Impact des modifications de surface des implants sur les résultats à long terme du traitement chirurgical de la péri-implantite : une revue systématique

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RÉSUMÉ

La péri-implantite est une maladie inflammatoire affectant les tissus mous et l'os de soutien des implants dentaires et pouvant conduire, en l'absence de traitement, à la perte implantaire. De nombreuses approches chirurgicales sont utilisées pour sa prise en charge, mais l'influence des caractéristiques de surface implantaire sur le succès à long terme du traitement reste incertaine. Cette revue systématique a analysé des études cliniques humaines avec un suivi minimal de 3 ans évaluant les résultats du traitement chirurgical de la péri-implantite en fonction du type de surface implantaire. Dix-sept études ont été incluses. Globalement, les implants à surface rugueuse (modifiée) présentaient un risque plus élevé de récidive de la péri-implantite et de perte implantaire que les implants à surface lisse (usinée/tournée). Les approches chirurgicales reconstructrices, incluant greffes osseuses et/ou membranes, semblaient offrir des résultats cliniques et radiographiques plus favorables que les approches non reconstructrices. Toutefois, la certitude des preuves était faible en raison d'une hétérogénéité méthodologique importante, de petits effectifs et d'un risque de biais. Des essais cliniques prospectifs à long terme sont nécessaires pour confirmer ces observations.

INTRODUCTION

Introduction

Les implants dentaires ont profondément transformé l'arsenal thérapeutique de la réhabilitation orale contemporaine en offrant une solution à la fois fiable, fonctionnelle et biologiquement compatible pour le remplacement des dents absentes. Le concept du traitement implantaire utilisant des vis en titane comme alternative aux solutions prothétiques amovibles a été introduit pour la première fois par Brånemark en 1965, marquant ainsi un véritable changement de paradigme dans le domaine de la dentisterie restauratrice. Depuis cette innovation fondatrice, la thérapeutique implanto-portée n'a cessé d'évoluer pour devenir une modalité de traitement largement acceptée et couramment utilisée, en particulier pour la réhabilitation des arcades partiellement édentées (1-4). L'adoption généralisée des implants dentaires repose sur leur capacité à restaurer la fonction masticatoire et l'esthétique de manière hautement prévisible, contribuant ainsi à une profonde transformation de la pratique clinique quotidienne.

De nombreuses études longitudinales et observationnelles ont systématiquement mis en évidence des taux de survie élevés des implants dentaires, renforçant davantage l'attrait de cette approche thérapeutique. Plusieurs investigations ont rapporté des taux de survie supérieurs à 90 % après cinq années de mise en fonction (2, 5). Plus récemment, une revue systématique regroupant des études prospectives à long terme a rapporté des taux de survie généralement supérieurs à 90 % sur une période de suivi de 5 à 10 ans, demeurant autour de 78 % après imputation à 20 ans de suivi. Par ailleurs, cinq études rétrospectives avec un suivi d'au moins 20 ans ont mis en évidence un taux de survie implantaire d'environ 88 %, même lorsque des causes de perte implantaire de nature multifactorielle étaient prises en compte (6). Pris dans leur ensemble, ces résultats confirment que les implants dentaires constituent une solution de remplacement dentaire hautement prévisible et durable.

Au-delà de ces résultats favorables en termes de survie, les réhabilitations implanto-portées présentent des avantages cliniques supplémentaires. Le traitement implantaire permet en effet de remplacer une dent absente sans nécessiter la préparation irréversible des dents adjacentes saines, comme c'est le cas pour les prothèses fixes conventionnelles (fixed dental prostheses, FDP). Cette préservation du capital dentaire, combinée à des taux de survie élevés démontrés à long terme, a largement contribué à la reconnaissance et à l'acceptation du traitement implantaire en dentisterie moderne. Néanmoins, cette approche thérapeutique n'est pas exempte d'inconvénients. Ceux-ci incluent notamment des coûts de traitement relativement élevés par rapport aux alternatives prothétiques amovibles ou fixes, ainsi que la survenue possible de complications d'ordre technique et biologique (7).

Malgré les taux de survie élevés rapportés, les complications biologiques affectant les tissus péri-implantaires sont relativement fréquentes et constituent un défi clinique majeur. Parmi celles-ci, les maladies péri-implantaires – et en particulier la péri-implantite – se sont imposées comme une menace significative pour le succès à long

terme des réhabilitations implanto-portées. La péri-implantite se caractérise par une inflammation de la muqueuse péri-implantaire associée à une perte progressive de l'os de soutien (8). Les données épidémiologiques indiquent que la péri-implantite touche environ 19,53 % des patients et 12,53 % des implants, soulignant ainsi sa prévalence considérable et son importance clinique (9).

L'étiologie de la péri-implantite est multifactorielle ; toutefois, le biofilm oral est largement reconnu comme le principal facteur étiologique initiant et maintenant le processus pathologique (10). À l'instar de la parodontite, la colonisation microbienne et la maturation du biofilm déclenchent une réponse inflammatoire de l'hôte qui conduit ultimement à la destruction tissulaire. Dans ce contexte, les interactions entre les micro-organismes et les surfaces implantaires revêtent une importance particulière, dans la mesure où elles influencent l'adhésion bactérienne précoce, le développement du biofilm et la composition microbienne. Par conséquent, les caractéristiques de surface des implants ont fait l'objet d'une attention croissante en tant que facteur potentiel impliqué dans la pathogenèse des maladies péri-implantaires.

Caractéristiques de surface des implants

Les implants originaux développés par Brånemark (Nobel Biocare) étaient caractérisés par une surface dite « lisse », également qualifiée de surface usinée ou tournée. Ces implants étaient laissés inchangés après leur fabrication, à l'exception des procédures de décontamination et de stérilisation. Bien que décrites comme lisses, des observations microscopiques révèlent une surface en réalité minimalement rugueuse, résultant des traces laissées par les instruments d'usinage lors du processus de fabrication (11, 12). Pendant de nombreuses années, ces implants usinés ont constitué la référence en implantologie orale, principalement en raison de leurs résultats cliniques favorables et prévisibles (13).

Au fil du temps, des modifications de surface implantaire ont été introduites dans le but d'accélérer la cicatrisation osseuse et d'améliorer l'ancrage des implants en titane (14). Les surfaces implantaires modifiées – communément désignées comme « rugueuses » – ont été largement évaluées dans des études in vitro et in vivo (14-16). Ces modifications sont obtenues par des techniques de fabrication additives ou soustractives, qui augmentent la rugosité de surface et modifient la composition chimique superficielle (17). Dans les années 1990, des données probantes ont montré que les implants présentant un certain degré de rugosité induisaient une réponse osseuse plus importante que les implants à surface lisse (11). Ces observations ont conduit à un abandon progressif des surfaces usinées conventionnelles au profit des surfaces modifiées, qui se sont ensuite largement imposées en pratique clinique.

L'objectif principal des modifications de surface est d'améliorer la stabilité primaire et de favoriser l'ostéointégration, définie comme une connexion structurale et fonctionnelle directe entre la surface implantaire et l'os environnant(16, 18). Une ostéointégration améliorée est généralement associée à des niveaux plus élevés de contact direct os-implant (bone-to-implant contact, BIC), obtenus sur des périodes de cicatrisation plus courtes. La topographie des surfaces implantaires est classiquement divisée en macro-,

micro- et nano-topographie. La macrotopographie fait référence à la géométrie globale de l'implant, telle qu'un design conique ou cylindrique, tandis que la microtopographie correspond à la rugosité de surface à l'échelle micrométrique. Cette micro-rugosité peut être modifiée par diverses techniques, notamment l'attaque acide, le sablage ou la projection plasma (12, 16, 17, 19).

Il a été rapporté que les procédures de rugosification de surface influencent également la composition chimique des surfaces implantaires, rendant difficile la distinction entre les effets biologiques attribuables à la rugosité elle-même et ceux liés aux modifications chimiques de surface (20). Parmi les techniques additives, la projection plasma de titane (titanium plasma spraying, TPS) a historiquement été l'une des méthodes les plus utilisées. Cette technique consiste à injecter des particules de titane dans un chalumeau plasma à haute température, entraînant leur fusion sur la surface implantaire et la création d'une surface fortement rugueuse (19).

Des développements ultérieurs ont inclus la projection plasma d'hydroxyapatite (HA) et d'autres revêtements bioactifs, visant à reproduire l'environnement biochimique et l'architecture de l'os humain. Ces revêtements avaient pour objectif non seulement d'améliorer l'ostéointégration, mais également de réduire l'adhésion bactérienne et, par conséquent, le développement des maladies péri-implantaires (17, 19).

Les techniques soustractives ont également été largement adoptées. Le sablage consiste à projeter des particules céramiques sur la surface implantaire, produisant différents degrés de rugosité en fonction de la taille des particules utilisées (17). L'attaque acide, généralement réalisée à l'aide d'acides chlorhydrique ou nitrique, modifie davantage la topographie de surface. Souvent, le sablage et l'attaque acide sont combinés, donnant naissance à la surface dite SLA (sandblasted and acid-etched). Les surfaces SLA présentent des valeurs de rugosité inférieures à celles des surfaces TPS, mais supérieures à celles des surfaces usinées (11).

Plus récemment, la nano-topographie – correspondant à des structures de surface comprises entre 1 et 100 nm – a suscité un intérêt croissant au sein de la communauté scientifique. Bien que les modifications à l'échelle nanométrique soient supposées influencer le comportement cellulaire, leurs effets biologiques demeurent encore largement incompris (12, 21).

En 2004, Albrektsson et Wennerberg (11) ont proposé un système de classification des surfaces implantaires basé sur la rugosité moyenne (Sa) : surfaces lisses (Sa < 0,5 µm), minimalement rugueuses (Sa = 0,5–1 µm), modérément rugueuses (Sa = 1–2 µm) et rugueuses (Sa > 2 µm). Bien que le terme « lisse » continue d'être employé en pratique clinique, la majorité des implants contemporains appartiennent à la catégorie des surfaces modérément rugueuses (11).

Les modifications chimiques et topographiques des surfaces implantaires ont joué un rôle central dans les performances cliniques favorables observées avec les implants modernes. Un rapport de consensus publié en 2009 a conclu que les surfaces modérément rugueuses et rugueuses présentaient une intégration osseuse plus

prononcée que les surfaces lisses et minimalement rugueuses (22). De plus, des taux de survie implantaire plus élevés ont été rapportés pour les implants à surface modifiée comparativement aux implants usinés (23, 24).

Toutefois, les données concernant le rôle des caractéristiques de surface implantaire en tant que facteur de risque des complications biologiques restent limitées. Certaines études ont suggéré que les implants présentant des surfaces très rugueuses, telles que les surfaces TPS et HA, étaient associés à une incidence plus élevée de péri-implantite (25, 26). Renvert et al. (27) ont néanmoins conclu que les données concernant l'influence des caractéristiques de surface sur l'initiation de la péri-implantite faisaient défaut, bien que des études expérimentales indiquent que les propriétés de surface puissent influencer la progression de la maladie. Des études précliniques in vivo suggèrent par ailleurs une progression plus rapide et une sévérité accrue de la péri-implantite autour des implants à surface modifiée par rapport aux surfaces tournées, ainsi que des différences entre divers types de surfaces modifiées (28, 29).

En outre, les caractéristiques de surface implantaire semblent influencer les résultats thérapeutiques après le traitement de la péri-implantite. Plusieurs études cliniques ont rapporté des résultats à court et à long terme moins favorables, ainsi que des taux de récidive plus élevés, lors du traitement de la péri-implantite autour d'implants à surface modifiée (30-32).

Complications

Les études longitudinales rapportent des taux de survie implantaire allant de 90,5 % à 100 % après un suivi d'au moins cinq ans, et de 85,5 % à 100 % après dix ans (2, 33). Malgré ces taux élevés, des échecs implantaires et des complications peuvent survenir (24). Les maladies péri-implantaires constituent l'une des complications biologiques les plus fréquemment associées au traitement implantaire (2, 34, 35).

La mucosite péri-implantaire et la péri-implantite sont regroupées sous le terme de maladies péri-implantaires. Zitzmann et Berglundh (36) ont décrit la péri-implantite comme une lésion inflammatoire destructrice d'étiologie microbienne affectant à la fois les tissus mous et durs péri-implantaires. Tandis que la mucosite péri-implantaire est limitée à la muqueuse péri-implantaire, la péri-implantite implique une perte progressive de l'os de soutien.

Bien que les maladies péri-implantaires partagent des similitudes avec la gingivite et la parodontite, des différences anatomiques et histologiques importantes existent. Les implants sont dépourvus de ligament parodontal et sont directement ankylosés à l'os. Les fibres de collagène autour des implants sont orientées verticalement et ne s'insèrent pas dans la surface implantaire, contrairement aux fibres autour des dents, qui s'insèrent horizontalement dans le cément (37). Bien que des profils bactériens similaires soient observés dans la parodontite et la péri-implantite (10, 38), ces différences anatomiques contribuent à un tableau pathologique plus agressif dans la péri-implantite (39).

Des études histologiques ont démontré que les lésions de péri-implantite sont approximativement deux fois plus étendues que celles de la parodontite et sont en contact direct avec l'os de soutien (40). La perte osseuse progresse également plus rapidement autour des implants que des dents, en particulier autour des implants à surface rugueuse (41, 42).

Traitement de la péri-implantite

L'objectif principal du traitement de la péri-implantite est d'éliminer l'inflammation, de favoriser la cicatrisation des tissus péri-implantaires et de restaurer les structures et fonctions perdues (43, 44). De nombreuses revues systématiques ont abordé le traitement de la péri-implantite (45-50), mettant en évidence une hétérogénéité considérable des protocoles thérapeutiques et des résultats.

La thérapie non chirurgicale seule s'est révélée parfois insuffisante pour le traitement de la péri-implantite (44, 49), ce qui a conduit à l'approche chirurgicale (44, 46). Les interventions chirurgicales offrent un accès direct aux défauts péri-implantaires, permettant la décontamination de la surface implantaire et, lorsque cela est indiqué, la mise en œuvre de procédures régénératives. Des stratégies chirurgicales non régénératives et régénératives ont été décrites, incluant notamment l'implantoplastie, l'ostéoplastie, la chirurgie résectrice et la régénération osseuse guidée (guided bone regeneration, GBR).

Malgré l'abondance des recherches, aucune méthode de décontamination de surface n'a démontré une supériorité claire (47), et la prévisibilité à long terme des approches régénératives demeure incertaine (51). Il est particulièrement notable que, bien que de nombreuses revues aient évalué les différentes modalités chirurgicales, aucune ne se soit spécifiquement concentrée sur l'influence de la topographie de surface implantaire sur les résultats du traitement chirurgical de la péri-implantite.

Malgré plusieurs décennies de recherche consacrées aux modifications de surface implantaire, à la pathogenèse des maladies péri-implantaires et aux stratégies chirurgicales de traitement, une lacune majeure persiste concernant le rôle de la topographie de surface implantaire dans la détermination des résultats thérapeutiques après un traitement chirurgical de la péri-implantite. La littérature existante s'est principalement concentrée sur la survie implantaire, l'ostéointégration ou l'efficacité globale des traitements, sans intégrer de manière systématique les caractéristiques de surface comme facteur modulateur des résultats cliniques et radiographiques. En outre, les données disponibles demeurent fragmentées et hétérogènes, limitant ainsi la possibilité de tirer des conclusions définitives et de guider la prise de décision clinique.

L'originalité du présent travail doctoral réside dans son évaluation ciblée et systématique de la topographie de surface implantaire en tant que déterminant des résultats du traitement chirurgical de la péri-implantite chez l'être humain. En synthétisant les données cliniques et radiographiques issues de différentes catégories de surfaces implantaires, ce travail vise à déterminer si les implants à surface rugueuse et lisse présentent des schémas de cicatrisation, des réponses thérapeutiques et une stabilité à

long terme distincts après une intervention chirurgicale. Ce faisant, cette thèse ambitionne de combler un fossé critique entre l'ingénierie des surfaces implantaires et la gestion clinique des maladies péri-implantaires, en apportant des données originales et cliniquement pertinentes susceptibles d'orienter le choix des implants, la planification thérapeutique et les stratégies de maintenance à long terme chez les patients atteints de péri-implantite.

RÉFÉRENCES

1. Spiekermann H, Jansen VK, Richter EJ. A 10-year follow-up study of IMZ and TPS implants in the edentulous mandible using bar-retained overdentures. Int J Oral Maxillofac Implants. 1995;10(2):231-43.
2. Jung RE, Zembic A, Pjetursson BE, Zwahlen M, Thoma DS. Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. Clin Oral Implants Res. 2012;23 Suppl 6:2-21.
3. Attard NJ, Zarb GA. Implant prosthodontic management of partially edentulous patients missing posterior teeth: the Toronto experience. J Prosthet Dent. 2003;89(4):352-9.
4. Esposito M, Ardebili Y, Worthington HV. Interventions for replacing missing teeth: different types of dental implants. Cochrane Database Syst Rev. 2014(7):Cd003815.
5. Lang NP, Berglundh T, Heitz-Mayfield LJ, Pjetursson BE, Salvi GE, Sanz M. Consensus statements and recommended clinical procedures regarding implant survival and complications. Int J Oral Maxillofac Implants. 2004;19 Suppl:150-4.
6. Kupka JR, König J, Al-Nawas B, Sagheb K, Schiegnitz E. How far can we go? A 20-year meta-analysis of dental implant survival rates. Clin Oral Investig. 2024;28(10):541.
7. Hanif A, Qureshi S, Sheikh Z, Rashid H. Complications in implant dentistry. Eur J Dent. 2017;11(1):135-40.
8. Renvert S, Persson GR, Pirih FQ, Camargo PM. Peri-implant health, peri-implant mucositis, and peri-implantitis: Case definitions and diagnostic considerations. J Periodontol. 2018;89 Suppl 1:S304-s12.
9. Diaz P, Gonzalo E, Villagra LJG, Miegimolle B, Suarez MJ. What is the prevalence of peri-implantitis? A systematic review and meta-analysis. BMC Oral Health. 2022;22(1):449.
10. Mombelli A, Décaillet F. The characteristics of biofilms in peri-implant disease. J Clin Periodontol. 2011;38 Suppl 11:203-13.
11. Albrektsson T, Wennerberg A. Oral implant surfaces: Part 1--review focusing on topographic and chemical properties of different surfaces and in vivo responses to them. Int J Prosthodont. 2004;17(5):536-43.
12. Dohan Ehrenfest DM, Coelho PG, Kang BS, Sul YT, Albrektsson T. Classification of osseointegrated implant surfaces: materials, chemistry and topography. Trends Biotechnol. 2010;28(4):198-206.
13. Albrektsson T, Dahl E, Enbom L, Engevall S, Engquist B, Eriksson AR, et al. Osseointegrated oral implants. A Swedish multicenter study of 8139 consecutively inserted Nobelpharma implants. J Periodontol. 1988;59(5):287-96.
14. Cooper LF. A role for surface topography in creating and maintaining bone at titanium endosseous implants. J Prosthet Dent. 2000;84(5):522-34.
15. Longo G, Ioannidu CA, Scotto d'Abusco A, Superti F, Misiano C, Zanoni R, et al. Improving Osteoblast Response In Vitro by a Nanostructured Thin Film with Titanium Carbide and Titanium Oxides Clustered around Graphitic Carbon. PLoS One. 2016;11(3):e0152566.
16. Wennerberg A, Albrektsson T. Effects of titanium surface topography on bone integration: a systematic review. Clin Oral Implants Res. 2009;20 Suppl 4:172-84.

17. Annunziata M, Guida L. The Effect of Titanium Surface Modifications on Dental Implant Osseointegration. Front Oral Biol. 2015;17:62-77.
18. Coelho PG, Granjeiro JM, Romanos GE, Suzuki M, Silva NR, Cardaropoli G, et al. Basic research methods and current trends of dental implant surfaces. J Biomed Mater Res B Appl Biomater. 2009;88(2):579-96.
19. Smeets R, Stadlinger B, Schwarz F, Beck-Broichsitter B, Jung O, Precht C, et al. Impact of Dental Implant Surface Modifications on Osseointegration. Biomed Res Int. 2016;2016:6285620.
20. Junker R, Dimakis A, Thoneick M, Jansen JA. Effects of implant surface coatings and composition on bone integration: a systematic review. Clin Oral Implants Res. 2009;20 Suppl 4:185-206.
21. Wennerberg A, Albrektsson T. On implant surfaces: a review of current knowledge and opinions. Int J Oral Maxillofac Implants. 2010;25(1):63-74.
22. Lang NP, Jepsen S. Implant surfaces and design (Working Group 4). Clin Oral Implants Res. 2009;20 Suppl 4:228-31.
23. Jimbo R, Albrektsson T. Long-term clinical success of minimally and moderately rough oral implants: a review of 71 studies with 5 years or more of follow-up. Implant Dent. 2015;24(1):62-9.
24. Chrcanovic BR, Albrektsson T, Wennerberg A. Reasons for failures of oral implants. J Oral Rehabil. 2014;41(6):443-76.
25. Astrand P, Engquist B, Anzén B, Bergendal T, Hallman M, Karlsson U, et al. A three-year follow-up report of a comparative study of ITI Dental Implants and Brånemark System implants in the treatment of the partially edentulous maxilla. Clin Implant Dent Relat Res. 2004;6(3):130-41.
26. Karoussis IK, Brägger U, Salvi GE, Bürgin W, Lang NP. Effect of implant design on survival and success rates of titanium oral implants: a 10-year prospective cohort study of the ITI Dental Implant System. Clin Oral Implants Res. 2004;15(1):8-17.
27. Renvert S, Polyzois I, Claffey N. How do implant surface characteristics influence peri-implant disease? J Clin Periodontol. 2011;38 Suppl 11:214-22.
28. Hussein A, Shah M, Atieh MA, Alhimairi S, Amir-Rad F, Elbishari H. Influence of Implant Surfaces on Peri-Implant Diseases – A Systematic Review and Meta-Analysis. Int Dent J. 2025;75(1):75-85.
29. Stavropoulos A, Bertl K, Winning L, Polyzois I. What is the influence of implant surface characteristics and/or implant material on the incidence and progression of peri-implantitis? A systematic literature review. Clin Oral Implants Res. 2021;32 Suppl 21:203-29.
30. Carcuac O, Derks J, Abrahamsson I, Wennström JL, Berglundh T. Risk for recurrence of disease following surgical therapy of peri-implantitis-A prospective longitudinal study. Clin Oral Implants Res. 2020;31(11):1072-7.
31. Garaicoa-Pazmino C, Lin GH, Alkandery A, Parra-Carrasquer C, Suárez-López Del Amo F. Influence of implant surface characteristics on the initiation, progression and treatment outcomes of peri-implantitis: A systematic review and meta-analysis based on animal model studies. Int J Oral Implantol (Berl). 2021;14(4):367-82.
32. Romandini M, Bougas K, Alibegovic L, Hosseini S, Carcuac O, Berglundh T, et al. Long-term outcomes and prognostic factors of surgical treatment of peri-implantitis - A retrospective study. Clin Oral Implants Res. 2024;35(3):321-9.

33. Hjalmarsson L, Gheisarifar M, Jemt T. A systematic review of survival of single implants as presented in longitudinal studies with a follow-up of at least 10 years. Eur J Oral Implantol. 2016;9 Suppl 1:S155-62.
34. Lang NP, Wilson TG, Corbet EF. Biological complications with dental implants: their prevention, diagnosis and treatment. Clin Oral Implants Res. 2000;11 Suppl 1:146-55.
35. Pjetursson BE, Brägger U, Lang NP, Zwahlen M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). Clin Oral Implants Res. 2007;18 Suppl 3:97-113.
36. Zitzmann NU, Berglundh T. Definition and prevalence of peri-implant diseases. J Clin Periodontol. 2008;35(8 Suppl):286-91.
37. Smeets R, Henningsen A, Jung O, Heiland M, Hammächer C, Stein JM. Definition, etiology, prevention and treatment of peri-implantitis--a review. Head Face Med. 2014;10:34.
38. Renvert S, Roos-Jansåker AM, Lindahl C, Renvert H, Rutger Persson G. Infection at titanium implants with or without a clinical diagnosis of inflammation. Clin Oral Implants Res. 2007;18(4):509-16.
39. Berglundh T, Zitzmann NU, Donati M. Are peri-implantitis lesions different from periodontitis lesions? J Clin Periodontol. 2011;38 Suppl 11:188-202.
40. Berglundh T, Gislason O, Lekholm U, Sennerby L, Lindhe J. Histopathological observations of human periimplantitis lesions. J Clin Periodontol. 2004;31(5):341-7.
41. Carcuac O, Abrahamsson I, Albouy JP, Linder E, Larsson L, Berglundh T. Experimental periodontitis and peri-implantitis in dogs. Clin Oral Implants Res. 2013;24(4):363-71.
42. Albouy JP, Abrahamsson I, Berglundh T. Spontaneous progression of experimental peri-implantitis at implants with different surface characteristics: an experimental study in dogs. J Clin Periodontol. 2012;39(2):182-7.
43. Heitz-Mayfield LJ. Diagnosis and management of peri-implant diseases. Aust Dent J. 2008;53 Suppl 1:S43-8.
44. Herrera D, Berglundh T, Schwarz F, Chapple I, Jepsen S, Sculean A, et al. Prevention and treatment of peri-implant diseases-The EFP S3 level clinical practice guideline. J Clin Periodontol. 2023;50 Suppl 26:4-76.
45. Roos-Jansåker AM, Renvert S, Egelberg J. Treatment of peri-implant infections: a literature review. J Clin Periodontol. 2003;30(6):467-85.
46. Klinge B, Gustafsson A, Berglundh T. A systematic review of the effect of anti-infective therapy in the treatment of peri-implantitis. J Clin Periodontol. 2002;29 Suppl 3:213-25; discussion 32-3.
47. Claffey N, Clarke E, Polyzois I, Renvert S. Surgical treatment of peri-implantitis. J Clin Periodontol. 2008;35(8 Suppl):316-32.
48. Esposito M, Grusovin MG, Worthington HV. Interventions for replacing missing teeth: treatment of peri-implantitis. Cochrane Database Syst Rev. 2012;1(1):Cd004970.
49. Renvert S, Roos-Jansåker AM, Claffey N. Non-surgical treatment of peri-implant mucositis and peri-implantitis: a literature review. J Clin Periodontol. 2008;35(8 Suppl):305-15.
50. Faggion CM, Jr., Chambrone L, Listl S, Tu YK. Network meta-analysis for evaluating interventions in implant dentistry: the case of peri-implantitis treatment. Clin Implant Dent Relat Res. 2013;15(4):576-88.

51. Renvert S, Polyzois I, Claffey N. Surgical therapy for the control of peri-implantitis. Clin Oral Implants Res. 2012;23 Suppl 6:84-94.
52. Vernon JJ, Raïf EM, Aw J, Attenborough E, Jha A, Do T. Dental implant surfaces and their interaction with the oral microbiome. Dentistry Review. 2022;2(4):100060.
53. Wassmann T, Kreis S, Behr M, Buergers R. The influence of surface texture and wettability on initial bacterial adhesion on titanium and zirconium oxide dental implants. International Journal of Implant Dentistry. 2017;3(1):32.
54. Aghazadeh A, Persson GR, Stavropoulos A, Renvert S. Reconstructive treatment of peri-implant defects-Results after three and five years. Clin Oral Implants Res. 2022;33(11):1114-24.
55. Deppe H, Horch HH, Neff A. Conventional versus CO2 laser-assisted treatment of peri-implant defects with the concomitant use of pure-phase beta-tricalcium phosphate: a 5-year clinical report. Int J Oral Maxillofac Implants. 2007;22(1):79-86.
56. Jemt T, Eriksson J. Bone Loss Before and After Peri-implantitis Surgery: A 7-Year Retrospective Observational Study. Int J Oral Maxillofac Implants. 2021;36(6):1199-210.
57. Khoury F, Buchmann R. Surgical therapy of peri-implant disease: a 3-year follow-up study of cases treated with 3 different techniques of bone regeneration. J Periodontol. 2001;72(11):1498-508.
58. La Monaca G, Pranno N, Annibali S, Cristalli MP, Polimeni A. Clinical and radiographic outcomes of a surgical reconstructive approach in the treatment of peri-implantitis lesions: A 5-year prospective case series. Clin Oral Implants Res. 2018;29(10):1025-37.
59. La Monaca G, Pranno N, Annibali S, Polimeni A, Cristalli MP. A 10-Year Follow-Up of Reconstructive Treatment of Peri-Implantitis Using Mineralized Dehydrated Allograft and Resorbable Membrane: A Retrospective Case Series. Clin Oral Implants Res. 2024.
60. Leonhardt A, Dahlén G, Renvert S. Five-year clinical, microbiological, and radiological outcome following treatment of peri-implantitis in man. J Periodontol. 2003;74(10):1415-22.
61. Mercado F, Hamlet S, Ivanovski S. Regenerative surgical therapy for peri-implantitis using deproteinized bovine bone mineral with 10% collagen, enamel matrix derivative and Doxycycline-A prospective 3-year cohort study. Clin Oral Implants Res. 2018;29(6):583-91.
62. Noelken R, Westphal L, Schiegnitz E, Al-Nawas B. Hard and soft tissue regeneration of severe peri-implantitis defects with the laser-assisted peri-implant defect regeneration technique: 3-year results. Int J Implant Dent. 2023;9(1):3.
63. Roccuzzo M, Fierravanti L, Pittoni D, Dalmasso P, Roccuzzo A. Implant survival after surgical treatment of peri-implantitis lesions by means of deproteinized bovine bone mineral with 10% collagen: 10-year results from a prospective study. Clin Oral Implants Res. 2020;31(8):768-76.
64. Roccuzzo M, Mirra D, Pittoni D, Ramieri G, Roccuzzo A. Reconstructive treatment of peri-implantitis infrabony defects of various configurations: 5-year survival and success. Clin Oral Implants Res. 2021;32(10):1209-17.
65. Roccuzzo M, Pittoni D, Roccuzzo A, Charrier L, Dalmasso P. Surgical treatment of peri-implantitis intrabony lesions by means of deproteinized bovine bone mineral with 10% collagen: 7-year-results. Clin Oral Implants Res. 2017;28(12):1577-83.

66. Roos-Jansåker AM, Lindahl C, Persson GR, Renvert S. Long-term stability of surgical bone regenerative procedures of peri-implantitis lesions in a prospective case-control study over 3 years. J Clin Periodontol. 2011;38(6):590-7.
67. Roos-Jansåker AM, Persson GR, Lindahl C, Renvert S. Surgical treatment of peri-implantitis using a bone substitute with or without a resorbable membrane: a 5-year follow-up. J Clin Periodontol. 2014;41(11):1108-14.
68. Schwarz F, Sahm N, Bieling K, Becker J. Surgical regenerative treatment of peri-implantitis lesions using a nanocrystalline hydroxyapatite or a natural bone mineral in combination with a collagen membrane: a four-year clinical follow-up report. J Clin Periodontol. 2009;36(9):807-14.

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Impact of implant surface modifications on long-term outcome of surgical peri-implantitis treatment: a systematic review

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Introduction: Peri-implantitis is an inflammatory disease that compromises peri-implant tissues and supporting bone, potentially leading to implant loss. Although several surgical treatment strategies have been proposed, it remains unclear whether implant surface characteristics (smooth vs. rough) influence long-term treatment outcomes.

Methods: A systematic review was conducted to evaluate clinical studies with a minimum follow-up of 3 years that assessed the outcomes of surgical treatment of peri-implantitis in relation to implant surface type. Data extraction focused on recurrence of peri-implantitis, implant survival, clinical parameters, radiographic outcomes, and the type of surgical approach used (reconstructive vs. non-reconstructive).

Results: Seventeen clinical studies were included. Outcomes varied according to implant surface characteristics. Rough (modified) surfaces were generally associated with a higher risk of recurrence of peri-implantitis and implant loss compared with smooth (machined/turned) surfaces. Reconstructive surgical approaches, especially those involving bone grafts and membranes, demonstrated more favorable outcomes compared with non-reconstructive approaches.

Discussion: Despite observed trends, the certainty of the evidence remains low due to heterogeneity between studies, small sample sizes, and methodological limitations. Further well-designed long-term clinical trials are needed to clarify the role of implant surface characteristics in the long-term success of peri-implantitis surgical treatment.

Systematic Review Registration: PROSPERO (CRD420251129791).

KEYWORDS

peri-implantitis, surgical peri-implantitis treatment, treatment outcome, explantation, implant surface, long-term outcomes, bone loss, implant survival

Impact of Implant Surface Modifications on Long-Term Outcome of Surgical Peri-Implantitis Treatment: A Systematic Review

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Abstract
Peri-implantitis is an inflammatory disease that compromises peri-implant tissues and supporting bone, potentially leading to implant loss. Although several surgical treatment strategies have been proposed, it remains unclear whether implant surface characteristics (smooth vs. rough) influence long-term treatment outcomes.

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1. Introduction

Dental implants have significantly advanced oral rehabilitation, providing highly predictable solutions for tooth replacement. For instance, a recent systematic review reported that long-term prospective studies on dental implants show high survival rates, typically exceeding 90% over 5–10 years and remaining around 78% after imputation at 20 years follow-up. In addition, five retrospective studies with ≥20 years of follow-up reported an implant survival rate of approximately 88%, including multifactorial causes(6).

However, despite the high survival rates, biological complications at implants are rather common. In particular, peri-implantitis, which is characterized by peri-implant mucosal inflammation and progressive bone loss, affects approximately 19.53% of patients and 12.53% of implants, highlighting its relevance in clinical practice (9). As the main etiological factor for peri-implantitis is the oral biofilm, microbial to implant surface interactions seem to play an important role in disease pathogenesis. Indeed, surface modifications (e.g., sandblasting, acid-etching, anodization, etc) aiming in enhancing implant surface bioactivity, substantially impact on microbial colonization and biofilm development (28, 29, 31, 52, 53). Indeed, although the incidence of peri-implantitis seems not to differ between modified and non-modified (i.e., turned) implants in the clinic, progression and severity of peri-implantitis appear linked to implant surface properties; specifically, pre-clinical *in vivo* studies indicate a faster disease progression at modified implants compared with turned implants, as well as differences in disease progression among various modified surfaces (28, 29). Moreover it seems that implant surface characteristics may impact on treatment outcomes both in the short-term but also on the long-term, with implants with a modified surface demonstrating less positive results and higher recurrence rates (30-32).

Despite technological advancements and improved treatment approaches, the impact of implant surface modifications on peri-implantitis outcomes remains unclear. Therefore, this systematic review aims to evaluate whether varying implant surface topographies influence clinical and radiographic outcomes following surgical peri-implantitis treatment in humans. The findings may offer critical insights guiding the selection of implant surface characteristics to enhance treatment efficacy.

2. Materials and methods

Study Design

This review was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was registered in PROSPERO (ID: CRD420251129791.).

Search Strategy

To identify relevant studies, we systematically searched PubMed, Embase, and the Cochrane Library. The search strategy was carried out in English language from database inception for articles published between 2000 to 2025. Two investigators (AZ and PG) independently reviewed the search results and screened the titles and abstracts. Full texts of all potentially eligible studies were obtained. In PubMed, the following search strategy was used: "(Periimplantitis OR peri-implantitis OR peri implantitis OR periimplant OR peri-implant OR peri implant) AND (treatment outcome OR therapy OR surgical treatment OR regenerative OR regeneration OR tissue

regeneration OR reconstructive surgery OR bone graft OR bone substitute OR membranes OR surgical flap OR open flap debridement OR resective OR implantoplasty OR surface decontamination) AND (surface characteristics OR surface roughness OR material characteristics OR titanium surface OR implant types OR implant surfaces OR surface topography OR surface analysis) AND (implant survival OR bone loss OR recurrence OR retreatment OR radiographic stability OR long-term OR 3 years OR follow-up)." This search strategy was adapted to suit the other electronic sources. The reference lists of retrieved articles were also checked to identify additional studies of interest. Any inconsistencies were resolved b consensus with a third investigator (CG). The complete search strategies for all databases are provided in Appendix 2.

Criteria for Considering Studies for This Review

Study design: Randomized controlled trials, prospective studies, retrospective studies, case-control studies, and case series were included. No specific cut-off criteria for sample size were applied, given the limited availability of data. Additionally, two case series with very small sample sizes were included due to their clinical relevance. Eligibility required that included studies explicitly reported the implant surface type(s) of the implants investigated.

Population: Human studies. Patients with osseointegrated dental implants diagnosed with peri-implantitis, treated surgically, with a follow-up period of at least 3 years (or an average ≥3 years).
Intervention: Surgical therapy for peri-implantitis.
Comparator: Different implant surface types, characterized by variations in macro-, micro-, and nano-scale surface roughness, topography, and material composition. Surfaces were categorized as non-modified (i.e turned, smooth, machihed), modified (rough), or mixed (hybrid) , depending on their reported surface characteristics.

Outcomes:
Primary Outcome:

- Percentage of implants with recurrence of peri-implantitis requiring re-treatment or explantation or simply defined as treatment failure by the authors.

Secondary Outcomes:

- Implant loss (due to any reason)
- Disease resolution defined by reduction of probing depth (PD) without bleeding on probing (BOP) or suppuration
- Radiographic bone loss or gain assessed by mean changes in bone levels or percentage of implants with stable bone levels post-treatment
- Mean probing depth (PD) post-treatment

Subgroup synthesis: The outcomes were further stratified based on implant surface types and surgical approach:

1. Turned (machined/non-modified surfaces)
    - a. Non-reconstructive surgical approach
    - b. Reconstructive surgical approach (regardless the technique or materials used)
2. Modified (rough surfaces)
    - a. Non-reconstructive surgical approach

- b. Reconstructive surgical approach (regardless the technique or materials used)

3. Mixed or unspecified surfaces
    - a. Non-reconstructive surgical approach
    - b. Reconstructive surgical approach (regardless the technique or materials used)

Data Collection Two investigators independently extracted key data from the included articles. The inter-rater agreement for study selection was assessed using Cohen's kappa statistics. Inter-rater reliability was assessed using Cohen's kappa statistic on a subset of 20% of studies, yielding a kappa of 0.85, indicating a high level of agreement. Discrepancies were resolved through discussion or consultation with a third reviewer (CG). For each article, we extracted study features (i.e., study design, year of publication, number of enrolled patients), type of intervention, and outcome measures were extracted. Correct data extraction was controlled in a subset of randomly selected studies by the third investigator.

Assessment of Risk of Bias
Two investigators independently appraised the risk of bias of the included studies using the Cochrane Risk of Bias Tool 2.0 (RoB2) for RCTs. For non-RCTs the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool was used. Any inconsistencies were resolved by consensus with a third investigator (CG).

Data Synthesis
Preliminary analyses of available data revealed high heterogeneity, precluding meaningful meta-analysis. Therefore, a narrative synthesis was conducted. These limitations included significant heterogeneity in implant surface types, surgical techniques, and reported outcome measures across studies. To enhance clarity and readability, findings were systematically summarized in tables according to pre-defined outcomes and subgroup analyses.
Data extraction was performed separately for each treatment group within studies containing multiple groups, while data from studies with a single treatment group were extracted accordingly. Results were categorized based on implant surface types and surgical approaches as follows:

1. Turned (machined/non-modified surfaces) a. Non-reconstructive surgical approach b. Reconstructive surgical approach (regardless the technique or materials used)
2. Modified (rough surfaces) a. Non-reconstructive surgical approach b. Reconstructive surgical approach (regardless the technique or materials used)
3. Mixed or unspecified surfaces a. Non-reconstructive surgical approach b. Reconstructive surgical approach (regardless the technique or materials used)

Findings were systematically summarized in tables according to pre-defined outcomes and subgroup analyses to enhance clarity and readability.

Within each treatment group, data were systematically collected on key parameters, including sample size (number of participants and implants), criteria used to define peri-

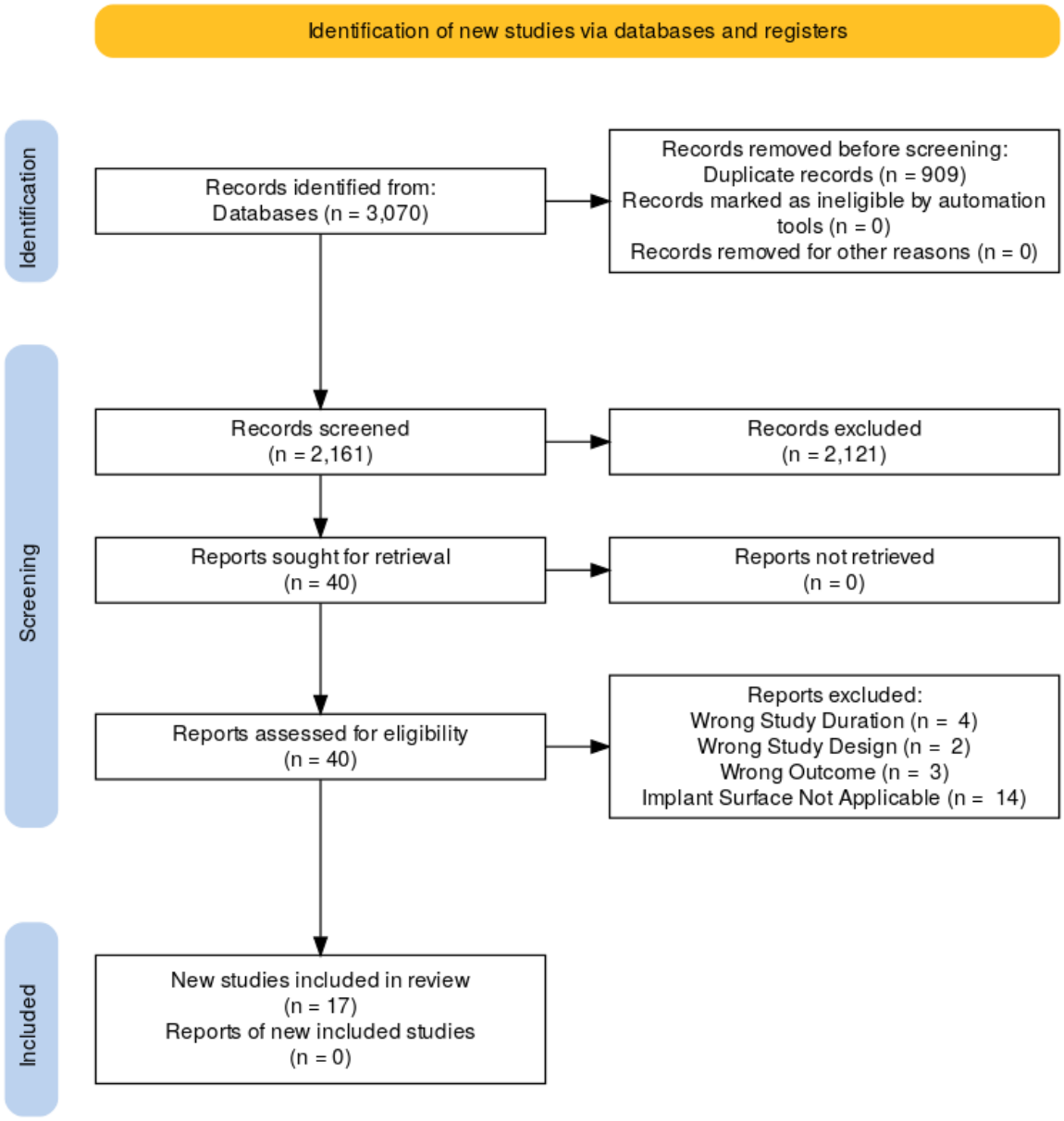
implantitis, type of bone substitute, membrane used (if applicable), follow-up periods, implant system, and implant surface characteristics**.**

3. Results

Study selection

The literature search process is illustrated in the flowchart below (Figure 1). In total, there are 17 studies included in the analysis (30, 32, 54-68). Among them, 8 are prospective cohort studies, 3 are retrospective cohort studies, 1 are randomized controlled trials. The remaining studies include 1 each of the following types: prospective clinical study, retrospective observational study, and prospective case series. A detailed description of the study characteristics can be found in the results in Tables 2a and 2b.

Figure 1. *PRISMA Flow Diagram*



Study populations

Peri-implantitis

Across the 17 studies analyzed, various diagnostic criteria have been employed to identify peri-implantitis, reflecting differences in study designs and clinical considerations (30, 32, 54-68). The most commonly reported diagnostic parameters include probing depth (PD), bleeding on probing (BOP), suppuration, and radiographic evidence of bone loss.

Probing Depth (PD):

A probing depth threshold of ≥6 mm is frequently used as a criterion to identify peri-implantitis, as observed in studies by Carcuac et al. (2020), Romandini et al. (2023), and Roccuzzo et al. (2017, 2020, 2021) (15, 16, 26-28). Other studies, such as Aghazadeh et al. (2022) and Noelken et al. (2023), set a threshold of ≥5 mm, which is similar to the >4 mm threshold considered indicative of disease by Mercado et al. (2018) and Schwarz et al. (2009)(24, 25, 31, 32). This variation highlights differences at diagnosis across studies.

Bleeding on Probing (BOP) and Suppuration:

The presence of BOP and/or suppuration was consistently reported as a diagnostic marker in all studies. It serves as an indicator of ongoing inflammation and peri-implant tissue destruction. Studies such as La Monaca et al. (2018, 2024) and Khoury & Buchmann (2001) emphasize the importance of these clinical signs in combination with radiographic findings for accurate diagnosis (20-22).

Radiographic Bone Loss:

Radiographic evaluation of bone loss is another widely accepted criterion for peri-implantitis diagnosis. The threshold for bone loss varies among studies, with the most commonly reported value being ≥3 mm, as seen in Romandini et al. (2023), and(16). Other studies, including Carcuac et al. (2020) and Aghazadeh et al. (2022), defined progressive bone loss based on post-treatment changes or specific defect characteristics, such as angular defects of ≥3 mm (15, 32). A more conservative threshold of ≥1.8 mm was applied in studies such as Roos-Jansåker et al. (2011, 2014), reflecting the variability in bone loss progression (29, 30).

Variability in Diagnostic Criteria:

Despite a general agreement on the primary diagnostic signs—probing depth, BOP/suppuration, and radiographic bone loss—variability exists in the specific thresholds and additional criteria applied across studies.

A detailed overview of the case definitions used to include patients with peri-implantitis in each study (treatment group) is provided in Table 1.

Table 1: Definitions of periimplantitis

Study	Definition of periimplantitis
Aghazadeh et al., 2022 (32)	Probing pocket depths of at least 5 mm, presence of bleeding on probing and/or suppuration, radiographic bone loss of 2 mm or more from implant placement to screening, and an angular peri-implant bone defect of 3 mm or greater
Carcuac et al., 2020 (15)	Probing pocket depths of 6 mm or more, presence of bleeding on probing, reduced marginal bone level and progressive bone loss greater than 1 mm post-treatment
Deppe et al., 2007 (18)	Probing pocket depths of at least 5 mm, presence of bleeding on probing, radiographic evidence of progressive vertical bone loss, and clinical signs of inflammation
Jemt etal., 2021 (19)	Bone loss exceeding 0.4 mm, mucosal inflammation, presence of plaque and/or suppuration, and radiographic evidence of marginal bone loss
Khoury et al., 2001 (20)	Bone loss of more than 50% of the implant length, augmented probing depths, bleeding on probing, and radiographic evidence of intrabony defects
La Monaca et al., 2018 (21)	Progressive bone loss of 3 mm or more detected on radiographs, the presence of bleeding on probing and/or suppuration, and probing depths of at least 5 mm
La Monaca et al., 2024 (22)	Progressive angular bone loss of at least 3 mm beyond crestal bone level changes, the presence of bleeding on gentle probing and/or suppuration, and implants in function for more than 12 months
Leonhardt et al., 2003 (23)	Marginal bone loss of at least three implant threads compared to baseline radiographs, bleeding on probing and/or suppuration from peri-implant sulci, and microbiological confirmation of peri-implant pathogens
Mercado et al., 2018 (24)	Probing pocket depths exceeding 4 mm, the presence of bleeding on probing and/or suppuration, a minimum radiographic bone loss of 20%, and implants that have been in function for at least 2 years
Noelken et al., 2023 (25)	Probing pocket depths greater than 5 mm, the presence of bleeding on probing and suppuration, and radiographically confirmed bone loss
Roccuzzo et al., 2017 (26)	Probing pocket depths of at least 6 mm, no implant mobility, bleeding on probing and/or suppuration, and radiographic bone loss exceeding three implant threads compared to baseline
Roccuzzo et al., 2020 (27)	Probing pocket depths of 6 mm or greater, the presence of bleeding on probing and/or suppuration, radiographic bone loss beyond crestal changes, and the absence of implant mobility
Roccuzzo et al., 2021 (28)	Probing pocket depths reach or exceed 6 mm, bleeding on probing, radiographic evidence of progressive bone loss, and the presence of pus or inflammation
Romandini et al., 2024 (16)	Probing pocket depths of 6 mm or more, bleeding and/or suppuration on probing, and radiographic evidence of marginal bone loss equal to or greater than 3 mm
Roos-Jansåker et al., 2011 (29)	Radiographic bone loss of at least 1.8 mm following the first year in function, the presence of bleeding and/or pus on probing, and inclusion criteria of non-mobile implants
Roos-Jansåker et al., 2014 (30)	Radiographic bone loss of at least 3 threads (≥1.8 mm), the presence of a vertical defect component, and bleeding on probing and/or suppuration
Schwarz et al., 2009 (31)	Probing pocket depths greater than 4 mm, presence of bleeding on probing and/or suppuration, radiographic evidence of bone loss, and an intrabony defect component of at least 3 mm

Primary Outcome: Recurrence and Treatment Failure
The included studies demonstrated that implant surface characteristics influenced recurrence rates following surgical peri-implantitis treatment. Modified (rough) surfaces consistently showed higher recurrence compared with turned (machined) surfaces. Carcuac et al. (2020) reported an overall recurrence of 44%, with a significantly increased risk for modified surfaces (OR 5.1) (15). Similarly, Romandini et al. (2024) found a retreatment rate of 24.3%. In contrast, studies involving turned surfaces, such as Leonhardt et al. (2003), reported more stable outcomes (23). These findings indicate that surface roughness is a key determinant of recurrence and long-term treatment stability. Studies by Schwarz et al. (2009), Mercado et al. (2018), and Noelken et al. (2023) documented relatively stable outcomes without explicitly reporting significant recurrence rates (24, 25, 31)**.**

Secondary Outcomes
Implant Loss:
Implant loss was more frequent among rough surface implants, especially TPS, with Roccuzzo et al. (2020) reporting loss in 45% of TPS implants (27), and Leonhardt et al. (2003) reporting 27% for turned surfaces (23). SLA surfaces demonstrated better survival than TPS, with 20% vs. 45% loss after 10 years (27). Modified surfaces were identified as a strong predictor of implant loss (HR 4.5)(16). Turned surfaces generally exhibited lower long-term loss risk, around 20%, compared to modified ones (16).. Lower implant loss rates were generally associated with reconstructive surgical approaches, as observed by Noelken et al. (2023, 8.3%) (25) and La Monaca et al. (2024) (22), 8.8%.

Disease Resolution and Probing Depth (PD):
Reconstructive surgery generally improved PD irrespective of surface, but rough surfaces demonstrated greater variability. Mercado et al. (2018) reported PD reduction from 8.9 mm to 3.5 mm on micro-rough implants (24) , while Noelken et al. (2023) achieved PD reduction from 5.05 mm to 3.08 mm in predominantly rough implants(25) identifying disease resolution. Roccuzzo et al. (2017, 2020) observed significant PD improvements for SLA implants compared with TPS (26, 27). Turned implants (Leonhardt et al., 2003) also demonstrated significant PD reduction (23). Conversely, non-reconstructive surgical approaches such as that of Deppe et al. (2007) with predominantly rough surfaces showed initial short-term PD reductions with inconsistent long-term stability (18).

Radiographic Bone Changes:
Bone regeneration outcomes were surface-dependent. Reconstructive procedures around rough implants, particularly SLA, showed consistent bone gain (Roccuzzo et al. 2017: +2.1 mm; 2020: +2.7 mm) (26, 27). TPS implants demonstrated less favorable long-term stability, even with grafting (27). Smooth (turned) surfaces were rarely evaluated in regenerative contexts, limiting conclusions. Khoury & Buchmann (2001) reported substantial bone gain (3.2 mm) on rough implants with autografts (20) , while Roos-Jansåker et al. (2011, 2014) found stable bone gain (1.1–1.6 mm) in predominantly machined implants (29, 30).

Subgroup Analyses

Turned surfaces: Showed moderate long-term stability, but implant loss remained high when treated non-reconstructively (23). Reconstructive data were limited but suggested stable outcomes (29, 30).

Modified (rough) surfaces: Non-reconstructive approaches resulted in high recurrence and implant loss (15, 16). Reconstructive approaches improved outcomes, with SLA surfaces outperforming TPS (26, 27).

Mixed surfaces: Outcomes were heterogeneous. Laser-assisted non-reconstructive therapy demonstrated short-term benefits (Deppe et al. 2007) (18), but Jemt & Eriksson (2021) reported long-term bone loss regardless of surface type (19). Reconstructive treatments showed better results with natural bone mineral combined with a collagen membrane (NBM+CM) compared to nanocrystalline hydroxyapatite (NHA) (31), but surface-specific differences remained underreported. Aghazadeh et al. (2022) reported improved outcomes with xenograft (BDX) usage (32).

The detailed study characteristics and outcomes are presented in Tables 2a and 2b.

Table 2a: Summary of clinical studies evaluating treatments of peri-implantitis: surface types, materials, and outcomes

Author (Year)	Implant Surface	Implant Brand	Patients (initial/follow-up)	Implants (initial/follow-up)	Type of Treatment	Materials Used	Follow-up Period	Surface Impact
Aghazadeh et al. (2022) (32)	Mixed (Turned and medium-rough)	Not explicitly stated, categorized by surface type	45 (AB:22/16, BDX:23/23)	75 (AB:36/25, BDX:39/38)	Reconstructive surgery (autogenous bone, xenograft, collagen membrane)	Autogenous bone, xenograft (Bio-Oss), collagen membrane (OsseoGuard), titanium curettes, hydrogen peroxide, azithromycin, CHX rinse	5 years	No significant difference (turned vs medium-rough surfaces)
Carcuac et al. (2020) (15)	Mixed (modified/non-modified)	Not specified, classified as non-modified/modified	100/73	179/130	Open-flap debridement, surface decontamination, pocket elimination	Systemic antibiotics, local antiseptics	5 years	Modified surfaces higher recurrence risk (OR 5.1, 95% CI: 1.6–16.5)
Deppe et al. (2007) (18)	Mixed (rough predominantly)	IMZ, Frialit-2, Brånemark, Straumann screw-type	32	73 (Conventional:34, Laser:39)	Conventional vs CO_2 laser-assisted (soft tissue resection/augmentation)	CO_2 laser, air-powder abrasive, β-TCP/autogenous bone, Gore-Tex membrane	5 years	Superior outcomes with CO_2 laser in non-reconstructive therapy
Jemt & Eriksson (2021) (19)	Mixed (Turned and moderately rough surfaces)	Brånemark (turned), TiUnite, Astra Tech OsseoSpeed, Lifecore RBM	122 (initially 134, 12 lost)	614/453	Non-reconstructive surgery (mechanical cleaning, osseous recontouring, antibiotics)	Mechanical debridement, hydrogen peroxide 10%, systemic antibiotics	Mean 7.3 years	No significant difference (turned vs moderately rough surfaces)
Khoury & Buchmann (2001) (20)	Rough surfaces	IMZ, Frialit-2 (Friadent GmbH)	25	41	Reconstructive surgery (autogenous bone ± membranes)	Autogenous bone, ePTFE/Bioabsorbable barriers, CHX, citric acid, hydrogen peroxide, systemic antibiotics	3 years	No surface comparison (all rough)
La Monaca et al. (2024) (22)	Rough (TiUnite surface)	Nobel Biocare (Brånemark System, Göteborg)	34/23	34/20	Reconstructive surgery (MDBA, resorbable membrane, chemical/mechanical decontamination)	MDBA (Puros), collagen membrane (Bio-Gide), hydrogen peroxide, CHX solution, tetracycline hydrochloride, systemic antibiotics (Amox/clav,	10 years	All rough (TiUnite); no surface-specific comparison

						Metronidazole)		
La Monaca et al. (2018) (21)	Rough (TiUnite surface)	Nobel Biocare (Brånemark System, Göteborg)	34	34	Reconstructive surgical therapy (MDBA, resorbable collagen membrane, chemical/mechanical decontamination)	MDBA (Puros), resorbable membrane (Bio-Gide), hydrogen peroxide, CHX 0.2%, tetracycline hydrochloride, systemic antibiotics	5 years	All rough (TiUnite); no surface comparison
Leonhardt et al. (2003) (23)	Turned surfaces	Brånemark System (Nobel Biocare)	9	26	Surgical non-reconstructive therapy + systemic antibiotics	Hydrogen peroxide 10%, individualized antibiotics (metronidazole, amoxicillin, tetracycline, ciprofloxacin, clindamycin), CHX rinse	5 years	All turned surfaces; not directly analyzed
Mercado et al. (2018) (24)	Rough (Micro-rough)	Branemark TiUnite (46.66%), Astra Tech (26.66%), Straumann (10%), Others (16.66%)	30	30	Regenerative surgery (DBBMC, EMD, doxycycline, EDTA, ultrasonic scaler)	DBBMC, EMD, doxycycline, EDTA 24%, ultrasonic scaler, chlorhexidine 0.12%	36 months	Not specifically analyzed (micro-rough surfaces)
Noelken et al. (2023) (25)	Mixed (rough predominantly)	Straumann, Ankylos, Brånemark, NobelActive, NobelPerfect, Frialit I, OsseoSpeed, Camlog, ICX	18	24	LAPIDER (laser-assisted regeneration, autogenous bone, CT graft)	Er:YAG laser, autogenous bone chips, doxycycline, CT graft, resorbable sutures	3 years	No direct comparison; rough surfaces only
Roccuzzo et al. (2017) (26)	Rough (SLA and TPS)	Straumann (SLA, TPS)	26/24	26/24	Regenerative surgery (DBBMC, EDTA, CHX)	DBBMC (Bio-Oss Collagen), EDTA 24%, CHX gel 1%, antibiotics (Amoxicillin/clavulanic acid)	7 years	SLA better clinical outcomes than TPS (significant)
Roccuzzo et al. (2020) (27)	Rough (SLA and TPS)	Straumann (SLA, TPS)	26/14	26/14	Regenerative surgery (DBBMC, EDTA, CHX)	DBBMC (Bio-Oss Collagen), EDTA 24%, CHX gel 1%, antibiotics (Amoxicillin/clavulanic acid)	10 years	SLA superior survival/outcomes compared to TPS
Roccuzzo et al. (2021) (28)	Rough (SLA)	Straumann (SLA implants)	75/51	75/64	Reconstructive surgery (DBBMC, EDTA, CHX	DBBMC, EDTA 24%, CHX 1% gel, titanium	5 years	Uniform (all SLA surfaces)

					gel, titanium curettes, connective tissue graft)	curettes, titanium brush, connective tissue graft, systemic antibiotics		
Romandini et al. (2024) (16)	Mixed (Turned and Modified)	Nobel Biocare (74.2%), Astra Tech (18%), Straumann (6.7%), Neoss (1.1%)	149	267	Non-reconstructive surgical therapy (titanium-coated curettes, systemic antibiotics)	Titanium-coated curettes, saline/CHX gauze, selective systemic antibiotics (Amoxicillin)	Mean 7 years (range 1-18 years)	Modified surfaces significantly higher implant loss risk (HR=4.5)
Roos-Jansåker et al. (2011) (29)	Primarily machined, few modified (rough)	Brånemark (majority), Astra Tech (minority)	38/32	65/56	Reconstructive surgery (Algipore ± membrane)	Algipore, Osseoquest membrane, H_2O_2 3%, antibiotics (amoxicillin, metronidazole), CHX 0.1% rinse	3 years	No significant impact reported (mostly machined)
Roos-Jansåker et al. (2014) (30)	Primarily machined, few modified (rough)	Brånemark (majority), Astra Tech (minority)	38/25	Not initially specified/45	Reconstructive surgery (Algipore ± membrane)	Algipore, Osseoquest membrane, H_2O_2 3%, antibiotics (amoxicillin, metronidazole), CHX rinse	5 years	No significant impact (mostly machined surfaces)
Schwarz et al. (2009) (31)	Mixed (machined and rough surfaces)	Brånemark, Camlog, ITI, KSI Bauer Schraube, Zimmer, ZL-Duraplant	22/19	22/19	Regenerative surgery (NBM+CM vs. NHA)	NBM (BioOss), CM (BioGide), NHA (Ostim), plastic curettes, CHX 0.2%	48 months	Surface-specific outcomes not detailed

Table 2b: Comparative outcomes of clinical studies on peri-implantitis treatments: implant surfaces, secondary outcomes, and long-term surface impact

Author (Year)	Implant Loss (%)	Disease Resolution	Radiographic Bone Loss/Gain	Mean PD Post-treatment	Subgroup Analysis (by surface & approach)	Conclusions Surface Impact
Aghazadeh et al. (2022) (32)	AB: 1 fractured, BDX: 1 fractured (both initially)	PD reduction AB: 1.7 mm, BDX: 2.8 mm at 5 years	AB: -0.7 mm (loss), BDX: +1.6 mm (gain)	AB: PD reduced by 1.7 mm, BDX: by 2.8 mm at 5 years	BDX superior to AB; reconstructive approach only, no surface-specific outcomes detailed	BDX superior to AB; supportive maintenance every 3 months emphasized. No significant difference (turned vs medium-rough surfaces)
Carcuac et al. (2020) (15)	20.8%	Not explicitly combined; PD≥6mm at 1 year = increased recurrence (OR 7.4)	Stable from year 1; further loss >1mm in 13.1%	5.0 mm (stable from year 1 at 4.9 mm)	Non-modified: 17% recurrence, Modified: 52% recurrence; no explicit surgical subgroup	Surgical treatment effective, but 44% recurrence; modified surfaces, deep residual PD major risk factors. Modified surfaces higher recurrence risk (OR 5.1, 95% CI: 1.6–16.5)
Deppe et al. (2007) (18)	17.8%	Superior PD reduction laser (1.0-2.4 mm at 4 months)	Laser better short-term bone gain; long-term similar outcomes	Laser: 1.0-2.4 mm, Conventional: 2.4-7.9 mm (long-term)	Laser superior in soft tissue resection; similar in augmentation	Laser beneficial in non-reconstructive procedures; similar long-term results in augmentation. Superior outcomes with CO_2 laser in non-reconstructive therapy
Jemt & Eriksson (2021) (19)	16.7%	Not explicitly reported; primarily bone-level outcomes	Increased bone loss post-treatment (0.26 mm/year)	PD not explicitly reported	No significant differences between surface types; increased bone loss post-treatment	Surgical treatment ineffective long-term; bone loss accelerated post-treatment, edentulous worse prognosis. No significant difference (turned vs moderately

						rough surfaces)
Khoury & Buchmann (2001) (20)	0% explicitly reported	PD improvement: Bone alone 8.0→2.9 mm, worse with membranes (7.7→5.1 mm)	Significant bone gain (bone alone 3.2 mm, membranes lower)	Bone alone: 2.9 mm; Non-resorbable: 2.8 mm; Bioabsorbable: 5.1 mm	Bone alone superior; membranes caused high complications	Bone grafting alone effective; membranes did not enhance outcomes, increased complications. No surface comparison (all rough)
La Monaca et al. (2024) (22)	8.8%	Composite success: 53%, PD significantly reduced to 2.95 mm at 10 years	Mean bone gain: 1.07 mm (stable 10 years)	Reduced from 6.33 mm to 2.95 mm at 10 years	Reconstructive approach only; stable bone gain, PD improvement, composite success 53%	Long-term reconstructive therapy stable; supportive therapy crucial, defect severity not significant. All rough (TiUnite); no surface-specific comparison
La Monaca et al. (2018) (21)	0%	PD reduced initially, increased by 5 years (4.62 mm, nonsignificant from baseline)	Initial significant bone gain (1 year), gradual loss by 5 years	4.62 mm at 5 years (from 5.93 mm baseline)	Reconstructive surgery initially effective, unstable outcomes long-term	Initial benefits lost over time, no implants lost; unpredictable outcomes long-term. All rough (TiUnite); no surface comparison
Leonhardt et al. (2003) (23)	27%	Significant reduction plaque (100%→11%) and bleeding (100%→5%)	Stable in 9 implants, gain in 6 implants, loss in 4 implants	Not explicitly reported; clinical signs significantly improved	Non-reconstructive approach; success 58%, significant clinical improvements	Limited success (58%); smoking negatively impacted outcomes. All rough surfaces; not directly analyzed
Mercado et al. (2018) (24)	0%	Mean PD from 8.9 mm to 3.5 mm; BOP/suppuration from 100% to 20%	Bone gain (6.92 mm to 2.60 mm mean bone loss at 36 months)	Reduced from 8.9 mm to 3.5 mm at 36 months	Regenerative (reconstructive) approach only, significant PD reduction and bone gain; success 56.7%	Regenerative treatment effective (56.7% success); regular supportive therapy critical. Not specifically analyzed (micro-rough surfaces)
Noelken et al. (2023) (25)	8.3%	PD significantly reduced (5.05 to 3.08 mm),	Significant bone gain (Interproximal 3.1 mm, Buccal 3.5	Final PD 3.08 mm	LAPIDER effective for severe defects; significant	LAPIDER provided substantial regeneration and aesthetic

		BOP 100% to 36.4%	mm, Lingual 1.46 mm)		hard/soft tissue regeneration	improvements. No direct comparison; rough surfaces only
Roccuzzo et al. (2017) (26)	16.7% overall (SLA:16.7%, TPS:28.6%)	Significant PD reduction, SLA (3.2 mm), TPS (3.4 mm); BOP SLA (7.5%), TPS (30%)	Significant bone fill SLA (2.1 mm gain), TPS (2.0 mm gain)	SLA: 3.2 mm, TPS: 3.4 mm	Regenerative approach better for SLA vs. TPS implants	DBBMC effective; SLA surfaces significantly better clinical outcomes than TPS.
Roccuzzo et al. (2020) (27)	SLA:20%, TPS:45%	Significant PD reduction SLA (3.2 mm), TPS (3.4 mm); BOP significantly reduced	SLA substantial gain (2.7 mm), TPS moderate gain (2.0 mm)	SLA: 3.2 mm, TPS: 3.5 mm	SLA implants superior long-term survival/outcomes	DBBMC stable outcomes; SLA significantly better than TPS long-term
Roccuzzo et al. (2021) (28)	17%	PD 6.89 mm to 4.06 mm; BOP 70.6% to 17.2%	Substantial bone fill; no numeric specifics reported	Reduced from 6.89 mm to 4.06 mm at 5 years	Reconstructive approach only; SLA implants only, survival 80%, success 45.3%, significant PD reduction	Reconstructive protocol effective; adherence to supportive therapy significantly improves outcomes.
Romandini et al. (2024) (16)	19.9%	Not explicitly; high recurrence, retreatment common (24.3%)	Mean additional bone loss: 0.97 mm; >1 mm loss in 42.4%	Not explicitly detailed post-treatment; baseline deepest PD 7.8 mm	Turned surfaces significantly better prognosis; modified surfaces high loss risk (HR=4.5)	High recurrence; surface type crucial predictor, severe baseline bone loss/suppuration increase loss risk. Modified surfaces significantly higher implant loss risk (HR=4.5)
Roos-Jansåker et al. (2011) (29)	0%	Clinical measures not explicitly detailed	Stable bone fill: bone graft (1.3 mm), membrane (1.6 mm), no significant difference	Not explicitly reported	Stable outcomes, no significant membrane advantage	Algipore ± membrane effective, stable bone fill, membrane no additional advantage. No significant impact reported (mostly machined)
Roos-Jansåker et al. (2014) (30)	0%	PD reduction: 3.0-3.3 mm, BOP significantly reduced	Bone gain stable: 1.1-1.3 mm, no significant membrane advantage	2.6-2.7 mm	No significant advantage with membrane	Stable results; membrane no additional advantage over bone substitute alone.

						No significant impact (mostly machined surfaces).
Schwarz et al. (2009) (31)	0% explicitly reported (1 discontinued)	NBM+CM: PD reduction 2.5 mm, NHA: 1.1 mm, BOP significantly reduced	NBM+CM superior bone fill compared to NHA	NBM+CM: 4.6 mm, NHA: 5.8 mm	NBM+CM significantly better than NHA	NBM+CM superior long-term clinical/radiographic outcomes vs NHA. Surface-specific outcomes not detailed.

Combined Legend for Tables 2a and 2b
AB, Autogenous Bone;
BDX, Bovine-derived Xenograft;
BOP, Bleeding on Probing;
CAL, Clinical Attachment Level;
CHX, Chlorhexidine;
CI, Confidence Interval;
CM, Collagen Membrane;
CO_2, Carbon dioxide;
CT, Connective Tissue;
DBBMC, Deproteinized Bovine Bone Mineral with Collagen;
DH, Defect Height;
EMD, Enamel Matrix Derivative;
ePTFE, expanded Polytetrafluoroethylene;
H_2O_2, Hydrogen Peroxide;
HR, Hazard Ratio;
LAPIDER, Laser-Assisted Peri-Implant Defect Regeneration;
MBL, Marginal Bone Level;
MDBA, Mineralized Dehydrated Bone Allograft;
NBM, Natural Bone Mineral;
NHA, Nanocrystalline Hydroxyapatite;
OR, Odds Ratio;
PD, Probing Depth;
P-IS, Peri-implantitis Surgery;
SLA, Sandblasted Large grit Acid-etched;
SOP, Suppuration on Probing;
TPS, Titanium Plasma-Sprayed;
β-TCP, Beta-tricalcium phosphate.

Risk of bias

The risk of bias assessment for the 17 included studies highlights several concerns across different domains.

The RCT (Schwarz 2009) had some concerns(31).

Among the non-randomized studies, serious risk of bias was frequently noted in selection of participants (e.g., Aghazadeh 2022, Carcuac 2020, La Monaca 2024) (15, 17, 22)and missing data (e.g., Roccuzzo 2020, Romandini 2024, Roos-Jansaker 2014) (16, 27, 30). However, intervention classification and reporting of results were generally at low risk across studies. Confounding and deviations from interventions were rated as moderate risk in most cases.

Ten studies were judged to have a serious overall bias, primarily due to participant selection and missing data. The remaining studies had a moderate overall bias, with issues mainly related to confounding and missing data.

Certainty of evidence for the main outcomes was assessed using the GRADE approach and is presented in Supplementary Table S1. Overall, the certainty was judged to be very low to low across all outcomes, primarily due to serious risk of bias, high heterogeneity of diagnostic criteria and outcome definitions, small sample sizes, and imprecision of effect estimates.

Table 3a: Risk of bias assessment for RCTs: RoB 2 risk of bias assessment

Study	Bias arising from the randomization process	Bias due to deviations from intended interventions	Bias due to missing outcome data	Bias in measurement of the outcome	Bias in selection of the reported result	Overall bias
Schwarz 2009 (31)	Low	Low	Some concerns	Low	Low	Some concerns

Table 3b: Risk of bias assessment for non- RCTs: ROBINS-i risk of bias assessment

Study	Bias due to confounding	Bias in selection of participants into the study	Bias in classification of interventions	Bias due to deviations from intended interventions	Bias due to missing data	Bias in measurement of outcomes	Bias in selection of reported results	Overall bias
Aghazadeh 2022 (32)	Moderate	Serious	Low	Moderate	Serious	Moderate	Low	Serious
Carcuac 2020 (15)	Moderate	Serious	Low	Moderate	High	Low	Low	Serious
Deppe 2007 (18)	Moderate	Moderate	Low	Moderate	Serious	Moderate	Low	Serious
Jemt et al 2021 (19)	Moderate	Serious	Low	Moderate	Serious	Moderate	Low	Serious
Khoury 2001 (20)	Serious	Low	Moderate	Moderate	Low	Moderate	Low	Moderate
La Monaca 2018 (21)	Moderate	Moderate	Low	Moderate	Serious	Low	Low	Moderate
La Monaca 2024 (22)	Serious	Serious	Low	Moderate	Serious	Moderate	Low	Serious
Leonhardt 2003 (23)	Moderate	Low	Low	Moderate	Low	Moderate	Low	Moderate
Mercado 2018 (24)	Moderate	Low	Low	Moderate	Low	Low	Low	Moderate
Noelken 2023 (25)	Moderate	Moderate	Low	Moderate	Serious	Moderate	Low	Moderate
Roccuzzo 2017 (26)	Moderate	Moderate	Low	Moderate	Moderate	Low	Low	Moderate

Roccuzzo 2020 (27)	Moderate	Serious	Low	Moderate	Serious	Low	Low	Serious
Roccuzzo 2021 (28)	Moderate	Serious	Low	Moderate	Serious	Moderate	Low	Serious
Romandini 2024 (16)	Moderate	Serious	Low	Moderate	Serious	Moderate	Low	Serious
Roos-Jansaker 2011 (29)	Moderate	Serious	Low	Moderate	Serious	Low	Low	Serious
Roos-Jansaker 2014 (30)	Moderate	Serious	Low	Moderate	Serious	Low	Low	Serious

4. Discussion

This systematic review aimed to evaluate the impact of implant surface characteristics on the long-term outcomes of surgical treatment of peri-implantitis. The main findings indicate that modified (rough) surfaces are consistently associated with higher recurrence and implant loss compared with turned (machined) surfaces. Within rough surfaces, SLA implants achieved more favorable outcomes than TPS, particularly in reconstructive contexts (15, 16, 26-28). In contrast, smooth implants demonstrated comparatively lower recurrence (23). These results underscore that implant surface topography can be a determinant of surgical treatment prognosis.

The effectiveness of peri-implantitis surgery is influenced by both treatment modality and implant surface. For non-regenerative procedures, modified surfaces were repeatedly associated with worse outcomes: Carcuac et al. (2020) reported a 44% recurrence rate with rough implants (15), while Romandini et al. (2023) identified modified surfaces such as TiUnite and SLA as predictors of implant loss (16). In contrast, turned surfaces showed more stable disease suppression (23).
For regenerative approaches, implant surface also played a key role. SLA implants demonstrated favorable long-term bone gain and PD reduction (26-28), whereas TPS implants performed poorly even when grafting was applied (27). Although smooth implants were less frequently studied in regenerative contexts, available evidence suggests they may perform adequately when combined with supportive therapy (29, 30).

Bone regeneration outcomes differed substantially according to surface characteristics. Greater bone fill was generally reported around rough surfaces when grafting materials were used. Khoury and Buchmann (2001) observed a 2.4 mm gain at 12 months using autogenous grafts on rough implants (20). Roccuzzo et al. (2017, 2020) reported significant defect reduction with xenografts, particularly in SLA implants, while TPS implants showed limited stability (26, 27). Comparable results with alloplastic materials were also noted (33, 34). However, bone regeneration around smooth surfaces was less favorable: Roos-Jansåker et al. (2014) reported limited improvement with alloplastic grafts (30). Thus, while rough implants may predispose to recurrence, they also appear to support more pronounced bone regeneration after reconstructive procedures.

This paradox may be explained by surface-related biology. Rough surfaces are harder to decontaminate and accumulate more plaque (35, 36), yet they may stabilize the

coagulum and promote defect fill (37). Accordingly, radiographic bone gain does not necessarily correspond to re-osseointegration, as several animal studies identified connective tissue interposition rather than true reattachment (38-40).

The role of membranes in guided bone regeneration (GBR) has also been linked to implant surfaces. Khoury et al. (2001) showed greater bone gain with non-resorbable membranes around rough implants (20), while Deppe et al. (2007) observed comparable results with resorbable membranes (18). These data suggest that both membrane type and surface roughness influence regenerative outcomes. Furthermore, clinical studies and experimental models in dogs indicate that rough surfaces generally achieve greater defect fill than smooth surfaces under GBR conditions (37).

Surface characteristics may also impact soft tissue attachment. Excessively smooth surfaces can impair mucosal adhesion, as Quirynen et al. (1996) observed attachment loss on polished abutments compared with stable CAL around commercially available surfaces (41). Other studies support that maintaining a certain degree of roughness enhances soft tissue sealing (42). These findings provide a biological explanation for the improved clinical outcomes of rough implants after GBR, despite their higher susceptibility to recurrence.

Interpretation of the evidence is complicated by considerable heterogeneity. Defect morphology influences outcomes, with narrower defects showing better results (17, 43), yet most studies failed to provide detailed descriptions, limiting cross-study comparisons. Moreover, peri-implantitis definitions varied widely: Roccuzzo et al. (2017) required ≥6 mm PD and bone loss exceeding three implant threads (26), while Mercado et al. (2018) used ≥4 mm PD and ≥20% radiographic bone loss (24). Measurement variability further complicates interpretation (44). Such inconsistencies directly affect assessment of surface-related outcomes and hinder robust comparisons across studies.

This review is limited by the substantial heterogeneity among the included studies, particularly in peri-implantitis diagnostic criteria, defect morphology, surgical techniques, and outcome measures. Most studies were small in size, lacked standardized definitions, and many were judged to have a serious overall risk of bias, especially in participant selection and missing data. Confounding variables were insufficiently controlled, further reducing certainty. Furthermore, the restriction to English-language studies may have introduced language bias, potentially leading to omission of relevant non-English publications. Applying the GRADE framework, the certainty of the available evidence was rated as very low to low for all main outcomes, reflecting methodological shortcomings and heterogeneity among the included studies. These limitations restrict the generalizability of the findings and reinforce the need for well-designed, adequately powered randomized controlled trials with standardized definitions and longer follow-up.

Conclusion

The effectiveness of peri-implantitis surgery is influenced by implant surface characteristics and treatment modality. Modified surfaces are generally more prone to recurrence and implant loss, with SLA implants performing better than TPS, while turned surfaces appear less susceptible but remain insufficiently studied in regenerative

contexts. Reconstructive approaches combined with supportive care consistently provide the most favorable outcomes. Given the very low to low certainty of the evidence with heterogenous results, current findings should be interpreted with caution, and well-designed long-term randomized trials with standardized definitions and consistent surface classifications are urgently needed. Future trials should adopt standardized outcome definitions (e.g., PD thresholds, BOP, radiographic bone loss criteria) to allow comparability across studies. Research should focus on RCTs directly comparing surface types, long-term follow-up, and adjustment for confounding factors such as defect morphology and maintenance compliance. Addressing these gaps will clarify the role of implant surface modifications.

Clinical Implications:
When planning peri-implantitis surgery, implant surface characteristics should be taken into account, but they must not be considered in isolation. Evidence indicates that reconstructive approaches yield more reliable outcomes than non-reconstructive ones, particularly for rough implants, with SLA surfaces performing more favorably than TPS. Turned (machined) surfaces appear less prone to recurrence, although data on regenerative protocols remain scarce. These observations suggest that implant surface may influence prognosis, yet it represents only one part of a complex clinical picture. Patient-related risk factors (such as smoking, systemic conditions, low compliance and/or adherence to supportive care) exert a profound effect on long-term success and may outweigh surface-related differences. Surgical decision-making should therefore be individualized, integrating implant surface type, defect morphology, patient risk profile, and anticipated compliance. The use of biomaterials and barrier membranes may enhance regenerative outcomes around rough implants, but clinicians should be cautious, as radiographic bone gain does not necessarily reflect true re-osseointegration, and complete defect resolution is rarely achievable.
Nevertheless, these clinical implications must be interpreted with caution. The available evidence is heterogeneous, often based on small studies with differing peri-implantitis definitions, inconsistent outcome measures, and a serious overall risk of bias. The evidence was rated as very low to low for all main outcomes. This means that while current data can guide clinical choices, they cannot provide definitive recommendations.

5. Apendix

Appendix 1 –excluded studies

Authors and Date	Study Title	Reason for Exclusion
Afrashtehfar et al. 2024 (45)	Guided bone regeneration improves defect fill and reconstructive outcomes in 3-wall peri-implantitis defects	Implant type not taken into consideration
Astolfi et al. 2021 (46)	Influence of removing or leaving the prosthesis after regenerative surgery in peri-implant defects: retrospective study: 32 clinical cases with 2 to 8 years of follow-up	Outcomes reported not correlated to implant type
Behneke et al. 2000 (47)	Treatment of peri-implantitis defects with autogenous bone grafts: six-month to 3-year results of a prospective study in 17 patients	Implant type not taken into consideration
Berglundh 2018 (48)	Long- term outcome of surgical treatment of periimplantitis. A 2-11-year retrospective study	Minimum study duration less than 3 years
Bianchini et al. 2020 (49)	Implantoplasty enhancing peri-implant bone stability over a 3-year follow-up: a case series	Implant type not taken into consideration
Bianchini et al. (2024) (50)	Clinical and radiographic outcomes of resective surgery with adjunctive implantoplasty over a 6- to 11-year follow-up: a case series	Implants treated with implantoplasty, which creates a modified surface texture differing from the original implant surface
Carcuac et al. 2016 (51)	Adjunctive systemic and local antimicrobial therapy in the surgical treatment of peri-implantitis: a randomized controlled clinical trial	Study duration less than 3 years
Chiang et al. 2024 (52)	Operating microscope-assisted reconstructive strategy for peri-implantitis: A case series report	Implant type not taken into consideration
Cortellini et al. 2021 (53)	Papilla preservation and minimally invasive surgery for the treatment of peri-implant osseous defects. Clinical and radiographic outcomes of a 5-year retrospective study	Implant type not taken into consideration
Froum et al. 2012 (54)	Successful management of peri-implantitis with a regenerative approach: a consecutive series of 51 treated implants with 3- to 7.5-year follow-up	Outcomes mentioned not correlated to implant surfaces
Froum et al. 2015 (55)	A regenerative approach to the successful treatment of peri-implantitis: a consecutive series of 170 implants in 100 patients with 2- to 10-year follow-up	Implant type not taken into consideration
Khayat et al. 2024 (56)	Bone regeneration following implantoplasty: a retrospective cohort study with long-term radiographic assessment	Implant type not taken into consideration
Lombardo et al. 2019 (57)	Successful management of peri-implantitis around short and ultrashort single-crown implants: a case series with a 3-year follow-up	Implant type not taken into consideration
Monje et al. 2022 (58)	Principles of combined surgical therapy for the management of peri-implantitis	Incorrect study design
Parma-Benfenati et al. 2020 (59)	Long-term outcome of surgical regenerative treatment of peri-implantitis: a 2- to 21-year retrospective evaluation	Study duration less than 3 years (varied for 2 to 21 years)
Renvert et al. 2012 (60)	Surgical therapy for the control of peri-implantitis	Incorrect study design
Renvert et al 2024 (61)	The efficacy of reconstructive therapy in the surgical management of peri-implantitis: A 3-year follow-up of a randomized clinical trial	Implant type not taken into consideration
Sarmiento et al. 2018 (62)	Surgical alternatives for treating peri-implantitis	Implant type not taken into consideration
Schwarz et al. 2015 (63)	Reentry after combined surgical resective and regenerative therapy of advanced peri-implantitis: a retrospective analysis of five cases	Implant type not taken into consideration
Schwarz et al. 2014 (64)	Combined surgical therapy of advanced peri-implantitis lesions with concomitant soft tissue volume augmentation. A case series	Study duration less than 3 years

Schwarz et al. 2013 (65)	Four-year follow-up of combined surgical therapy of advanced peri-implantitis evaluating two methods of surface decontamination	Implants treated with implantoplasty, which creates a modified surface texture differing from the original implant surface
Schwarz et al. 2017 (66)	Combined surgical therapy of advanced peri-implantitis evaluating two methods of surface decontamination: a 7-year follow-up observation	Implants treated with implantoplasty, which creates a modified surface texture differing from the original implant surface
Wang et al. 2021 (67)	Laser-assisted regenerative surgical therapy for peri-implantitis: A randomized controlled clinical trial	Study duration less than 3 years

Appendix 2 – Full Search Strategies

Database	Search Strategy
PubMed (MEDLINE via PubMed)	(Periimplantitis OR peri-implantitis OR peri implantitis OR periimplant OR peri-implant OR peri implant) AND (treatment outcome OR therapy OR surgical treatment OR regenerative OR regeneration OR tissue regeneration OR reconstructive surgery OR bone graft OR bone substitute OR membranes OR surgical flap OR open flap debridement OR resective OR implantoplasty OR surface decontamination) AND (surface characteristics OR surface roughness OR material characteristics OR titanium surface OR implant types OR implant surfaces OR surface topography OR surface analysis) AND (implant survival OR bone loss OR recurrence OR retreatment OR radiographic stability OR long-term OR 3 years OR follow-up)
Embase	('periimplantitis'/exp OR periimplantitis OR 'peri-implantitis' OR 'peri implantitis' OR periimplant OR 'peri-implant' OR 'peri implant') AND ('treatment outcome'/exp OR therapy OR 'surgical treatment'/exp OR 'regenerative therapy'/exp OR regeneration OR 'tissue regeneration' OR 'reconstructive surgery'/exp OR 'bone graft'/exp OR 'bone substitute'/exp OR membranes OR 'surgical flap' OR 'open flap debridement' OR resective OR implantoplasty OR 'surface decontamination') AND ('surface property'/exp OR 'surface roughness'/exp OR 'material property'/exp OR 'titanium surface' OR 'implant type'/exp OR 'implant surface'/exp OR 'surface topography'/exp OR 'surface analysis') AND ('dental implant survival'/exp OR 'bone loss'/exp OR recurrence OR retreatment OR 'radiographic stability' OR 'long term' OR '3 years' OR 'follow-up')
Cochrane Library	(periimplantitis OR "peri-implantitis" OR "peri implantitis" OR periimplant OR "peri-implant" OR "peri implant") AND ("treatment outcome" OR therapy OR "surgical treatment" OR regenerative OR regeneration OR "tissue regeneration" OR "reconstructive surgery" OR "bone graft" OR "bone substitute" OR membranes OR "surgical flap" OR "open flap debridement" OR resective OR implantoplasty OR "surface decontamination") AND ("surface characteristics" OR "surface roughness" OR "material characteristics" OR "titanium surface" OR "implant types" OR "implant surfaces" OR "surface topography" OR "surface analysis") AND ("implant survival" OR "bone loss" OR recurrence OR retreatment OR "radiographic stability" OR "long term" OR "3 years" OR "follow-up")

References

1. Albrektsson T, Wennerberg A. On osseointegration in relation to implant surfaces. Clin Implant Dent Relat Res. 2019;21 Suppl 1:4-7.
2. Rupp F, Liang L, Geis-Gerstorfer J, Scheideler L, Hüttig F. Surface characteristics of dental implants: A review. Dent Mater. 2018;34(1):40-57.
3. Shayeb MA, Elfadil S, Abutayyem H, Shqaidef A, Marrapodi MM, Cicciù M, et al. Bioactive surface modifications on dental implants: a systematic review and meta-analysis of osseointegration and longevity. Clin Oral Investig. 2024;28(11):592.
4. Souza JCM, Sordi MB, Kanazawa M, Ravindran S, Henriques B, Silva FS, et al. Nano-scale modification of titanium implant surfaces to enhance osseointegration. Acta Biomater. 2019;94:112-31.
5. Matos GRM. Surface Roughness of Dental Implant and Osseointegration. J Maxillofac Oral Surg. 2021;20(1):1-4.
6. Romero-Serrano M, Romero-Ruiz MM, Herrero-Climent M, Rios-Carrasco B, Gil-Mur J. Correlation between Implant Surface Roughness and Implant Stability: A Systematic Review. Dent J (Basel). 2024;12(9).
7. Kupka JR, König J, Al-Nawas B, Sagheb K, Schiegnitz E. How far can we go? A 20-year meta-analysis of dental implant survival rates. Clin Oral Investig. 2024;28(10):541.
8. Renvert S, Persson GR, Pirih FQ, Camargo PM. Peri-implant health, peri-implant mucositis, and peri-implantitis: Case definitions and diagnostic considerations. J Periodontol. 2018;89 Suppl 1:S304-s12.
9. Diaz P, Gonzalo E, Villagra LJG, Miegimolle B, Suarez MJ. What is the prevalence of peri-implantitis? A systematic review and meta-analysis. BMC Oral Health. 2022;22(1):449.
10. Hussein A, Shah M, Atieh MA, Alhimairi S, Amir-Rad F, Elbishari H. Influence of Implant Surfaces on Peri-Implant Diseases – A Systematic Review and Meta-Analysis. Int Dent J. 2025;75(1):75-85.
11. Stavropoulos A, Bertl K, Winning L, Polyzois I. What is the influence of implant surface characteristics and/or implant material on the incidence and progression of peri-implantitis? A systematic literature review. Clin Oral Implants Res. 2021;32 Suppl 21:203-29.
12. Garaicoa-Pazmino C, Lin GH, Alkandery A, Parra-Carrasquer C, Suárez-López Del Amo F. Influence of implant surface characteristics on the initiation, progression and treatment outcomes of peri-implantitis: A systematic review and meta-analysis based on animal model studies. Int J Oral Implantol (Berl). 2021;14(4):367-82.
13. Vernon JJ, Raïf EM, Aw J, Attenborough E, Jha A, Do T. Dental implant surfaces and their interaction with the oral microbiome. Dentistry Review. 2022;2(4):100060.
14. Wassmann T, Kreis S, Behr M, Buergers R. The influence of surface texture and wettability on initial bacterial adhesion on titanium and zirconium oxide dental implants. International Journal of Implant Dentistry. 2017;3(1):32.
15. Carcuac O, Derks J, Abrahamsson I, Wennström JL, Berglundh T. Risk for recurrence of disease following surgical therapy of peri-implantitis-A prospective longitudinal study. Clin Oral Implants Res. 2020;31(11):1072-7.

16. Romandini M, Bougas K, Alibegovic L, Hosseini S, Carcuac O, Berglundh T, et al. Long-term outcomes and prognostic factors of surgical treatment of peri-implantitis - A retrospective study. Clin Oral Implants Res. 2024;35(3):321-9.
17. Aghazadeh A, Persson GR, Renvert S. Impact of bone defect morphology on the outcome of reconstructive treatment of peri-implantitis. International Journal of Implant Dentistry. 2020;6.
18. Deppe H, Horch HH, Neff A. Conventional versus CO2 laser-assisted treatment of peri-implant defects with the concomitant use of pure-phase beta-tricalcium phosphate: a 5-year clinical report. Int J Oral Maxillofac Implants. 2007;22(1):79-86.
19. Jemt T, Eriksson J. Bone Loss Before and After Peri-implantitis Surgery: A 7-Year Retrospective Observational Study. Int J Oral Maxillofac Implants. 2021;36(6):1199-210.
20. Khoury F, Buchmann R. Surgical therapy of peri-implant disease: a 3-year follow-up study of cases treated with 3 different techniques of bone regeneration. J Periodontol. 2001;72(11):1498-508.
21. La Monaca G, Pranno N, Annibali S, Cristalli MP, Polimeni A. Clinical and radiographic outcomes of a surgical reconstructive approach in the treatment of peri-implantitis lesions: A 5-year prospective case series. Clin Oral Implants Res. 2018;29(10):1025-37.
22. La Monaca G, Pranno N, Annibali S, Polimeni A, Cristalli MP. A 10-Year Follow-Up of Reconstructive Treatment of Peri-Implantitis Using Mineralized Dehydrated Allograft and Resorbable Membrane: A Retrospective Case Series. Clin Oral Implants Res. 2024.
23. Leonhardt A, Dahlén G, Renvert S. Five-year clinical, microbiological, and radiological outcome following treatment of peri-implantitis in man. J Periodontol. 2003;74(10):1415-22.
24. Mercado F, Hamlet S, Ivanovski S. Regenerative surgical therapy for peri-implantitis using deproteinized bovine bone mineral with 10% collagen, enamel matrix derivative and Doxycycline-A prospective 3-year cohort study. Clin Oral Implants Res. 2018;29(6):583-91.
25. Noelken R, Westphal L, Schiegnitz E, Al-Nawas B. Hard and soft tissue regeneration of severe peri-implantitis defects with the laser-assisted peri-implant defect regeneration technique: 3-year results. Int J Implant Dent. 2023;9(1):3.
26. Roccuzzo M, Pittoni D, Roccuzzo A, Charrier L, Dalmasso P. Surgical treatment of peri-implantitis intrabony lesions by means of deproteinized bovine bone mineral with 10% collagen: 7-year-results. Clin Oral Implants Res. 2017;28(12):1577-83.
27. Roccuzzo M, Fierravanti L, Pittoni D, Dalmasso P, Roccuzzo A. Implant survival after surgical treatment of peri-implantitis lesions by means of deproteinized bovine bone mineral with 10% collagen: 10-year results from a prospective study. Clin Oral Implants Res. 2020;31(8):768-76.
28. Roccuzzo M, Mirra D, Pittoni D, Ramieri G, Roccuzzo A. Reconstructive treatment of peri-implantitis infrabony defects of various configurations: 5-year survival and success. Clin Oral Implants Res. 2021;32(10):1209-17.
29. Roos-Jansåker AM, Lindahl C, Persson GR, Renvert S. Long-term stability of surgical bone regenerative procedures of peri-implantitis lesions in a prospective case-control study over 3 years. J Clin Periodontol. 2011;38(6):590-7.

30. Roos-Jansåker AM, Persson GR, Lindahl C, Renvert S. Surgical treatment of peri-implantitis using a bone substitute with or without a resorbable membrane: a 5-year follow-up. J Clin Periodontol. 2014;41(11):1108-14.
31. Schwarz F, Sahm N, Bieling K, Becker J. Surgical regenerative treatment of peri-implantitis lesions using a nanocrystalline hydroxyapatite or a natural bone mineral in combination with a collagen membrane: a four-year clinical follow-up report. J Clin Periodontol. 2009;36(9):807-14.
32. Aghazadeh A, Persson GR, Stavropoulos A, Renvert S. Reconstructive treatment of peri-implant defects-Results after three and five years. Clin Oral Implants Res. 2022;33(11):1114-24.
33. Wohlfahrt JC, Lyngstadaas SP, Rønold HJ, Saxegaard E, Ellingsen JE, Karlsson S, et al. Porous titanium granules in the surgical treatment of peri-implant osseous defects: a randomized clinical trial. Int J Oral Maxillofac Implants. 2012;27(2):401-10.
34. Roccuzzo M, Bonino F, Bonino L, Dalmasso P. Surgical therapy of peri-implantitis lesions by means of a bovine-derived xenograft: comparative results of a prospective study on two different implant surfaces. J Clin Periodontol. 2011;38(8):738-45.
35. Subramani K, Jung RE, Molenberg A, Hammerle CH. Biofilm on dental implants: a review of the literature. Int J Oral Maxillofac Implants. 2009;24(4):616-26.
36. Saulacic N, Schaller B. Prevalence of Peri-Implantitis in Implants with Turned and Rough Surfaces: a Systematic Review. J Oral Maxillofac Res. 2019;10(1):e1.
37. Persson LG, Berglundh T, Lindhe J, Sennerby L. Re-osseointegration after treatment of peri-implantitis at different implant surfaces. An experimental study in the dog. Clin Oral Implants Res. 2001;12(6):595-603.
38. Persson LG, Araújo MG, Berglundh T, Gröndahl K, Lindhe J. Resolution of peri-implantitis following treatment. An experimental study in the dog. Clin Oral Implants Res. 1999;10(3):195-203.
39. Schwarz F, Jepsen S, Herten M, Sager M, Rothamel D, Becker J. Influence of different treatment approaches on non-submerged and submerged healing of ligature induced peri-implantitis lesions: an experimental study in dogs. J Clin Periodontol. 2006;33(8):584-95.
40. You TM, Choi BH, Zhu SJ, Jung JH, Lee SH, Huh JY, et al. Treatment of experimental peri-implantitis using autogenous bone grafts and platelet-enriched fibrin glue in dogs. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007;103(1):34-7.
41. Quirynen M, Bollen CM, Papaioannou W, Van Eldere J, van Steenberghe D. The influence of titanium abutment surface roughness on plaque accumulation and gingivitis: short-term observations. Int J Oral Maxillofac Implants. 1996;11(2):169-78.
42. Dorkhan M, Yücel-Lindberg T, Hall J, Svensäter G, Davies JR. Adherence of human oral keratinocytes and gingival fibroblasts to nano-structured titanium surfaces. BMC Oral Health. 2014;14:75.
43. Polyzois I, Renvert S, Bosshardt DD, Lang NP, Claffey N. Effect of Bio-Oss on osseointegration of dental implants surrounded by circumferential bone defects of different dimensions: an experimental study in the dog. Clin Oral Implants Res. 2007;18(3):304-10.
44. Koldsland OC, Scheie AA, Aass AM. Prevalence of peri-implantitis related to severity of the disease with different degrees of bone loss. J Periodontol. 2010;81(2):231-8.

45. Afrashtehfar KI, Alfallaj HA, Fernandez E, Hussaini S. Guided bone regeneration improves defect fill and reconstructive outcomes in 3-wall peri-implantitis defects. Evid Based Dent. 2024.
46. Astolfi V, Gómez-Menchero A, Ríos-Santos JV, Bullón P, Galeote F, Ríos-Carrasco B, et al. Influence of Removing or Leaving the Prosthesis after Regenerative Surgery in Peri-Implant Defects: Retrospective Study: 32 Clinical Cases with 2 to 8 Years of Follow-Up. Int J Environ Res Public Health. 2021;18(2).
47. Behneke A, Behneke N, d'Hoedt B. Treatment of peri-implantitis defects with autogenous bone grafts: six-month to 3-year results of a prospective study in 17 patients. Int J Oral Maxillofac Implants. 2000;15(1):125-38.
48. Berglundh T, Wennström JL, Lindhe J. Long-term outcome of surgical treatment of peri-implantitis. A 2-11-year retrospective study. Clin Oral Implants Res. 2018;29(4):404-10.
49. Bianchini MA, Galarraga-Vinueza ME, Bedoya KA, Correa BB, de Souza Magini R, Schwarz F. Implantoplasty Enhancing Peri-implant Bone Stability Over a 3-Year Follow-up: A Case Series. Int J Periodontics Restorative Dent. 2020;40(1):e1-e8.
50. Bianchini MA, Kuhlkamp LF, Schwarz F, Galarraga-Vinueza ME. Clinical and Radiographic Outcomes of Resective Surgery with Adjunctive Implantoplasty Over a 6- to 11-Year Follow-up: A Case Series. Int J Periodontics Restorative Dent. 2024;44(4):466-76.
51. Carcuac O, Derks J, Charalampakis G, Abrahamsson I, Wennström J, Berglundh T. Adjunctive Systemic and Local Antimicrobial Therapy in the Surgical Treatment of Peri-implantitis: A Randomized Controlled Clinical Trial. J Dent Res. 2016;95(1):50-7.
52. Chiang YC, Sirinirund B, Rodriguez A, Velasquez D, Chan HL. Operating microscope-assisted reconstructive strategy for peri-implantitis: A case series report. Clin Adv Periodontics. 2024;14(3):149-56.
53. Cortellini P, Cortellini S, Bonaccini D, Tonetti MS. Papilla preservation and minimally invasive surgery for the treatment of peri-implant osseous defects. Clinical and radiographic outcomes of a 5-year retrospective study. Clin Oral Implants Res. 2021;32(11):1384-96.
54. Froum SJ, Froum SH, Rosen PS. Successful management of peri-implantitis with a regenerative approach: a consecutive series of 51 treated implants with 3- to 7.5-year follow-up. Int J Periodontics Restorative Dent. 2012;32(1):11-20.
55. Froum SJ, Froum SH, Rosen PS. A Regenerative Approach to the Successful Treatment of Peri-implantitis: A Consecutive Series of 170 Implants in 100 Patients with 2- to 10-Year Follow-up. Int J Periodontics Restorative Dent. 2015;35(6):857-63.
56. Khayat P, Aidan D, Calatrava J, Wang HL. Bone Regeneration Following Implantoplasty: A Retrospective Cohort Study with Long-Term Radiographic Assessment. Int J Periodontics Restorative Dent. 2024;0(0):1-17.
57. Lombardo G, Marincola M, Cicconetti A, Simancas-Pallares MA, Pighi J, Lehrberg J, et al. Successful Management of Peri-Implantitis around Short and Ultrashort Single-Crown Implants: A Case Series with a 3-Year Follow-Up. Int J Dent. 2019;2019:5302752.
58. Monje A, Schwarz F. Principles of Combined Surgical Therapy for the Management of Peri-Implantitis. Clin Adv Periodontics. 2022;12(1):57-63.

59. Parma-Benfenati S, Tinti C, Romano F, Roncati M, Aimetti M. Long-Term Outcome of Surgical Regenerative Treatment of Peri-implantitis: A 2- to 21-Year Retrospective Evaluation. Int J Periodontics Restorative Dent. 2020;40(4):487-96.
60. Renvert S, Polyzois I, Claffey N. Surgical therapy for the control of peri-implantitis. Clin Oral Implants Res. 2012;23 Suppl 6:84-94.
61. Renvert S, Giovannoli J-L, Rinke S. The efficacy of reconstructive therapy in the surgical management of peri-implantitis: A 3-year follow-up of a randomized clinical trial. J Clin Periodontol. 2024;51(10):1267-76.
62. Sarmiento HL, Norton M, Korostoff J, Ko KI, Fiorellini JP. Surgical Alternatives for Treating Peri-implantitis. Int J Periodontics Restorative Dent. 2018;38(5):665-71.
63. Schwarz F, John G, Becker J. Reentry After Combined Surgical Resective and Regenerative Therapy of Advanced Peri-implantitis: A Retrospective Analysis of Five Cases. The International journal of periodontics & restorative dentistry. 2015;35:647-53.
64. Schwarz F, Sahm N, Becker J. Combined surgical therapy of advanced peri-implantitis lesions with concomitant soft tissue volume augmentation. A case series. Clin Oral Implants Res. 2014;25(1):132-6.
65. Schwarz F, Hegewald A, John G, Sahm N, Becker J. Four-year follow-up of combined surgical therapy of advanced peri-implantitis evaluating two methods of surface decontamination. J Clin Periodontol. 2013;40(10):962-7.
66. Schwarz F, John G, Schmucker A, Sahm N, Becker J. Combined surgical therapy of advanced peri-implantitis evaluating two methods of surface decontamination: a 7-year follow-up observation. J Clin Periodontol. 2017;44(3):337-42.
67. Wang CW, Ashnagar S, Gianfilippo RD, Arnett M, Kinney J, Wang HL. Laser-assisted regenerative surgical therapy for peri-implantitis: A randomized controlled clinical trial. J Periodontol. 2021;92(3):378-88.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The authors declare that no financial support was received from implant manufacturers or commercial entities.

Author Contributions

Alkisti Zekeridou (AZ) and Panagiotis Gardelis (PG) contributed equally to the conception, design, and drafting of the systematic review protocol, as well as the data acquisition and interpretation. Catherine Giannopoulou (CG) provided critical revisions and contributed to the methodological framework and data interpretation. Andreas Stavropoulos (AS) supervised the project, provided expert guidance, contributed to the conception, design of the systematic review protocol and contributed to the final review and approval of the manuscript. All authors (AZ, PG, CG, AS) have read and approved the final version of the manuscript.

DISCUSSION

Le traitement chirurgical de la péri-implantite est aujourd'hui reconnu comme une modalité thérapeutique efficace permettant d'améliorer les paramètres cliniques et radiographiques associés à cette pathologie inflammatoire complexe. Plusieurs revues systématiques ont rapporté des améliorations significatives des profondeurs de poche, du saignement au sondage et des niveaux osseux péri-implantaires après différentes approches chirurgicales, qu'elles soient non régénératives ou reconstructives (47, 69, 70). Dans ce contexte, les procédures régénératives ont été développées avec l'objectif biologique explicite d'obtenir une ré-osseointégration, et ont montré des degrés variables de succès selon les protocoles appliqués (47, 71, 72).

Il est désormais bien établi que la ré-osseointégration peut survenir sur une surface implantaire précédemment contaminée, pour autant qu'une décontamination adéquate soit réalisée (70). Cette capacité biologique a été démontrée dans plusieurs études animales utilisant des modèles de péri-implantite induite chez le chien(73-75). Bien que l'extrapolation directe de ces résultats à la pratique clinique humaine puisse être discutée, le modèle canin de péri-implantite induite par ligature est largement considéré comme une représentation acceptable des défauts péri-implantaires observés chez l'humain et demeure couramment utilisé dans la recherche expérimentale sur le traitement de la péri-implantite (76).

Influence de la morphologie du défaut péri-implantaire

La configuration du défaut osseux péri-implantaire constitue un facteur déterminant du pronostic thérapeutique. Des études expérimentales ont montré que des défauts plus étroits et mieux contenus présentaient un potentiel régénératif supérieur après traitement chirurgical de la péri-implantite induite (77). En parallèle, des études cliniques ont également souligné l'impact de la morphologie du défaut sur les résultats des traitements reconstructifs (77, 78).

Toutefois, une limite méthodologique majeure de la majorité des études cliniques incluses réside dans l'absence fréquente de description détaillée de la morphologie des défauts péri-implantaires, ce qui complique la comparaison inter-études des résultats radiographiques et limite l'interprétation du potentiel régénératif réel des différentes approches thérapeutiques.

Hétérogénéité des définitions de la péri-implantite

L'interprétation des données disponibles est entravée par une hétérogénéité marquée dans les définitions de la péri-implantite. Bien que toutes les études incluses aient requis la présence d'une perte osseuse péri-implantaire, des différences substantielles ont été observées concernant les seuils diagnostiques de profondeur de sondage, de saignement, de suppuration au sondage, ainsi que la quantité minimale de perte osseuse requise.

Par exemple, Roos-Jansåker et al. (2011) ont défini la péri-implantite comme une perte osseuse progressive ≥ trois spires associées à un saignement et/ou une suppuration (66), tandis que Schwarz et al. (2017) ont exigé la présence d'un défaut intra-osseux avec une PPD > 6 mm et une composante intra-osseuse > 3 mm radiographiquement détectable (79). Cette variabilité est d'autant plus problématique que les mesures des niveaux osseux péri-implantaires sont associées à une erreur inter-examinateur estimée à environ 0,4 mm (80), ce qui peut influencer de manière significative la classification de la présence ou de l'absence de péri-implantite.

Rôle des caractéristiques de surface implantaire

Les caractéristiques de surface implantaire ont été largement étudiées en relation avec différents aspects de la péri-implantite. Bien que certaines analyses n'aient pas identifié la surface implantaire comme un facteur prédictif direct de l'apparition de la maladie (81), il est clairement démontré que la topographie de surface influence de manière significative la formation et la maturation du biofilm bactérien (82), les implants rugueux présentant une accumulation et une rétention bactériennes plus marquées que les implants lisses (83).

Les données issues de la présente revue systématique indiquent que les surfaces modifiées sont globalement associées à des taux plus élevés de récidive et de perte implantaire par rapport aux surfaces tournées. Carcuac et al. (2020) ont rapporté un taux de récidive de 44 % après chirurgie de la péri-implantite autour d'implants à surface rugueuse (30), tandis que Romandini et al. (2024) ont identifié les surfaces modifiées, notamment TiUnite et SLA, comme des facteurs pronostiques indépendants de perte implantaire à long terme (32). À l'inverse, les implants à surface tournée ont montré une suppression plus stable de la maladie après traitement non régénératif (60).

Par ailleurs, une revue systématique de Renvert et al. (2012) a conclu que la capacité de ré-osseointégration pouvait être influencée par les caractéristiques de surface implantaire (51). D'un point de vue théorique, les surfaces rugueuses constituent un défi accru en termes de décontamination, ce qui pourrait compromettre le contrôle à long terme de l'inflammation. Toutefois, des études expérimentales ont montré une ré-osseointégration plus prononcée sur des surfaces rugueuses que sur des surfaces lisses après traitement chirurgical non régénératif (84). Persson et al. (2001) ont suggéré que les surfaces rugueuses pourraient offrir un support mécanique favorable à la stabilisation du caillot sanguin, facilitant ainsi la cicatrisation osseuse le long de la surface implantaire (84).

Résultats des traitements non régénératifs

Les données cliniques disponibles ne permettent pas de mettre en évidence de différences nettes en termes de régénération osseuse entre les surfaces implantaires après chirurgie non régénérative. Leonhardt et al. (2003) ont rapporté à la fois des gains et des pertes osseuses autour d'implants à surface lisse après 12 mois de suivi, tandis que des résultats comparables ont été observés autour d'implants rugueux dans d'autres études (60).

Bien que la chirurgie résective, avec ou sans implantoplastie ou ostéoplastie, puisse être efficace dans le contrôle de la péri-implantite (51, 85), aucune différence radiographique claire liée à la topographie de surface implantaire n'a pu être identifiée.

Résultats des approches reconstructives et régénératives

Lorsque le traitement chirurgical inclut l'utilisation de matériaux de comblement, une augmentation plus marquée du niveau osseux péri-implantaire est observée autour des implants rugueux. Le gain osseux le plus prononcé (2,4 mm) a été rapporté par Khoury et Buchmann (2001) après utilisation d'une greffe autogène (57). Des résultats similaires ont été observés avec des xénogreffes, en particulier autour des implants SLA, avec une stabilité à long terme rapportée jusqu'à 10 ans (63-65). En revanche, les implants TPS ont montré une stabilité osseuse limitée, même en présence de matériaux de comblement (63).

Des matériaux alloplastiques ont également montré une capacité de comblement des défauts péri-implantaires autour des implants rugueux (86, 87). En revanche, lorsque des matériaux alloplastiques ont été utilisés autour d'implants à surface lisse, l'effet sur le niveau osseux était nettement moins prononcé (67).

Régénération osseuse guidée, membranes et tissus mous

La régénération osseuse guidée, combinant matériaux de comblement et membranes, semble induire globalement des gains osseux plus importants autour des implants rugueux que lisses, ce qui est en accord avec les résultats d'études animales après traitements non régénératifs (84). Toutefois, plusieurs études expérimentales ont mis en évidence la présence d'un tissu conjonctif interposé entre l'os néoformé et la surface implantaire (73, 74, 88), suggérant que la régénération osseuse radiographique ne correspond pas nécessairement à une véritable ré-osseointégration.

Le rôle des membranes demeure controversé. Khoury et Buchmann (2001) ont montré des gains osseux supérieurs avec des membranes non résorbables par rapport aux membranes résorbables autour d'implants rugueux (57), tandis que Deppe et al. (2007) ont rapporté des résultats comparables avec des membranes résorbables (55). Lorsque des membranes non résorbables ont été utilisées en association avec des matériaux alloplastiques autour d'implants lisses, les gains osseux étaient nettement inférieurs (66, 89) .

Les caractéristiques de surface implantaire influencent également la qualité de l'attache des tissus mous péri-implantaires. Une rugosité excessive ou insuffisante peut compromettre le scellement muqueux. Quirynen et al. (1996) ont observé une perte d'attache autour de surfaces polies, tandis que des surfaces commerciales standard permettaient un maintien plus stable des niveaux d'attache (90). Ces observations sont soutenues par des études in vitro montrant une meilleure adhésion cellulaire sur des surfaces présentant un certain degré de rugosité (91).

Conclusion

Les modifications de surface implantaire ont démontré leur capacité à améliorer l'osseointégration initiale et les taux de survie implantaire (6, 92). Toutefois, elles sont également associées à une susceptibilité accrue à l'accumulation bactérienne, ce qui pourrait contribuer au développement et à la récidive des maladies péri-implantaires. Renvert et al. (2012) ont conclu que les preuves disponibles restaient limitées quant à l'influence directe des caractéristiques de surface sur la progression de la péri-implantite établie (51). Dans un contexte de prévalence croissante de la péri-implantite (9), l'identification de stratégies thérapeutiques optimales demeure une priorité clinique et scientifique.

Les résultats de ce travail suggèrent que l'efficacité du traitement chirurgical de la péri-implantite dépend à la fois des caractéristiques de surface implantaire et de la modalité thérapeutique choisie. Les surfaces modifiées sont globalement associées à un risque plus élevé de récidive et de perte implantaire, bien que les implants à surface SLA présentent des résultats plus favorables que ceux à surface TPS. À l'inverse, les implants à surface tournée semblent moins sujets à la récidive, mais leur comportement dans des contextes reconstructifs demeure insuffisamment documenté. Les approches reconstructives, lorsqu'elles sont associées à un programme de maintenance rigoureux, apparaissent comme les stratégies offrant les résultats les plus stables.

Toutefois, ces observations doivent être interprétées avec prudence en raison du faible niveau de certitude des preuves disponibles et de l'hétérogénéité méthodologique des études incluses. Des essais cliniques randomisés, bien conçus, avec des définitions standardisées des critères cliniques et radiographiques et des suivis à long terme, sont nécessaires pour mieux comprendre le rôle spécifique des surfaces implantaires et permettre des comparaisons fiables entre études.

En pratique, les caractéristiques de surface implantaire doivent être prises en compte dans la planification du traitement chirurgical de la péri-implantite, sans être considérées isolément.

La prise de décision clinique doit rester individualisée et intégrer les facteurs liés au patient, tels que le tabagisme, les conditions systémiques et la compliance au suivi, qui peuvent avoir un impact majeur sur le succès à long terme. Enfin, bien que l'utilisation de biomatériaux et de membranes puisse améliorer les résultats régénératifs, les cliniciens doivent garder à l'esprit que les gains osseux radiographiques ne reflètent pas nécessairement une ré-osseointégration complète et que la résolution totale des défauts péri-implantaires demeure rarement atteignable.

RÉFÉRENCES

1. Spiekermann H, Jansen VK, Richter EJ. A 10-year follow-up study of IMZ and TPS implants in the edentulous mandible using bar-retained overdentures. Int J Oral Maxillofac Implants. 1995;10(2):231-43.
2. Jung RE, Zembic A, Pjetursson BE, Zwahlen M, Thoma DS. Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. Clin Oral Implants Res. 2012;23 Suppl 6:2-21.
3. Attard NJ, Zarb GA. Implant prosthodontic management of partially edentulous patients missing posterior teeth: the Toronto experience. J Prosthet Dent. 2003;89(4):352-9.
4. Esposito M, Ardebili Y, Worthington HV. Interventions for replacing missing teeth: different types of dental implants. Cochrane Database Syst Rev. 2014(7):Cd003815.
5. Lang NP, Berglundh T, Heitz-Mayfield LJ, Pjetursson BE, Salvi GE, Sanz M. Consensus statements and recommended clinical procedures regarding implant survival and complications. Int J Oral Maxillofac Implants. 2004;19 Suppl:150-4.
6. Kupka JR, König J, Al-Nawas B, Sagheb K, Schiegnitz E. How far can we go? A 20-year meta-analysis of dental implant survival rates. Clin Oral Investig. 2024;28(10):541.
7. Hanif A, Qureshi S, Sheikh Z, Rashid H. Complications in implant dentistry. Eur J Dent. 2017;11(1):135-40.
8. Renvert S, Persson GR, Pirih FQ, Camargo PM. Peri-implant health, peri-implant mucositis, and peri-implantitis: Case definitions and diagnostic considerations. J Periodontol. 2018;89 Suppl 1:S304-s12.
9. Diaz P, Gonzalo E, Villagra LJG, Miegimolle B, Suarez MJ. What is the prevalence of peri-implantitis? A systematic review and meta-analysis. BMC Oral Health. 2022;22(1):449.
10. Mombelli A, Décaillet F. The characteristics of biofilms in peri-implant disease. J Clin Periodontol. 2011;38 Suppl 11:203-13.
11. Albrektsson T, Wennerberg A. Oral implant surfaces: Part 1--review focusing on topographic and chemical properties of different surfaces and in vivo responses to them. Int J Prosthodont. 2004;17(5):536-43.
12. Dohan Ehrenfest DM, Coelho PG, Kang BS, Sul YT, Albrektsson T. Classification of osseointegrated implant surfaces: materials, chemistry and topography. Trends Biotechnol. 2010;28(4):198-206.
13. Albrektsson T, Dahl E, Enbom L, Engevall S, Engquist B, Eriksson AR, et al. Osseointegrated oral implants. A Swedish multicenter study of 8139 consecutively inserted Nobelpharma implants. J Periodontol. 1988;59(5):287-96.
14. Cooper LF. A role for surface topography in creating and maintaining bone at titanium endosseous implants. J Prosthet Dent. 2000;84(5):522-34.
15. Longo G, Ioannidu CA, Scotto d'Abusco A, Superti F, Misiano C, Zanoni R, et al. Improving Osteoblast Response In Vitro by a Nanostructured Thin Film with Titanium Carbide and Titanium Oxides Clustered around Graphitic Carbon. PLoS One. 2016;11(3):e0152566.
16. Wennerberg A, Albrektsson T. Effects of titanium surface topography on bone integration: a systematic review. Clin Oral Implants Res. 2009;20 Suppl 4:172-84.

17. Annunziata M, Guida L. The Effect of Titanium Surface Modifications on Dental Implant Osseointegration. Front Oral Biol. 2015;17:62-77.
18. Coelho PG, Granjeiro JM, Romanos GE, Suzuki M, Silva NR, Cardaropoli G, et al. Basic research methods and current trends of dental implant surfaces. J Biomed Mater Res B Appl Biomater. 2009;88(2):579-96.
19. Smeets R, Stadlinger B, Schwarz F, Beck-Broichsitter B, Jung O, Precht C, et al. Impact of Dental Implant Surface Modifications on Osseointegration. Biomed Res Int. 2016;2016:6285620.
20. Junker R, Dimakis A, Thoneick M, Jansen JA. Effects of implant surface coatings and composition on bone integration: a systematic review. Clin Oral Implants Res. 2009;20 Suppl 4:185-206.
21. Wennerberg A, Albrektsson T. On implant surfaces: a review of current knowledge and opinions. Int J Oral Maxillofac Implants. 2010;25(1):63-74.
22. Lang NP, Jepsen S. Implant surfaces and design (Working Group 4). Clin Oral Implants Res. 2009;20 Suppl 4:228-31.
23. Jimbo R, Albrektsson T. Long-term clinical success of minimally and moderately rough oral implants: a review of 71 studies with 5 years or more of follow-up. Implant Dent. 2015;24(1):62-9.
24. Chrcanovic BR, Albrektsson T, Wennerberg A. Reasons for failures of oral implants. J Oral Rehabil. 2014;41(6):443-76.
25. Astrand P, Engquist B, Anzén B, Bergendal T, Hallman M, Karlsson U, et al. A three-year follow-up report of a comparative study of ITI Dental Implants and Brånemark System implants in the treatment of the partially edentulous maxilla. Clin Implant Dent Relat Res. 2004;6(3):130-41.
26. Karoussis IK, Brägger U, Salvi GE, Bürgin W, Lang NP. Effect of implant design on survival and success rates of titanium oral implants: a 10-year prospective cohort study of the ITI Dental Implant System. Clin Oral Implants Res. 2004;15(1):8-17.
27. Renvert S, Polyzois I, Claffey N. How do implant surface characteristics influence peri-implant disease? J Clin Periodontol. 2011;38 Suppl 11:214-22.
28. Hussein A, Shah M, Atieh MA, Alhimairi S, Amir-Rad F, Elbishari H. Influence of Implant Surfaces on Peri-Implant Diseases – A Systematic Review and Meta-Analysis. Int Dent J. 2025;75(1):75-85.
29. Stavropoulos A, Bertl K, Winning L, Polyzois I. What is the influence of implant surface characteristics and/or implant material on the incidence and progression of peri-implantitis? A systematic literature review. Clin Oral Implants Res. 2021;32 Suppl 21:203-29.
30. Carcuac O, Derks J, Abrahamsson I, Wennström JL, Berglundh T. Risk for recurrence of disease following surgical therapy of peri-implantitis-A prospective longitudinal study. Clin Oral Implants Res. 2020;31(11):1072-7.
31. Garaicoa-Pazmino C, Lin GH, Alkandery A, Parra-Carrasquer C, Suárez-López Del Amo F. Influence of implant surface characteristics on the initiation, progression and treatment outcomes of peri-implantitis: A systematic review and meta-analysis based on animal model studies. Int J Oral Implantol (Berl). 2021;14(4):367-82.
32. Romandini M, Bougas K, Alibegovic L, Hosseini S, Carcuac O, Berglundh T, et al. Long-term outcomes and prognostic factors of surgical treatment of peri-implantitis - A retrospective study. Clin Oral Implants Res. 2024;35(3):321-9.

33. Hjalmarsson L, Gheisarifar M, Jemt T. A systematic review of survival of single implants as presented in longitudinal studies with a follow-up of at least 10 years. Eur J Oral Implantol. 2016;9 Suppl 1:S155-62.
34. Lang NP, Wilson TG, Corbet EF. Biological complications with dental implants: their prevention, diagnosis and treatment. Clin Oral Implants Res. 2000;11 Suppl 1:146-55.
35. Pjetursson BE, Brägger U, Lang NP, Zwahlen M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). Clin Oral Implants Res. 2007;18 Suppl 3:97-113.
36. Zitzmann NU, Berglundh T. Definition and prevalence of peri-implant diseases. J Clin Periodontol. 2008;35(8 Suppl):286-91.
37. Smeets R, Henningsen A, Jung O, Heiland M, Hammächer C, Stein JM. Definition, etiology, prevention and treatment of peri-implantitis--a review. Head Face Med. 2014;10:34.
38. Renvert S, Roos-Jansåker AM, Lindahl C, Renvert H, Rutger Persson G. Infection at titanium implants with or without a clinical diagnosis of inflammation. Clin Oral Implants Res. 2007;18(4):509-16.
39. Berglundh T, Zitzmann NU, Donati M. Are peri-implantitis lesions different from periodontitis lesions? J Clin Periodontol. 2011;38 Suppl 11:188-202.
40. Berglundh T, Gislason O, Lekholm U, Sennerby L, Lindhe J. Histopathological observations of human periimplantitis lesions. J Clin Periodontol. 2004;31(5):341-7.
41. Carcuac O, Abrahamsson I, Albouy JP, Linder E, Larsson L, Berglundh T. Experimental periodontitis and peri-implantitis in dogs. Clin Oral Implants Res. 2013;24(4):363-71.
42. Albouy JP, Abrahamsson I, Berglundh T. Spontaneous progression of experimental peri-implantitis at implants with different surface characteristics: an experimental study in dogs. J Clin Periodontol. 2012;39(2):182-7.
43. Heitz-Mayfield LJ. Diagnosis and management of peri-implant diseases. Aust Dent J. 2008;53 Suppl 1:S43-8.
44. Herrera D, Berglundh T, Schwarz F, Chapple I, Jepsen S, Sculean A, et al. Prevention and treatment of peri-implant diseases-The EFP S3 level clinical practice guideline. J Clin Periodontol. 2023;50 Suppl 26:4-76.
45. Roos-Jansåker AM, Renvert S, Egelberg J. Treatment of peri-implant infections: a literature review. J Clin Periodontol. 2003;30(6):467-85.
46. Klinge B, Gustafsson A, Berglundh T. A systematic review of the effect of anti-infective therapy in the treatment of peri-implantitis. J Clin Periodontol. 2002;29 Suppl 3:213-25; discussion 32-3.
47. Claffey N, Clarke E, Polyzois I, Renvert S. Surgical treatment of peri-implantitis. J Clin Periodontol. 2008;35(8 Suppl):316-32.
48. Esposito M, Grusovin MG, Worthington HV. Interventions for replacing missing teeth: treatment of peri-implantitis. Cochrane Database Syst Rev. 2012;1(1):Cd004970.
49. Renvert S, Roos-Jansåker AM, Claffey N. Non-surgical treatment of peri-implant mucositis and peri-implantitis: a literature review. J Clin Periodontol. 2008;35(8 Suppl):305-15.
50. Faggion CM, Jr., Chambrone L, Listl S, Tu YK. Network meta-analysis for evaluating interventions in implant dentistry: the case of peri-implantitis treatment. Clin Implant Dent Relat Res. 2013;15(4):576-88.

51. Renvert S, Polyzois I, Claffey N. Surgical therapy for the control of peri-implantitis. Clin Oral Implants Res. 2012;23 Suppl 6:84-94.
52. Vernon JJ, Raïf EM, Aw J, Attenborough E, Jha A, Do T. Dental implant surfaces and their interaction with the oral microbiome. Dentistry Review. 2022;2(4):100060.
53. Wassmann T, Kreis S, Behr M, Buergers R. The influence of surface texture and wettability on initial bacterial adhesion on titanium and zirconium oxide dental implants. International Journal of Implant Dentistry. 2017;3(1):32.
54. Aghazadeh A, Persson GR, Stavropoulos A, Renvert S. Reconstructive treatment of peri-implant defects-Results after three and five years. Clin Oral Implants Res. 2022;33(11):1114-24.
55. Deppe H, Horch HH, Neff A. Conventional versus CO2 laser-assisted treatment of peri-implant defects with the concomitant use of pure-phase beta-tricalcium phosphate: a 5-year clinical report. Int J Oral Maxillofac Implants. 2007;22(1):79-86.
56. Jemt T, Eriksson J. Bone Loss Before and After Peri-implantitis Surgery: A 7-Year Retrospective Observational Study. Int J Oral Maxillofac Implants. 2021;36(6):1199-210.
57. Khoury F, Buchmann R. Surgical therapy of peri-implant disease: a 3-year follow-up study of cases treated with 3 different techniques of bone regeneration. J Periodontol. 2001;72(11):1498-508.
58. La Monaca G, Pranno N, Annibali S, Cristalli MP, Polimeni A. Clinical and radiographic outcomes of a surgical reconstructive approach in the treatment of peri-implantitis lesions: A 5-year prospective case series. Clin Oral Implants Res. 2018;29(10):1025-37.
59. La Monaca G, Pranno N, Annibali S, Polimeni A, Cristalli MP. A 10-Year Follow-Up of Reconstructive Treatment of Peri-Implantitis Using Mineralized Dehydrated Allograft and Resorbable Membrane: A Retrospective Case Series. Clin Oral Implants Res. 2024.
60. Leonhardt A, Dahlén G, Renvert S. Five-year clinical, microbiological, and radiological outcome following treatment of peri-implantitis in man. J Periodontol. 2003;74(10):1415-22.
61. Mercado F, Hamlet S, Ivanovski S. Regenerative surgical therapy for peri-implantitis using deproteinized bovine bone mineral with 10% collagen, enamel matrix derivative and Doxycycline-A prospective 3-year cohort study. Clin Oral Implants Res. 2018;29(6):583-91.
62. Noelken R, Westphal L, Schiegnitz E, Al-Nawas B. Hard and soft tissue regeneration of severe peri-implantitis defects with the laser-assisted peri-implant defect regeneration technique: 3-year results. Int J Implant Dent. 2023;9(1):3.
63. Roccuzzo M, Fierravanti L, Pittoni D, Dalmasso P, Roccuzzo A. Implant survival after surgical treatment of peri-implantitis lesions by means of deproteinized bovine bone mineral with 10% collagen: 10-year results from a prospective study. Clin Oral Implants Res. 2020;31(8):768-76.
64. Roccuzzo M, Mirra D, Pittoni D, Ramieri G, Roccuzzo A. Reconstructive treatment of peri-implantitis infrabony defects of various configurations: 5-year survival and success. Clin Oral Implants Res. 2021;32(10):1209-17.
65. Roccuzzo M, Pittoni D, Roccuzzo A, Charrier L, Dalmasso P. Surgical treatment of peri-implantitis intrabony lesions by means of deproteinized bovine bone mineral with 10% collagen: 7-year-results. Clin Oral Implants Res. 2017;28(12):1577-83.

66. Roos-Jansåker AM, Lindahl C, Persson GR, Renvert S. Long-term stability of surgical bone regenerative procedures of peri-implantitis lesions in a prospective case-control study over 3 years. J Clin Periodontol. 2011;38(6):590-7.
67. Roos-Jansåker AM, Persson GR, Lindahl C, Renvert S. Surgical treatment of peri-implantitis using a bone substitute with or without a resorbable membrane: a 5-year follow-up. J Clin Periodontol. 2014;41(11):1108-14.
68. Schwarz F, Sahm N, Bieling K, Becker J. Surgical regenerative treatment of peri-implantitis lesions using a nanocrystalline hydroxyapatite or a natural bone mineral in combination with a collagen membrane: a four-year clinical follow-up report. J Clin Periodontol. 2009;36(9):807-14.
69. Daugela P, Cicciù M, Saulacic N. Surgical Regenerative Treatments for Peri-Implantitis: Meta-analysis of Recent Findings in a Systematic Literature Review. J Oral Maxillofac Res. 2016;7(3):e15.
70. Mombelli A, Moëne R, Décaillet F. Surgical treatments of peri-implantitis. Eur J Oral Implantol. 2012;5 Suppl:S61-70.
71. Mombelli A, Feloutzis A, Brägger U, Lang NP. Treatment of peri-implantitis by local delivery of tetracycline. Clinical, microbiological and radiological results. Clin Oral Implants Res. 2001;12(4):287-94.
72. Ramanauskaite A, Obreja K, Sader R, Khoury F, Romanos G, Koo KT, et al. Surgical Treatment of Periimplantitis With Augmentative Techniques. Implant Dent. 2019;28(2):187-209.
73. Persson LG, Araújo MG, Berglundh T, Gröndahl K, Lindhe J. Resolution of peri-implantitis following treatment. An experimental study in the dog. Clin Oral Implants Res. 1999;10(3):195-203.
74. Schwarz F, Jepsen S, Herten M, Sager M, Rothamel D, Becker J. Influence of different treatment approaches on non-submerged and submerged healing of ligature induced peri-implantitis lesions: an experimental study in dogs. J Clin Periodontol. 2006;33(8):584-95.
75. Alhag M, Renvert S, Polyzois I, Claffey N. Re-osseointegration on rough implant surfaces previously coated with bacterial biofilm: an experimental study in the dog. Clin Oral Implants Res. 2008;19(2):182-7.
76. Schwarz F, Herten M, Sager M, Bieling K, Sculean A, Becker J. Comparison of naturally occurring and ligature-induced peri-implantitis bone defects in humans and dogs. Clin Oral Implants Res. 2007;18(2):161-70.
77. Polyzois I, Renvert S, Bosshardt DD, Lang NP, Claffey N. Effect of Bio-Oss on osseointegration of dental implants surrounded by circumferential bone defects of different dimensions: an experimental study in the dog. Clin Oral Implants Res. 2007;18(3):304-10.
78. Aghazadeh A, Persson GR, Renvert S. Impact of bone defect morphology on the outcome of reconstructive treatment of peri-implantitis. International Journal of Implant Dentistry. 2020;6.
79. Schwarz F, John G, Schmucker A, Sahm N, Becker J. Combined surgical therapy of advanced peri-implantitis evaluating two methods of surface decontamination: a 7-year follow-up observation. J Clin Periodontol. 2017;44(3):337-42.
80. Koldsland OC, Scheie AA, Aass AM. Prevalence of peri-implantitis related to severity of the disease with different degrees of bone loss. J Periodontol. 2010;81(2):231-8.

81. Saulacic N, Schaller B. Prevalence of Peri-Implantitis in Implants with Turned and Rough Surfaces: a Systematic Review. J Oral Maxillofac Res. 2019;10(1):e1.
82. Teughels W, Van Assche N, Sliepen I, Quirynen M. Effect of material characteristics and/or surface topography on biofilm development. Clin Oral Implants Res. 2006;17 Suppl 2:68-81.
83. Subramani K, Jung RE, Molenberg A, Hammerle CH. Biofilm on dental implants: a review of the literature. Int J Oral Maxillofac Implants. 2009;24(4):616-26.
84. Persson LG, Berglundh T, Lindhe J, Sennerby L. Re-osseointegration after treatment of peri-implantitis at different implant surfaces. An experimental study in the dog. Clin Oral Implants Res. 2001;12(6):595-603.
85. Bianchini MA, Galarraga-Vinueza ME, Bedoya KA, Correa BB, de Souza Magini R, Schwarz F. Implantoplasty Enhancing Peri-implant Bone Stability Over a 3-Year Follow-up: A Case Series. Int J Periodontics Restorative Dent. 2020;40(1):e1-e8.
86. Wohlfahrt JC, Lyngstadaas SP, Rønold HJ, Saxegaard E, Ellingsen JE, Karlsson S, et al. Porous titanium granules in the surgical treatment of peri-implant osseous defects: a randomized clinical trial. Int J Oral Maxillofac Implants. 2012;27(2):401-10.
87. Roccuzzo M, Bonino F, Bonino L, Dalmasso P. Surgical therapy of peri-implantitis lesions by means of a bovine-derived xenograft: comparative results of a prospective study on two different implant surfaces. J Clin Periodontol. 2011;38(8):738-45.
88. You TM, Choi BH, Zhu SJ, Jung JH, Lee SH, Huh JY, et al. Treatment of experimental peri-implantitis using autogenous bone grafts and platelet-enriched fibrin glue in dogs. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007;103(1):34-7.
89. Schwarz F, Sahm N, Becker J. Combined surgical therapy of advanced peri-implantitis lesions with concomitant soft tissue volume augmentation. A case series. Clin Oral Implants Res. 2014;25(1):132-6.
90. Quirynen M, Bollen CM, Papaioannou W, Van Eldere J, van Steenberghe D. The influence of titanium abutment surface roughness on plaque accumulation and gingivitis: short-term observations. Int J Oral Maxillofac Implants. 1996;11(2):169-78.
91. Dorkhan M, Yücel-Lindberg T, Hall J, Svensäter G, Davies JR. Adherence of human oral keratinocytes and gingival fibroblasts to nano-structured titanium surfaces. BMC Oral Health. 2014;14:75.
92. Romero-Serrano M, Romero-Ruiz MM, Herrero-Climent M, Rios-Carrasco B, Gil-Mur J. Correlation between Implant Surface Roughness and Implant Stability: A Systematic Review. Dent J (Basel). 2024;12(9).

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Impact of implant surface modifications on long-term outcome of surgical peri-implantitis treatment: a systematic review

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Introduction: Peri-implantitis is an inflammatory disease that compromises peri-implant tissues and supporting bone, potentially leading to implant loss. Although several surgical treatment strategies have been proposed, it remains unclear whether implant surface characteristics (smooth vs. rough) influence long-term treatment outcomes.
Methods: A systematic review was conducted to evaluate clinical studies with a minimum follow-up of 3 years that assessed the outcomes of surgical treatment of peri-implantitis in relation to implant surface type. Data extraction focused on recurrence of peri-implantitis, implant survival, clinical parameters, radiographic outcomes, and the type of surgical approach used (reconstructive vs. non-reconstructive).
Results: Seventeen clinical studies were included. Outcomes varied according to implant surface characteristics. Rough (modified) surfaces were generally associated with a higher risk of recurrence of peri-implantitis and implant loss compared with smooth (machined/turned) surfaces. Reconstructive surgical approaches, especially those involving bone grafts and membranes, demonstrated more favorable outcomes compared with non-reconstructive approaches.
Discussion: Despite observed trends, the certainty of the evidence remains low due to heterogeneity between studies, small sample sizes, and methodological limitations. Further well-designed long-term clinical trials are needed to clarify the role of implant surface characteristics in the long-term success of peri-implantitis surgical treatment.

Systematic Review Registration: PROSPERO (CRD420251129791).

KEYWORDS

peri-Implantitis, surgical peri-implantitis treatment, treatment outcome, explantation, implant surface, long-term outcomes, bone loss, implant survival

1 Introduction

Dental implants have significantly advanced oral rehabilitation, providing highly predictable solutions for tooth replacement. For instance, a recent systematic review reported that long-term prospective studies on dental implants show high survival rates, typically exceeding 90% over 5–10 years and remaining around 78% after imputation at 20 years follow-up. In addition, five retrospective studies with ≥20 years of follow-up reported an implant survival rate of approximately 88%, including multifactorial causes (1).

However, despite the high survival rates, biological complications at implants are rather common. In particular, peri-implantitis, which is characterized by peri-implant mucosal inflammation and progressive bone loss, affects approximately 19.53% of patients and 12.53% of implants, highlighting its relevance in clinical practice (2). As the main etiological factor for peri-implantitis is the oral biofilm, microbial to implant surface interactions seem to play an important role in disease pathogenesis. Indeed, surface modifications (e.g., sandblasting, acid-etching, anodization, etc) aiming in enhancing implant surface bioactivity, substantially impact on microbial colonization and biofilm development (3–7). Indeed, although the incidence of peri-implantitis seems not to differ between modified and non-modified (i.e., turned) implants in the clinic, progression and severity of peri-implantitis appear linked to implant surface properties; specifically, pre-clinical *in vivo* studies indicate a faster disease progression at modified implants compared with turned implants, as well as differences in disease progression among various modified surfaces (5, 7). Moreover it seems that implant surface characteristics may impact on treatment outcomes both in the short-term but also on the long-term, with implants with a modified surface demonstrating less positive results and higher recurrence rates (3, 8, 9).

Despite technological advancements and improved treatment approaches, the impact of implant surface modifications on peri-implantitis outcomes remains unclear. Therefore, this systematic review aims to evaluate whether varying implant surface topographies influence clinical and radiographic outcomes following surgical peri-implantitis treatment in humans. The findings may offer critical insights guiding the selection of implant surface characteristics to enhance treatment efficacy.

2 Materials and methods

2.1 Study design

This review was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was registered in PROSPERO (ID: CRD420251129791).

2.2 Search strategy

To identify relevant studies, we systematically searched PubMed, Embase, and the Cochrane Library. The search strategy was carried out in English language from database inception for articles published between 2000 and 2025. Two investigators (AZ and PG) independently reviewed the search results and screened the titles and abstracts. Full texts of all potentially eligible studies were obtained. In PubMed, the following search strategy was used: "(Periimplantitis OR peri-implantitis OR peri implantitis OR periimplant OR peri-implant OR peri implant) AND (treatment outcome OR therapy OR surgical treatment OR regenerative OR regeneration OR tissue regeneration OR reconstructive surgery OR bone graft OR bone substitute OR membranes OR surgical flap OR open flap debridement OR resective OR implantoplasty OR surface decontamination) AND (surface characteristics OR surface roughness OR material characteristics OR titanium surface OR implant types OR implant surfaces OR surface topography OR surface analysis) AND (implant survival OR bone loss OR recurrence OR retreatment OR radiographic stability OR long-term OR 3 years OR follow-up)." This search strategy was adapted to suit the other electronic sources. The reference lists of retrieved articles were also checked to identify additional studies of interest. Any inconsistencies were resolved by consensus with a third investigator (CG). The complete search strategies for all databases are provided in Appendix 2.

2.3 Criteria for considering studies for this review

2.3.1 Study design

Randomized controlled trials, prospective studies, retrospective studies, case-control studies, and case series were included. No specific cut-off criteria for sample size were applied, given the limited availability of data. Additionally, two case series with very small sample sizes were included due to their clinical relevance. Eligibility required that included studies explicitly reported the implant surface type(s) of the implants investigated.

2.3.2 Population

Human studies. Patients with osseointegrated dental implants diagnosed with peri-implantitis, treated surgically, with a follow-up period of at least 3 years (or an average ≥3 years).

2.3.3 Intervention

Surgical therapy for peri-implantitis.

2.3.4 Comparator

Different implant surface types, characterized by variations in macro-, micro-, and nano-scale surface roughness, topography, and material composition. Surfaces were categorized as non-modified (i.e turned, smooth, machihed), modified (rough), or mixed (hybrid), depending on their reported surface characteristics.

2.4 Outcomes

2.4.1 Primary outcome

- Percentage of implants with recurrence of peri-implantitis requiring re-treatment or explantation or simply defined as treatment failure by the authors.

2.4.2 Secondary outcomes

- Implant loss (due to any reason)
- Disease resolution defined by reduction of probing depth (PD) without bleeding on probing (BOP) or suppuration
- Radiographic bone loss or gain assessed by mean changes in bone levels or percentage of implants with stable bone levels post-treatment
- Mean probing depth (PD) post-treatment

Subgroup synthesis: The outcomes were further stratified based on implant surface types and surgical approach:

1. Turned (machined/non-modified surfaces)
    - a. Non-reconstructive surgical approach
    - b. Reconstructive surgical approach (regardless the technique or materials used)
2. Modified (rough surfaces)
    - a. Non-reconstructive surgical approach
    - b. Reconstructive surgical approach (regardless the technique or materials used)
3. Mixed or unspecified surfaces
    - a. Non-reconstructive surgical approach
    - b. Reconstructive surgical approach (regardless the technique or materials used)

2.5 Data collection

Two investigators independently extracted key data from the included articles. The inter-rater agreement for study selection was assessed using Cohen's kappa statistics. Inter-rater reliability was assessed using Cohen's kappa statistic on a subset of 20% of studies, yielding a kappa of 0.85, indicating a high level of agreement. Discrepancies were resolved through discussion or consultation with a third reviewer (CG). For each article, we extracted study features (i.e., study design, year of publication, number of enrolled patients), type of intervention, and outcome measures. Correct data extraction was controlled in a subset of randomly selected studies by the third investigator.

2.6 Assessment of risk of bias

Two investigators independently appraised the risk of bias of the included studies using the Cochrane Risk of Bias Tool 2.0 (RoB2) for RCTs. For non-RCTs the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool was used. Any inconsistencies were resolved by consensus with a third investigator (CG).

2.7 Data synthesis

Preliminary analyses of available data revealed high heterogeneity, precluding meaningful meta-analysis. Therefore, a narrative synthesis was conducted. These limitations included significant heterogeneity in implant surface types, surgical techniques, and reported outcome measures across studies. To enhance clarity and readability, findings were systematically summarized in tables according to pre-defined outcomes and subgroup analyses.

Data extraction was performed separately for each treatment group within studies containing multiple groups, while data from studies with a single treatment group were extracted accordingly. Results were categorized based on implant surface types and surgical approaches as follows:

1. Turned (machined/non-modified surfaces) a. Non-reconstructive surgical approach b. Reconstructive surgical approach (regardless the technique or materials used)
2. Modified (rough surfaces) a. Non-reconstructive surgical approach b. Reconstructive surgical approach (regardless the technique or materials used)
3. Mixed or unspecified surfaces a. Non-reconstructive surgical approach b. Reconstructive surgical approach (regardless the technique or materials used)

Findings were systematically summarized in tables according to pre-defined outcomes and subgroup analyses to enhance clarity and readability.

Within each treatment group, data were systematically collected on key parameters, including sample size (number of participants and implants), criteria used to define peri-implantitis, type of bone substitute, membrane used (if applicable), follow-up periods, implant system, and implant surface characteristics.

3 Results

3.1 Study selection

The literature search process is illustrated in the flowchart below (Figure 1). In total, there are 17 studies included in the analysis (8–24). Among them, 8 are prospective cohort studies, 3 are retrospective cohort studies, 1 are randomized controlled trials. The remaining studies include 1 each of the following types: prospective clinical study, retrospective observational study, and prospective case series. A detailed description of the study characteristics can be found in the results in Tables 1a,b.

3.2 Study populations

3.2.1 Peri-implantitis

Across the 17 studies analyzed, various diagnostic criteria have been employed to identify peri-implantitis, reflecting differences in study designs and clinical considerations (8–24). The most commonly reported diagnostic parameters include probing depth (PD), bleeding on probing (BOP), suppuration, and radiographic evidence of bone loss.

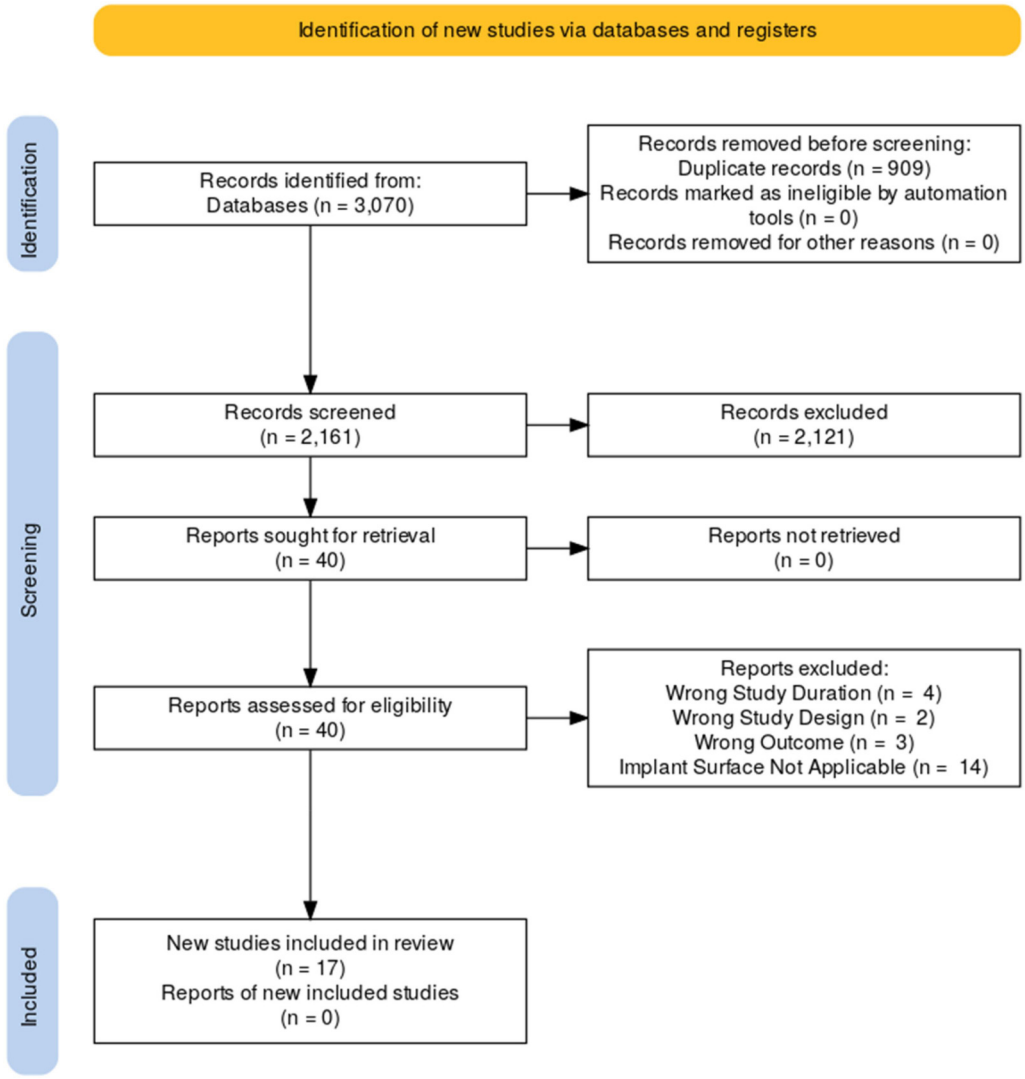

FIGURE 1
PRISMA flow diagram.

3.2.2 Probing depth (PD)

A probing depth threshold of ≥6 mm is frequently used as a criterion to identify peri-implantitis, as observed in studies by Carcuac et al., Romandini et al., and Roccuzzo et al. (15, 16, 26–28). Other studies, such as Aghazadeh et al. and Noelken et al., set a threshold of ≥5 mm, which is similar to the >4 mm threshold considered indicative of disease by Mercado et al. and Schwarz et al. (24, 25, 31, 32). This variation highlights differences at diagnosis across studies.

3.2.3 Bleeding on probing (BOP) and suppuration

The presence of BOP and/or suppuration was consistently reported as a diagnostic marker in all studies. It serves as an indicator of ongoing inflammation and peri-implant tissue destruction. Studies such as La Monaca et al. and Khoury & Buchmann emphasize the importance of these clinical signs in combination with radiographic findings for accurate diagnosis (20–22).

3.2.4 Radiographic bone loss

Radiographic evaluation of bone loss is another widely accepted criterion for peri-implantitis diagnosis. The threshold for bone loss varies among studies, with the most commonly reported value being ≥3 mm, as seen in Romandini et al. (16). Other studies, including Carcuac et al. and Aghazadeh et al., defined progressive bone loss based on post-treatment changes or specific defect characteristics, such as angular defects of ≥3 mm (15, 32). A more conservative threshold of ≥1.8 mm was applied in studies such as Roos-Jansåker et al., reflecting the variability in bone loss progression (29, 30).

TABLE 1a Summary of clinical studies evaluating treatments of peri-implantitis: surface types, materials, and outcomes.

Author (year)	Implant surface	Implant brand	Patients (initial/ follow-up)	Implants (initial/ follow-up)	Type of treatment	Materials used	Follow-up period	Surface impact
Aghazadeh et al. (2022) (32)	• Mixed (Turned and medium-rough)	• Not explicitly stated, categorized by surface type	• 45 (AB:22/16, BDX:23/23)	• 75 (AB:36/25, BDX:39/38)	• Reconstructive surgery (autogenous bone, xenograft, collagen membrane)	• Autogenous bone, xenograft (Bio-Oss), collagen membrane (OsseoGuard), titanium curettes, hydrogen peroxide, azithromycin, CHX rinse	• 5 years	• No significant difference (turned vs. medium-rough surfaces)
Carcuac et al. (2020) (15)	• Mixed (modified/non-modified)	• Not specified, classified as non-modified/modified	• 100/73	• 179/130	• Open-flap debridement, surface decontamination, pocket elimination	• Systemic antibiotics, local antiseptics	• 5 years	• Modified surfaces higher recurrence risk (OR 5.1, 95% CI: 1.6–16.5)
Deppe et al. (2007) (18)	• Mixed (rough predominantly)	• IMZ, Frialit-2, Brånemark, Straumann screw-type	• 32	• 73 (Conventional:34, Laser:39)	• Conventional vs. CO_2 laser-assisted (soft tissue resection/augmentation)	• CO_2 laser, air-powder abrasive, β-TCP/autogenous bone, Gore-Tex membrane	• 5 years	• Superior outcomes with CO_2 laser in non-reconstructive therapy
Jemt & Eriksson (2021) (19)	• Mixed (Turned and moderately rough surfaces)	• Brånemark (turned), TiUnite, Astra Tech OsseoSpeed, Lifecore RBM	• 122 (initially 134, 12 lost)	• 614/453	• Non-reconstructive surgery (mechanical cleaning, osseous recontouring, antibiotics)	• Mechanical debridement, hydrogen peroxide 10%, systemic antibiotics	• Mean 7.3 years	• No significant difference (turned vs. moderately rough surfaces)
Khoury & Buchmann (2001) (20)	• Rough surfaces	• IMZ, Frialit-2 (Friadent GmbH)	• 25	• 41	• Reconstructive surgery (autogenous bone ± membranes)	• Autogenous bone, ePTFE/Bioabsorbable barriers, CHX, citric acid, hydrogen peroxide, systemic antibiotics	• 3 years	• No surface comparison (all rough)
La Monaca et al. (2024) (22)	• Rough (TiUnite surface)	• Nobel Biocare (Brånemark System, Göteborg)	• 34/23	• 34/20	• Reconstructive surgery (MDBA, resorbable membrane, chemical/mechanical decontamination)	• MDBA (Puros), collagen membrane (Bio-Gide), hydrogen peroxide, CHX solution, tetracycline hydrochloride, systemic antibiotics (Amox/clav, Metronidazole)	• 10 years	• All rough (TiUnite); no surface-specific comparison
La Monaca et al. (2018) (21)	• Rough (TiUnite surface)	• Nobel Biocare (Brånemark System, Göteborg)	• 34	• 34	• Reconstructive surgical therapy (MDBA, resorbable collagen membrane, chemical/mechanical decontamination)	• MDBA (Puros), resorbable membrane (Bio-Gide), hydrogen peroxide, CHX 0.2%, tetracycline hydrochloride, systemic antibiotics	• 5 years	• All rough (TiUnite); no surface comparison
Leonhardt et al. (2003) (23)	• Turned surfaces	• Brånemark System (Nobel Biocare)	• 9	• 26	• Surgical non-reconstructive therapy + systemic antibiotics	• Hydrogen peroxide 10%, individualized antibiotics (metronidazole, amoxicillin, tetracycline, ciprofloxacin, clindamycin), CHX rinse	• 5 years	• All turned surfaces; not directly analyzed
Mercado et al. (2018) (24)	• Rough (Micro-rough)	• Branemark TiUnite (46.66%), Astra Tech (26.66%), Straumann (10%), Others (16.66%)	• 30	• 30	• Regenerative surgery (DBBMC, EMD, doxycycline, EDTA, ultrasonic scaler)	• DBBMC, EMD, doxycycline, EDTA 24%, ultrasonic scaler, chlorhexidine 0.12%	• 36 months	• Not specifically analyzed (micro-rough surfaces)

(*Continued*)

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TABLE 1a Continued

Author (year)	Implant surface	Implant brand	Patients (initial/ follow-up)	Implants (initial/ follow-up)	Type of treatment	Materials used	Follow-up period	Surface impact
Noelken et al. (2023) (25)	• Mixed (rough predominantly)	• Straumann, Ankylos, Brånemark, NobelActive, NobelPerfect, Frialit I, OsseoSpeed, Camlog, ICX	• 18	• 24	• LAPIDER (laser-assisted regeneration, autogenous bone, CT graft)	• Er:YAG laser, autogenous bone chips, doxycycline, CT graft, resorbable sutures	• 3 years	• No direct comparison; rough surfaces only
Roccuzzo et al. (2017) (26)	• Rough (SLA and TPS)	• Straumann (SLA, TPS)	• 26/24	• 26/24	• Regenerative surgery (DBBMC, EDTA, CHX)	• DBBMC (Bio-Oss Collagen), EDTA 24%, CHX gel 1%, antibiotics (Amoxicillin/ clavulanic acid)	• 7 years	• SLA better clinical outcomes than TPS (significant)
Roccuzzo et al. (2020) (27)	• Rough (SLA and TPS)	• Straumann (SLA, TPS)	• 26/14	• 26/14	• Regenerative surgery (DBBMC, EDTA, CHX)	• DBBMC (Bio-Oss Collagen), EDTA 24%, CHX gel 1%, antibiotics (Amoxicillin/ clavulanic acid)	• 10 years	• SLA superior survival/ outcomes compared to TPS
Roccuzzo et al. (2021) (28)	• Rough (SLA)	• Straumann (SLA implants)	• 75/51	• 75/64	• Reconstructive surgery (DBBMC, EDTA, CHX gel, titanium curettes, connective tissue graft)	• DBBMC, EDTA 24%, CHX 1% gel, titanium curettes, titanium brush, connective tissue graft, systemic antibiotics	• 5 years	• Uniform (all SLA surfaces)
Romandini et al. (2024) (16)	• Mixed (Turned and Modified)	• Nobel Biocare (74.2%), Astra Tech (18%), Straumann (6.7%), Neoss (1.1%)	• 149	• 267	• Non-reconstructive surgical therapy (titanium-coated curettes, systemic antibiotics)	• Titanium-coated curettes, saline/CHX gauze, selective systemic antibiotics (Amoxicillin)	• Mean 7 years (range 1-18 years)	• Modified surfaces significantly higher implant loss risk (HR = 4.5)
Roos-Jansåker et al. (2011) (29)	• Primarily machined, few modified (rough)	• Brånemark (majority), Astra Tech (minority)	• 38/32	• 65/56	• Reconstructive surgery (Algipore ± membrane)	• Algipore, Osseoquest membrane, H_2O_2 3%, antibiotics (amoxicillin, metronidazole), CHX 0.1% rinse	• 3 years	• No significant impact reported (mostly machined)
Roos-Jansåker et al. (2014) (30)	• Primarily machined, few modified (rough)	• Brånemark (majority), Astra Tech (minority)	• 38/25	• Not initially specified/ 45	• Reconstructive surgery (Algipore ± membrane)	• Algipore, Osseoquest membrane, H_2O_2 3%, antibiotics (amoxicillin, metronidazole), CHX rinse	• 5 years	• No significant impact (mostly machined surfaces)
Schwarz et al. (2009) (31)	• Mixed (machined and rough surfaces)	• Brånemark, Camlog, ITI, KSI Bauer Schraube, Zimmer, ZL-Duraplant	• 22/19	• 22/19	• Regenerative surgery (NBM + CM vs. NHA)	• NBM (BioOss), CM (BioGide), NHA (Ostim), plastic curettes, CHX 0.2%	• 48 months	• Surface-specific outcomes not detailed

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TABLE 1b Comparative outcomes of clinical studies on peri-implantitis treatments: implant surfaces, secondary outcomes, and long-term surface impact.

Author (year)	Implant loss (%)	Disease resolution	Radiographic bone loss/gain	Mean PD post-treatment	Subgroup analysis (by surface & approach)	Conclusions surface impact
Aghazadeh et al. (2022) (32)	• AB: 1 fractured, BDX: 1 fractured (both initially)	• PD reduction AB: 1.7 mm, BDX: 2.8 mm at 5 years	• AB: −0.7 mm (loss), BDX: + 1.6 mm (gain)	• AB: PD reduced by 1.7 mm, BDX: by 2.8 mm at 5 years	• BDX superior to AB; reconstructive approach only, no surface-specific outcomes detailed	• BDX superior to AB; supportive maintenance every 3 months emphasized.No significant difference (turned vs. medium-rough surfaces)
Carcuac et al. (2020) (15)	• 20.8%	• Not explicitly combined; PD ≥ 6 mm at 1 year = increased recurrence (OR 7.4)	• Stable from year 1; further loss >1 mm in 13.1%	• 5.0 mm (stable from year 1 at 4.9 mm)	• Non-modified: 17% recurrence, Modified: 52% recurrence; no explicit surgical subgroup	• Surgical treatment effective, but 44% recurrence; modified surfaces, deep residual PD major risk factors.Modified surfaces higher recurrence risk (OR 5.1, 95% CI: 1.6–16.5)
Deppe et al. (2007) (18)	• 17.8%	• Superior PD reduction laser (1.0–2.4 mm at 4 months)	• Laser better short-term bone gain; long-term similar outcomes	• Laser: 1.0–2.4 mm, Conventional: 2.4–7.9 mm (long-term)	• Laser superior in soft tissue resection; similar in augmentation	• Laser beneficial in non-reconstructive procedures; similar long-term results in augmentation.Superior outcomes with CO_2 laser in non-reconstructive therapy
Jemt & Eriksson (2021) (19)	• 16.7%	• Not explicitly reported; primarily bone-level outcomes	• Increased bone loss post-treatment (0.26 mm/year)	• PD not explicitly reported	• No significant differences between surface types; increased bone loss post-treatment	• Surgical treatment ineffective long-term; bone loss accelerated post-treatment, edentulous worse prognosis.No significant difference (turned vs. moderately rough surfaces)
Khoury & Buchmann (2001) (20)	• 0% explicitly reported	• PD improvement: Bone alone 8.0→2.9 mm, worse with membranes (7.7→5.1 mm)	• Significant bone gain (bone alone 3.2 mm, membranes lower)	• Bone alone: 2.9 mm; Non-resorbable: 2.8 mm; Bioabsorbable: 5.1 mm	• Bone alone superior; membranes caused high complications	• Bone grafting alone effective; membranes did not enhance outcomes, increased complications.No surface comparison (all rough)
La Monaca et al. (2024) (22)	• 8.8%	• Composite success: 53%, PD significantly reduced to 2.95 mm at 10 years	• Mean bone gain: 1.07 mm (stable 10 years)	• Reduced from 6.33 mm to 2.95 mm at 10 years	• Reconstructive approach only; stable bone gain, PD improvement, composite success 53%	• Long-term reconstructive therapy stable; supportive therapy crucial, defect severity not significant.All rough (TiUnite); no surface-specific comparison
La Monaca et al. (2018) (21)	• 0%	• PD reduced initially, increased by 5 years (4.62 mm, nonsignificant from baseline)	• Initial significant bone gain (1 year), gradual loss by 5 years	• 4.62 mm at 5 years (from 5.93 mm baseline)	• Reconstructive surgery initially effective, unstable outcomes long-term	• Initial benefits lost over time, no implants lost; unpredictable outcomes long-term.All rough (TiUnite); no surface comparison
Leonhardt et al. (2003) (23)	• 27%	• Significant reduction plaque (100%→11%) and bleeding (100%→5%)	• Stable in 9 implants, gain in 6 implants, loss in 4 implants	• Not explicitly reported; clinical signs significantly improved	• Non-reconstructive approach; success 58%, significant clinical improvements	• Limited success (58%); smoking negatively impacted outcomes.All rough surfaces; not directly analyzed
Mercado et al. (2018) (24)	• 0%	• Mean PD from 8.9 mm to 3.5 mm; BOP/suppuration from 100% to 20%	• Bone gain (6.92 mm to 2.60 mm mean bone loss at 36 months)	• Reduced from 8.9 mm to 3.5 mm at 36 months	• Regenerative (reconstructive) approach only, significant PD reduction and bone gain; success 56.7%	• Regenerative treatment effective (56.7% success); regular supportive therapy critical.Not specifically analyzed (micro-rough surfaces)

(*Continued*)

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TABLE 1b Continued

Author (year)	Implant loss (%)	Disease resolution	Radiographic bone loss/gain	Mean PD post-treatment	Subgroup analysis (by surface & approach)	Conclusions surface impact
Noelken et al. (2023) (25)	• 8.3%	• PD significantly reduced (5.05 to 3.08 mm), BOP 100% to 36.4%	• Significant bone gain (Interproximal 3.1 mm, Buccal 3.5 mm, Lingual 1.46 mm)	• Final PD 3.08 mm	• LAPIDER effective for severe defects; significant hard/soft tissue regeneration	• LAPIDER provided substantial regeneration and aesthetic improvements.No direct comparison; rough surfaces only
Roccuzzo et al. (2017) (26)	• 16.7% overall (SLA:16.7%, TPS:28.6%)	• Significant PD reduction, SLA (3.2 mm), TPS (3.4 mm); BOP SLA (7.5%), TPS (30%)	• Significant bone fill SLA (2.1 mm gain), TPS (2.0 mm gain)	• SLA: 3.2 mm, TPS: 3.4 mm	• Regenerative approach better for SLA vs. TPS implants	• DBBMC effective; SLA surfaces significantly better clinical outcomes than TPS.
Roccuzzo et al. (2020) (27)	• SLA:20%, TPS:45%	• Significant PD reduction SLA (3.2 mm), TPS (3.4 mm); BOP significantly reduced	• SLA substantial gain (2.7 mm), TPS moderate gain (2.0 mm)	• SLA: 3.2 mm, TPS: 3.5 mm	• SLA implants superior long-term survival/outcomes	• DBBMC stable outcomes; SLA significantly better than TPS long-term
Roccuzzo et al. (2021) (28)	• 17%	• PD 6.89 mm to 4.06 mm; BOP 70.6% to 17.2%	• Substantial bone fill; no numeric specifics reported	• Reduced from 6.89 mm to 4.06 mm at 5 years	• Reconstructive approach only; SLA implants only, survival 80%, success 45.3%, significant PD reduction	• Reconstructive protocol effective; adherence to supportive therapy significantly improves outcomes.
Romandini et al. (2024) (16)	• 19.9%	• Not explicitly; high recurrence, retreatment common (24.3%)	• Mean additional bone loss: 0.97 mm; >1 mm loss in 42.4%	• Not explicitly detailed post-treatment; baseline deepest PD 7.8 mm	• Turned surfaces significantly better prognosis; modified surfaces high loss risk (HR = 4.5)	• High recurrence; surface type crucial predictor, severe baseline bone loss/suppuration increase loss risk.Modified surfaces significantly higher implant loss risk (HR = 4.5)
Roos-Jansåker et al. (2011) (29)	• 0%	• Clinical measures not explicitly detailed	• Stable bone fill: bone graft (1.3 mm), membrane (1.6 mm), no significant difference	• Not explicitly reported	• Stable outcomes, no significant membrane advantage	• Algipore ± membrane effective, stable bone fill, membrane no additional advantage.No significant impact reported (mostly machined)
Roos-Jansåker et al. (2014) (30)	• 0%	• PD reduction: 3.0–3.3 mm, BOP significantly reduced	• Bone gain stable: 1.1–1.3 mm, no significant membrane advantage	• 2.6–2.7 mm	• No significant advantage with membrane	• Stable results; membrane no additional advantage over bone substitute alone.No significant impact (mostly machined surfaces).
Schwarz et al. (2009) (31)	• 0% explicitly reported (1 discontinued)	• NBM + CM: PD reduction 2.5 mm, NHA: 1.1 mm, BOP significantly reduced	• NBM + CM superior bone fill compared to NHA	• NBM + CM: 4.6 mm, NHA: 5.8 mm	• NBM + CM significantly better than NHA	• NBM + CM superior long-term clinical/radiographic outcomes vs. NHA.Surface-specific outcomes not detailed.

AB, autogenous bone; BDX, bovine-derived xenograft; BOP, bleeding on probing; CAL, clinical attachment level; CHX, chlorhexidine; CI, confidence interval; CM, collagen membrane; CO_2, carbon dioxide; CT, connective tissue; DBBMC, deproteinized bovine bone mineral with collagen; DH, defect height; EMD, enamel matrix derivative; ePTFE, expanded polytetrafluoroethylene; H_2O_2, hydrogen peroxide; HR, hazard ratio; LAPIDER, laser-assisted peri-implant defect regeneration; MBL, marginal bone level; MDBA, mineralized dehydrated bone allograft; NBM, natural bone mineral; NHA, nanocrystalline hydroxyapatite; OR, odds ratio; PD, probing depth; P-IS, peri-implantitis surgery; SLA, sandblasted large grit acid-etched; SOP, suppuration on probing; TPS, titanium plasma-sprayed; β-TCP, beta-tricalcium phosphate.

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3.2.5 Variability in diagnostic criteria

Despite a general agreement on the primary diagnostic signs—probing depth, BOP/suppuration, and radiographic bone loss—variability exists in the specific thresholds and additional criteria applied across studies.

A detailed overview of the case definitions used to include patients with peri-implantitis in each study (treatment group) is provided in Table 2.

3.3 Primary outcome: recurrence and treatment failure

The included studies demonstrated that implant surface characteristics influenced recurrence rates following surgical peri-implantitis treatment. Modified (rough) surfaces consistently showed higher recurrence compared with turned (machined) surfaces. Carcuac et al. reported an overall recurrence of 44%, with a significantly increased risk for modified surfaces (OR 5.1) (15). Similarly, Romandini et al. found a retreatment rate of 24.3%. In contrast, studies involving turned surfaces, such as Leonhardt et al., reported more stable outcomes (23). These findings indicate that surface roughness is a key determinant of recurrence and long-term treatment stability. Studies by Schwarz et al., Mercado et al. and Noelken et al. documented relatively stable outcomes without explicitly reporting significant recurrence rates (24, 25, 31).

3.4 Secondary outcomes

3.4.1 Implant loss

Implant loss was more frequent among rough surface implants, especially TPS, with Roccuzzo et al. reporting loss in 45% of TPS implants (27), and Leonhardt et al. reporting 27% for turned surfaces (23). SLA surfaces demonstrated better survival than TPS, with 20% vs. 45% loss after 10 years (27). Modified surfaces were identified as a strong predictor of implant loss (HR 4.5) (16). Turned surfaces generally exhibited lower long-term loss risk, around 20%, compared to modified ones (16). Lower implant loss rates were generally associated with reconstructive surgical approaches, as observed by Noelken et al. 8.3% (25) and La Monaca et al. (22), 8.8%.

3.4.2 Disease resolution and probing depth (PD)

Reconstructive surgery generally improved PD irrespective of surface, but rough surfaces demonstrated greater variability. Mercado et al. (2018) reported PD reduction from 8.9 mm to 3.5 mm on micro-rough implants (24), while Noelken et al. achieved PD reduction from 5.05 mm to 3.08 mm in

TABLE 2 Definitions of periimplantitis.

Study	Definition of periimplantitis
Aghazadeh et al., 2022 (32)	Probing pocket depths of at least 5 mm, presence of bleeding on probing and/or suppuration, radiographic bone loss of 2 mm or more from implant placement to screening, and an angular peri-implant bone defect of 3 mm or greater
Carcuac et al., 2020 (15)	Probing pocket depths of 6 mm or more, presence of bleeding on probing, reduced marginal bone level and progressive bone loss greater than 1 mm post-treatment
Deppe et al., 2007 (18)	Probing pocket depths of at least 5 mm, presence of bleeding on probing, radiographic evidence of progressive vertical bone loss, and clinical signs of inflammation
Jemt etal., 2021 (19)	Bone loss exceeding 0.4 mm, mucosal inflammation, presence of plaque and/or suppuration, and radiographic evidence of marginal bone loss
Khoury et al., 2001 (20)	Bone loss of more than 50% of the implant length, augmented probing depths, bleeding on probing, and radiographic evidence of intrabony defects
La Monaca et al., 2018 (21)	Progressive bone loss of 3 mm or more detected on radiographs, the presence of bleeding on probing and/or suppuration, and probing depths of at least 5 mm
La Monaca et al., 2024 (22)	Progressive angular bone loss of at least 3 mm beyond crestal bone level changes, the presence of bleeding on gentle probing and/or suppuration, and implants in function for more than 12 months
Leonhardt et al., 2003 (23)	Marginal bone loss of at least three implant threads compared to baseline radiographs, bleeding on probing and/or suppuration from peri-implant sulci, and microbiological confirmation of peri-implant pathogens
Mercado et al., 2018 (24)	Probing pocket depths exceeding 4 mm, the presence of bleeding on probing and/or suppuration, a minimum radiographic bone loss of 20%, and implants that have been in function for at least 2 years
Noelken et al., 2023 (25)	Probing pocket depths greater than 5 mm, the presence of bleeding on probing and suppuration, and radiographically confirmed bone loss
Roccuzzo et al., 2017 (26)	Probing pocket depths of at least 6 mm, no implant mobility, bleeding on probing and/or suppuration, and radiographic bone loss exceeding three implant threads compared to baseline
Roccuzzo et al., 2020 (27)	Probing pocket depths of 6 mm or greater, the presence of bleeding on probing and/or suppuration, radiographic bone loss beyond crestal changes, and the absence of implant mobility
Roccuzzo et al., 2021 (28)	Probing pocket depths reach or exceed 6 mm, bleeding on probing, radiographic evidence of progressive bone loss, and the presence of pus or inflammation
Romandini et al., 2024 (16)	Probing pocket depths of 6 mm or more, bleeding and/or suppuration on probing, and radiographic evidence of marginal bone loss equal to or greater than 3 mm
Roos-Jansåker et al., 2011 (29)	Radiographic bone loss of at least 1.8 mm following the first year in function, the presence of bleeding and/or pus on probing, and inclusion criteria of non-mobile implants
Roos-Jansåker et al., 2014 (30)	Radiographic bone loss of at least 3 threads (≥1.8 mm), the presence of a vertical defect component, and bleeding on probing and/or suppuration
Schwarz et al., 2009 (31)	Probing pocket depths greater than 4 mm, presence of bleeding on probing and/or suppuration, radiographic evidence of bone loss, and an intrabony defect component of at least 3 mm

TABLE 3a Risk of bias assessment for RCTs: RoB 2 risk of bias assessment.

Study	Bias arising from the randomization process	Bias due to deviations from intended interventions	Bias due to missing outcome data	Bias in measurement of the outcome	Bias in selection of the reported result	Overall bias
Schwarz 2009 (31)	Low	Low	Some concerns	Low	Low	Some concerns

predominantly rough implants (25) identifying disease resolution. Roccuzzo et al. observed significant PD improvements for SLA implants compared with TPS (26, 27). Turned implants Leonhardt et al., also demonstrated significant PD reduction (23). Conversely, non-reconstructive surgical approaches such as that of Deppe et al. with predominantly rough surfaces showed initial short-term PD reductions with inconsistent long-term stability (18).

3.4.3 Radiographic bone changes

Bone regeneration outcomes were surface-dependent. Reconstructive procedures around rough implants, particularly SLA, showed consistent bone gain (Roccuzzo et al. + 2.1 mm; + 2.7 mm) (26, 27). TPS implants demonstrated less favorable long-term stability, even with grafting (27). Smooth (turned) surfaces were rarely evaluated in regenerative contexts, limiting conclusions. Khoury & Buchmann reported substantial bone gain (3.2 mm) on rough implants with autografts (20), while Roos-Jansåker et al. found stable bone gain (1.1–1.6 mm) in predominantly machined implants (29, 30).

3.5 Subgroup analyses

3.5.1 Turned surfaces

Showed moderate long-term stability, but implant loss remained high when treated non-reconstructively (23). Reconstructive data were limited but suggested stable outcomes (29, 30).

3.5.2 Modified (rough) surfaces

Non-reconstructive approaches resulted in high recurrence and implant loss (15, 16). Reconstructive approaches improved outcomes, with SLA surfaces outperforming TPS (26, 27).

3.5.3 Mixed surfaces

Outcomes were heterogeneous. Laser-assisted non-reconstructive therapy demonstrated short-term benefits Deppe et al. (18), but Jemt & Eriksson reported long-term bone loss regardless of surface type (19). Reconstructive treatments showed better results with natural bone mineral combined with a collagen membrane (NBM + CM) compared to nanocrystalline hydroxyapatite (NHA) (31), but surface-specific differences remained underreported. Aghazadeh et al. reported improved outcomes with xenograft (BDX) usage (32).

The detailed study characteristics and outcomes are presented in Tables 1a,b.

3.6 Risk of bias

The risk of bias assessment for the 17 included studies highlights several concerns across different domains (Tables 3a and b).

The RCT (Schwarz 2009) had some concerns (31).

Among the non-randomized studies, serious risk of bias was frequently noted in selection of participants e.g., Aghazadeh, Carcuac, and La Monaca (15, 17, 22) and missing data e.g., Roccuzzo, Romandini, Roos-Jansaker (16, 27, 30). However, intervention classification and reporting of results were generally at low risk across studies. Confounding and deviations from interventions were rated as moderate risk in most cases.

Ten studies were judged to have a serious overall bias, primarily due to participant selection and missing data. The remaining studies had a moderate overall bias, with issues mainly related to confounding and missing data.

Certainty of evidence for the main outcomes was assessed using the GRADE approach and is presented in Supplementary Table S1. Overall, the certainty was judged to be very low to low across all outcomes, primarily due to serious risk of bias, high heterogeneity of diagnostic criteria and outcome definitions, small sample sizes, and imprecision of effect estimates.

4 Discussion

This systematic review aimed to evaluate the impact of implant surface characteristics on the long-term outcomes of surgical treatment of peri-implantitis. The main findings indicate that modified (rough) surfaces are consistently associated with higher recurrence and implant loss compared with turned (machined) surfaces. Within rough surfaces, SLA implants achieved more favorable outcomes than TPS, particularly in reconstructive contexts (15, 16, 26–28). In contrast, smooth implants demonstrated comparatively lower recurrence (23). These results underscore that implant surface topography can be a determinant of surgical treatment prognosis.

The effectiveness of peri-implantitis surgery is influenced by both treatment modality and implant surface. For non-regenerative procedures, modified surfaces were repeatedly associated with worse outcomes: Carcuac et al. reported a 44% recurrence rate with rough implants (15), while Romandini et al. identified modified surfaces such as TiUnite and SLA as predictors of implant loss (16). In contrast, turned surfaces showed more stable disease suppression (23).

For regenerative approaches, implant surface also played a key role. SLA implants demonstrated favorable long-term bone gain

TABLE 3b Risk of bias assessment for non- RCTs: ROBINS-i risk of bias assessment.

Study	Bias due to confounding	Bias in selection of participants into the study	Bias in classification of interventions	Bias due to deviations from intended interventions	Bias due to missing data	Bias in measurement of outcomes	Bias in selection of reported results	Overall bias
Aghazadeh 2022 (32)	Moderate	Serious	Low	Moderate	Serious	Moderate	Low	Serious
Carcuac 2020 (15)	Moderate	Serious	Low	Moderate	High	Low	Low	Serious
Deppe 2007 (18)	Moderate	Moderate	Low	Moderate	Serious	Moderate	Low	Serious
Jemt et al. 2021 (19)	Moderate	Serious	Low	Moderate	Serious	Moderate	Low	Serious
Khoury 2001 (20)	Serious	Low	Moderate	Moderate	Low	Moderate	Low	Moderate
La Monaca 2018 (21)	Moderate	Moderate	Low	Moderate	Serious	Low	Low	Moderate
La Monaca 2024 (22)	Serious	Serious	Low	Moderate	Serious	Moderate	Low	Serious
Leonhardt 2003 (23)	Moderate	Low	Low	Moderate	Low	Moderate	Low	Moderate
Mercado 2018 (24)	Moderate	Low	Low	Moderate	Low	Low	Low	Moderate
Noelken 2023 (25)	Moderate	Moderate	Low	Moderate	Serious	Moderate	Low	Moderate
Roccuzzo 2017 (26)	Moderate	Moderate	Low	Moderate	Moderate	Low	Low	Moderate
Roccuzzo 2020 (27)	Moderate	Serious	Low	Moderate	Serious	Low	Low	Serious
Roccuzzo 2021 (28)	Moderate	Serious	Low	Moderate	Serious	Moderate	Low	Serious
Romandini 2024 (16)	Moderate	Serious	Low	Moderate	Serious	Moderate	Low	Serious
Roos-Jansaker 2011 (29)	Moderate	Serious	Low	Moderate	Serious	Low	Low	Serious
Roos-Jansaker 2014 (30)	Moderate	Serious	Low	Moderate	Serious	Low	Low	Serious

and PD reduction (26–28), whereas TPS implants performed poorly even when grafting was applied (27). Although smooth implants were less frequently studied in regenerative contexts, available evidence suggests they may perform adequately when combined with supportive therapy (29, 30).

Bone regeneration outcomes differed substantially according to surface characteristics. Greater bone fill was generally reported around rough surfaces when grafting materials were used. Khoury and Buchmann observed a 2.4 mm gain at 12 months using autogenous grafts on rough implants (20). Roccuzzo et al. reported significant defect reduction with xenografts, particularly in SLA implants, while TPS implants showed limited stability (26, 27). Comparable results with alloplastic materials were also noted (33, 34). However, bone regeneration around smooth surfaces was less favorable: Roos-Jansåker et al. reported limited improvement with alloplastic grafts (30). Thus, while rough implants may predispose to recurrence, they also appear to support more pronounced bone regeneration after reconstructive procedures.

This paradox may be explained by surface-related biology. Rough surfaces are harder to decontaminate and accumulate more plaque (35, 36), yet they may stabilize the coagulum and promote defect fill (37). Accordingly, radiographic bone gain does not necessarily correspond to re-osseointegration, as several animal studies identified connective tissue interposition rather than true reattachment (38–40).

The role of membranes in guided bone regeneration (GBR) has also been linked to implant surfaces. Khoury et al. showed greater bone gain with non-resorbable membranes around rough implants (20), while Deppe et al. observed comparable results with resorbable membranes (18). These data suggest that both membrane type and surface roughness influence regenerative outcomes. Furthermore, clinical studies and experimental models in dogs indicate that rough surfaces generally achieve greater defect fill than smooth surfaces under GBR conditions (37).

Surface characteristics may also impact soft tissue attachment. Excessively smooth surfaces can impair mucosal adhesion, as Quirynen et al. observed attachment loss on polished abutments compared with stable CAL around commercially available surfaces (41). Other studies support that maintaining a certain degree of roughness enhances soft tissue sealing (42). These findings provide a biological explanation for the improved clinical outcomes of rough implants after GBR, despite their higher susceptibility to recurrence.

Interpretation of the evidence is complicated by considerable heterogeneity. Defect morphology influences outcomes, with narrower defects showing better results (17, 43), yet most studies failed to provide detailed descriptions, limiting cross-study comparisons. Moreover, peri-implantitis definitions varied widely: Roccuzzo et al. required ≥6 mm PD and bone loss exceeding three implant threads (26), while Mercado et al. used ≥4 mm PD and ≥20% radiographic bone loss (24). Measurement variability further complicates interpretation (44). Such inconsistencies directly affect assessment of surface-related outcomes and hinder robust comparisons across studies.

This review is limited by the substantial heterogeneity among the included studies, particularly in peri-implantitis diagnostic

criteria, defect morphology, surgical techniques, and outcome measures. Most studies were small in size, lacked standardized definitions, and many were judged to have a serious overall risk of bias, especially in participant selection and missing data. Confounding variables were insufficiently controlled, further reducing certainty. Furthermore, the restriction to English-language studies may have introduced language bias, potentially leading to omission of relevant non-English publications. Applying the GRADE framework, the certainty of the available evidence was rated as very low to low for all main outcomes, reflecting methodological shortcomings and heterogeneity among the included studies. These limitations restrict the generalizability of the findings and reinforce the need for well-designed, adequately powered randomized controlled trials with standardized definitions and longer follow-up.

5 Conclusion

The effectiveness of peri-implantitis surgery is influenced by implant surface characteristics and treatment modality. Modified surfaces are generally more prone to recurrence and implant loss, with SLA implants performing better than TPS, while turned surfaces appear less susceptible but remain insufficiently studied in regenerative contexts. Reconstructive approaches combined with supportive care consistently provide the most favorable outcomes. Given the very low to low certainty of the evidence with heterogenous results, current findings should be interpreted with caution, and well-designed long-term randomized trials with standardized definitions and consistent surface classifications are urgently needed. Future trials should adopt standardized outcome definitions (e.g., PD thresholds, BOP, radiographic bone loss criteria) to allow comparability across studies. Research should focus on RCTs directly comparing surface types, long-term follow-up, and adjustment for confounding factors such as defect morphology and maintenance compliance. Addressing these gaps will clarify the role of implant surface modifications.

5.1 Clinical implications

When planning peri-implantitis surgery, implant surface characteristics should be taken into account, but they must not be considered in isolation. Evidence indicates that reconstructive approaches yield more reliable outcomes than non-reconstructive ones, particularly for rough implants, with SLA surfaces performing more favorably than TPS. Turned (machined) surfaces appear less prone to recurrence, although data on regenerative protocols remain scarce. These observations suggest that implant surface may influence prognosis, yet it represents only one part of a complex clinical picture.

Patient-related risk factors (such as smoking, systemic conditions, low compliance and/or adherence to supportive care) exert a profound effect on long-term success and may outweigh surface-related differences. Surgical decision-making should therefore be individualized, integrating implant surface type, defect morphology, patient risk profile, and anticipated compliance. The use of biomaterials and barrier membranes may enhance regenerative outcomes around rough implants, but clinicians should be cautious, as radiographic bone gain does not necessarily reflect true re-osseointegration, and complete defect resolution is rarely achievable.

Nevertheless, these clinical implications must be interpreted with caution. The available evidence is heterogeneous, often based on small studies with differing peri-implantitis definitions, inconsistent outcome measures, and a serious overall risk of bias. The evidence was rated as very low to low for all main outcomes. This means that while current data can guide clinical choices, they cannot provide definitive recommendations.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

PG: Conceptualization, Formal analysis, Methodology, Data curation, Writing – original draft, Writing – review & editing, Investigation. CG: Formal analysis, Methodology, Data curation, Writing – review & editing. AS: Conceptualization, Formal analysis, Methodology, Data curation, Investigation, Writing – review & editing, Project administration. AZ: Supervision, Conceptualization, Methodology, Formal analysis, Data curation, Investigation, Writing – original draft, Writing – review & editing.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fdmed.2025.1661369/full#supplementary-material

References

1. Albrektsson T, Wennerberg A. On osseointegration in relation to implant surfaces. *Clin Implant Dent Relat Res*. (2019) 21(Suppl 1):4–7. doi: 10.1111/cid.12742

2. Rupp F, Liang L, Geis-Gerstorfer J, Scheideler L, Hüttig F. Surface characteristics of dental implants: a review. *Dent Mater*. (2018) 34(1):40–57. doi: 10.1016/j.dental.2017.09.007

3. Shayeb MA, Elfadil S, Abutayyem H, Shqaidef A, Marrapodi MM, Cicciù M, et al. Bioactive surface modifications on dental implants: a systematic review and meta-analysis of osseointegration and longevity. *Clin Oral Investig*. (2024) 28(11):592. doi: 10.1007/s00784-024-05958-y

4. Souza JCM, Sordi MB, Kanazawa M, Ravindran S, Henriques B, Silva FS, et al. Nano-scale modification of titanium implant surfaces to enhance osseointegration. *Acta Biomater*. (2019) 94:112–31. doi: 10.1016/j.actbio.2019.05.045

5. Matos GRM. Surface roughness of dental implant and osseointegration. *J Maxillofac Oral Surg*. (2021) 20(1):1–4. doi: 10.1007/s12663-020-01437-5

6. Romero-Serrano M, Romero-Ruiz MM, Herrero-Climent M, Rios-Carrasco B, Gil-Mur J. Correlation between implant surface roughness and implant stability: a systematic review. *Dent J (Basel)*. (2024) 12(9):276. doi: 10.3390/dj12090276

7. Kupka JR, König J, Al-Nawas B, Sagheb K, Schiegnitz E. How far can we go? A 20-year meta-analysis of dental implant survival rates. *Clin Oral Investig*. (2024) 28(10):541. doi: 10.1007/s00784-024-05929-3

8. Renvert S, Persson GR, Pirih FQ, Camargo PM. Peri-implant health, peri-implant mucositis, and peri-implantitis: case definitions and diagnostic considerations. *J Periodontol*. (2018) 89(Suppl 1):S304–s12. doi: 10.1002/JPER.17-0588

9. Diaz P, Gonzalo E, Villagra LJG, Miegimolle B, Suarez MJ. What is the prevalence of peri-implantitis? A systematic review and meta-analysis. *BMC Oral Health*. (2022) 22(1):449. doi: 10.1186/s12903-022-02493-8

10. Hussein A, Shah M, Atieh MA, Alhimairi S, Amir-Rad F, Elbishari H. Influence of implant surfaces on peri-implant diseases – A systematic review and meta-analysis. *Int Dent J*. (2025) 75(1):75–85. doi: 10.1016/j.identj.2024.10.007

11. Stavropoulos A, Bertl K, Winning L, Polyzois I. What is the influence of implant surface characteristics and/or implant material on the incidence and progression of peri-implantitis? A systematic literature review. *Clin Oral Implants Res*. (2021) 32(Suppl 21):203–29. doi: 10.1111/clr.13859

12. Garaicoa-Pazmino C, Lin GH, Alkandery A, Parra-Carrasquer C, Suárez-López Del Amo F. Influence of implant surface characteristics on the initiation, progression and treatment outcomes of peri-implantitis: a systematic review and meta-analysis based on animal model studies. *Int J Oral Implantol (Berl)*. (2021) 14(4):367–82.

13. Vernon JJ, Raïf EM, Aw J, Attenborough E, Jha A, Do T. Dental implant surfaces and their interaction with the oral microbiome. *Dentistry Review*. (2022) 2(4):100060. doi: 10.1016/j.dentre.2022.100060

14. Wassmann T, Kreis S, Behr M, Buergers R. The influence of surface texture and wettability on initial bacterial adhesion on titanium and zirconium oxide dental implants. *Int J Implant Dent*. (2017) 3(1):32. doi: 10.1186/s40729-017-0093-3

15. Carcuac O, Derks J, Abrahamsson I, Wennström JL, Berglundh T. Risk for recurrence of disease following surgical therapy of peri-implantitis-A prospective longitudinal study. *Clin Oral Implants Res*. (2020) 31(11):1072–7. doi: 10.1111/clr.13653

16. Romandini M, Bougas K, Alibegovic L, Hosseini S, Carcuac O, Berglundh T, et al. Long-term outcomes and prognostic factors of surgical treatment of peri-implantitis - A retrospective study. *Clin Oral Implants Res*. (2024) 35(3):321–9. doi: 10.1111/clr.14228

17. Aghazadeh A, Persson GR, Renvert S. Impact of bone defect morphology on the outcome of reconstructive treatment of peri-implantitis. *Int J Implant Dent*. (2020) 6. doi: 10.1186/s40729-020-00219-5

18. Deppe H, Horch HH, Neff A. Conventional versus CO2 laser-assisted treatment of peri-implant defects with the concomitant use of pure-phase beta-tricalcium phosphate: a 5-year clinical report. *Int J Oral Maxillofac Implants*. (2007) 22(1):79–86.

19. Jemt T, Eriksson J. Bone loss before and after peri-implantitis surgery: a 7-year retrospective observational study. *Int J Oral Maxillofac Implants*. (2021) 36(6):1199–210. doi: 10.11607/jomi.9175

20. Khoury F, Buchmann R. Surgical therapy of peri-implant disease: a 3-year follow-up study of cases treated with 3 different techniques of bone regeneration. *J Periodontol*. (2001) 72(11):1498–508. doi: 10.1902/jop.2001.72.11.1498

21. La Monaca G, Pranno N, Annibali S, Cristalli MP, Polimeni A. Clinical and radiographic outcomes of a surgical reconstructive approach in the treatment of peri-implantitis lesions: a 5-year prospective case series. *Clin Oral Implants Res*. (2018) 29(10):1025–37. doi: 10.1111/clr.13369

22. La Monaca G, Pranno N, Annibali S, Polimeni A, Cristalli MP. A 10-year follow-up of reconstructive treatment of peri-implantitis using mineralized dehydrated allograft and resorbable membrane: a retrospective case series. *Clin Oral Implants Res*. (2024) 36:325–38. doi: 10.1111/clr.14385

23. Leonhardt A, Dahlén G, Renvert S. Five-year clinical, microbiological, and radiological outcome following treatment of peri-implantitis in man. *J Periodontol*. (2003) 74(10):1415–22. doi: 10.1902/jop.2003.74.10.1415

24. Mercado F, Hamlet S, Ivanovski S. Regenerative surgical therapy for peri-implantitis using deproteinized bovine bone mineral with 10% collagen, enamel matrix derivative and doxycycline-A prospective 3-year cohort study. *Clin Oral Implants Res*. (2018) 29(6):583–91. doi: 10.1111/clr.13256

25. Noelken R, Westphal L, Schiegnitz E, Al-Nawas B. Hard and soft tissue regeneration of severe peri-implantitis defects with the laser-assisted peri-implant defect regeneration technique: 3-year results. *Int J Implant Dent*. (2023) 9(1):3. doi: 10.1186/s40729-023-00467-1

26. Roccuzzo M, Pittoni D, Roccuzzo A, Charrier L, Dalmasso P. Surgical treatment of peri-implantitis intrabony lesions by means of deproteinized bovine bone mineral with 10% collagen: 7-year-results. *Clin Oral Implants Res*. (2017) 28(12):1577–83. doi: 10.1111/clr.13028

27. Roccuzzo M, Fierravanti L, Pittoni D, Dalmasso P, Roccuzzo A. Implant survival after surgical treatment of peri-implantitis lesions by means of deproteinized bovine bone mineral with 10% collagen: 10-year results from a prospective study. *Clin Oral Implants Res*. (2020) 31(8):768–76. doi: 10.1111/clr.13628

28. Roccuzzo M, Mirra D, Pittoni D, Ramieri G, Roccuzzo A. Reconstructive treatment of peri-implantitis infrabony defects of various configurations: 5-year survival and success. *Clin Oral Implants Res*. (2021) 32(10):1209–17. doi: 10.1111/clr.13818

29. Roos-Jansåker AM, Lindahl C, Persson GR, Renvert S. Long-term stability of surgical bone regenerative procedures of peri-implantitis lesions in a prospective case-control study over 3 years. *J Clin Periodontol*. (2011) 38(6):590–7. doi: 10.1111/j.1600-051X.2011.01729.x

30. Roos-Jansåker AM, Persson GR, Lindahl C, Renvert S. Surgical treatment of peri-implantitis using a bone substitute with or without a resorbable membrane: a 5-year follow-up. *J Clin Periodontol*. (2014) 41(11):1108–14. doi: 10.1111/jcpe.12308

31. Schwarz F, Sahm N, Bieling K, Becker J. Surgical regenerative treatment of peri-implantitis lesions using a nanocrystalline hydroxyapatite or a natural bone mineral in combination with a collagen membrane: a four-year clinical follow-up report. *J Clin Periodontol*. (2009) 36(9):807–14. doi: 10.1111/j.1600-051X.2009.01443.x

32. Aghazadeh A, Persson GR, Stavropoulos A, Renvert S. Reconstructive treatment of peri-implant defects-results after three and five years. *Clin Oral Implants Res*. (2022) 33(11):1114–24. doi: 10.1111/clr.13994

33. Wohlfahrt JC, Lyngstadaas SP, Rønold HJ, Saxegaard E, Ellingsen JE, Karlsson S, et al. Porous titanium granules in the surgical treatment of peri-implant osseous defects: a randomized clinical trial. *Int J Oral Maxillofac Implants*. (2012) 27(2):401–10.

34. Roccuzzo M, Bonino F, Bonino L, Dalmasso P. Surgical therapy of peri-implantitis lesions by means of a bovine-derived xenograft: comparative results of a prospective study on two different implant surfaces. *J Clin Periodontol*. (2011) 38(8):738–45. doi: 10.1111/j.1600-051X.2011.01742.x

35. Subramani K, Jung RE, Molenberg A, Hammerle CH. Biofilm on dental implants: a review of the literature. *Int J Oral Maxillofac Implants*. (2009) 24(4):616–26.

36. Saulacic N, Schaller B. Prevalence of peri-implantitis in implants with turned and rough surfaces: a systematic review. *J Oral Maxillofac Res*. (2019) 10(1):e1. doi: 10.5037/jomr.2019.10101

37. Persson LG, Berglundh T, Lindhe J, Sennerby L. Re-osseointegration after treatment of peri-implantitis at different implant surfaces. An experimental study in the dog. *Clin Oral Implants Res*. (2001) 12(6):595–603. doi: 10.1034/j.1600-0501.2001.120607.x

38. Persson LG, Araújo MG, Berglundh T, Gröndahl K, Lindhe J. Resolution of peri-implantitis following treatment. An experimental study in the dog. *Clin Oral Implants Res*. (1999) 10(3):195–203. doi: 10.1034/j.1600-0501.1999.100302.x

39. Schwarz F, Jepsen S, Herten M, Sager M, Rothamel D, Becker J. Influence of different treatment approaches on non-submerged and submerged healing of ligature induced peri-implantitis lesions: an experimental study in dogs. *J Clin Periodontol*. (2006) 33(8):584–95. doi: 10.1111/j.1600-051X.2006.00956.x

40. You TM, Choi BH, Zhu SJ, Jung JH, Lee SH, Huh JY, et al. Treatment of experimental peri-implantitis using autogenous bone grafts and platelet-enriched fibrin glue in dogs. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. (2007) 103(1):34–7. doi: 10.1016/j.tripleo.2006.01.005

41. Quirynen M, Bollen CM, Papaioannou W, Van Eldere J, van Steenberghe D. The influence of titanium abutment surface roughness on plaque accumulation and gingivitis: short-term observations. *Int J Oral Maxillofac Implants*. (1996) 11(2):169–78.

42. Dorkhan M, Yücel-Lindberg T, Hall J, Svensäter G, Davies JR. Adherence of human oral keratinocytes and gingival fibroblasts to nano-structured titanium surfaces. *BMC Oral Health*. (2014) 14(75). doi: 10.1186/1472-6831-14-75

43. Polyzois I, Renvert S, Bosshardt DD, Lang NP, Claffey N. Effect of bio-Oss on osseointegration of dental implants surrounded by circumferential bone defects of different dimensions: an experimental study in the dog. *Clin Oral Implants Res*. (2007) 18(3):304–10. doi: 10.1111/j.1600-0501.2007.01207.x

44. Koldsland OC, Scheie AA, Aass AM. Prevalence of peri-implantitis related to severity of the disease with different degrees of bone loss. *J Periodontol*. (2010) 81(2):231–8. doi: 10.1902/jop.2009.090269

45. Afrashtehfar KI, Alfallaj HA, Fernandez E, Hussaini S. Guided bone regeneration improves defect fill and reconstructive outcomes in 3-wall peri-implantitis defects. *Evid Based Dent*. (2024) 26:29–31. doi: 10.1038/s41432-024-01073-9

46. Astolfi V, Gómez-Menchero A, Ríos-Santos JV, Bullón P, Galeote F, Ríos-Carrasco B, et al. Influence of removing or leaving the prosthesis after regenerative surgery in peri-implant defects: retrospective study: 32 clinical cases with 2 to 8 years of follow-up. *Int J Environ Res Public Health*. (2021) 18(2):645. doi: 10.3390/ijerph18020645

47. Behneke A, Behneke N, d'Hoedt B. Treatment of peri-implantitis defects with autogenous bone grafts: six-month to 3-year results of a prospective study in 17 patients. *Int J Oral Maxillofac Implants*. (2000) 15(1):125–38.

48. Berglundh T, Wennström JL, Lindhe J. Long-term outcome of surgical treatment of peri-implantitis. A 2-11-year retrospective study. *Clin Oral Implants Res*. (2018) 29(4):404–10. doi: 10.1111/clr.13138

49. Bianchini MA, Galarraga-Vinueza ME, Bedoya KA, Correa BB, de Souza Magini R, Schwarz F. Implantoplasty enhancing peri-implant bone stability over a 3-year follow-up: a case series. *Int J Periodontics Restorative Dent*. (2020) 40(1): e1–8. doi: 10.11607/prd.3849

50. Bianchini MA, Kuhlkamp LF, Schwarz F, Galarraga-Vinueza ME. Clinical and radiographic outcomes of resective surgery with adjunctive implantoplasty over a 6- to 11-year follow-up: a case series. *Int J Periodontics Restorative Dent*. (2024) 44(4):466–76. doi: 10.11607/prd.6756

51. Carcuac O, Derks J, Charalampakis G, Abrahamsson I, Wennström J, Berglundh T. Adjunctive systemic and local antimicrobial therapy in the surgical treatment of peri-implantitis: a randomized controlled clinical trial. *J Dent Res*. (2016) 95(1):50–7. doi: 10.1177/0022034515601961

52. Chiang YC, Sirinirund B, Rodriguez A, Velasquez D, Chan HL. Operating microscope-assisted reconstructive strategy for peri-implantitis: a case series report. *Clin Adv Periodontics*. (2024) 14(3):149–56. doi: 10.1002/cap.10265

53. Cortellini P, Cortellini S, Bonaccini D, Tonetti MS. Papilla preservation and minimally invasive surgery for the treatment of peri-implant osseous defects. Clinical and radiographic outcomes of a 5-year retrospective study. *Clin Oral Implants Res*. (2021) 32(11):1384–96. doi: 10.1111/clr.13826

54. Froum SJ, Froum SH, Rosen PS. Successful management of peri-implantitis with a regenerative approach: a consecutive series of 51 treated implants with 3- to 7.5-year follow-up. *Int J Periodontics Restorative Dent*. (2012) 32(1):11–20.

55. Froum SJ, Froum SH, Rosen PS. A regenerative approach to the successful treatment of peri-implantitis: a consecutive series of 170 implants in 100 patients with 2- to 10-year follow-up. *Int J Periodontics Restorative Dent*. (2015) 35(6):857–63. doi: 10.11607/prd.2571

56. Khayat P, Aidan D, Calatrava J, Wang HL. Bone regeneration following implantoplasty: a retrospective cohort study with long-term radiographic assessment. *Int J Periodontics Restorative Dent*. (2024) 0(0):1–17. doi: 10.11607/prd.7422

57. Lombardo G, Marincola M, Cicconetti A, Simancas-Pallares MA, Pighi J, Lehrberg J, et al. Successful management of peri-implantitis around short and ultrashort single-crown implants: a case series with a 3-year follow-up. *Int J Dent*. (2019) 2019:5302752. doi: 10.1155/2019/5302752

58. Monje A, Schwarz F. Principles of combined surgical therapy for the management of peri-implantitis. *Clin Adv Periodontics*. (2022) 12(1):57–63. doi: 10.1002/cap.10186

59. Parma-Benfenati S, Tinti C, Romano F, Roncati M, Aimetti M. Long-Term outcome of surgical regenerative treatment of peri-implantitis: a 2- to 21-year retrospective evaluation. *Int J Periodontics Restorative Dent*. (2020) 40(4):487–96. doi: 10.11607/prd.4647

60. Renvert S, Polyzois I, Claffey N. Surgical therapy for the control of peri-implantitis. *Clin Oral Implants Res*. (2012) 23(Suppl 6):84–94. doi: 10.1111/j.1600-0501.2012.02554.x

61. Renvert S, Giovannoli J-L, Rinke S. The efficacy of reconstructive therapy in the surgical management of peri-implantitis: a 3-year follow-up of a randomized clinical trial. *J Clin Periodontol*. (2024) 51(10):1267–76. doi: 10.1111/jcpe.14049

62. Sarmiento HL, Norton M, Korostoff J, Ko KI, Fiorellini JP. Surgical alternatives for treating peri-implantitis. *Int J Periodontics Restorative Dent*. (2018) 38(5):665–71. doi: 10.11607/prd.3639

63. Schwarz F, John G, Becker J. Reentry after combined surgical resective and regenerative therapy of advanced peri-implantitis: a retrospective analysis of five cases. *Int J Periodontics Restorative Dent*. (2015) 35:647–53. doi: 10.11607/prd.2320

64. Schwarz F, Sahm N, Becker J. Combined surgical therapy of advanced peri-implantitis lesions with concomitant soft tissue volume augmentation. A case series. *Clin Oral Implants Res*. (2014) 25(1):132–6. doi: 10.1111/clr.12103

65. Schwarz F, Hegewald A, John G, Sahm N, Becker J. Four-year follow-up of combined surgical therapy of advanced peri-implantitis evaluating two methods of surface decontamination. *J Clin Periodontol*. (2013) 40(10):962–7. doi: 10.1111/jcpe.12143

66. Schwarz F, John G, Schmucker A, Sahm N, Becker J. Combined surgical therapy of advanced peri-implantitis evaluating two methods of surface decontamination: a 7-year follow-up observation. *J Clin Periodontol*. (2017) 44(3):337–42. doi: 10.1111/jcpe.12648

67. Wang CW, Ashnagar S, Gianfilippo RD, Arnett M, Kinney J, Wang HL. Laser-assisted regenerative surgical therapy for peri-implantitis: a randomized controlled clinical trial. *J Periodontol*. (2021) 92(3):378–88. doi: 10.1002/JPER.20-0040

Appendix

Appendix 1 Excluded studies.

Authors and date	Study title	Reason for exclusion
Afrashtehfar et al. 2024 (45)	Guided bone regeneration improves defect fill and reconstructive outcomes in 3-wall peri-implantitis defects	Implant type not taken into consideration
Astolfi et al. 2021 (46)	Influence of removing or leaving the prosthesis after regenerative surgery in peri-implant defects: retrospective study: 32 clinical cases with 2–8 years of follow-up	Outcomes reported not correlated to implant type
Behneke et al. 2000 (47)	Treatment of peri-implantitis defects with autogenous bone grafts: six-month to 3-year results of a prospective study in 17 patients	Implant type not taken into consideration
Berglundh 2018 (48)	Long- term outcome of surgical treatment of periimplantitis. A 2–11-year retrospective study	Minimum study duration less than 3 years
Bianchini et al. 2020 (49)	Implantoplasty enhancing peri-implant bone stability over a 3-year follow-up: a case series	Implant type not taken into consideration
Bianchini et al. (2024) (50)	Clinical and radiographic outcomes of resective surgery with adjunctive implantoplasty over a 6- to 11-year follow-up: a case series	Implants treated with implantoplasty, which creates a modified surface texture differing from the original implant surface
Carcuac et al. 2016 (51)	Adjunctive systemic and local antimicrobial therapy in the surgical treatment of peri-implantitis: a randomized controlled clinical trial	Study duration less than 3 years
Chiang et al. 2024 (52)	Operating microscope-assisted reconstructive strategy for peri-implantitis: A case series report	Implant type not taken into consideration
Cortellini et al. 2021 (53)	Papilla preservation and minimally invasive surgery for the treatment of peri-implant osseous defects. Clinical and radiographic outcomes of a 5-year retrospective study	Implant type not taken into consideration
Froum et al. 2012 (54)	Successful management of peri-implantitis with a regenerative approach: a consecutive series of 51 treated implants with 3- to 7.5-year follow-up	Outcomes mentioned not correlated to implant surfaces
Froum et al. 2015 (55)	A regenerative approach to the successful treatment of peri-implantitis: a consecutive series of 170 implants in 100 patients with 2- to 10-year follow-up	Implant type not taken into consideration
Khayat et al. 2024 (56)	Bone regeneration following implantoplasty: a retrospective cohort study with long-term radiographic assessment	Implant type not taken into consideration
Lombardo et al. 2019 (57)	Successful management of peri-implantitis around short and ultrashort single-crown implants: a case series with a 3-year follow-up	Implant type not taken into consideration
Monje et al. 2022 (58)	Principles of combined surgical therapy for the management of peri-implantitis	Incorrect study design
Parma-Benfenati et al. 2020 (59)	Long-term outcome of surgical regenerative treatment of peri-implantitis: a 2- to 21-year retrospective evaluation	Study duration less than 3 years (varied for 2–21 years)
Renvert et al. 2012 (60)	Surgical therapy for the control of peri-implantitis	Incorrect study design
Renvert et al. 2024 (61)	The efficacy of reconstructive therapy in the surgical management of peri-implantitis: A 3-year follow-up of a randomized clinical trial	Implant type not taken into consideration
Sarmiento et al. 2018 (62)	Surgical alternatives for treating peri-implantitis	Implant type not taken into consideration
Schwarz et al. 2015 (63)	Reentry after combined surgical resective and regenerative therapy of advanced peri-implantitis: a retrospective analysis of five cases	Implant type not taken into consideration
Schwarz et al. 2014 (64)	Combined surgical therapy of advanced peri-implantitis lesions with concomitant soft tissue volume augmentation. A case series	Study duration less than 3 years
Schwarz et al. 2013 (65)	Four-year follow-up of combined surgical therapy of advanced peri-implantitis evaluating two methods of surface decontamination	Implants treated with implantoplasty, which creates a modified surface texture differing from the original implant surface
Schwarz et al. 2017 (66)	Combined surgical therapy of advanced peri-implantitis evaluating two methods of surface decontamination: a 7-year follow-up observation	Implants treated with implantoplasty, which creates a modified surface texture differing from the original implant surface
Wang et al. 2021 (67)	Laser-assisted regenerative surgical therapy for peri-implantitis: A randomized controlled clinical trial	Study duration less than 3 years

Appendix 2 Full search strategies.

Database	Search Strategy
PubMed (MEDLINE via PubMed)	(Periimplantitis OR peri-implantitis OR peri implantitis OR periimplant OR peri-implant OR peri implant) AND (treatment outcome OR therapy OR surgical treatment OR regenerative OR regeneration OR tissue regeneration OR reconstructive surgery OR bone graft OR bone substitute OR membranes OR surgical flap OR open flap debridement OR resective OR implantoplasty OR surface decontamination) AND (surface characteristics OR surface roughness OR material characteristics OR titanium surface OR implant types OR implant surfaces OR surface topography OR surface analysis) AND (implant survival OR bone loss OR recurrence OR retreatment OR radiographic stability OR long-term OR 3 years OR follow-up)
Embase	('periimplantitis'/exp OR periimplantitis OR 'peri-implantitis' OR 'peri implantitis' OR periimplant OR 'peri-implant' OR 'peri implant') AND ('treatment outcome'/exp OR therapy OR 'surgical treatment'/exp OR 'regenerative therapy'/exp OR regeneration OR 'tissue regeneration' OR 'reconstructive surgery'/exp OR 'bone graft'/exp OR 'bone substitute'/exp OR membranes OR 'surgical flap' OR 'open flap debridement' OR resective OR implantoplasty OR 'surface decontamination') AND ('surface property'/exp OR 'surface roughness'/exp OR 'material property'/exp OR 'titanium surface' OR 'implant type'/exp OR 'implant surface'/exp OR 'surface topography'/exp OR 'surface analysis') AND ('dental implant survival'/exp OR 'bone loss'/exp OR recurrence OR retreatment OR 'radiographic stability' OR 'long term' OR '3 years' OR 'follow-up')
Cochrane library	(periimplantitis OR "peri-implantitis" OR "peri implantitis" OR periimplant OR "peri-implant" OR "peri implant") AND ("treatment outcome" OR therapy OR "surgical treatment" OR regenerative OR regeneration OR "tissue regeneration" OR "reconstructive surgery" OR "bone graft" OR "bone substitute" OR membranes OR "surgical flap" OR "open flap debridement" OR resective OR implantoplasty OR "surface decontamination") AND ("surface characteristics" OR "surface roughness" OR "material characteristics" OR "titanium surface" OR "implant types" OR "implant surfaces" OR "surface topography" OR "surface analysis") AND ("implant survival" OR "bone loss" OR recurrence OR retreatment OR "radiographic stability" OR "long term" OR "3 years" OR "follow-up")