Clinical outcomes and complications of posterior three-unit porcelain-fused-to-metal restoration combined with tooth-implant-supported prosthesis: A meta-analysis

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Abstract Background/purpose: The three-unit bridge that combines a natural tooth and an implant provides extended treatment possibilities for partially edentulous patients. We conducted a systematic review and meta-analysis of clinical trials to evaluate three-unit porcelain-fused-to-metal (PFM) tooth-implant-supported prosthesis (TISP) compared with implant-supported-prosthesis (ISP) reconstruction outcomes and complications.

Materials and methods: The PubMed, Embase, and Cochrane library databases were searched for articles published before February 2021. The meta-analysis used a random-effects model to calculate overall effect size. The study was registered with PROSPERO (number: CRD42021232606).

Results: Seven articles published between 2004 and 2015, with sample sizes ranging from 10 to 250 patients were included. No significant difference in the prosthesis failure rate, implant failure rate, prosthesis technical complication rate, implant technical complication rate,

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Introduction

Missing teeth is a common chronic condition; especially in individuals with missing posterior teeth, the risk of clicking sounds in the temporomandibular joint is significantly increased. In addition, other conditions of the dentition, including drift and tipping, may occur, which causes secondary changes in the occlusal contact and affects overall occlusal function.

In the past, patients edentulous in the posterior molar region had been treated with a removable partial denture supported by mucous and abutment teeth or by a cantilever bridge supported by teeth.

From the 1960s to early 1980s, research on dental implants peaked. Prior to this period, dental implants were mainly used to treat completely edentulous patients; however, they were gradually used in the treatment of partially edentulous patients with fixed partial dentures supported by free-standing implants. In 1986, Ericsson et al. first explored the reconstruction of the fixed bridge pattern by combining an osseointegrated titanium implant with the natural tooth. Although studies have reported favorable results for treatment involving the combination of the tooth and implant, the complications of natural tooth intrusion and fracture or loosening of the implant components have also been reported. Moreover, in the case of a missing posterior tooth, because of the presence of important anatomical structures, such as the maxillary sinus or the inferior alveolar nerve in the posterior region, a treatment plan must also account for the limited bone mass. Connecting the implant to the distal-end natural tooth can not only reduce the number of implants required to achieve sufficient support, but also help avoid the neural tube or the maxillary sinus, thereby simplifying the surgical procedure. In addition, this approach can help retain the prosthesis with the corresponding proprioceptive periodontal ligament and can eliminate the requirement of cantilever bridges.

Furthermore, researchers have used a non-rigid connector or have taken advantage of either the flexibility of the implant components for the three-unit TISP or the metal ductility of porcelain fused to metal (PFM) to make the natural tooth in the tooth-implant-supported prosthesis (TISP) move slightly in the alveolar bone; this is done to enable uniform stress distribution between the prosthesis elements to compensate for the low mobility between the natural tooth and the implant. Although many studies have investigated three-unit TISP designs, the combination of natural teeth and implants remains controversial in clinical practice and integral studies are also scant. Therefore, we conducted a systematic literature review and meta-analysis of clinical trials to evaluate the outcomes and possible complications of three-unit PFM TISP reconstruction in patients who are partially edentulous in the posterior region. The study results can be used as a reference for posterior tooth missing implant treatment in the future.

Materials and methods

Selection criteria

We reviewed the clinical trials or quasi-randomized controlled trials that evaluated the outcome of TISP in the treatment of a posterior partially edentulous ridge. To be included in our study, the trials were required to describe the following: (1) the inclusion and exclusion criteria for patient selection, (2) treatment using a combination of TISP, (3) treatment with implant-supported prosthesis (ISP), (4) prosthesis design with ceramic metal materials, and (5) clinical results and complications. We excluded trials with at least one of the following: (1) immediate loading protocol, (2) single crown and multunit prostheses, (3) use of zirconia core ceramic material, (4) cantilever bridge design, or (5) duplicate reporting of patient cohorts.

Search strategy and screening process

We identified eligible studies by conducting a keyword search in the electronic databases of PubMed, EMBASE, and Cochrane Library. The following terms and Boolean operators were used in MeSH and free text search: fixed partial denture, combination tooth-implant, partially edentulous ridge. The "related articles" feature in PubMed was used to expand the search scope. No language restrictions were used in the search and all available clinical trials were considered. In addition, we used references from related articles to identify other potentially relevant studies. No publication year restrictions were applied, where articles published up to February 2021 were considered. PROSPERO, an online international prospective register of systematic reviews, curated by the National Institute for Health Research, has accepted our systematic review (number: CRD 42021232606).

Data extraction

Two reviewers (Y.C.H. and T.W.H.) independently extracted information from the clinical trials pertaining to
participants, inclusion and exclusion criteria, use of TISP and ISP technologies, clinical outcome, and complications. The individual records of the two reviewers were compared, and any disagreement was resolved through adjudication by a third reviewer (M.Y.).

Methodological quality appraisal

The risk of bias in nonrandomized studies of interventions (ROBINS-I) tool was used to evaluate non-randomized contrail trials (non-RCTs) by two reviewers (Y.C.H. and T.W.H.) independently. The assessment domains included the following: overall bias at preintervention, intervention, and postintervention.

Outcome assessment

The primary outcomes were the failure rate of different implant and restoration techniques, including those of prosthesis, natural tooth treatment, and an implant. Secondary outcomes were rate of complications, including biological complications of the tooth (including invasion, dental caries, apical lesions, fractures, mobility, and bone loss), technical complications of the prosthesis (including fracture of the framework, cracked or chipping of the ceramic, and loosening), and technical complications in the implant (including loss of fixation screws and the presence of abutment fractures). Marginal bone level change (MBLC) around the implant also assessed.

Statistical analysis

Review Manager version 5.4 software was used (Cochrane Collaboration, Oxford, England) for statistical analysis. The meta-analysis was performed according to the PRISMA guidelines. The relative effect size of the dichotomous variables was indicated by the risk ratio (RR), and the mean difference was reported in subsequent results. The accuracy of the effect size was indicated by the 95% confidence interval (CI). The DerSimonian and Laird random-effects model was used to calculate the pooled estimate of RRs. This model provides a relatively wide CI and an estimate of the average treatment effect for statistically heterogeneous trials. Only data of studies that exhibited sufficient clinical and methodological similarity were pooled. An $I^2$ test was used to assess statistical heterogeneity and to aid the comparison of variances between studies. The results of the $I^2$ test reflects the proportion of heterogeneity in the total variation of the effect value.

Results

Characteristics of inclusive trials

As illustrated in the flowchart in Fig. 1, our preliminary search resulted in 676 eligible studies. After screening the titles and abstracts, we excluded 591 studies that were duplicated to the study topic. Of the remaining 85 trials, 29 trials were identified as related to TISP and ISP after we read the full text and discussed its content. Among them, 22 trials were excluded after inspection with exclusion criteria, including 3 cohorts from same population, 1 questionnaire, 8 cross arch long span design, 5 multunit prostheses, 1 IMZ implant restoration, 3 no control group, and 1 porcelain fused to zirconia (PFZ) restoration. Finally, a total of seven articles were included in our research analysis. The seven clinical trials were published between 2004 and 2015, with sample sizes ranging from 10 to 250 patients (Table 1). Four of the included studies compared the results between TISP and ISP, and the remaining three compared the results of three to five parallel groups. Moreover, of the included studies, five were prospective and two were retrospective in design. Regarding implant selection in the included trials, two studies used the extraconnected straight abutment two-stage Branemark system, three studies used the one-stage Straumann straight abutment system, one used the two-stage straight abutment TVS Zimmer Biomet system, and one did not report an implant brand in detail. The integration time of the implant in the alveolar bone was 3–6 months.

The time for which teeth were missing was more than 1 year in all studies, and all patients had sufficient bone width and depth conditions that were conducive to implant treatment without bone augmentation. Moreover, all the patients in the included trials had the following characteristics: sufficient maxillomandibular space between the upper and lower dentition that was conducive to designing prosthesis with adequate metal and ceramic thickness; unilateral or bilateral residual edentulous ridge in the maxilla or mandible; acceptable tooth condition, specifically, healthy periodontal condition and vital teeth or teeth that had complete root canal therapy; healthy systemic condition; and no smoking or drinking habits. Among the included trials, the implant diameter was at least 3 mm and the length was at least 8 mm. The implant position was at least 11 mm from the center of the distal abutment. The bridge connectors used were of the rigid, noncantilever type. Six studies used the PFM as the prosthesis material, and one study mostly used PFM. Five trials used three-unit bridges, one used three-to-four-unit bridges, and one mostly used three-unit bridges. In all studies, the opposing dentition was replaced by either fixed prosthesis or natural teeth. Furthermore, two studies excluded cases with parafunction, and the remaining studies did not describe parafunction.

The methodologic quality of the included studies is summarized in Table 2. The evaluation was conducted using the checklist of ROBINS-I tool for assessing the risk of bias where the overall bias, five of the trials are moderate and two are low.

Failure rate

All the included studies reported the prosthesis failure rate. Six investigations reported failure due to a complete
loss of implants and abutment teeth, and one trial reported a complete loss of abutment and a replacement of the fixed partial denture. Of the studies, one failed to report the number of implants and rate of natural tooth failure.

In our meta-analysis, overall prosthesis failure rate was nonsignificant between the TISP and ISP groups, with an RR of 1.65 (95% CI: 0.8 to 3.41; P = 0.18; Fig. 2), and no heterogeneity was noticed (Chi² = 2.73, df = 4, P = 0.60; I² = 0%). The pooled results indicated no significant differences in the implant failure rate, with an RR of 1.71 (95% CI: 0.73 to 3.96; P = 0.21; Fig. 3), and no heterogeneity was detected (Chi² = 1.74, df = 3, P = 0.63; I² = 0%). Natural tooth failure rate was reported to be 4.3% in Gunne et al. and 3.8% in Lindh et al. No natural tooth failure was reported in the remaining studies.

**Complication rate**

Biological complications related to natural tooth was reported to be 2.9% by Akca et al. due to endodontic treatment, 16.7% by Bragger et al. due to caries and periodontitis, 4.3% by Gunne et al. due to caries, 26.9% by

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Figure 1  Flowchart of study selection.
Lindh et al.\textsuperscript{26} due to fracture devitalized cement breakage, and 0\% by Mostafa et al.\textsuperscript{27} No trial reported natural tooth intrusion. Six studies\textsuperscript{23–27,29} demonstrated no significant differences in technical complications related to the prosthesis including porcelain fracture and gold screw loosening between the TISP and ISP groups, with an RR of 0.61 (95\% CI: 0.36 to 1.05; \(P = 0.08\); Fig. 4). No heterogeneity was found (Chi\(^2 = 1.64, df = 3, P = 0.65; I^2 = 0\%).

| Authors (year) | Study design | Inclusion criteria | No. of patients | No. of prostheses | No. of implant and implant brand | No. of teeth | Prosthesis design |
|----------------|--------------|-------------------|----------------|------------------|---------------------------------|--------------|------------------|
| Akca et al.\textsuperscript{23} (2008) | Prospective | Edentulous arches (>5 mm wide and >12 mm high). Tooth missing >1 year. Crown-root ratio 2:3. No periodontal problem. | T: 26 | T-I: 34 | I-I: 15 | T-I: 30 (ITI system) | T-I: 34 | RCNC. 14 mm distal to abutment (center to center) three-unit FPD. |
| Bragger et al.\textsuperscript{24} (2001) | Retrospective | Occlusal and functional parameters were assessed | T-I: 15 | T-I: 18 | I-I: 33 | I-I: 40 | T-T: 58 | T-I: 19 | I-I: 84 (ITI system) | T-I: 18 | T-T: 124 | RCNC. Median number of units was 3 (range, 2–14). RCNC. (Precision attachment fixed with horizontal gold screw). |
| Gunne et al.\textsuperscript{25} (1999) | Prospective | Patients with Kennedy Class I residual dentition in the mandible and complete maxillary dentures. | T-I: 23 | T-I: 23 | I-I: 23 (Split mouth) | T-I: 23 | I-I: 46 (Novel Branemark system) | | | |
| Lindh et al.\textsuperscript{26} (2001) | Prospective | Patients with Kennedy I residual dentition in the maxilla. | T: 26 | T-I: 26 | I-I: 26 | T-I: 26 | I-I: 56 (Novel Branemark system) | T-I: 26 | | |
| Mostafa et al.\textsuperscript{27} (2015) | Prospective | Patients with Kennedy Class II residual dentition in the mandible. Maxillomandibular space >5 mm. The opposing arch was fully dentate or replaced FPD. | T-I: 10 | T-I: 10 | I-I: 10 | T-I: 10 | I-I: 20 (Zimmer Biomet system) | T-I: 10 | | |
| Rammelsberg et al.\textsuperscript{28} (2013) | Retrospective | All FPDs placed on implants or a combination of teeth and implants with a conventional loading procedure. | T: 166 | T-I: 48 | NC I-I: 91 | C I-I: 27 | T-I: 52 | NC I-I: 189 | Nil | RCNC or RCC. Most were three- or four-unit FPDs. |
| Remeo et al.\textsuperscript{29} (2004) | Prospective | A favorable maxillomandibular relationship. Parafuction habit was excluded. | T: 250 | T-I: 13 | NC I-I: 137 | C I-I: 42 | SC: 106 | OD: 37 | T-I: 31 | NC I-I: 295 | C I-I: 84 | SC: 1065 | OD: 114 (ITI system) | T-I: 31 | RCNC or RCC. Most were three-unit FPDs. |

Abbreviations: T-I: tooth-implant-supported prosthesis; I-I: implant-supported prosthesis; T-T: tooth-supported prosthesis; RCNC: rigid connector with noncantilever design; RCC: rigid connector with cantilever design; SC: single crown; OD: over denture; NC: non-cantilever; C: cantilever; FPD: fixed partial denture.
Six trials23–27,29 demonstrated no significant differences in technical complications related to the implant including abutment fracture and screw loosening between the TISP and ISP groups, with an RR of 1.76 (95% CI: 0.41 to 7.53; P = 0.45; Fig. 5). No significant heterogeneity was noted (Chi² = 2.26, df = 3, P = 0.52; I² = 0%).

Marginal bone level change around the implant

Four trials23,25–27 assessed the MBLC around the implants. The marginal bone loss did not significantly differ between the TISP and ISP groups, with an RR of −0.46 (95% CI: −0.95 to −0.02; P = 0.06; Fig. 6). The I² value was 68% in these

Table 2  Nonrandomized study evaluated using Risk of Bias in Nonrandomized Studies of Interventions (ROBINS-I).

| Author          | 2008     | 2001     | 1999    | 2001    | 2015    | 2013    | 2014    |
|-----------------|----------|----------|---------|---------|---------|---------|---------|
| Preintervention | Bias due to confounding | Moderate | Moderate | Low | Low | Low | Moderate | Moderate |
| Selection bias  | Low      | Moderate | Low | Low | Low | Low | Low |
| At intervention | Bias in classification of interventions | Low | Low | Low | Low | Low | Low |
| Deviation from intended interventions | Low | Low | Low | Low | Low | Low | Low |
| Bias due to missing data attrition | Low | Moderate | Low | Moderate | Low | Low | Low |
| Bias in measurement of outcomes | Low | Low | Low | Low | Low | Low | Low |
| Bias in selection of reported results | Low | Low | Low | Low | Low | Low | Low |
| Overall bias    | Moderate | Moderate | Low | Moderate | Low | Moderate | Moderate |

Figure 2  Forest plot of prosthesis failure rate outcome. No significant difference was observed between the tooth-implant-supported prosthesis (TISP) and implant-supported prosthesis (ISP) groups.

Figure 3  Forest plot of implant failure rate outcome. No significant difference was observed between the tooth-implant-supported prosthesis (TISP) and implant-supported prosthesis (ISP) groups.
groups, indicating heterogeneity between trials ($\chi^2 = 9.93$, df = 3, $P = 0.03$; $I^2 = 68\%$).

Discussion

The main challenge in connecting the tooth to the implant lies in the 10-fold difference in mobility between the tooth and implant, which is caused by the periodontal ligament (PDL). This difference in supported function leads stresses the biomechanical system when bite force is applied. At the implant, a bending moment with a cantilever effect might be generated under loading force. In addition, when the internal stress of the prosthesis system is transmitted, the stress is mainly concentrated in and around the implant, causing technical complications, such as prosthesis fracture, porcelain chipping or fracture, and loosening or fracture of the implant abutment and screw.

The overall prosthesis failure rate in the present review did not significantly differ between the TISP and ISP groups (6.4% vs 5.8%, $P = 0.18$). In addition, the overall implant failure rate in the TISP and ISP groups was 4.8% and 3.7%, respectively, with no significant differences. The natural tooth failure rate ranged from 0% to 4.3%. In the study by Remeo et al., the TISP group had the highest prosthesis failure rate of 23.1%, and three prostheses failed due to implant loss, two of which were lost before the fifth year and one was lost in the seventh year. It was unclear why the study reported only 13 prostheses in the TISP group. In the study by Gunne et al., the prosthesis failure rates in the ISP and TISP groups were as high as 17.4% and 13%,
respectively. In this study, 3 of the 23 loaded TISPs failed due to loss of two implants and one natural tooth, and 4 of the 23 ISPs failed due to loss of the supporting implant within the first 24 months. However, in other studies, the prosthetic failure rates in both the TISP and ISP groups were maintained below 5%.23,24,26–28 Gunne et al. reported the highest implant failure rates of 8.7% and 10.8% in the TISP and ISP groups, respectively.25 All seven failed implants occurred within the first 2 years. By contrast, Akca et al.23 and Mostafa et al.27 reported no implant failure during the 2-year observation. The remaining studies reported implant failure rates below 5% in both the TISP and ISP groups. Thus, the failure rate between the TISP and ISP groups were similar.

The common biological complications related to the natural tooth in the TISP group were tooth fracture and endodontic treatment and the prevalence ranged from 0% to 26.9%. In these studies, the teeth were fixed in the bridge or double crown with permanent cement and only patients with periodontal healthy teeth or vital teeth or with complete root canal–treated teeth were included.9 Block et al. demonstrated that root canal–treated teeth are weak because in their study, five natural teeth extracted due to fracture were treated by root canal therapy and they were fractured at the interface of the post and root surface—in all, 27 out of 60 teeth were root canal–treated. However, in the study by Akca et al.23 only four natural teeth used as abutment underwent endodontic treatment, and no fracture was reported. Moreover, only one tooth required endodontic treatment of all 34 abutments. In the study by Lindh et al.,26,27 26 natural teeth were used as abutment, of which 15 were root canal–treated. In this study, only one tooth broke after more than 2 years of treatment, and only three teeth lost pulp activity and required endodontic treatment. These findings jointly indicate that root canal–treated teeth do not impede TISP. Furthermore many studies have suggested the use of freestanding implants because they provide even stress distribution and thereby prevent complications.30,31 However, we found that implant-related complication was nonsignificantly in the TISP group than in the ISP group. Moreover, prosthetics-related complication was nonsignificantly lower in the TISP group than in the ISP group. This finding was inconsistent with previous research.

According to the recommendations of Pratheep et al., when a tooth and implant support was used, the fixed partial denture pontic should be as short as possible and should not exceed a span of three units.32 Moreover, Lin et al. concluded that compared with the connector, the distribution of bite force and stress more greatly affects the outcome.33 Furthermore, Huang et al. demonstrated that repeated load fatigue is a central reason why dental implant—supported systems fail.34 Therefore, the occlusal loading force and the moment generated by the bridge span might be an important cause of clinical complications of TISP. To avoid excessive load, the number of implants can be increased and the bridge span distance can be reduced, thus exerting a small load on the tooth and guiding most of the load to the implant. This approach might optimize the stress distribution in the system and reduce complications.

When the natural tooth and implant are connected, natural tooth intrusion might occur.9,35 Several theories have been proposed to explain this phenomenon, but the most important factor seemed to be the effect of stress caused by the implant system components and the connectors on the restoration. In a meta-analysis, Lang et al. reported that 5.2% of abutments were affected by intrusion, and most of them occurred when non-rigid connections were used.7 In addition, Tsaousoglou et al. reported 8.12% of intrusions in the non-rigid connection group but no intrusion in the rigid connection group.35 In the present review, which used the rigid connection design, no natural tooth intrusion occurred. Thus, the rigid connection design has clinical advantages in avoiding tooth intrusion. However, some finite element analyses have shown that compared with rigid connections, the bone stress around the implant is smaller in non-rigid connections and that non-rigid connections are more effective in compensating for the difference in mobility between the tooth and implant under axial load. To effectively prevent rotation of the prosthesis supported by the implant, the load can be reduced in the TISP.36,37 Therefore, whether the use of non-rigid or rigid connections for natural tooth intrusion is more effective remains inconclusive.

In terms of implant MBLC, four trials in the present review demonstrated that marginal bone loss did not significantly differ between the TISP and ISP groups. In addition, a longitudinal retrospective radiographic evaluation study by Naert et al. with 398 implants connected to teeth and 1022 fixed dentures supported by only implants showed that the change in bone level between ISP implants and TISP implants was up to 16 years. However, this change was not statistically significant.38 Goodacre et al. systematically reviewed clinical research from 1981 to 1997. Such research investigated implant complications and the implant-supported bone resorption of full dentures, overdentures, and fixed dentures. Total bone resorption in the first year was 0.4–1.6 mm (average, 0.93 mm) and approximately 0–0.2 mm after the second year, with an average annual increase of 0.1 mm.39 According to Smith’s 1989 dental implant success criteria (Smith et al., 1989), after one year of occlusal force, the annual bone loss ought to be maintained below 0.2 mm.40 Therefore, regardless of whether ISP or TISP was applied, the MBLC was within the acceptable range. Significant heterogeneity was detected in the implant MBLC (I² = 68%), which may be attributed to the difference in the angular positioning of the radiation and the difference in the numerical calculation of the observation aspect. However, no significant difference was noted in other comparisons.

In summary, the failure rates were similar in the TISP and ISP groups in all studies that adopted a prospective design or a split mouth design, except in the retrospective studies of Bragger et al. and Rammelsberg et al.24,29 These trials that used the same implant system, treatment methods, treatment procedures, prosthesis materials, and laboratory processes, which makes their results more convincing. However, in the study by Gunne et al. and Mostafa et al.,25,27 the number of patients was 23 and 10, respectively. Because of this small sample size and the lack of a random allocation distribution, the results of these studies are less generalizable. Therefore, long-term randomized studies with a large sample size are required to thoroughly understand the difference in outcomes between
the two groups. Nevertheless, the use of the appropriate number of implants to reduce the bridge span distance and control the occlusal load for careful planning, the risk of bending effect could be minimized and favorable outcomes can be achieved. In cases where the tooth can be connected to the implant, the benefits outweigh the risks, and retaining the natural tooth is worth considering. In addition, using natural tooth as the abutment for implant prosthetics is a potentially reliable treatment option.

In conclusion, our study concluded that the failure rate of implant and prosthesis and the incidence of biological and technical complications in patients with partially missing teeth treated with three-unit PFM TISP group is not significant different from those of ISP group. Therefore, although patients with posterior missing teeth are currently clinically treated with free-standing implants as the main treatment plan. In order to preserve natural teeth or reduce the complexity of implant surgery, a prosthetic treatment plan that connects natural tooth to implant may be another effective treatment option.

Declaration of competing interest
The authors have no conflicts of interest relevant to this article.

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