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Review article

Network meta-analysis of survival rate and complications in implant-supported single crowns with different abutment materials

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ABSTRACT

Objectives: To compare the survival rate of abutments, marginal bone loss and peri-implant soft tissue discoloration among implant-supported single crowns with different abutment materials.

Data: Randomized controlled trials (RCTs), controlled clinical trials, and cohort studies of implant-supported single crowns with different dental abutment materials.

Sources: A systematic search was conducted by an electronic search in 6 databases without restrictions on September 16, 2018, complemented by a manual search. “Grey” literatures were also searched.

Study selection: Of 3417 studies initially retrieved, thirteen were eligible for inclusion. After studies selected and data extraction, pair-wise and network meta-analyses were performed to analyze the survival rate of the abutment, the marginal bone loss and the soft tissue discoloration. The risk of bias was assessed based on the Cochrane guidelines, Newcastle-Ottawa scale, and funnel plots. Statistical heterogeneity, inconsistencies, and cumulative ranking were also evaluated.

Results: Fourteen RCTs and nine non-RCTs were included. No significant differences was detected among titanium (Ti), zirconia (Zr), gold (Au), and alumina (Al) abutments in terms of survival rate (excluding Al < Ti ($P < 0.05$), marginal bone loss (excluding Zr < Ti ($P < 0.05$) and Au > Zr ($P < 0.05$)), or discoloration of peri-implant soft tissue. Additionally, Ti abutment had the highest cumulative ranking of survival rate (97.9%); Al abutment had the lowest marginal bone loss (81.4%) and Zr abutment had the least discoloration of peri-implant soft tissue (84.8%).

Conclusions: Ti abutment has a comparable survival rate with Zr, but better than Al. In addition, Zr abutment has a better effect in maintaining the marginal bone level, compared with Au and Ti. However, there was no difference in the discoloration of peri-implant soft tissue among Au, Ti, and Zr abutment.

Clinical significance: Based on the results of our network meta-analysis, Zr might be a recommended abutment material considering the clinical efficacy of implant-supported single crowns.

1. Introduction

With the increasing success of implantation and improvements in implantation technology, more patients are choosing dental implants to replace their missing teeth [1]. The dental abutment typically refers to the intermediate structure between the implant and prosthesis, which can provide support and allow retention of the prosthesis, and plays a role in anti-rotation and positioning. However, the dental abutment can also affect the soft and hard tissue around the implant [2]. Currently, various dental abutment materials are available, among which, metal and ceramic abutments are most commonly used in clinical practice [3]. The metal abutment has high strength, but may result in the mucosa discoloration around the implant, which can affect the esthetic effect of the final restoration [4]. Ceramic abutment has better light transmission and a color closer to the natural teeth, but its strength is lower than that of the metal abutment [5]. Selecting an appropriate dental abutment is crucial for prognosis outcome and aesthetic effect of implant-supported single crowns [6,7].

Previous systematic reviews and meta-analyses have shown the effect of different dental abutment materials on the survival rate of

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abutment and complications of implant-supported single crowns [6–10]. However, there are still some limitations of these systematic reviews. For example, some reviews only examined titanium (Ti) abutments or did not compare the different dental abutment materials simultaneously [6–8]. In addition, these previous reports did not generate relevance rankings for the dental abutment materials. Furthermore, previous systematic reviews did not include all the effects of technical, biological and aesthetic complications. Therefore, it could be necessary to undertake a more comprehensive and up-to-date systematic review on implant-supported single crowns with different dental abutment materials, and to provide relevance rankings for the various dental abutment materials.

Compared with the traditional pair-wise meta-analysis, network meta-analysis (also known as multiple treatment comparison) allows us to synthesize data from both direct and indirect comparisons of various regimens [11,12]. Clinicians should consider all data that may be relevant when comparing different treatment options, and multiple treatment comparisons can be performed with a wide network of studies [13]. In addition, network meta-analysis allows us to estimate the rank probability *via* various approaches [12].

Therefore, the aim of this network meta-analysis was to compare the clinical efficacy of different dental abutment materials for the survival rate of abutment, the marginal bone loss and the peri-implant soft tissue discoloration in implant-supported single crowns, providing clinical recommendations for the appropriate abutment selection for the long-term success of implant-supported single crowns.

2. Materials and methods

This network meta-analysis was performed based on the international guidelines for conducting and reporting systematic reviews, and the pairwise and network meta-analysis [14,15]. And it was registered in the International Prospective Register of Systematic Review (PROSPERO-CRD42018114270).

2.1. PICOS question

According to the recommendations by the Centre for Evidence-Based Medicine (University of Oxford, Oxford, UK), the participants, interventions, comparisons, outcomes and study designs (PICOS) question was as follows: How do abutment materials influence the survival rate of the abutment, the marginal bone loss and the peri-implant soft tissue discoloration in implant-supported single crowns?

Patients: systemically healthy patients with dentition defects, restored with implant-supported single crowns.

Intervention: implant-supported single crowns.

Comparator: different abutment material (titanium, zirconia, gold, alumina, *etc*.).

Outcomes: the survival rate of the abutment, the marginal bone loss and the peri-implant soft tissue discoloration.

Study designs: randomized controlled trials (RCTs), controlled clinical trials (CCTs), prospective or retrospective cohort studies.

2.2. Inclusion criteria

The inclusion and exclusion criteria were set according to the PICOS model [16] as follows:

i Clinical studies on patients with dentition defects.
ii Dentition defects restored by implant-supported single crowns with different abutment material (titanium, zirconia, gold, alumina, *etc*.).
iii Studies with quantitative outcomes including the survival rate of the abutment, the marginal bone loss or the peri-implant soft tissue discoloration.
iv Randomized controlled trials (RCTs), controlled clinical trials (CCTs), prospective or retrospective cohort studies.

2.3. Exclusion criteria

i Animal experiments and *in vitro* studies.
ii The restoration was not implant-supported single crown.
iii Studies that did not include the quantitative results of the survival rate of the abutment, the marginal bone loss or the peri-implant soft tissue discoloration.
iv Case studies, unpublished materials, and review papers.

2.4. Information sources and literature search

Six databases including Medline, EMBASE, Web of Science, CENTRAL (Cochrane Library), CNKI (China National Knowledge Infrastructure), and the Chinese Biomedical Literature Database were searched for relevant studies. No search restrictions were applied and the databases were searched from inception up to September 16, 2018, to identify all English- and Chinese-language studies exploring the effects of different dental abutment materials used for implant-supported single crowns. The following text and MeSH terms were used to search the databases: “dental implant”, “dental abutment” and “single crown”. The search strategy was demonstrated in detail in the Appendix (S1). For the “grey” literatures, such as ClinicalTrials.gov, the International Clinical Trials Registry Platform, ProQuest Dissertation Abstracts and Thesis database, and the System for Information on Gray Literature in Europe Database were also searched. Besides, as a supplement to the electronic search, manual search was conducted to review the reference lists of related papers and review articles.

2.5. Study selection

Randomized controlled trials (RCTs), controlled clinical trials (CCTs), and prospective and retrospective cohort studies that compared different dental abutment materials used for implant-supported single crowns were reviewed in terms of the survival rate of abutment, the marginal bone loss, and the peri-implant soft tissue discoloration.

Two authors independently screened the study titles and abstracts, searched for studies that met the inclusion criteria for full-text evaluation, and selected those that met all requirements. In studies with at least three arms, any arm not relevant to our analysis was excluded. If the two authors disagreed during this process, a third author was consulted and an agreement was reached through discussion.

2.6. Data collection process and data items

The information and data required for this study were extracted from the selected studies by two authors. The extracted information and data included: first author, publication year, country, study design, final follow-up period, intervention, comparison among different dental abutment materials, the number of different dental abutment materials, survival rate of abutment, and complications. During this process, any discrepancy was resolved through a consensus discussion with a third author. Data on the final follow-up period were extracted if there were multiple follow-up periods in one study [17].

2.7. Risk of bias in individual and across studies

The quality and risk of bias of the selected RCTs were assessed using the Cochrane collaboration tool [18]. Regarding non-randomized studies, quality and risk of bias were evaluated using the Newcastle-Ottawa scale [19]. RCTs had a low risk of bias when all bias indices were rated as low risk; risk of bias was moderate when one or more bias measures had an uncertain result; and all other cases were considered as high risk [20]. Regarding the risk of bias of non-randomized studies, assessed by an ordinal star scoring scale, higher scores indicated a higher study quality [19]. The possibility of publication bias in the included studies was assessed using funnel plots [21]. The above steps were performed by two authors independently. Any disagreement was resolved by consulting a third author and reaching an agreement through discussion.

2.8. Summary measures and synthesis of results

First of all, we performed traditional pair-wise meta-analysis, using a fixed or random effects model, to synthesize studies comparing the same pair of dental implant abutment materials. The results were provided as odds ratios (ORs) or mean differences (MDs) with 95% confidence intervals (CIs). Statistical significance was considered at $P < 0.05$.

Second, we constructed a random-effects network within a most frequent model using STATA software to directly and indirectly compare different dental implant abutment materials, to ensure the most comprehensive comparison of any given pair of dental implant abutment materials [22]. Statistical significance was considered at $P < 0.05$ based on 95% CIs.

The ranking of all dental abutment materials was also estimated on intervention and outcome (survival rate, marginal bone loss, and peri-implant soft tissue discoloration). The surface under the cumulative ranking (SUCRA) was calculated when ranking the materials on all outcomes.

All data of pair-wise meta-analysis and network meta-analysis were analyzed by STATA (version 14, Stata Corp, College Station, TX, USA).

2.9. Additional analyses

In the traditional pair-wise meta-analysis, heterogeneity across studies was assessed by I^2, where $I^2 > 50\%$ indicated moderate to high heterogeneity [23]. Equal heterogeneity of parameters τ across all comparisons was assumed and accounted for correlations induced by multiple-arm studies. We assessed statistical heterogeneity throughout the entire network using the τ^2 statistic, as estimated based on frequentist models. A loop-specific approach was applied to evaluate local inconsistencies within every closed triangular loop in the network. A design by treatment interaction model was also used to check the assumption of consistency in the global network [24]. Chi-square test was used to determine inconsistency in any data source within the global network based on p values greater than 0.05.

3. Results

3.1. Study selection

After searching six databases, and manually searching the reference sections of relevant articles, 33,773,377 and 40 records were identified, respectively. In total, 927 duplicate articles were excluded. An additional 2408 articles were excluded as they did not meet the inclusion criteria after filtering the titles and abstracts. We reviewed the full texts of the remaining 82 articles and selected 23 articles that compared four different implant abutment materials (Fig. 1).

The kappa values for the agreement between the reviewers of screening titles and abstracts were 0.92 and of full-text evaluation were 0.95, which indicated an “almost perfect” inter-agreement [25].

3.2. Study characteristics

The basic characteristics of the 23 included studies are shown in Table 1. Among the studies, 14 (61%) were RCTs and 9 (39%) were CCTs, or prospective or retrospective cohort studies. The 23 studies were published from 2001 to 2018; 14 studies explored differences between Ti and zirconia (Zr) abutments [26–39], 6 studies explored differences between Ti, Zr, and gold (Au; containing gold, gold-hued Ti, or Ti nitride) abutments [40–45], 2 studies explored the differences between Ti and alumina (Al) abutments [46,47], and 1 study explored the difference between Zr and Al abutments [48]. We established a network for comparing Ti, Zr, Au, and Al abutments, in terms of the survival rate of the abutment, marginal bone loss and discoloration of peri-implant soft tissue (Fig. 2). In Fig. 2, each node represents a different dental abutment material. The connections between the nodes denote direct comparisons; node size and the thickness of connections vary according to the number of studies compared.

3.3. Risk of bias within studies

Apart from one RCT with a high risk of bias, all of the included RCTs had a moderate risk of bias. The most common type of bias was selective reporting. The mean risk of bias of non-randomized studies was 6.8 stars on the Newcastle-Ottawa scale. Among the nine non-randomized studies, five studies had a low risk of bias (7–8 stars) and four had a moderate risk (6 stars). Detailed information on the RCTs and non-randomized studies were provided in the Appendix (S2, S3).

3.4. Result of individual studies and synthesis of results

Forest plots of pairwise meta-analyses in terms of survival rate of the abutment, marginal bone loss and discoloration of peri-implant soft tissue were provided in the appendix (S4). The results show that no significant difference was detected between Zr and Ti, Al and Ti, Al and Zr in terms of the survival rate of different abutment materials. In terms of marginal bone loss, there was no significant difference between Al and Ti, Au and Ti, while Au was significantly higher than Zr (MD = 0.26 [0.02, 0.50], $P < 0.05$) and Zr was significantly lower than Ti (MD = −0.08 [−0.15, -0.01], $P < 0.05$). Besides, there was no significant difference between Zr and Ti in terms of discoloration of peri-implant soft tissue, but Au was significantly higher than Zr (MD = 0.96 [0.09, 1.82], $P < 0.05$) and Au was significantly lower than Ti (MD = −1.49 [−2.73, −0.25], $P < 0.05$).

The results of the network meta-analysis regarding survival rate of abutment, marginal bone loss and discoloration of peri-implant soft tissue were summarized in Fig. 3. The results of the survival rate of abutment indicated that there was no significant difference between Zr and Ti, Al and Zr, while Al was significantly lower than Ti (MD = 8.75 [1.31, 58.21], $P < 0.05$). In terms of marginal bone loss, there was no significant difference between Al and Ti, Au and Ti, Al and Zr, Au and Al, but Zr was significantly lower than Ti (MD = −0.07 [-0.14, -0.01], $P < 0.05$) and Au was significantly higher than Zr (MD = 0.28 [0.01, 0.54], $P < 0.05$). Furthermore, there was no significant difference between Zr and Ti, Au and Ti, Au and Zr with respect to discoloration of peri-implant soft tissue.

3.5. Rank probabilities

The cumulative ranking of the different dental abutment materials, in terms of survival rate of the abutment, marginal bone loss, and discoloration of peri-implant soft tissue, was shown in Fig. 4. According to the SUCRA plots, Ti had the highest probability (97.9%) of being the best option in terms of survival rate, followed by Zr (39.4%) and Al (12.7%). In terms of marginal bone loss, Al had the highest probability (81.4%) of being the best option, followed by Zr (79.3%), Ti (34.9%), and Au (4.4%). Finally, Zr showed the highest probability (84.8%) of being the best option in terms of discoloration of peri-implant soft tissue, followed by Au (55.6%) and Ti (9.6%).

3.6. Risk of bias across studies

Publication bias was assessed using funnel plots (S5). According to the network meta-analysis, there was no significant asymmetry nor evidence of significant bias among the selected studies in terms of survival rate of abutment, marginal bone loss, or discoloration in the peri-implant soft tissue in implant-supported single crowns.

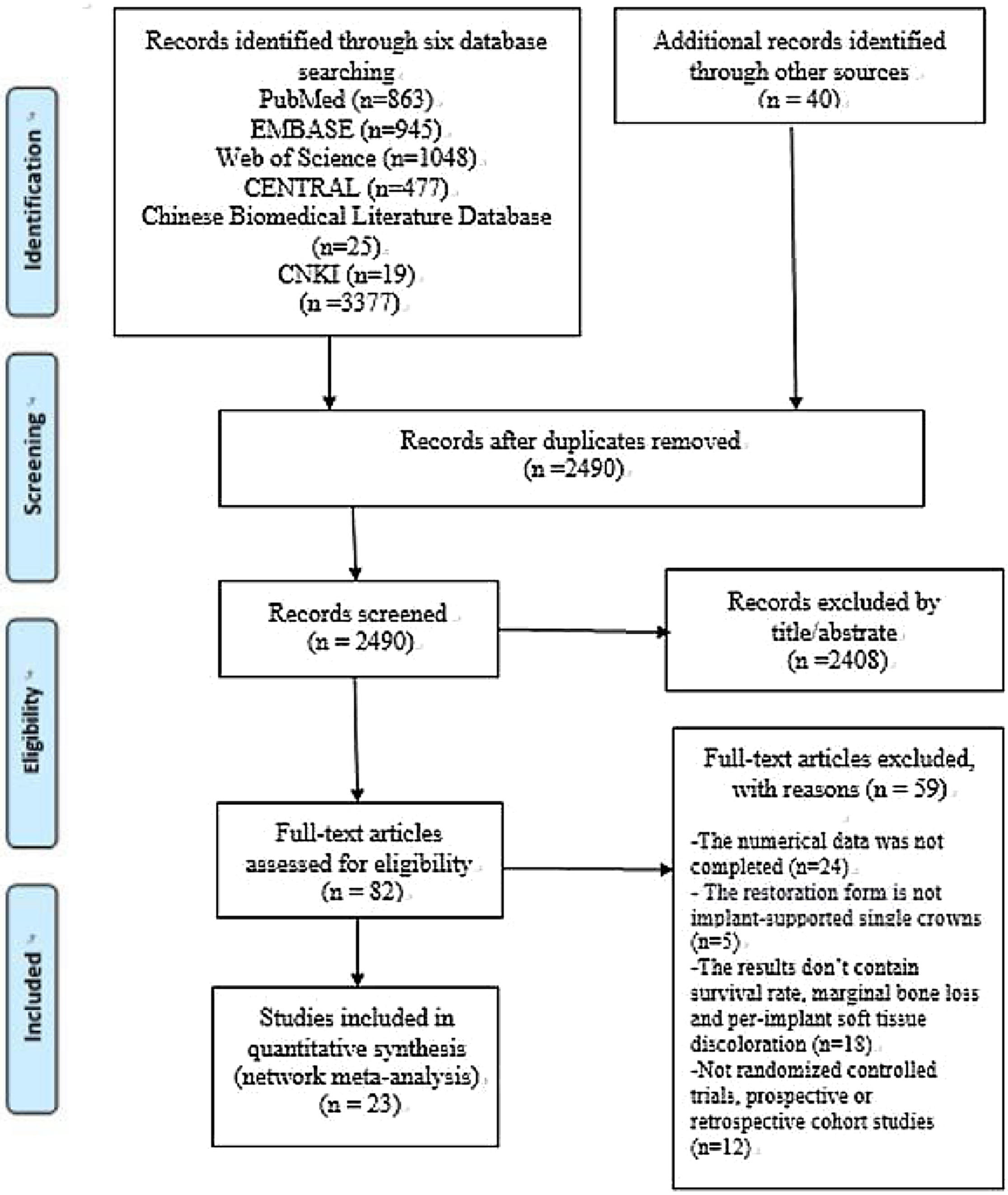

Fig. 1. PRISMA flow program for study selection of this systematic review and network meta-analysis.

3.7. Additional analyses

Based on pairwise meta-analysis of survival rate data, there was no significant evidence of statistical heterogeneity in the Zr *vs.* Ti (I^2 = 0%) or Al *vs.* Ti (I^2 = 0%) comparison. In terms of marginal bone loss, we compared Zr and Ti (I^2 = 54.8%) and Al and Ti (I^2 = 0%). There was significant evidence of heterogeneity in terms of discoloration of peri-implant soft tissue in the Zr *vs.* Ti (I^2 = 79.8%), Au *vs.* Ti (I^2 = 58.9%), and Au *vs.* Zr (I^2 = 50.3%) comparisons. Excluding discoloration of peri-implant soft tissue, no evidence of statistical inconsistency was found in the network meta-analysis of survival rate of abutment and marginal bone loss. Details of the heterogeneity of pairwise and network meta-analyses were provided in the Appendix (S5, S6). Since the local inconsistency results were not accurate, we also evaluated global inconsistency. No significant evidence of global inconsistency was found within the network for survival rate of abutment (P = 0.3802) or marginal bone loss (P = 0.6435), but we did observe inconsistency for discoloration of peri-implant soft tissue (P = 0.0046).

4. Discussion

The purpose of this study was to identify the most suitable abutment material for prosthetic implants, in terms of survival rate of the abutment, marginal bone loss, and discoloration of peri-implant soft tissue in implant-supported single crowns, by comparing different dental abutment materials. Based on the existing evidence from 23 included studies indicated that Ti abutments have a similar survival rate with Zr abutments, but better than Al abutments. In addition, Zr abutment is better than Au and Ti abutment in terms of maintaining marginal bone.

Table 1
The characteristics of the included studies in the final network meta-analysis (n = 23).

First author of study	Year	Country	Study design	Final follow-up time	Comparison of abutment materials	Number of comparisons	Survival rate and Complications
Andersson	2001	USA	RCT	3 years	Ti/Al	10/10	②
Li	2007	China	CCT	2 years	Ti/Al	11/8	①②
Chen	2008	China	Prospective	2 years	Zr/Al	18/17	①
Sailer	2009	Switzerland	RCT	1 year	Ti/Zr	12/19	③
Zembic	2009	Switzerland	RCT	3 years	Ti/Zr	10/18	②③
Hosseini	2011	Denmark	RCT	1 year	Ti/Zr	37/38	②
Bressan	2011	Italy	Prospective	immediately	Ti/Zr/Au	20/20/20	③
Hosseini	2012	Denmark	Prospective	3 years	Ti/Zr/Au	21/52/25	②
Lops	2013	Italy	RCT	5 years	Ti/Zr	44/37	②
Zembic	2013	Switzerland	RCT	5 years	Ti/Zr	10/18	②
Albornoz	2014	Italy	RCT	1 year	Ti/Zr	14/11	①②
Cosgarea	2014	Romania	RCT	immediately	Ti/Zr	11/11	③
Wang	2014	China	RCT	1 year	Ti/Zr	19/23	②
Diego	2014	Italy	Prospective	2 years	Ti/Zr	16/20	①
Kim	2015	USA	Retrospective	immediately	Ti/Zr/Au	10/10/10	③
Ferrari	2016	Italy	RCT	3 years	Ti/Zr	31/28	①
Baldini	2016	Italy	RCT	1 year	Ti/Zr	12/10	②
Lops	2016	Italy	Prospective	2 years	Ti/Zr	14/19	①②
Martinez-Rus	2017	Switzerland	RCT	immediately	Ti/Zr/Au	20/20/20	③
Ferrari	2017	Italy	RCT	immediately	Ti/Zr/Au	30/28/31	③
Li	2017	China	CCT	1 year	Ti/Zr	20/20	②
Lops	2017	Italy	Prospective	immediately	Ti/Zr/Au	15/15/15	③
Bosch	2018	Zurich	RCT	1.5 years	Ti/Zr	16/12	②③

RCT: randomized controlled trial, CCT: controlled clinical trial, Ti: titanium; Zr: zirconia; Al: alumina; Au: golden.
①Survival rate of abutment; ②Marginal bone loss; ③Discoloration of peri-implant soft tissue.

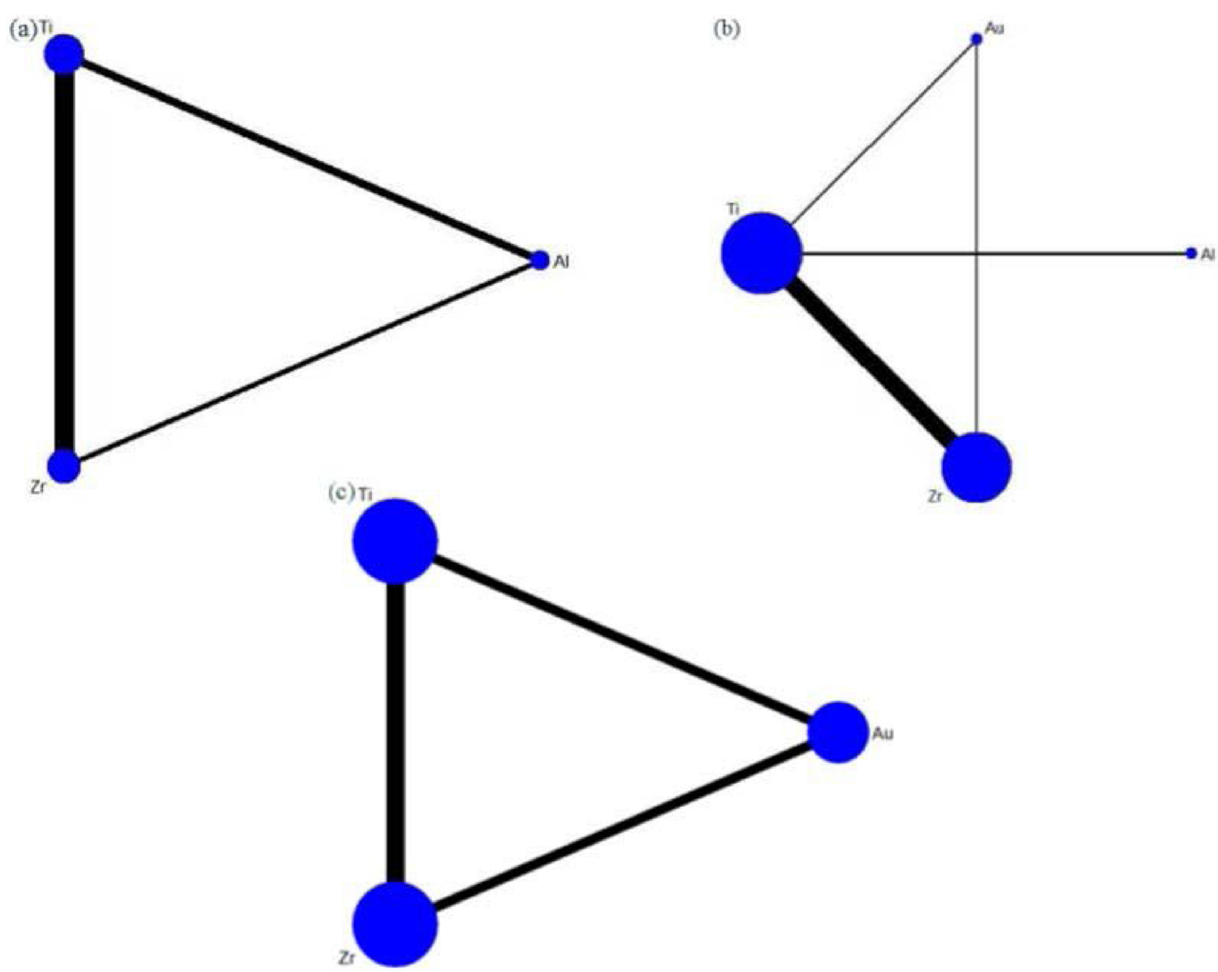

Fig. 2. Network established for multiple-abutment material comparisons: (a) survival rate of abutment; (b) marginal bone loss; (c) discoloration of peri-implant soft tissue.

(a) Ti	4.16 (0.97,17.86)	8.75 (1.31,58.21)
0.24 (0.06,1.03)	Zr	2.10 (0.27,16.52)
0.11 (0.02,0.76)	0.48 (0.06,3.74)	Al

(b) Al	0.02 (-0.14,0.19)	0.10 (-0.06,0.25)	0.30 (-0.01,0.61)
-0.02 (-0.19,0.14)	Zr	0.07 (0.01,0.14)	0.28 (0.01,0.54)
-0.10 (-0.25,0.06)	-0.07 (-0.14,-0.01)	Ti	0.20 (-0.06,0.47)
-0.30 (-0.61,0.01)	-0.28 (-0.54,-0.01)	-0.20 (-0.47,0.06)	Au

(C) Zr	0.48 (-1.09,2.05)	1.30 (-0.07,2.66)
-0.48 (-2.05,1.09)	Au	0.82 (-0.80,2.44)
-1.30 (-2.66,0.07)	-0.82 (-2.44,0.80)	Ti

Fig. 3. League table presenting Network (on the lower triangle) and pairwise (on the upper triangle) results of different abutment materials: (a) survival rate of abutment; (b) marginal bone loss; (c) discoloration of peri-implant soft tissue.

However, there was no difference among the Au, Ti, and Zr abutments in terms of discoloration of peri-implant soft tissue.

A systematic review and meta-analysis was performed to evaluate and summarize the results of RCTs [49]. Due to the limited number of RCTs comparing the survival rate, marginal bone loss, and discoloration of peri-implant soft tissue among different abutment materials, we also included prospective and retrospective cohort studies.

Our results indicated that the survival rate of the dental abutment was in the order of Ti > Zr > Al. However, excluding the comparison of Al *vs.* Ti (MD = 8.75 [1.31, 58.21], $P < 0.05$), there were no significant differences among the materials. In addition, cumulative ranking showed that the survival rates of Ti, Zr, and Al dental abutment materials ranged from high to low. This result agrees with previous studies [35,48]. In the studies included in our meta-analysis, the

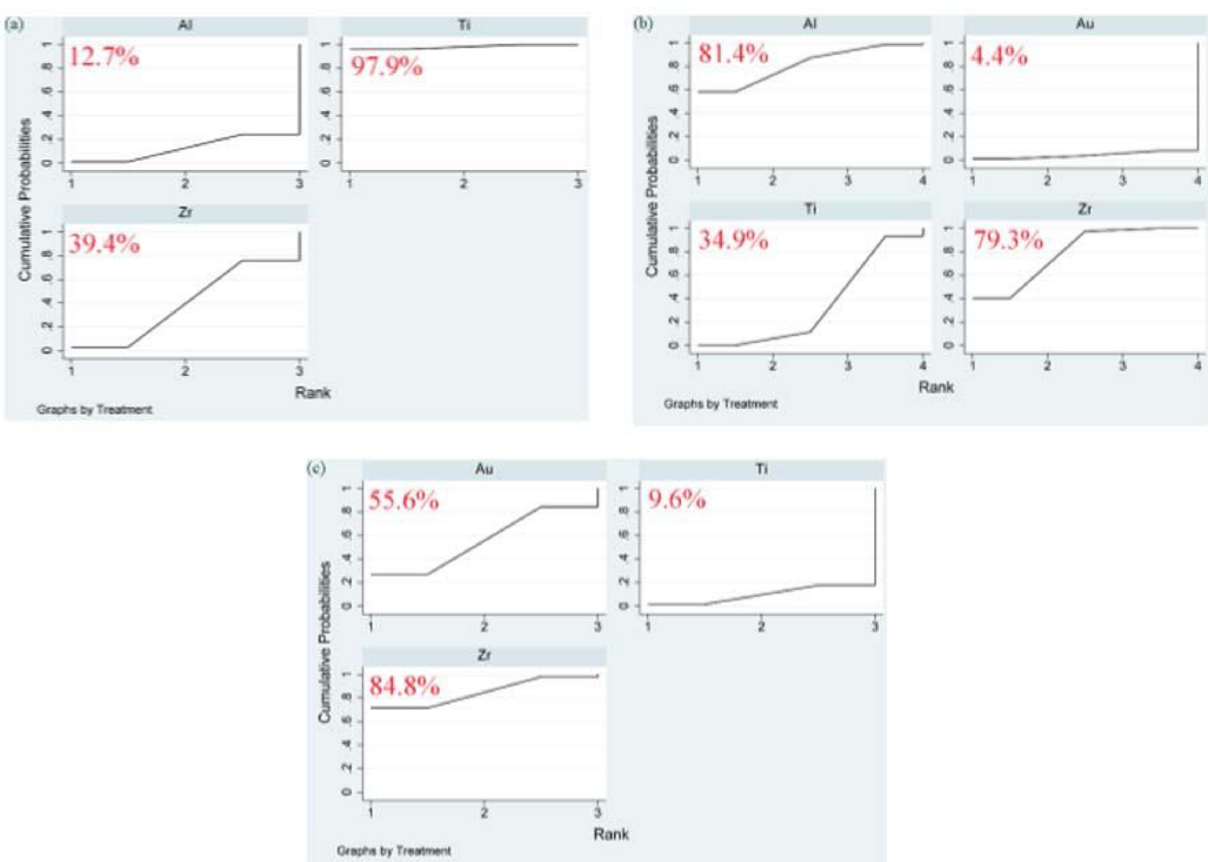

Fig. 4. Surface under the cumulative ranking curves (SUCRA) primary and secondary outcome of different abutment materials: (a) survival rate of abutment; (b) marginal bone loss; (c) discoloration of peri-implant soft tissue.

fracture abutment materials were all ceramics. The major reason for this result may be the difference of fracture resistance between metal and ceramic abutments. An *in vitro* study shows that the fracture resistance of Ti abutment was 1454 N, while Zr was 443.6 N and Al was 422.5 N [50]. Another study also indicated that metal abutment was significantly higher than Zr abutment in terms of fracture resistance, but both of them met the clinical requirement [51]. Besides, the difference of flexural strength between metal and ceramic abutments may also result in different mechanical behavior. Some researches show that the flexural strength of Zr abutment is 900–1200 MPa, which is nearly twice than that of Al abutment [50,52], and the flexural strength of Ti abutment was nearly 2000 MPa [53]. However, considering that the number of studies comparing Ti with Zr abutment survival rates was relatively small, further studies are required.

Good osseointegration is important for successful implant restoration, and marginal bone loss is always used to evaluate the success of implant restorations [54]. Based on the results of our network meta-analysis, the marginal bone loss of dental abutment material was in the order of Au > Ti > Zr > Al. However, aside from the Zr *vs.* Ti (MD = -0.07 [-0.14, -0.01], $P < 0.05$) and Au *vs.* Zr (MD = 0.28 [0.01, 0.54], $P < 0.05$) comparisons in terms of marginal bone loss, there were no significant difference among the materials. Al had the highest cumulative rank, followed by Zr, Ti, and Au. This agrees with a previous systematic review showing that ceramic abutments had less marginal bone loss than Ti abutments [55]. Some researches show that bacterial adhesion may be affected by the implant abutment materials, and count of bacterial adhesion on ceramic abutments surface was significantly less than that on metal abutments surface [56,57]. Ceramic abutments are easier to be polished than metal abutments, which can greatly reduce the bacterial colonization and adhesion [58]. This might be the reason that metal abutments have a higher marginal bone loss than ceramic abutments. However, the results of another previous systematic review differed from our results, possibly since it included only four RCTs [7]. Recently, a meta-analysis on the biological effects of abutment material and the stability of marginal bone showed that no abutment material had a significant difference to Ti in terms of marginal bone loss [10]. However, it should be noted that the previous review was larger in scope than our study; we only included single crown repairs, while the previous review also included fixed dental prosthesis. In addition, some certain comparisons (such as Al *vs.* Zr, Au *vs.* Zr, Au *vs.* Al) were absent from the previous review but were included in our meta-analysis. These factors may explain the differences between our results and the previous reviews. It also should be noted that the distortion and elongation of X-rays due to radiation exposure, and the used of different X-ray angles, hampers accurate assessment of marginal bone loss in implants [59]. In addition, the follow-up periods varied among the studies included in our meta-analysis, which may have affected the results.

The increasing popularity and success rate of implant restoration has resulted in a greater focus on aesthetic outcomes, where the discoloration of peri-implant soft tissue is a key indicator [28]. Although the discoloration of peri-implant soft tissue in the current study was in the order of Ti > Au > Zr, there were no significant differences among the varied abutment materials. Moreover, cumulative ranking shows that discoloration of peri-implant soft tissue of Zr, Au, and Ti dental abutment materials ranged from low to high. These results were similar to those of previous studies, which also showed no significant differences among Ti, Zr, and Au abutments with respect to discoloration of peri-implant soft tissue [3,39,40,60]. However, a previous meta-analysis showed that Zr, Ti and Au abutments had significant differences in terms of this outcome [8]. The differences may stem from an RCT that was included in our study but not in previous meta-analyses, in which Zr and Ti abutments had similar peri-implant soft tissue discoloration outcomes [26]. In addition, extracted data from a study makes a difference [32]. We extracted data after the crown cementation, whereas previous meta-analyses used data obtained before the crown cementation. Furthermore, the effect of dental abutment materials on soft tissue around the implant is modified by the thickness of the mucosa, which may explain the lack of a significant difference in mucosal discoloration among the different dental abutment materials [61]. Besides, one thing we should pay more attention to is that there was significant heterogeneity in terms of discoloration of peri-implant soft tissue. Several factors might lead to this result. First, the included studies were not only RCTs, but also prospective and retrospective cohort studies. In addition, the follow-up time varied among these studies. Furthermore, the color measurement point on the peri-implant tissue and the evaluation index of tissue discoloration differ a lot across the included studies. Therefore, in order to reduce the heterogeneity of color test, uniform test site of the soft tissue, evaluation index and follow –up time should be recommended in the future RCTs.

There are also other factors that might influence the results of this study, for instance, the location of the implants. However, there was no direct comparison of different location of the implants in these included studies, and some studies even didn't mention the location of the implants [35,45,46]. In some studies, all the implants located in the anterior area [33,36–38,43,47,48], while in some other studies, all the implants located in the posterior area [28,32,40]. We also found that Ti, Zr and Au abutments were both used in the anterior and posterior area, but Al abutments were only used in the anterior area, which might be owing to the insufficient mechanical strength of Al abutments [50,62,63]. Therefore, the exact effect of implants location could not be concluded from this network meta-analysis and further RCT**s** were required to take this factor into consideration.

This is the first network meta-analysis comparing the survival rate of the abutment, marginal bone loss, and discoloration of peri-implant soft tissue among implant-supported single crowns with different dental abutment materials. However, there were several limitations to this study. First, due to a lack of sufficient RCTs, CCTs and prospective and retrospective cohort studies were also included in our meta-analysis, which may have influenced the results. Second, the sample sizes of the included studies were insufficient to draw definitive conclusions. Third, some of the included studies had a short follow-up period, and the final follow-up period also varied among them; this may have caused heterogeneity in the outcomes. Fourth, maintaining the integrity of a repair requires long-term maintenance of oral health and regular review, but the effect of patient compliance on the clinical outcomes was not mentioned in most of the included studies. Fifth, this meta-analysis was limited to articles published in English and Chinese and available in six major literature databases, which may have resulted in selection bias. Additionally, the included RCTs with moderate risk of bias may influence the real outcome, and the significant heterogeneity in regard to discoloration of peri-implant soft tissue might also affect the results. To address these issues, further high-quality, well-designed randomized clinical trials with larger sample sizes are required.

5. Conclusions

Based on our network meta-analysis, Ti abutments have a similar survival rate with Zr abutments, but better than Al abutments. In addition, Zr abutment is better than Au and Ti abutment in terms of maintaining marginal bone. However, there was no difference among the Au, Ti, and Zr abutments in terms of discoloration of peri-implant soft tissue. Based on our results and the cumulative ranking, Zr might be a recommended abutment material considering the clinical efficacy of implant-supported single crowns.

Conflict of interest statement

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jdent.2019.04.007.

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