Systematic Review

A systematic review assessing the osseoincorporation potential of trabecular dental implants: A current evidence and future directions

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Abstract

Statement of Problem: There is lack of evidence of studies conducted to compare the integration of soft and hard tissues of conventional implants and porous tantalum trabecular metal (PTTM dental implants).

Purpose: This systematic review assessed the clinical outcomes evaluating the hard and soft-tissue parameters for PTTM dental implants when compared with conventional titanium dental implants.

Materials and Methods: The Preferred Reporting Items for Systematic review based on PRISMA 2020 checklist was used as guideline for reporting this protocol. The search was conducted in SCOPUS, PUBMED, Cochrane library, and EMBASE databases for the studies published from January 1, 2010, to January 1, 2023. The chosen publications' cross-references were further examined, and studies whose whole texts were not available through the computerized search were manually looked up.

Results: Through search strategy a total of 1152 articles were yielded. After screening titles and abstracts, 9 articles were further screened for full text. After critical analysis, according to the eligibility criteria of this review, 7 articles were included in this systematic review for data extraction. Four studies revealed mean of 98.8% survival rate for trabecular implants. Histologically, 2 studies showed upregulation of bone morphogenic proteins, collagens, and growth factors with respect to trabecular dental implants.

Conclusion: From this study, it can be concluded that PTTM dental implants showed a better osseoincorporation potential than titanium implants. However, a longer follow-up period is required to assess its true potential.

Keywords: Implant surface, osseoincorporation, trabecular dental implants

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INTRODUCTION

For more than 50 years, dental implants have been used to replace lost teeth. They have transformed the process of replacing lost teeth with a high success rate, which makes them a significant contribution to dentistry. The implant material's capacity to fuse with the surrounding tissue will determine its success. However, a number of variables, including implant material, quantity and quality

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of bone, and implant loading circumstances, affect this integration.[1]

There are a number of factors affecting overall percentage of bone attachment, such as surrounding tissues' composition and the implant surface characteristics. Over the past three decades, a number of surface modifications to dental implants have been made in an attempt to increase the overall percentage of bone attachment. These modifications may include coating, acid etching, grit blasting, or combinations of these methods. It has been demonstrated that increasing implant surface roughness enhances osseointegration or bone on-growth more effectively than machining the surface of the implant.[2]

A surface modification with three-dimensional roughness of porous tantalum trabecular metal (PTTM) was introduced recently wherein there is a modification of the mid-section of the implant body which differs from conventional implant in which the surface modifications are carried out onto the solid implant surface. PTTM material has similar elastic modulus to bone and is 80% porous with microstructures like bone. Dental implants composed of titanium with PTTM enhancements have a surface area that is over 70% larger. The porous component of PTTM dental implant allows neovascularization which permits bone growth onto and into the implant structure which is termed as osseoincorporation which differs from osseointegration in which there is only bone ongrowth on the implant surface.[3] Numerous techniques, such as implant stability (ISQ values), crestal bone loss, histomorphometric analysis, and gene expression can be used to access this osseoincorporation.

Patients with a history of chemotherapy, radiation, metabolic disorders and smoking are clearly at risk for implant failure, according to a recent meta-analysis on the subject. Furthermore, a number of studies found that patients with diabetes, radiation therapy, or other compromised medical conditions had a worse prognosis during the healing process. Therefore, in situations where titanium alloy fails to osseointegrate, PTTM implants have demonstrated improved biocompatibility and biomechanical qualities that promote osseoincorporation in a number of *in vitro* and clinical tests.[4]

Since there is lack of evidence on the literature pertaining to the comparison of PTTM dental implants and conventional titanium implants on hard and soft-tissue integration, this systematic review aims at assessing the osseoincorporation potential of PTTM dental implants.

METHODS

Key question and protocol

The PRISMA 2020 guideline served as the basis for the preparation and execution of this systematic review's procedure. This review's objective was to offer an answer to the following question: "Is there an enhancement in the osseointegration potential of trabecular dental implants when compared to conventional titanium dental implants?" [Table A].

Eligibility criteria

Inclusion criteria

1. Study design: Randomized control trial (RCT), clinical trial, prospective and retrospective clinical studies, and nonrandomized clinical trials
2. Studies published between January 1, 2010, and January 1, 2023
3. Studies published in the English language
4. Studies that included partially edentulous patients requiring implants measuring implant stability, histopathological analysis, peri-implant soft-tissue health and marginal bone loss following implant placement with a minimum follow-up period of 2 weeks were included in this study.

Exclusion criteria

1. Studies conducted on animals, *in vitro* study, case reports, case series, and review studies
2. Studies which include completely edentulous patients requiring implant placement
3. Studies that were not accessible.

Information sources

Data search was done through the databases PubMed, Cochrane, EMBASE, and SCOPUS from January 1, 2010,

Table A: PICO format

Framework item	Description
Population	Adult patients above 18 years
Intervention	Immediate or delayed placement of tantalum implants reinforced with titanium metal or PTTM-like implant test cylinders
Comparison	Presence or absence of a control group using any other similar implant/implant prototype
Outcome	Osseoincorporation measured clinically/histologically or by any other means through hard and soft-tissue changes Primary outcome: Implant stability, crestal bone loss Secondary outcome: Peri-implant soft-tissue health, histopathological analysis, patient-reported outcomes

PTTM: Porous tantalum trabecular metal

to January 1, 2023. A literature search approach was created utilizing terms associated with Titanium-tantalum dental implants, titanium tantalum dental implants, porous trabecular dental implants, trabecular dental implants, implant design, osseoincorporation.

Search strategy

A thorough search of the Cochrane Library, SCOPUS, EMBASE, and PubMed was conducted. When searching PubMed, SCOPUS, EMBASE, and the Cochrane Library, the dates of publication were set from January 1, 2010, to January 1, 2023. Language restrictions were applied and studies in the English language were selected. No filters text availability was set. The literature was reviewed using keywords to determine the search terms [Table 1].

Study selection

The titles and abstracts gathered using the search approach were separately reviewed by two reviewers, including those that satisfied the inclusion requirements. To verify eligibility, full-text publications were then examined in their entirety. The reviewers discussed and worked out any confusion regarding the inclusion of the study. Seven studies for the systematic review were ultimately found through the search. For every instance, the rationale behind the exclusion of studies was recorded. The journal names, research authors, and the institutions where the studies were carried out were not hidden from the reviewers.

Data collection process

With the assistance of a specialist, a standardized data extraction form was created in Microsoft Excel [Table 2]. Three or four entries were initially made in the Excel document, which was then examined by a specialist.

Table 1: Search strategy

Search strategy	Articles hit	Articles selected
Titanium-tantalum dental implants	7	2
Titanium tantalum dental implants	90	5
Porous tantalum dental implants	40	4
Trabecular dental implants	682	1
Osseoincorporation	11	1
Osseoincorporation and titanium-tantalum dental implants	1	2
Osseoincorporation and titanium tantalum dental implants	7	3
Osseoincorporation and porous tantalum dental implants	9	2
Osseoincorporation and trabecular dental implants	10	2
Osseoincorporation and implant design	7	2
Implant design and titanium-tantalum dental implants	1	2
Implant design and titanium tantalum dental implants	25	3
Implant design and porous tantalum dental implants	19	4
Implant design and trabecular dental implants	7	2
Implant design and osseoincorporation	236	3

Discussions were used to settle any disputes between the writers. The following standards were established in advance for data extraction:

1. Research involving patients who needed implants but were partially edentulous, assessing implant stability, marginal bone loss, and peri-implant soft-tissue health after implant implantation with a minimum 2-week follow-up time
2. Research in which the follow-up was detailed; if not, the variations among groups in terms of follow-up were suitably explained and adhered to.

Data synthesis

This systematic review lacks data amenable to meta-analysis due to heterogeneity of the data obtained from the 7 full text articles which were included in the systematic review. There was a high range of variability among the included studies which included nonuniformity in terms of outcomes, follow-up, lack of control groups, study design, and articles including compromised patients.

RESULTS

Screening process

Using a search approach, 1152 entries were found in the Cochrane, SCOPUS, EMBASE, PUBMED, and PubMed databases. Filtering through 1152 titles was the second phase. Title screening resulted in the exclusion of 150 articles due to duplication. Nine hundred and ninety-three items were disqualified because they failed to meet the review's goal. One article was eliminated from the nine that were chosen because it lacked comprehensive literature. One of the eight articles was a proof of principle study; hence it was disqualified. Ultimately, seven articles were selected for the systematic review after meeting the qualifying requirements.

Study characteristics

Eight articles were ultimately selected for full text screening. Seven studies that underwent quantitative synthesis were left at the end. Excluded articles were omitted because full text was not available,[1] articles from years other than 2010 to 2023,[2] articles available in languages other than English,[3] study design: Case reports, *in vitro* studies, animal studies.[4]

After quantitative synthesis all 7 articles were included for systematic review. The screening process is depicted in Chart 1. In total, the included articles evaluated 897 implants (titanium and tantalum dental implants). The characteristics of each study are mentioned in detail in Table 2.

Table 2: Data extraction table

Follow up period	Authors conclusion
Examined at 7, 14,28 days and 1/30 [once a month] for next 18 months.	This study represents the first clinical trial of PTTM dental implants in post-oncological patients and our preliminary results indicate that PTTM dental implants could have a clinical efficacy in prosthetic rehabilitation of these patients.
Total study period 5 years. 1 year interim results evaluated	TM dental implants were clinically effective under various clinical conditions in an uncontrolled cross section of patients with and without concomitant health conditions.
Assessed at 2 weeks followed by 1,3,6, 12 months	Predictable clinical outocmes.
2, 3,6 and 12 wks of healing	PTTM implant osseoincorporation resulted from osteogenic tissue network over 12 weeks and was comparable to trabecular volumes in posterior edentulous jaws
2, 4 weeks	Within the limitations of the present study, PTTM exhibited a more robust response towards early bone formation and mineralization, which may potentially enhance early osseointegration.
5 years	1. PTTM-enhanced dental implants (TM implants) had a relatively lower risk of bone loss and higher probability for bone gain, especially in immediate implant placement. 2. Despite the fact that the use of DBM shows relatively less bone loss in both types of implant, bone graft did not have significant effect on marginal bone loss in the presence of different types of implants (TM versus Ti). 3. DBM may be a good alternative to autografts and other bone regenerative materials.
2 weeks for anterior4 weeks for posterior	Based on the limitations of this study, PTTM material enhances initial healing compared to Ti alloy in the mandible of healthy subjects. Further studies in other areas of the oral cavity, such as maxilla, and with different patient population such as diabetics or patients with osteopenia,are needed to examine if PTTM will have similar effects in patients with compromised implant healing due to systemic conditions or bone quality/quantity problems.

Risk of bias in studies

The Cochrane Risk of Bias was used to evaluate the included studies' quality independently by the two reviewers, and any disputes were settled after speaking with two experts [Table 3]. When evaluating quality, the possibility of prejudice was taken into account. Out of the seven study publications, two had unclear attrition bias, one had unclear reporting bias, one had high bias, five had high selection bias, one had unclear allocation concealment, five had high performance bias, one had unclear detection bias, and five had high detection bias. Figures 1 and 2 and Table 3 provide an overview of the risk of bias evaluations for every domain across all included trials. Research assessing the health of the soft tissues around implants, bone loss, and implant stability were assessed using Cochrane tool of risk of bias assessment.

Risk of bias graph of included studies is shown [Figure 3] in percentage. Highest bias was seen with other bias which included small sample size, studies including compromised patients and use of implant prototypes in the form of cylinders and other factors mentioned in detail in Table 3.

Overall, the quality was moderate to poor since only one RCT (Sompop *et al*., 2019[6]; assessed growth factors which of low risk when compared to the other studies) was available from the seven trials [Figure 4]. The other research included two split mouth control experiments, two studies with compromised participants (cancer patients, patients with osteopenic patients), and two clinical trials.

For quasi-experimental research, a JBI critical evaluation checklist was used. Meta-analysis was not possible due to the heterogeneity of the included studies and the lack of data.

DISCUSSION

The transitional metal Tantalum (Ta), was initially used in dentistry by Manlio Formiggini, an Italian dentist in 1947. However, he soon gave up on the metal due to problems in procuring and refining Ta. In the 1960s, the American dentist Leonard Linkow and Italian dentist Silvano Tramonte made another attempt to employ titanium as a dental implant material because of its corrosion resistance and biocompatibility, but titanium's ease of use and accessibility eclipsed their efforts.[5]

Due to the introduction of PTTM technology, dental implants can have a three dimensional scaffold for bone ingrowth and ongrowth. The multithreaded self-tapping titanium endosseous implant was modified to include the PTTM in its central region. Due to the trabecular pattern of the implant body, there is neovascularization which allows bone ingrowth and ongrowth promoting increased potential for bone gain.[6]

According to Alexandar Edelmann's study, TM implants showed more bone gain than TI implants and preserved peri-implant bone. The framework for improved bone regeneration by osseoincorporation, which includes neovascularization and bone ingrowth, is provided by the PTTM component of TM implants. There was 100% survival in TM implant and 98% in Ti group which led to an unclear attrition bias.[7] A lower risk of bias in the study was seen since the investigators and practitioner was blinded. A technique for processing tantalum using Laser Engineered

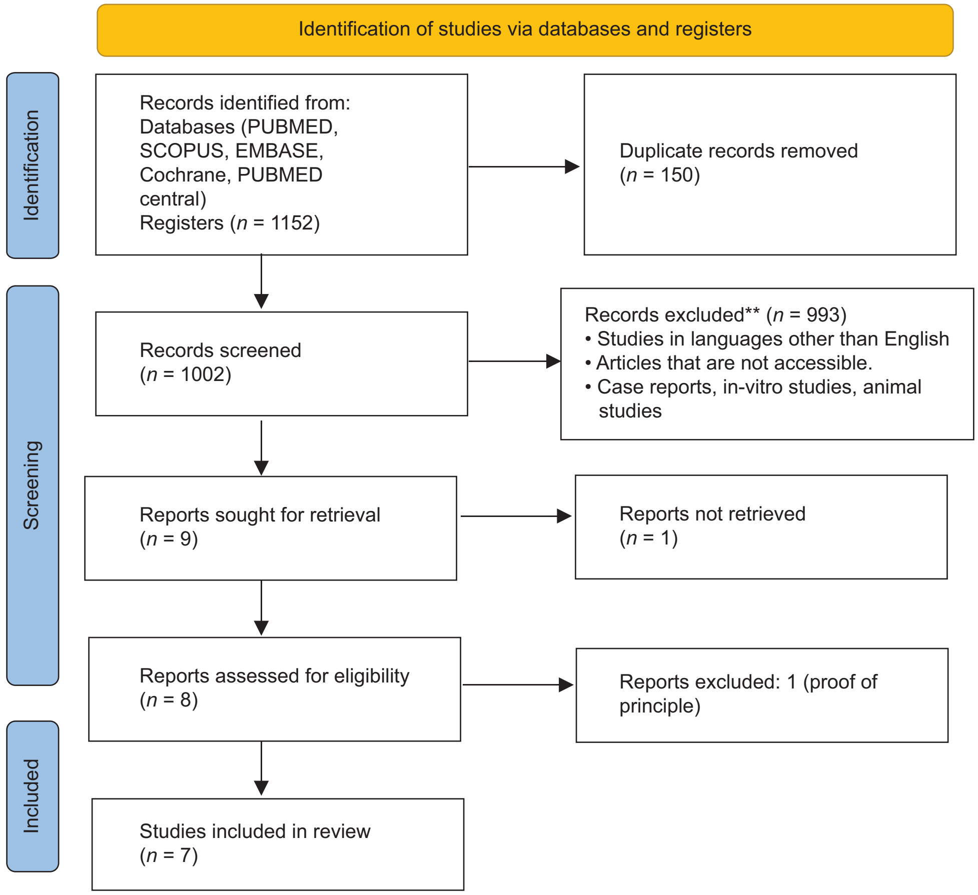

Chart 1: Screening process

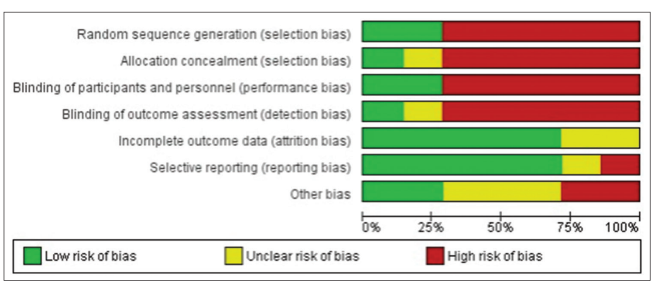

Figure 1: Risk of bias item presented as percentages across all included studies

Net Shaping to produce porous structures with different porosities was presented in a paper by Balla V. K. Porous tantalum samples with varying densities that were examined for mechanical properties were successfully created by the procedure. Comparing porous tantalum to porous titanium controls, *in vitro* experiments using human fetal osteoblasts demonstrated superior cell adhesion, proliferation, and differentiation as well as profuse extracellular matrix production. Because of its chemistry, wettability, and surface energy, the results indicate that porous tantalum can improve biological fixation, which makes it a suitable material for metallic implants in elderly patients.[8]

In the 1-year interrim report by Schlee *et al*., the clinical results indicated that the porous structure was biocompatible with cancellous bone and that PTTM-enhanced titanium dental implants could achieve vital bone and blood vessel ingrowth with a good prognosis for long-term clinical predictability.[9] However, this study had a high risk of bias since the case planning and surgical procedures were not standardized. This is in accordance with by Kim *et al*.'s study where they aimed to compare the stability of dental implants with a mid-section made of 3D tantalum porous to a traditional threaded titanium implant.[10]

Bencharit *et al*.'s histologic examination revealed a faster activation of bone-specific or osteoblastic genes based on the gene expression profile. The signaling pathways indicated that vascularization, osteogenesis, wound healing, and bone matrix were all stimulated concurrently. The PTTM group started to express these genes more than the Titanium alloy group at the 2-week mark, and the effects were more apparent at the 4-week mark. In terms of selection bias, detection bias, performance bias, reporting bias and attrition bias, this is the only study with minimal risk.[11]

Table 3: Risk of bias of individual studies

Risk of bias	Characteristics
Bias	Pierp Papi, 2014
Random sequence generation	High risk (no mention)
Allocation concealment	High risk (no mention)
Blinding of participants	High risk (no mention)
Blinding of outcome assessment	High risk (no mention)
Incomplete outcome data	Low risk (survival rate is 100%)
Selective reporting	Low risk (survival rate is 100%)
Other bias	High risk (small sample size and compromised population)
Bias	Marcus Schlee, 2015
Random sequence generation	High risk (interim report covers a subgroup of all subjects whose implants were place during the implant development period from October 2010 to June 2011 and who have completed 1 year of clinical monitoring after implant placement [focus group])
Allocation concealment	High risk (After discussing the treatment plan, alternative options, and answers to patient questions, each subject provided signed informed consent before implant treatment)
Blinding of participants	High risk (After discussing the treatment plan, alternative options, and answers to patient questions, each subject provided signed informed consent before implant treatment)
Blinding of outcome assessment	High risk (After discussing the treatment plan, alternative options, and answers to patient questions, each subject provided signed informed consent prior to implant treatment)
Incomplete outcome data	Unclear risk (11 patients with 15 implants were subsequently excluded for IFU contraindications. A total of seven implants failed in six subjects)
Selective reporting	High risk (11 patients with 15 implants were subsequently excluded for IFU contraindications)
Other bias	High risk (case planning and surgical procedures were left to the professional judgment of each investigator)
Bias	Christian Peron, 2016
Random sequence generation	High risk (nonrandomized)
Allocation concealment	Unclear risk (patient privacy was ensured by allocating identification numbers)
Blinding of participants	High risk (no mention regarding who made the assessment)
Blinding of outcome assessment	High risk (no mention regarding who made the assessment)
Incomplete outcome data	Low risk (1 year survival was 100%)
Selective reporting	Low risk (all outcomes were reported)
Other bias	Unclear risk (not discussed adequately)
Bias	Celia Clemente, 2018
Random sequence generation	Low risk (participants were randomly allocated to one of the four treatment groups)
Allocation concealment	High risk (not mentioned)
Blinding of participants	High risk (not mentioned)
Blinding of outcome assessment	High risk (not mentioned)
Incomplete outcome data	Low risk (all outcome reported)
Selective reporting	Low risk (all outcome reported)
Other bias	Low risk (PTTM prototypes were only used)
Bias	E.K Hefni
Random sequence generation	High risk (not applicable)
Allocation concealment	High risk (not applicable)
Blinding of participants	High risk (not mentioned)
Blinding of outcome assessment	High risk (not mentioned)
Incomplete outcome data	Low risk (all outcomes reported)
Selective reporting	Low risk (all outcomes reported)
Other bias	Unclear risk (osteopenic individuals in our study were under treatment with oral bisphosphonates, a class of drugs indicated in the prevention and treatment of illnesses associated to bony resorption)
Bias	Alexander R Edelmann, 2018
Random sequence generation	High risk (not applicable)
Allocation concealment	High risk (not applicable)
Blinding of participants	Low risk (all surgery and prosthodontic treatment procedures were performed by 1 practitioner [S.B.]. The charts were reviewed by 3 investigators [A.R.E, R.K.A, C.J.G] independent of the practitioner)
Blinding of outcome assessment	Low risk (all surgery and prosthodontic treatment procedures were performed by 1 practitioner [S.B]. The charts were reviewed by 3 investigators [A.R.E, R.K.A, C.J.G] independent of the practitioner)
Incomplete outcome data	Unclear risk (no implant was lost in the TM group [100% survival], and 3 implants failed in the Ti group [98% survival])
Selective reporting	Low risk (all the available data reported)
Other bias	Unclear risk (nine patients received both types of implants and were placed in implant group with largest count)
Bias	Sompop Bencharit, 2019
Random sequence generation	Low risk (titanium alloy or PTTM devices were randomly placed in the left or the right side of the edentulous areas in the mandible. Block randomization was used)
Allocation concealment	Low risk (randomization chart was generated prior to the recruitment and the surgeons were told at the time of the device placement of where the placement would be. The surgical operator was given the cylinders after all the osteotomy sites were prepared)
Blinding of participants	Low risk (randomization chart was generated before the recruitment and the surgeons were told at the time of the device placement of where the placement would be. The surgical operator was given the cylinders after all the osteotomy sites were prepared)

Contd...

Table 3: Contd...

Risk of bias	Characteristics
Blinding of outcome assessment	Unclear risk (an independent biostatistician reviewed the results and statistical analyses)
Incomplete outcome data	Low risk (Nil)
Selective reporting	Unclear risk (selected samples in the 4-week group were also subjected to histological analysis)
Other bias	Low risk (wound healing and osteogenesis signaling molecules also have similar expression patterns)

TM: Trabecular metal, PTTM: Porous tantalum TM, Instructions for use (IFU)

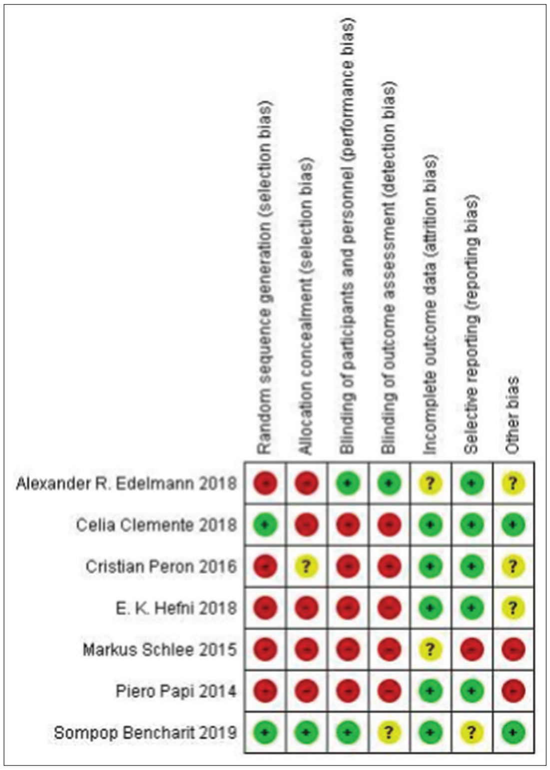

Figure 2: Risk of bias summary: Review authors' judgements about each risk of bias item for each included study

Another histological analysis of osteopenic subjects by Hefni *et al.* comparing gene expression profiles linked to osseointegration and healing in titanium cylinders and PTTM dental implants revealed a general trend of upregulation of the genes in the osteogenic pathway and a more distinct expression of genes regulating bone resorption in relation to PTTM dental implants. Because all results were provided, this study had a lower risk of bias.[2]

After 12 weeks of healing, almost 23% of the calcified bone penetrated the cylinders at a depth of 0.5 mm, according to Celia Clemente De Arriba's study, the first longitudinal histomorphometric investigation.[4] The potential of seeding BMSCs into porous tantalum for tissue repair applications was suggested by an *in vitro* study by Zhou and Liu that assessed the properties of porous tantalum and its regulatory effects on BMSCs. Due to the absence of information regarding the blinding procedure, there was a higher risk of bias in this study.[12]

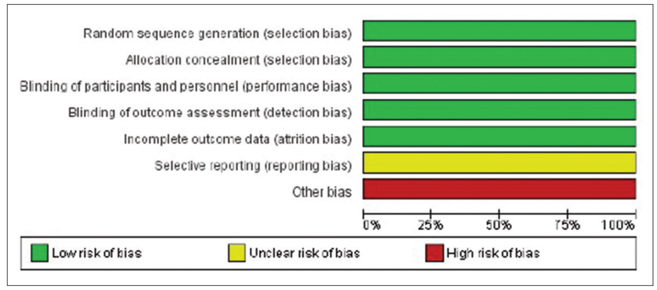

Figure 3: Risk of bias graph

A control group consisting of titanium implants was absent from a handful of the publications in this study.[13-15] The patients in the population were not standardized and included both healthy and impaired individuals. Due to variations in the chosen population's follow-up periods, the results assessed to evaluate osseoincorporation were not consistent. A few studies used both clinical and histological markers to evaluate osseoincorporation. Since few of the included studies used PTTM implants and few used PTTM prototypes (cylinders), the test groups in those studies were not standardized. There were not many included studies that did not measure the soft tissue health surrounding implants.

Conversely, to compare the primary stability of PTTM implants with Tapered Screw Vent (TSV) implants of varying diameters in two bone densities, Georgios E. Romanos carried out an *in vitro* study. There were 160 implants (80 TM and 80 TSV) in artificial bone blocks that represented bone qualities II and IV. The implants had narrow (3.7 mm) and conventional (4.1 mm) dimensions. Resonance frequency analysis and insertion torque were used to evaluate implant stability, and the results indicated that all groups had greater stability values in dense bone as opposed to soft bone. In both bone types, conventional-diameter implants were more stable than narrow implants. In soft bone, TSV implants outperformed TM implants in terms of stability.[16]

The systematic review's findings suggest that the PTTM structure permits osseoincorporation, which is the growth of bone into the porous structure through a combination of bone in growth and ongrowth and osseointegration. PTTM dental implants have

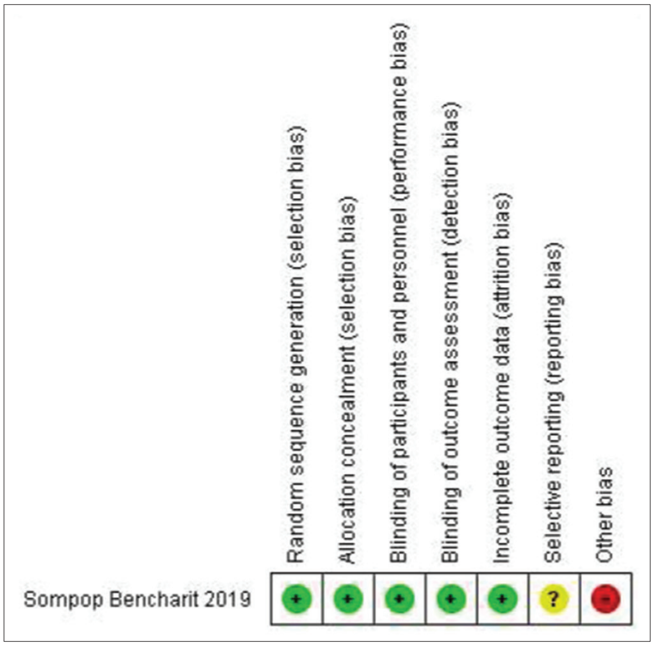

Figure 4: Risk of bias summary of Sompop Benchart 2019

higher secondary stability than traditional titanium alloy implants, which improves outcomes in high-risk scenarios such maxillofacial trauma, cleft lip and palate, and postoncologic patients.

Due to the heterogeneity among the included articles, the systematic review's results reveal severe bias, making meta-analysis impossible. As a result, the systematic review provides a lower level of evidence.

In light of the review's constraints, future research should concentrate on carrying out studies with longer follow-up periods that will provide information on the difficulties raised. Literature on patient satisfaction and quality of life is scarce. These results ought to be included by researchers in their investigations.

CONCLUSION

It is clear from this systematic review that the trabecular pattern of these implants resembles that of bone. PTTM dental implants demonstrated enhanced neovascularization, which encouraged the formation of new bone. Comparing PTTM dental implants to traditional titanium implants, there was a greater rise in osteogenic potential in patients with poor bone quality. Another finding was that there was a higher likelihood of bone gain and a relatively low risk of bone loss with rapid implant loading. Furthermore, the limited resistance to fracture and challenging retrievability of PTTM dental implants are clinical constraints.

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Conflicts of interest

There are no conflicts of interest.

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