; Retro, retrospective clinical study; U, university setting; Zr, zirconia.

TABLE 2 Study, patient, and restoration characteristics of the included studies on implant-supported SpCs.

Study			Patient					Implants		SpCs				
Author, Year	Design	Setting	Initial [*n*]	End of follow-up [*n*]	Drop-out [*n*]	Drop-out [%]	Mean age [years]	Initial [*n*]	Failed [*n*]	Initial [*n*]	Drop-out [*n*]	Screw-retained [*n*]	Cemented [*n*]	Number of units per SpCs
PFM Zr SpCs														
Fonseca et al. (2022)	Pro [RCT]	U	10	10	0	0	59	40	0	20	0	20	0	2
Guljé et al. (2021)	Pro [RCT]	U	95	85	10	11	54.5	209	3 BF & 2 AF	95	10	95	0	2 or 3
Daher et al. (2019)	Pro	U	26	24	2	8	49.2	160	7	48	0	48	0	3 or 4
Hsu et al. (2019)	Retro	U	135	104	31	23	49.8	201	2AF	97	Nr	0	97	2, 3 or 4
Ravidà et al. (2019)	Retro	U	52	Nr	Nr	Nr	60.2	156	13	52	Nr	40	12	3
Cesaretti et al. (2016)	Pro [RCT]	PP	30	30	0	0	Nr	49	1BF & 2AF	22	0	Nr	Nr	2 or 3
Clelland et al. (2016)	Pro [RCT]	U	18	15	3	17	56	32	0	15	Nr	14	1	2 or 3
Romeo et al. (2014)	Pro [RCT]	U	24	18	6	25	54.3	54	1BF	24	6	0	24	2 or 3
Vanlioglu et al. (2012)	Retro	U	95	95	0	0	41.2	18	Nr	18	0	0	18	2
Pieri et al. (2012)	Pro	PP	25	25	0	0	64.5	61	2	28	0	13	15	2 or 3
Nissan et al. (2011)	Pro	U	38	38	0	0	58	221	0	76	0	38	38	2 or 3
Ozkan et al. (2007)	Pro	U	63	63	0	0	46.9	28	Nr	14	0	Nr	Nr	2
Duncan et al. (2003)	Pro	U	32	32	0	0	43.2	32	0	15	0	Nr	Nr	2 or 3
Veneered Zr SpCs														
Roh et al. (2019)	Pro	U	8	Nr	Nr	Nr	Nr	30	0	12	0	0	12	2, 3 or 4
Larsson and Vult von Steyern (2016)	Pro [RCT]	U	15	14	1	7	Nr	51	Nr	21	0	0	21	2 or 3
Monolithic Zr SpCs														
Derksen et al. (2021)	Pro [RCT]	U	38	38	0	0	Nr	42	0	21	0	21	0	2
Roh et al. (2019)	Pro	U	11	Nr	Nr	Nr	Nr	30	0	13	0	0	13	2, 3 or 4
Monolithic LiSi2 SpCs														
Al-Sawaf et al. (2020)	Pro [RCT]	U	20	20	0	0	59	22	0	11	0	0	11	2
Degidi et al. (2019)	Pro	U	24	23	1	4	39.3	48	0	24	1	Na	Na	2
Degidi, Nardi, Sighinolfi, and Piattelli (2018)	Pro	U	67	63	4	6	43	134	1BF	65	2	Na	Na	2

Abbreviations: AF, failed implant after loading; BF, failed implant before loading; LiDi2, lithium disilicate; Na, not applicable; Nr, not reported; PFM, porcelain-fused-to-metal; PP, private practice setting; Pro, prospective clinical study; RCT, randomized controlled trial; Retro, retrospective clinical study; SpC, splinted crowns; U, university setting; Zr, zirconia.

TABLE 3 Annual failure rates and 3-year survival rates of implant-supported iFDPs with pontics.

Author, Year	iFDPs with pontics [*n*]	Mean follow-up [year]	Failures [*n*]	Total iFDPs with pontics exposure time	Estimated annual failure rate[a] (per 100 SpCs years)	Estimated survival after 3 years[a] [%]
PFM Zr iFDPs with pontics						
Nejatidanesh et al. (2020)	62	5	0	290	0%	100%
Shi et al. (2017)	152	5.2	8	790	1.0%	97.0%
Vanlioglu et al. (2012)	34	7	1	238	0.4%	98.7%
Ozkan et al. (2007)	56	2	0	168	0%	100%
Duncan et al. (2003)	6	3	0	18	0%	100%
Aparicio et al. (2001)	22	3	0	68	0%	100%
Total	332	4.7	9	1572		
Summary estimate (95% CI)[a]					0.57% (0.22–1.49%)	98.3% (95.6–99.3%)
Veneered Zr iFDPs with pontics						
Nejatidanesh et al. (2020)	52	5	1	230	0.4%	98.7%
Ferrini et al. (2018)	24	3	0	72	0%	100%
Shi et al. (2017)	127	5	6	535	1.1%	96.7%
Larsson and Vult von Steyern (2016)	4	10	0	40	0%	100%
Monaco et al. (2015)	44	1.8	2	77	2.6%	92.5%
Pozzi et al. (2012)	37	3.6	0	134	0%	100%
Total	288	3.8	9	1088		
Summary estimate (95% CI)[a]					0.83% (0.44–1.54%)	97.5% (95.5–98.7%)
Monolithic Zr iFDPs with pontics						
De Angelis et al. (2021)	25	2	0	75	0%	100%
Derksen et al. (2021)	24	1	0	24	0%	100%
Pol et al. (2020)	59	1	0	56	0%	100%
Koenig et al. (2019)	14	1.8	0	25	0%	100%
Cheng et al. (2018)	12	2	1	22	4.5%	87.3%
Degidi, Nardi, Gianluca, and Piattelli (2018)	76	5	1	353	0.3%	99.2%
Total	210	2.6	2	555		
Summary estimate (95% CI)[a]					0.36% (0.12–1.08%)	98.9% (96.8–99.6%)
Monolithic LiSi2 iFDPs with pontics						
Degidi et al. (2021)	50	2	1	99	1.0%	97.0%
Total	50	2	1	99		
Summary estimate (95% CI)[a]					1.01% (0.02–5.5%)	97.0% (84.8–99.9%)

Abbreviations: CI: confidence interval; iFDP, implant-supported fixed dental prostheses with pontics; LiDi2: lithium disilicate; [*n*]: number; PFM: porcelain-fused-to-metal; Zr: zirconia.

[a]Based on robust Poisson regression.

survival of the iFDPs with pontic. Six studies reporting on 288 restorations with a mean follow-up time of 3.8 years provided data on the survival of v-Zr implant-supported iFDPs with pontic. Four studies on 210 iFDPs with pontic after a mean follow-up time of 2.6 years provided data on the survival of monolithic or micro-veneered implant-supported iFDPs with pontic and one study with 50 restorations and a mean follow-up time of 2 years gave information on the survival rate of implant-supported reinforced glass–ceramic (lithium disilicate) iFDPs with pontics (Table 3).

The meta-analysis revealed an estimated annual failure rate of 0.57% (95% CI: 0.22–1.49%), translating into a 3-year survival rate of 98.3% (95% CI: 95.6–99.3%) for PFM iFDPs with pontic, annual failure rate of 0.83% (95% CI: 0.44–1.54%) and 3-year survival rate of 97.5% (95% CI: 95.5–98.7%) for v-Zr iFDPs with pontic, annual

TABLE 4 Annual failure rates and 3-year survival rates of implant-supported SpCs.

Author, Year	SpCs [n]	Mean follow-up [year]	Failures [n]	Total SpCs exposure time	Estimated annual failure rate[a] (per 100 SpCs years)	Estimated survival after 3 years[a] [%]
PFM Zr SpCs						
Fonseca et al. (2022)	20	2	0	40	0%	100%
Daher et al. (2019)	48	3	2	139	1.4%	95.8%
Hsu et al. (2019)	97	6.3	1	611	0.2%	99.5%
Cesaretti et al. (2016)	22	3	0	66	0%	100%
Clelland et al. (2016)	18	3	0	45	0%	100%
Romeo et al. (2014)	24	4.3	1	99	1.0%	97.0%
Vanlioglu et al. (2012)	18	7	1	126	0.8%	97.6%
Pieri et al. (2012)	28	2	0	56	0%	100%
Nissan et al. (2011)	76	5.3	0	402	0%	100%
Ozkan et al. (2007)	14	2	0	42	0%	100%
Duncan et al. (2003)	15	3	0	45	0%	100%
Total	380	4.4	5	1671		
Summary estimate (95 % CI)[a]					0.30% (0.11–0.80%)	99.1% (97.6–99.7%)
Veneered Zr SpCs						
Roh et al. (2019)	12	1	0	12	0%	100%
Larsson and Vult von Steyern (2016)	21	10	0	210	0%	100%
Total	33	6.7	0	222		
Summary estimate (95 % CI)[a]					0% (0–1.65%)	100% (95.2–100%)
Monolithic Zr SpCs						
Derksen et al. (2021)	21	1	0	21	0%	100%
Roh et al. (2019)	13	1	0	13	0%	100%
Total	34	1	0	34		
Summary estimate (95 % CI)[a]					0% (0–10.3%)	100% (73.5–100%)
Monolithic LiSi2 SpCs						
Al-Sawaf et al. (2020)	11	3	0	33	0%	100%
Degidi et al. (2019)	24	2	0	46	0%	100%
Degidi, Nardi, Sighinolfi, and Piattelli (2018)	65	3	2	188	1.1%	96.9%
Total	100	2.7	2	267		
Summary estimate (95 % CI)[a]					0.75% (0.31–1.79%)	97.8% (94.8–99.1%)

Abbreviations: CI, confidence interval; iSpC, implant-supported splinted crowns; LiDi2, lithium disilicate; [*n*], number; PFM, porcelain-fused-to-metal; Zr, zirconia.

[a]Based on robust Poisson regression.

failure rate of 0.36% (95% CI: 0.12–1.08%) and 3-year survival rate of 98.9% (95% CI: 96.8–99.6%) for monolithic or micro-veneered Zr iFDPs with pontic and annual failure rate of 1.01% (95% CI: 0.02–5.5%) and 3-year survival rate of 97.0% (95% CI: 84.8–99.9%) for reinforced glass–ceramic iFDPs with pontic (Table 3).

Formally investigating the relative failure rates of different types of implant-supported iFDPs with pontic by applying PFM iFDPs with pontic as reference, no statistically significant difference between the restoration materials was observed (Table 4). However, when the survival rates of monolithic Zr (98.9%) and monolithic reinforced glass–ceramic (97.0%) iFDPs with pontic where directly compared, the meta-analysis resulted in a tendency, however, not statistically significant, toward lower survival rates of reinforced glass–ceramic iFDPs with pontic ($p = .063$).

Investigating the number of implant-supported iFDPs with pontic that failed due to ceramic fractures such as fracture of the framework or catastrophic fracture of the veneering material, implant-supported reinforced glass–ceramic iFDPs with pontic demonstrated significantly ($p < .0001$) higher annual fracture rate (1.0%) compared with the other material groups (Table 6).

Meta-analysis comparing the overall failure and fracture rates of veneered and monolithic Zr implant-supported iFDPs with pontic demonstrated no significant difference ($p = .728$). Moreover, none of the 288 veneered Zr restorations analyzed failed due to framework fracture, and none of the 210 monolithic Zr iFDPs with pontic investigated failed due to catastrophic fracture of the veneering material. Combined, the annual framework fracture rate for monolithic Zr 0.36%, and the catastrophic ceramic fracture rate of 0.46% for v-Zr iFDPs with pontic did not show significant difference (Table 8).

3.4 | Survival and failure rates for implant-supported S_pCs

Eleven studies including 380 implant-supported PFM iS_pCs in the posterior area, with a mean follow-up period of 4.4 years, provided information regarding the survival of the restorations: two studies including 33 restorations with a mean follow-up time of 6.7 years provided information on the survival of v-Zr iS_pCs, 2 studies including 34 iS_pCs and a mean follow-up time of 1 year provided data on the survival of monolithic Zr iS_pCs and 3 studies reporting on 100 iS_pCs and a mean follow-up time of 2.7 years provided information on the survival rate of reinforced glass–ceramic (lithium disilicate) iS_pCs (Table 5).

The meta-analysis revealed an estimated annual failure rate of 0.30% (95% CI: 0.11–0.80%), translating into a 3-year survival rate of 99.1% (95% CI: 97.6–99.7%) for PFM iS_pCs, annual failure rate of 0% (95% CI: 0–1.65%), and 3-year survival rate of 100% (95% CI: 95.2–100%) for v-Zr S_pCs, annual failure rate of 0% (95% CI: 0–10.3%) and 3-year survival rate of 100% (95% CI: 73.5–100%) for monolithic Zr iS_pCs and annual failure rate of 0.75% (95% CI: 0.31–1.79%), and 3-year survival rate of 97.8% (95% CI: 94.8–99.1%) for reinforced glass–ceramic iS_pCs (Table 5).

The failures due to ceramic fractures were not investigated statistically due to the insufficient number of veneered and monolithic Zr implant-supported iS_pCs. None of the included Zr iS_pCs failed due to framework fracture or veneering/surface material fracture (Table 7).

Meta-analysis comparing implant-supported PFM iFDPs with pontic vs. implant-supported PFM iS_pCs did not reveal any significant difference ($p=.334$) when comparing the annual failure rates. However, significantly ($p=.042$) more PFM iFDPs with pontic were lost due to fracture of the veneering ceramic compared with PFM iS_pCs. The overall numbers for both configurations, however, were low (Table 9).

3.5 | Overall complication rates

Only a few of the included studies reported the total number of complications or the number of restorations free of all complications over the entire observation period. The annual complication rate of 1.93% was reported for implant-supported PFM iFDPs with pontic ($n=149$). Significantly higher ($p=.010$) annual complication rate of 11.76% was reported for monolithic Zr iFDPs with pontic ($n=96$; Table 6). The high overall complication rate calculated for monolithic Zr iFDPs with pontic is mainly affected by one study (Pol et al., 2020)

TABLE 5 Summary of annual failure rates, relative failure rates, and survival estimates for iFDPs with pontics with implant-supported PFM iFDPs as reference.

iFDPs material	iFDPs [n]	Total iFDPs exposure time	Mean follow-up [year]	Estimated annual failure rate[a] (95% CI)	3-year survival summary estimate[a] (95 % CI)	Relative failure rate[b] (95% CI)	p-value[b]
PFM iFDPs	332	1572	4.7	0.57% (0.22–1.49%)	98.3% (95.6–99.3%)	1.00 (Ref.)	
Veneered Zr iFDPs	288	1088	3.8	0.83% (0.44–1.54%)	97.5% (95.5–98.7%)	1.44 (0.50–4.20)	.495
Monolithic Zr iFDPs	210	555	2.6	0.36% (0.12–1.08%)	98.9% (96.8–99.6%)	0.63 (0.16–2.43)	.501
Monolithic LiDi2 iFDPs	50	99	3	1.01% (0.02–5.5%)	97.0% (84.8–99.9%)	1.76 (0.73–4.27)	.209

Abbreviations: CI, confidence interval; iFDP, implant-supported fixed dental prostheses with pontics; LiDi2, lithium disilicate; [n], number; PFM, porcelain-fused-to-metal; Zr, zirconia.

[a]Based on robust Poisson regression.

[b]Based on multivariable robust Poisson regression including all types of iFDPs.

TABLE 6 Overview of failures and technical complications of iFDPs made with different materials.

Complications & Failures	PFM iFDPs: Number of iFDPs [n]	PFM iFDPs: Estimated annual failure/complication rates[a] (95% CI)	Veneered Zr iFDPs: Number of iFDPs [n]	Veneered Zr iFDPs: Estimated annual failure/complication rates[a] (95% CI)	Monolithic Zr iFDPs: Number of iFDPs [n]	Monolithic Zr iFDPs: Estimated annual failure/complication rates[a] (95% CI)	Monolithic LiDi2 iFDPs: Number of iFDPs [n]	Monolithic LiDi2 iFDPs: Estimated annual failure/complication rates[a] (95% CI)
Overall failures due to ceramic fractures	385	0.36[a] (0.02–0.63)	288	0.46[a] (0.18–1.16)	210	0.36[a] (0.12–1.08)	50	1.0[a] (0.03–5.50)
Failure due to framework fractures	385	0.16[a] (0.03–0.67)	288	0[a] (0–0.34)	210	0.36[a] (0.12–1.08)	50	1.0[a] (0.03–5.50)
Failure due to catastrophic veneer fractures	385	0.25[a] (0.09–0.70)	288	0.46[a] (0.18–1.16)	134	0[a] (0–1.81)	0	Nr
Total number of ceramic chippings or fractures	393	2.20[a] (1.56–3.11)	353	4.95[a] (3.72–6.60)	210	0.18[a] (0.02–1.83)	0	Nr
Minor ceramic chippings	254	0.89[a] (0.49–1.65)	288	2.85[a] (2.16–3.76)	210	0.18[a] (0.02–1.83)	0	Nr
Major ceramic chippings–repair	254	0.90[a] (0.36–2.23)	288	1.65[a] (0.54–5.06)	210	0[a] (0–0.66)	0	Nr
Loss of retention	363	1.56[a] (0.40–6.13)	179	2.75[a] (1.38–5.46)	185	1.46[a] (0.21–10.27)	0	Nr
Screw loosening or fractures	267	2.36[a] (0.09–63.5)	188	8.33[a] (3.12–17.26)	172	0[a] (0–0.73)	0	Na

Abbreviations: AF, failed implant after loading; BF, failed implant before loading; CI, confidence interval; iFDP, implant-supported fixed dental prostheses with pontics; LiDi2, lithium disilicate; Na, not applicable; Nr, not reported; PFM, porcelain-fused-to-metal; PP, private practice setting; Pro, prospective clinical study; RCT, randomized controlled trial; Retro, retrospective clinical study; U, university setting; Zr, zirconia.

[a]Based on robust Poisson regression.

TABLE 7 Overview of failures and technical complications of SpCs made with different materials.

Complications & Failures	PFM SpC: Number of SpCs [n]	PFM SpC: Estimated annual failure/complication rates[a] (95% CI)	Veneered Zr SpCs: Number of SpCs [n]	Veneered Zr SpCs: Estimated annual failure/complication rates[a] (95% CI)	Monolithic Zr SpCs: Number of SpCs [n]	Monolithic Zr SpCs: Estimated annual failure/complication rates[a] (95% CI)	Monolithic LiDi2 SpCs: Number of SpCs [n]	Monolithic LiDi2 SpCs: Estimated annual failure/complication rates[a] (95% CI)
Overall complication rate	231	4.30[a] (2.86–6.45)	0	Nr	0	Nr	10	3.03[a] (0.08–15.76)
Overall failures due to ceramic fractures	527	0.04[a] (0.005–0.32)	33	0[a] (0–1.65)	34	0[a] (0–10.28)	100	0.75[a] (0.31–1.79)
Failure due to framework fractures	451	0.05[a] (0.006–0.39)	33	0[a] (0–1.65)	34	0[a] (0–10.28)	100	0.75[a] 0.31–1.79)
Failure due to catastrophic ceramic fractures	527	0.04[a] (0.005–0.32)	33	0[a] (0–1.65)	34	0[a] (0–10.28)	100	0[a] (0–1.37)
Total number of ceramic chippings or fractures	513	1.79[a] (1.04–3.10)	33	9.01[a] (8.87–9.15)	34	0[a] (0–10.28)	100	3.37[a] (0.94–12.13)
Minor ceramic chippings	290	1.71[a] (1.19–2.46)	33	9.01[a] (8.87–9.15)	34	0[a] (0–10.28)	100	3.37[a] (0.94–12.13)
Major ceramic chippings - repair	290	0.08[a] (0.009–0.71)	33	0[a] (0–1.65)	34	0[a] (0–10.28)	100	0[a] (0–1.37)
Loss of retention	288	0.81[a] (0.43–1.51)	12	0[a] (0–26.46)	34	0[a] (0–10.28)	76	0[a] (0–1.37)
Screw loosening or fractures	493	2.81[a] (1.14–6.93)	12	Na	13	0[a] (0–24.71)	100	0[a] (0–1.37)

Abbreviations: CI, confidence interval; LiDi2, lithium disilicate; Na, not applicable; Nr, not reported; PFM, porcelain-fused-to-metal; SpC, splinted crown; Zr, zirconia.

[a]Based on robust Poisson regression.

TABLE 8 Comparison of annual failure and complication rates for veneered and monolithic implant-supported iFDPs.

Failures/complications	Veneered Zr iFDPs		Monolithic Zr iFDPs		
	iFDPs [*n*]	Estimated annual failure rate[a] (95% CI)	iFDPs [*n*]	Estimated annual failure rate[a] (95% CI)	*p*-value[a]
Overall failures due to ceramic fractures	288	0.46[a] (0.18–1.16)	210	0.36[a] (0.12–1.08)	.728
Failure due to framework fractures	288	0[a] (0–0.34)	210	0.36[a] (0.12–1.08)	<.0001
Failure due to catastrophic ceramic fractures	288	0.46[a] (0.18–1.16)	134	0[a] (0–1.81)	<.0001
Total number of ceramic chippings or fractures	353	4.95[a] (3.72–6.60)	210	0.18[a] (0.02–1.83)	<.0001
Minor ceramic chippings	288	2.85[a] (2.16–3.76)	210	0.18[a] (0.02–1.83)	.015
Major ceramic chippings–repair	288	1.65[a] (0.54–5.06)	210	0[a] (0–0.66)	<.0001
Loss of retention	179	2.75[a] (1.38–5.46)	185	1.46[a] (0.21–10.27)	.527
Screw loosening or fractures	188	8.33[a] (3.12–17.26)	172	0[a] (0–0.73)	<.0001

Abbreviations: CI, confidence interval; iFDP, implant-supported fixed dental prostheses with pontics; Na, not applicable; Nr, not reported; Zr, zirconia.

[a]Based on robust Poisson regression.

reporting on 60 restorations with high incidence of cement-related complications such as loss of retention, misfit, and marginal gaps. Annual overall complication rate of 4.30% was reported for implant-supported PFM iS_pCs and of 3.03% for lithium disilicate iS_pCs. Meta-analysis formally comparing the overall annual complication rate of PFM iFDPs with pontic (1.93%) with the annual complication rate of PFM iS_pCs (4.30%) did not reach statistically significant difference ($p = .078$; Table 9).

3.6 | Technical complications

Forty of the included cohorts, reporting on 1636 implant-supported iFDPs, analyzed the incidence of ceramic chipping and fractures of the ceramic surface. The estimated average annual chipping rate when comparing the different material groups ranged from 0% to 9.01%. No surface chippings were reported for monolithic Zr iS_pCs ($n = 34$), followed by an annual chipping/fracture rate of 0.18% for monolithic Zr iFDPs with pontic ($n = 201$), 1.79% for PFM S_pCs ($n = 513$), 2.20% for PFM S_pCs ($n = 393$), 3.37% for reinforced glass–ceramic iS_pCs ($n = 100$), 4.95% for v-Zr iFDPs with pontic ($n = 353$), and 9.01% v-Zr S_pCs ($n = 33$; Tables 6 and 7). Meta-analysis formally analyzing the chipping/fracture rates of veneered Zr vs. monolithic Zr showed significantly ($p < .01$) higher complication rates for the total number of ceramic fractures and chippings, major chipping requiring repair and minor ceramic chippings that can be polished (Table 8). Furthermore, comparing ceramic fracture/chippings for PFM iFDPs with pontic vs. PFM S_pCs showed that significantly ($p = .05$) more iS_pCs experienced minor ceramic chippings and significantly ($p = .04$) more iFDPs with pontic, however, exhibited major ceramic chippings requiring repair (Table 9).

The estimated annual rate of loss of retention or fracture of the luting cement for iFDPs with pontic ranged from 1.46% to 2.75% with no statistically significant differences when comparing the different material groups or iFDPs with pontic with iS_pCs. Furthermore, the annual rate of screw-loosening ranged from 0% to 8.33% with the highest complication rate reported for v-Zr iFDPs with pontic (Tables 6 and 8). For screw-loosening no significant difference ($p = 0.744$) was reported between iFDPs with pontic and iS_pCs (Table 9).

3.7 | Risk of bias assessment of the included studies

All included RCTs were considered as prospective studies therefore 32 studies were assessed according to ROBINS-I tool. Only two of the included studies presented overall serious risk of bias and the remaining presented either overall low risk of bias (Derksen et al., 2021) or overall moderate risk of bias (Table S2).

4 | DISCUSSION

The findings of the present systematic review showed that all included reconstructions, regardless of their design (iFDPs with pontics or iS_pC_s) or material selection ranging from PFM to all-ceramic alternatives, exhibited favorable short-term outcomes and can, therefore, be considered clinically applicable. No significant differences regarding the survival rates were found ($p > .209$). Failure due to framework fracture or fractures of the entire reconstruction in case of monolithic reconstructions were mostly observed for reinforced glass–ceramic iFDPs, resulting in an annual failure rate of 1.0 compared to <0.46 for PFM and Zr reconstructions (monolithic, micro-veneered, veneered). Chipping was shown to be most prevalent for veneered Zr iFDPs with pontics highlighted by an annual failure rate of 4.95 (minor: 2.85, major: 1.65) for iFDPs with pontics compared to annual failure rates ranging from 0.18 to 2.20 for other included material solutions. This finding was even more significant when focusing on splinted crowns (annual failure rate of 9.01), however associated with questionable validity due to a reduced amount of included reconstructions ($n = 33$). Furthermore, meta-analyses indicated superiority of monolithic Zr iFDPs compared to veneered Zr-based reconstructions with respect to chipping of the veneering

TABLE 9 Comparison of annual failure and complication rates for PFM iFDPs with pontic and PFM SpCs.

Failures/complications	PFM SpCs iFDPs [*n*]	Estimated annual failure rate[a] (95% CI)	PFM SpCs SpCs [*n*]	Estimated annual failure rate[a] (95% CI)	*p*-value[a]
Overall failure rate	332	0.57[a] (0.22–1.49)	380	0.30[a] (0.11–0.80)	.334
Overall complication rate	149	1.93[a] (0.80–4.67)	231	4.30[a] (2.86–6.45)	.078
Overall failures due to ceramic fractures	385	0.36[a] (0.02–0.63)	527	0.04[a] (0.005–0.32)	.042
Failure due to framework fractures	385	0.16[a] (0.03–0.67)	451	0.05[a] (0.006–0.39)	.353
Failure due to catastrophic ceramic fractures	385	0.25[a] (0.09–0.70)	527	0.04[a] (0.005–0.32)	.105
Total number of ceramic chippings or fractures	393	2.20[a] (1.56–3.11)	513	1.79[a] (1.04–3.10)	.522
Minor ceramic chippings	254	0.89[a] (0.49–1.65)	290	1.71[a] (1.19–2.46)	.053
Major ceramic chippings–repair	254	0.90[a] (0.36–2.23)	290	0.08[a] (0.009–0.71)	.039
Loss of retention	363	1.56[a] (0.40–6.13)	288	0.81[a] (0.43–1.51)	.366
Screw loosening or fractures	267	2.36[a] (0.09–63.5)	493	2.81[a] (1.14–6.93)	.744

Abbreviations: CI, confidence interval; iFDPs, implant-supported fixed dental prostheses with pontics; PFM, porcelain-fused-to-metal; SpC, splinted crown.

[a]Based on robust Poisson regression.

ceramic ($p < .0001$), both for the prevalence of minor ($p = .015$) and major ($p = .0001$) delamination. Significantly less chipping of the veneering ceramic was found for monolithic iFDPs as compared to veneered reconstructions. Taking the limitation of short-term observations into account, the present review supports the application of monolithic high-strength ceramics such as Zr for implant-supported iFDPs in the posterior regions.

In the last decades, PFM was considered the gold standard material option for the fabrication of iFDPs, most specifically in the posterior region where high occlusal forces occur. Metal frameworks were successfully evaluated in clinical settings to exhibit the required fracture resistance crucial for good long-term clinical stability, without specific alloys proving to be particularly advantageous or disadvantageous (Sailer et al., 2018). For esthetic reasons, the metal frameworks had to be covered with veneering ceramic to reach a natural appearance. Although the excellent longevity of PFM implant restorations is well documented, along with the increase in digital fabrication technologies this material option seems to lose importance also because of time-consuming production (conventional or associated with increased tool wear in case of subtractive manufacturing) and post-processing (opaquing, veneering) mostly requires various manual steps (Karasan et al., 2023). Besides esthetics and efforts, another reason for a reduced prevalence of PFM reconstructions might be seen in increased costs associated with precious, gold-containing alloys (Jokstad et al., 2021). New digital fabrication technologies allowed for the introduction of new restorative materials with improved esthetical properties and acceptable clinical stability (Pjetursson et al., 2021). New high strength ceramics like a variety of Zr generations became available for the fabrication of dental restorations, as this ceramic necessarily needs to be processed with CAD/CAM technologies (Pjetursson et al., 2022). As an alternative, CAD/CAM glass ceramics with improved fracture strength like lithium disilicate were developed (Pjetursson et al., 2022). Due to their specific properties, these new restorative materials allowed for single- and multi-unit tooth- and implant-supported reconstructions at much lower costs compared to traditional PFM reconstructions (Pjetursson et al., 2021).

The main technical complication for PFM tooth- or implant-supported reconstructions is considered chipping of the veneering ceramic. Chipping can be superficial and of minor clinical importance (to be overcome by e.g., polishing the fracture zone), or extended (e.g., up to the framework material) and therefore being of major clinical importance, potentially resulting in failure (Pjetursson et al., 2007, 2014; Sailer et al., 2007). Several factors were found to attribute to the phenomenon of chipping of the veneering ceramic. Veneering ceramics are a rather weak glass–ceramic materials, directly dependent to be increased in strength by a supporting framework material and structure. The shape of the framework is crucial for the support of the veneering ceramic and, hence, must be carefully adapted to the individual clinical situation by the dental technician. Moreover, both framework and veneering material need to be specifically tailored regarding their chemical and physical properties (such as e.g., coefficient of thermal expansion, CTE) in order to prevent tension along the material interface during environmental exposure in the oral cavity or during manufacturing (e.g., sintering, cooling etc.). Finally, the technique of the veneering process, that is, the baking and sintering of the veneering ceramic onto the framework material was described to be a relevant factor to overcome the incidence of chip-off fractures. On one hand, the sintering process must be performed under high vacuum to eliminate the air inclusions in the veneering ceramic resulting from the veneering process. On the other hand, the temperature increase during the sintering of the veneering ceramic must be adapted to the framework material as well as the decrease after the baking, to reduce strain in the veneering ceramic. Clinically, occlusal and functional forces are of importance and can increase the risk for chipping. Even if it might be concluded that the occurrence of chipping fractures of veneered bi-layer reconstructions can be overcome by a long list of rules to be considered during material development and processing, feasibility of these highly technique-sensitive steps in daily clinical routine can be considered at least questionable.

Reviews addressing the outcomes of both tooth- and implant-supported restorations have shown, that chipping of the veneering ceramic is one major technical complication of veneered restorations, independent of the framework material (Pjetursson et al., 2017, 2018, 2021; Sailer et al., 2016, 2018). The combination of two types of materials revealing thin layers and a large-scale material interface remains to be the weak link at veneered restorations. At Zr-based restorations, chipping of the veneering ceramic was even shown to be the most prevalent technical problem, occurring in up to 50% of the restorations over an observation period of 5 years, and despite all improvements of materials and methods, never managed to be significantly reduced to the amount observed at other types of framework materials (Pjetursson et al., 2017, 2018, 2021; Sailer et al., 2016, 2018). The present review confirms these previous observations.

As mentioned earlier, new digital technologies and material improvements meanwhile allow for a monolithic, fully anatomic, design of the restorations. The application of either no veneering ceramic or only very thin layers (micro-veneering) for highly individual esthetic adaptation to, for example, natural adjacent teeth are required (Pieralli et al., 2018; Pjetursson et al., 2021; Rabel et al., 2018). At least for the short term, the present review showed that these more recent types of monolithic or micro-veneered restorations exhibited significantly less complications regarding chipping of the veneering ceramic when in function compared to bi-layered restorations, independent of the framework material (Pjetursson et al., 2021). Hence, monolithic or micro-veneered CAD/CAM ceramics like Zr should be preferred over veneered restorations independent of the framework material for multi-unit posterior implant reconstructions, from a technical but also from an economical point of view (Mühlemann et al., 2018). Regrettably, presently available data in the literature did not allow to distinguish between different Zr generations along with their significantly differing optical properties accompanied by diametrically differing mechanical properties. This needs to be considered by practitioners, since times in which it was clearly defined what is meant when speaking about Zr ceramics in dentistry (i.e., 3Y-TZP) meanwhile belong to the past. With the introduction of not only more translucent but also more fragile 4Y- or even 5Y-TZP and corresponding multilayer materials incorporating all these generations within a single blank, the term "zirconia" rather addresses a material group such as "metals" than a single ceramic material with specific and well-known mechanical properties. Therefore, the findings of the present work, when reporting about monolithic or (micro-) veneered Zr reconstructions should be handled with care and be associated with the most robust material generations (3Y-TZP). Transferring these outcomes to new generations materials (4Y-TZP, 5Y-TZP or multilayer materials), not part of the included literature, might result in misinterpretation and consecutive failure.

It is interesting to note, that not only occurrence of technical complications directly associated with mechanical properties of the evaluated materials (like fractures of the veneering ceramic) were found to be different when comparing the different types of included reconstructions. When focusing on technical complications like loss of retention (annual failure rate of 1.46 vs. 2.75) or screw-loosening (annual failure rate of 0 vs. 8.33), monolithic Zr iFDPs with pontics likewise performed better compared to veneered Zr iFDPs with pontics, even if the relevant material interface (i.e., implant-abutment interface or reconstruction-abutment interface) opposes the same material substrates away from the veneered areas. One explanation for this finding could be the exponential improvement in accuracy of CAD/CAM technologies in recent years, positively affecting the outcome of more recent (monolithic approaches) compared to less recent (veneered reconstructions) literature.

Another interesting observation made in the present review is that in clinical situations with posterior partial edentulism, no differences in the outcomes of iS_pCs compared to iFDPs with pontic could be found. From a short-term perspective, hence, the number of implants might be reduced to replace several adjacent missing posterior teeth. As a result, the invasiveness and morbidity, and finally the costs of the treatments may be reduced. The treatment using iFDPs with pontics instead of iS_pCs should at least be considered at treatment planning as a valid option to be discussed with the patient. For further confirmation and definition of new treatment concepts, however, longer observation periods and an increased portion of randomized controlled clinical studies with larger cohorts are needed. Also, implants of reduced length or narrow diameter need to be tested in the mentioned indications before final conclusions can be drawn.

To the knowledge of the authors, the present systematic review is the first one available in the literature comparing the outcomes of the different types of iFDPs, that is, iFDPs including non-implant-supported pontics vs. splinted single crowns. Both groups of reconstructions could be analyzed separately and compared. For PFM reconstructions, overall failure due to ceramic fracture occurred less frequently in case of iSpCs ($p = .042$) compared to the iFDPs with pontics, reaching statistical significance for major ceramic chippings ($p = .039$) and a tendency toward an increased prevalence of minor ceramic chippings ($p = .053$). One reason for this might be the reduced span of non-supported areas in between the single units of an iSpC compared to iFDPs with pontics associated with reduced flexibility of the framework structure, jeopardizing the integrity of a veneering layer brittle in nature. These findings must be interpreted with caution as the included iS_pC as the included material consist of a mixture of two implants with two splinted crowns and three implants with three splinted crowns (average 2.4 unites) compared with at least 3 units for the iFDPs with pontics.

The main limitation of the review should be considered the fact that the clinical follow-up of the analyzed restorations was rather short and that the total number of included iFDPs is rather small for some of the included material groups. Therefore, the process of this systematic review should be repeated in several years, when the follow-up time of the included studies reaches five or more years or more, and more research is published focusing on the topic of posterior iFDPs with pontics and iS_pCs.

5 | CONCLUSIONS

Implant-supported multi-unit restorations in the posterior area showed high 3-year survival rates ranging from 97% to 100%, regardless of the materials used. Prosthetic design, whether iS_pCs or iFDPs with pontic units, does not significantly impact clinical outcomes. Monolithic and micro-veneered Zr iFDPs with pontic units exhibit superior performance in ceramic fracture and chipping rates compared to PFM and veneered Zr. However, there is a lack of data regarding monolithic lithium disilicate. Furthermore, monolithic and micro-veneered Zr iS_pCs outperformed PFM, veneered Zr, and monolithic lithium disilicate in terms of annual ceramic fracture and chipping rates.

To minimize technical complications, monolithic zirconia is recommended for posterior iFDPs. However, it is important for clinicians and dental technicians to consider the specific properties of different zirconia types, as not all have been extensively validated in clinical studies. The studies included in this analysis primarily focused on 3Y-TZP zirconia with a flexural strength exceeding 1000 MPa, as well as multi-layered alternatives that combined 3Y-TZP and 5Y-TZP. Additionally, restoring multiple posterior missing teeth with iFDPs with pontic units can be a cost-effective and less invasive approach, provided the mechanical properties of the restorative material and implants are considered.

AUTHOR CONTRIBUTIONS

B. Pjetursson: Design of the study, interpretation of data, manuscript preparation and the initial draft, final review of the work; accountable for all aspects of the work. I. Sailer: Acquisition and interpretation of data, manuscript preparation and the initial draft, final review of the work; accountable for all aspects of the work. E. Merino-Higuera and F. Burkhardt: Acquisition of data, final review of the work; accountable for all aspects of the work. B. Spies: Manuscript preparation and the initial draft, final review of the work; accountable for all aspects of the work. D. Karasan: Design of the study, literature search, acquisition and interpretation of data, manuscript preparation and the initial draft, final review of the work; accountable for all aspects of the work.

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CONFLICT OF INTEREST STATEMENT

The authors have no specific conflict of interest related to the present systematic review. The authors do not have any financial interests, either directly or indirectly, in the products or information enclosed in the paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in the Tables S1 and S1.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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