UNIVERSIDADE ESTADUAL DE CAMPINAS
FACULDADE DE ODONTOLOGIA DE PIRACICABA

GUILHERME ALMEIDA BORGES

Próteses de arco completo sobre implante: atual estado da arte, perspectiva centrada no paciente e otimização mecânica de *abutments* utilizando filme de carbono tipo diamante

Full-arch implant prostheses: current state-of-art, patient-reported outcome measures and mechanical optimization of abutments using diamond-like carbon film

Piracicaba

2023

GUILHERME ALMEIDA BORGES

PRÓTESES DE ARCO COMPLETO SOBRE IMPLANTE: ATUAL ESTADO DA ARTE, PERSPECTIVA CENTRADA NO PACIENTE E OTIMIZAÇÃO MECÂNICA DE ABUTMENTS UTILIZANDO FILME DE CARBONO TIPO DIAMANTE

FULL-ARCH IMPLANT PROSTHESES: CURRENT STATE-OF-ART, PATIENT-REPORTED OUTCOME MEASURES AND MECHANICAL OPTIMIZATION OF ABUTMENTS USING DIAMOND-LIKE CARBON FILM

Tese apresentada à Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas como parte dos requisitos exigidos para a obtenção do título de Doutor em Clínica Odontológica, na Área de Prótese Dental.

Thesis presented to the Piracicaba Dental School of the University of Campinas in partial fulfillment of the requirements for the degree of Doctor in Clinical Dentistry in Dental Prosthesis area.

Orientador: Prof. Dr. Marcelo Ferraz Mesquita

Este exemplar corresponde à versão da tese defendida pelo aluno Guilherme Almeida Borges, e orientado pelo Prof. Dr. Marcelo Ferraz Mesquita.

Piracicaba

2023

Ficha catalográfica
Universidade Estadual de Campinas
Biblioteca da Faculdade de Odontologia de Piracicaba
Marilene Girello - CRB 8/6159

B644p	Borges, Guilherme Almeida, 1992- Próteses de arco completo sobre implante : atual estado da arte, perspectiva centrada no paciente e otimização mecânica de abutments utilizando filme de carbono tipo diamante / Guilherme Almeida Borges. – Piracicaba, SP : [s.n.], 2023. Orientador: Marcelo Ferraz Mesquita. Tese (doutorado) – Universidade Estadual de Campinas, Faculdade de Odontologia de Piracicaba. 1. Boca edentada. 2. Implantes dentários. 3. Tratamento de superfícies. I. Mesquita, Marcelo Ferraz, 1967-. II. Universidade Estadual de Campinas. Faculdade de Odontologia de Piracicaba. III. Título.

Informações Complementares

Título em outro idioma: Full-arch implant prostheses : current state-of-art, patient-reported outcome measures and mechanical optimization of abutments using a diamond-like carbon film
Palavras-chave em inglês:
Edentulous mouth
Dental implants
Surface treatment
Área de concentração: Prótese Dental
Titulação: Doutor em Clínica Odontológica
Banca examinadora:
Marcelo Ferraz Mesquita [Orientador]
Jairo Matozinho Cordeiro
Cleidiel Aparecido Araujo Lemos
Valentim Adelino Ricardo Barão
Raissa Micaella Marcello Machado
Data de defesa: 11-12-2023
Programa de Pós-Graduação: Clínica Odontológica

Identificação e informações acadêmicas do(a) aluno(a)
- ORCID do autor: https://orcid.org/0000-0003-4724-9834
- Currículo Lattes do autor: http://lattes.cnpq.br/8324125418593784

UNIVERSIDADE ESTADUAL DE CAMPINAS
Faculdade de Odontologia de Piracicaba

A Comissão Julgadora dos trabalhos de Defesa de Tese de Doutorado, em sessão pública realizada em 11 de dezembro de 2023, considerou o candidato GUILHERME ALMEIDA BORGES aprovado.

PROF. DR. MARCELO FERRAZ MESQUITA

PROF. DR. JAIRO MATOZINHO CORDEIRO

PROF. DR. CLEIDIEL APARECIDO ARAUJO LEMOS

PROF. DR. VALENTIM ADELINO RICARDO BARÃO

PROFª. DRª. RAISSA MICAELLA MARCELLO MACHADO

A Ata da defesa, assinada pelos membros da Comissão Examinadora, consta no SIGA/Sistema de Fluxo de Dissertação/Tese e na Secretaria do Programa da Unidade.

Dedicatória

A **Deus**, por compreender minhas limitações e permitir que o tempo juntamente com a trajetória me levassem a essa conquista.

Aos meus pais, **Jairo Borges Ferreira** e **Senilda Barbosa de Almeida Ferreira**. Sinto que sou privilegiado por ter duas grandes referências em minha vida. Uma extremamente determinada e autossuficiente chamada carinhosamente de mãe e outra sempre pronta, habilidosa e forte chamada de pai. Esses dois nomes juntos jamais serão traduzidos em palavras. Carrego comigo uma tatuagem marcada por vivencias, carinho e amor para demonstrar que nós estaremos sempre juntos. Vocês são meu alicerce e palavras jamais serão capazes de traduzir esse sentimento, entretanto ajudam a dizer: obrigado!

Ao meu irmão, **Thales Almeida Borges**, pelo amor, motivação, carinho e por nossa amizade. O tempo enriqueceu os nossos laços e permitiu que mesmo de longe você fizesse parte dessa trajetória.

Agradecimento especial

Ao meu orientador, **Prof. Dr. Marcelo Ferraz Mesquita**, pela oportunidade de ser um dos seus orientandos e permitir que a sua experiência docente e teórico-prática fossem compartilhadas ao longo dessa jornada. O senhor sempre valorizou o ensino com maestria partilhando detalhes de forma minuciosa. Aos que se permitem ouvir o senhor nunca poupou tempo para explicar. Levarei com carinho todas as conversas/ orientações logo pela manhã quando o senhor passava no laboratório para oferecer auxílio e saber se estava tudo caminhando bem. Agradeço também o entusiasmo diante de qualquer proposta levantada, possibilidade de trabalho a ser conduzido, colaboração interinstitucional, além disso, por respeitar minhas decisões. Assim como todos, encontrei percalços durante a minha trajetória na pós-graduação, seja por ser falta de experiência no âmbito da pesquisa, quando ingressei no mestrado, ou até mesmo por falta de suporte financiamento no doutorado para executar minha ideia inicialmente desenvolvida. Nesses momentos encontrei resiliência nas palavras e atitudes do senhor e descobri que quando faltam caminhos, criamos outros dando oportunidade ao desconhecido. Muito obrigado por sempre ser um exemplo de autenticidade, pela constante paciência, qualidade de orientação e por contribuir significativamente para o meu crescimento e amadurecimento profissional e pessoal. As oportunidades que o senhor me proporcionou foram únicas e acredito que dificilmente serei capaz de retribuir toda essa confiança, por esse motivo deixo expressa a minha sincera e eterna gratidão.

Ao professor **Dr. Valentim Adelino Ricardo Barão**, por todas as contribuições em cada capítulo dessa tese. Vejo claramente o senhor como um facilitador de conhecimento. Acredito que todos os que o procuram logo identificam o profissional dedicado em tudo que se propõe a fazer, inquieto por conhecimentos e aprendizados. Serei sempre grato por ter esse prisma de inspiração em cada vertente, seja enquanto docente ou pesquisador. Admiro seu senso crítico e preocupação com a excelência em pesquisa.

Agradecimento

À **Universidade Estadual de Campinas – UNICAMP**, na pessoa do Magnífico Reitor, **Prof. Dr. Antonio José de Almeida Meirelles**, pelo meu doutorado nesta instituição.

À **Faculdade de Odontologia de Piracicaba – UNICAMP**, na pessoa do seu Diretor, **Prof. Dr. Flávio Henrique Baggio Aguiar**, e Diretora Associada, **Profa. Dra. Karina Gonzales Silvério Ruiz**, pela oportunidade da realização do Programa de Pós-Graduação em Clínica Odontológica.

Ao Coordenador Geral da Pós-Graduação **Prof. Dr. Valentim A. R. Barão**.

Ao Programa de Pós-Graduação em Clínica Odontologia em nome da **Profa. Dra. Débora Alves Nunes Leite Lima**.

Aos **pacientes** da Faculdade de Odontologia de Piracicaba – UNICAMP por permitirem que o caminho da teoria se encontrasse com a prática. Além de serem a fonte inesgotável de paradigmas científicos que movem a prática baseada em evidência.

A **Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES)**, **Código de Financiamento 001**, fundamental para o desenvolvimento desta pesquisa.

Ao **Fundo de Apoio ao Ensino, Pesquisa e Extensão (FAEPEX), Código de Financiamento 2021/2501**, fundamental para o progresso desta pesquisa.

Aos professores **Dr. Americo Bortolazzo Correr, Dra. Mariana Barbosa Câmara de Souza & Dra. Renata Cunha Matheus Rodrigues Garcia** por carinhosamente e prontamente comporem a banca referente ao exame de Qualificação da presente Tese de Doutorado. Guardarei com carinho todas as palavras que instigaram novos conhecimentos e reflexões do atual cenário da pesquisa científica. A competência científica e clínica das quais vocês possuem, inspiram e guiam os caminhos da pós-graduação.

Aos docentes **Profa. Dra. Altair Del Bel Cury, Dra. Renata Cunha Matheus Rodrigues Garcia**, **Profa. Dra. Raissa Micaella Marcello Machado, Prof. Dr. Wander José**

da Silva, **Prof. Dr. Mauro Antônio de Arruda Nóbilo**, **Prof. Dr. Frederico Andrade e Silva**, **Prof. Dr. Wilkens Aurélio Buarque e Silva** e **Prof. Dr. Rafael Leonardo Xediek Consani** por todo o conhecimento compartilhado.

Aos técnicos **Eduardo Pinez - Laboratório de Prótese Total da FOP-UNICAMP** e **Gislaine Regina Alves Piton – Laboratório de Prótese Parcial Removível da FOP-UNICAMP** pela solicitude e prontidão em ajudar sempre que necessário.

À secretária do **Departamento de Prótese e Periodontia da FOP - UNICAMP**, **Sra. Eliete Aparecida Ferreira Marin**, pela atenção, solicitude e gentileza.

A todos os meus amigos do **Laboratório de Prótese Total**, **Thaís Barbin, Luana Figueiredo Matias, Bruna Egumi Nagay**, **Carolini Dini, Raphael Cavalcante Costa, Luís Fernando Miranda, Maria Helena Rossy Borges, João Pedro Silva, Juliana Andrade, Licínia Maria Ferreira Pignaton, Letícia Del Rio, Daniele Valente Veloso e Samuel Santana Malheiros** pela convivência, amizade e conhecimentos compartilhados.

Em especial à **Thaís Barbin** por ser minha dupla de atendimento clínico, pelo carinho e por dividir comigo mais que um grupo de pesquisa, momentos de felicidade e aprendizado. O tempo nos transformou em uma equipe da qual me orgulho imensamente de fazer parte. Levarei nossas memórias com muito amor em meu coração.

Em especial à **Bruna Egumi Nagay, Carolini Dini, Jairo Matozinho Cordeiro & Raphael Cavalcante Costa** por constantemente motivarem minha busca por novos aprendizados. Além disso, por serem sempre pacientes comigo. Vocês fizeram essa trajetória mais suave, sendo modelo de amizade e companheirismo. Guardarei carinhosamente todos os nossos momentos vividos. Deus confiou em mim todas essas amizades e eu sou/serei eternamente grato!

Aos amigos conquistados durante a Pós-graduação, em especial **Rodrigo Lins, Catharina Marques Sacramento, Tamires Pereira Dutra e Thayane Cerquiare Businari**. Obrigado pela amizade, apoio e bons momentos.

A família **Bettin**, em especial a **Fernando Ferreira Bettin**. Acreditei por muito tempo que estar fora de casa demandava unicamente resiliência e coragem para encarar as constantes mudanças e desafios. Entretanto fui agraciado com o sentimento de pertencimento e carinho que antes só recebia dos meus pais. Obrigado por fazerem a diferença nessa trajetória, alguns passos na nossa vida são mais difíceis que outros, porém com as pessoas certas o caminho se torna possível e alcançável. Agradeço por impulsionarem minhas escolhas e acreditarem no meu potencial enquanto pessoa e profissional.

Aos meus amigos da UNIMONTES-MG, **Cláudio Wagnus Xavier Lopes Júnior & Jéssica Rejane Durães Soares**, por acreditarem no meu potencial e sempre me incentivarem durante todo o processo. Agradeço por todos os bons momentos compartilhados em cada retorno à Minas Gerais.

Muito obrigado!

RESUMO

Com o intuito de avaliar as diferentes modalidades reabilitadoras em pacientes edêntulos, objetivou-se inicialmente contextualizar o atual estado-da-arte em reabilitações do tipo *overdenture*, em específico a frequência do financiamento (Capítulo #01) e individualmente a associação da (*i*) média de citação e (*ii*) fator de impacto JCR (Capítulo #02) com parâmetros bibliométricos das publicações ao longo dos anos. Sequencialmente, comparar quantitativamente por meta-análises próteses do tipo *overdenture* e total fixa em pacientes com mandíbulas edêntulas (Capítulo #03). Por fim, desenvolver um tratamento de superfície composto de carbono tipo diamante (DLC), mecanicamente resistente para pilares de prótese sobre implante, objetivando otimizar a longevidade das reabilitações mencionadas (Capítulo #04). A prevalência de estudos financiados foi de 34,8%. O financiamento foi associado a renda do país (P<0,01), em específico países de renda alta e média-alta sendo mais financiados do que aqueles com renda média-baixa e baixa. A Oceania e a América do Sul foram os continentes mais financiados (P<0,05). Ensaios clínicos randomizados (RCT) e não-randomizados (N-RCT), estudos *in vitro* e estudos *in silico* foram mais financiados (P<0,001). Os sistemas de conexão *stud* e bola foram mais financiados (P<0,01) do que os estudos com mais de 1 sistema de retenção. O financiamento aumentou ao longo do tempo (P<0,01), e os autores correspondentes com um índice-h mais alto tiveram mais estudos financiados (P<0,05). Enquanto que alta média de citação e alto fator de impacto JCR foram observados para estudos RCT, N-RCT, retrospectivos e in vitro (P<0,05). Estudos *in silico* apresentaram alta média de citação (P<0,001). Pesquisadores com alto índice-h foram mais propensos a ter alta média de citação e publicações com alto fator de impacto JCR (P<0,001). Além disso, autores seniores associados a uma rede internacional foram mais propensos a ter uma alta média de citações (P=0,001). Países de alta renda tiveram maior número de estudos com alta média de citação e alto fator de impacto JCR (P<0,05). Um alto fator de impacto JCR foi associado a artigos avaliando apenas a maxila ou a mandíbula (P<0,05). Os tópicos “configuração do implante” e “*macrodesign*” foram associados com alta média de citações (P<0,05). Em uma análise comparativa entre *overdentures vs*. próteses totais fixas, totalizou-se dez estudos incluídos e avaliados quantitativamente. Em 3 domínios do questionário de Qualidade de Vida Relacionada À Saúde Bucal (QVRSB), próteses fixas apresentaram maior qualidade de vida (P<0.01), especificamente para limitação funcional, incapacidade física e dor física. Próteses fixas também apresentaram maior satisfação (P<0.01) nos domínios de conforto, facilidade em mastigar, retenção e estabilidade. O mesmo padrão foi observado para a avaliação geral da

QVRSB e satisfação ($P=0.01$). Apenas para a facilidade de limpeza, *overdentures* obtiveram maior satisfação ($P<0.001$). Parâmetros clínicos não diferiram estatisticamente entre os grupos ($P>0.05$). Já o filme de DLC desenvolvido para pilares de prótese sobre implante evidenciou uma topografia de DLC lisa, compacta e uniforme, altamente resistente ao processo de desgaste. Além disso, o DLC otimizou as propriedades mecânicas e tribológicas do titânio. Parâmetros eletroquímicos também demonstraram o mesmo padrão, resultando em uma superfície anti-corrosiva. A citocompatibilidade em fibroblastos gengivais humanos foi confirmada, garantindo uma superfície segura por não induzir maior crescimento bacteriano. Conclui-se que bibliometricamente a reabilitação do tipo *overdenture* é uma modalidade historicamente consolidada com maior número de estudos financiados ao longo do tempo. Estudos clínicos (RCT, N-RCT e retrospectivos) e *in vitro* apresentaram alta média de citação e alto fator de impacto JCR. O mesmo padrão foi observado para pesquisadores com alto índice-h e localizado em países de renda alta. Próteses fixas mandibulares demonstraram ser um tratamento bem aceito conforme a perspectiva de saúde bucal dos pacientes. Entretanto, *overdentures* mandibulares não são menos eficientes que as próteses fixas, conforme os parâmetros clínicos. Destaca-se que a otimização de *abutments* em próteses sobre implante utilizando filme de DLC, deve ser considerada uma medida protetiva e citocompatível promissora. Tais características são comprovadas pela otimização das propriedades mecânicas, tribológicas e eletroquímicas.

Palavras-chave: Boca edentada. Implantes dentários. Tratamento de superfície.

ABSTRACT

To evaluate the different rehabilitation modalities in edentulous patients, the initial objective of this thesis was to review the current state-of-art in overdenture rehabilitation, specifically the frequency of funding (Chapter #01) and, individually, the association of (*i*) mean citation and (*ii*) JCR impact factor (Chapter #02) with bibliometric parameters of the articles over the years. Sequentially, quantitatively compare overdenture and fixed complete denture by meta-analysis in mandibular edentulous patients (Chapter #03). Additionally, to develop a mechanically resistant surface treatment for abutments used in implant-supported prosthesis, aiming to optimize the longevity of the mentioned rehabilitations (Chapter #04). The prevalence of funded studies was 34.8%. The parameter associated with the presence of funding was country income (P<.01), with those having a high and upper-middle income being more funded. Oceania and South America were the continents more frequently funded (P<.05), with Africa being the least frequent. Randomized (RCT) and nonrandomized (N-RCT) controlled trials, *in vitro* studies, and *in silico* studies were more funded (P<.001). Stud and ball attachment systems were more funded (P<.01) than studies with more than 1 retention system. Funding increased over time (P<.01), and corresponding authors with a higher h-index had more studies funded (P<.05). Data revealed a high mean citation and high JCR impact factor for RCT, N-RCT, retrospective, and in vitro studies (P<.05). In silico studies presented a high mean citation (P<.001). Senior researchers with a high h-index were more likely to have a high mean citation and publications with a high JCR impact factor (P<.001). Senior authors associated with an international network were more likely to have a high mean citation (P=.001). High-income countries had more studies with a high mean citation and JCR impact factor (P<.05). Higher JCR impact factors were associated with articles evaluating only the maxilla or mandible (P<.05). The topics “implant setting” and “macrodesign” were associated with a high mean citation (P<.05). In a comparative analysis between overdentures *vs*. complete fixed dentures in edentulous mandibles, a total of 10 studies were included and quantitatively evaluated. For 3 domains of oral healtherelated quality of life (OHRQoL), fixed prostheses showed significantly higher quality of life when compared with overdentures regarding functional limitation (P<.001), physical disability (P=.001), and physical pain (P=.003). Fixed prostheses also improved satisfaction, when compared with overdentures for comfort (P=.02), ease of mastication (P<.001), retention (P<.001), and stability (P<.001). The same pattern was observed for overall OHRQoL (P=.01) and satisfaction (P=.01) in which fixed prostheses improved patient satisfaction. Only ease of cleaning presented greater satisfaction for the overdenture group. Clinical parameters did not differ statistically (*P*>.05) between both types of prosthesis. The DLC film developed for abutments used in dental-implant prostheses showed a smooth, compact and uniform DLC topography, highly resistant to the wear process. Furthermore, the DLC optimized the mechanical and tribological properties of titanium. Electrochemical parameters also showed the same pattern, resulting in an anti-corrosive surface. Cytocompatibility in human gingival fibroblasts was confirmed, ensuring a safe surface by not inducing further bacterial growth. Regarding the above results, it can be concluded that bibliometrically, overdenture rehabilitation is a consolidated treatment, which presented a greater number of studies funded over time. Among the publication trends, clinical (RCT, N-RCT and retrospective) and in vitro studies presented a high mean citation and a high JCR impact factor. The same pattern was observed for senior researchers with a high h-index and located in high-income countries. Meanwhile mandibular fixed prostheses proved to be a well-accepted treatment according to the patients' oral health perspective. However, mandibular overdentures are no less efficient than fixed prostheses according to clinical parameters. It is noteworthy that the optimization of abutments in implant-supported prostheses using DLC film should be considered a promising protective and cytocompatible alternative. Such characteristics are proven by the optimization of mechanical, tribological and electrochemical properties.

Keywords: Edentulous. Dental implants. Surface treatment.

SUMÁRIO

1. INTRODUÇÃO

A documentação científica global por artigos na área de implantodontia aumentou notavelmente ao longo dos anos, incluindo tópicos relacionados a prótese como reabilitações do tipo *overdentures* (Alhajj et al., 2021; Alonso-Arroyo et al., 2019a; Barão et al., 2011; Chiang et al., 2018; Heneberg, 2016). Esse progresso científico aumentou, especialmente após 2002 com o Consenso de McGill em que próteses totais convencionais foram substituídas por *overdentures* mandibulares, sendo o tratamento de primeira escolha em pacientes edêntulos (Feine et al., 2002a). Concomitantemente, observou-se uma crescente instalação de implantes e alta aplicabilidade clínica de *overdentures*, ambos levando a comunidade científica a contribuir com um maior volume de publicações em periódicos indexados (Alhajj et al., 2021). Entretanto, dados parametrizados do atual estado da arte na área de *overdentures* ainda são insuficientes.

A bibliometria é uma técnica metodologicamente precisa e pertinente para o entendimento de dados (e.g., renda do país, origem geográfica, desenho metodológico do estudo, rede internacional entre os autores) relacionados a uma área de conhecimento para mapear sua evolução, além de descrever o objetivo dos estudos ao longo dos anos (Chiang et al., 2018). Esse agrupamento de artigos em uma mesma temática também fornece informações suficientes para avaliar as subáreas de interesse (e.g., reabilitações sob comparação, sistemas de retenção, local de reabilitação) frequentemente aplicadas em periódicos internacionalmente reconhecidos (Alarcón et al., 2017). Assim sendo, essas informações norteiam o progresso na implantodontia por meio de diferentes desenhos metodológicos, para fornecer dados com validade externa aos pacientes diretamente beneficiados e aos leitores/pesquisadores interessados (Buser et al., 2017; Tarazona et al., 2017).

Dados bibliométricos pregressos na área de implantodontia demonstraram que historicamente houve aumento com relação ao número de autores, rede colaborativa entre pesquisadores e financiamento em artigos científicos (Alonso-Arroyo et al., 2019a; Barão et al., 2011; Dini et al., 2022b, 2022a). Em relação ao aporte financeiro, observou-se maior número de publicações com financiamento (público ou privado) e alto subsídio em países europeus (Tarazona-Álvarez et al., 2021). Posteriormente a publicação, observou-se que esses artigos financiados foram citados com maior frequência e publicados em periódicos de alto fator de impacto, demonstrando o impacto científico na difusão de informações (Alonso-Arroyo et al., 2019a). Interessantemente, o financiamento pode estar relacionado à relevância de um campo científico (e.g., *overdentures* retida por implantes) e seu aprimoramento/importância ao longo dos anos. É indiscutível que o financiamento obtido da indústria está frequentemente presente e é ao mesmo tempo complementado por fontes governamentais, instituições de pesquisa/universidades, fundações e doações (Barão et al., 2011; Dini et al., 2022b; Pereira et al., 2022). Entretanto, uma abordagem bibliométrica para obter conclusões detalhadas em uma área de conhecimento como *overdentures* ainda não foi conduzida, tornando pertinente (#Capítulo nº 01) avaliar a frequência do financiamento e a produção científica na literatura relacionada a *overdentures* sobre implantes. Em específico, a prevalência de parâmetros bibliométricos (renda do país, continente, desenho do estudo, tópico do estudo, sistema de retenção, local de intervenção, número de instituições, número de disciplinas, rede internacional, ano, *índice-h* e média de citação por artigo) associados ao financiamento e à produção histórica ao longo dos anos em reabilitações com *overdenture* sobre implantes.

Uma vez que o financiamento permite entender o perfil dos estudos conduzidos e posteriormente publicados, questiona-se qual o impacto pós-publicação de outras métricas (média de citação e fator de impacto da *Journal Citation Reports:* JCR) na disseminação das informações disponíveis na literatura por intermédio de artigos científicos (Ahmad et al., 2019; Kurmis, 2003; Livas and Delli, 2018; Muniz et al., 2018). Em específico, o fator de impacto JCR é frequentemente aplicado para avaliar a qualidade de periódicos, sendo considerado um indicador bibliométrico clássico (Muniz et al., 2018). Ademais, esse parâmetro é definido como uma proporção anual entre citações e itens citáveis recentemente publicados. Destaca-se que autocitações excessivas podem inflar o fator de impacto JCR (Kurmis, 2003). Entretanto, um estudo bibliométrico anterior demonstrou diminuição na autocitação ao longo do tempo e uma correlação não significativa com o fator de impacto JCR, exibindo um ambiente editorial favorável em odontologia, cirurgia oral e medicina (Livas and Delli, 2018). Em odontologia, informações sobre a associação do fator de impacto JCR e dados bibliométricos em *overdenture* são limitadas e requerem entendimento.

A média de citação de um artigo é outro parâmetro que está relacionado ao fator de impacto JCR. Este método identifica trabalhos influentes em um campo de pesquisa, além de ser uma ferramenta adequada para quantificar o impacto de uma publicação, revista, tópico de discussão, autor e ao mesmo tempo tendências ao longo do tempo (Ibrahim et al., 2012). Em odontologia, poucos estudos avaliaram padrões de citação (Ahmad et al., 2019; Alarcón et al., 2017; Muniz et al., 2018; Nabil and Samman, 2012). Análises bibliométricas pregressas sobre contagem de citações ajudaram a fornecer informações de áreas dominantes de um campo de pesquisa (e.g., relação global do edentulismo), desigualdades históricas relacionadas à localização geográfica (e.g., Oriente Médio, África), número de citações, desenhos metodológicos com menos citações (e.g., relatos de casos/série de casos) e periódicos com contagem de citações ínfimas (Ahmad et al., 2019; Alarcón et al., 2017; Muniz et al., 2018; Nabil and Samman, 2012). Essas informações podem subsidiar autores antes de iniciar um novo projeto de pesquisa e também podem reduzir o tempo ao avaliar a literatura para acessar estudos relevantes (Clarke, 2002).

Diante do exposto, pressupõe-se que a média de citação e o fator de impacto JCR estariam associados a indicadores bibliométricos conforme descrições prévias (Ahmad et al., 2019, 2019; Alarcón et al., 2017; Kurmis, 2003; Livas and Delli, 2018; Muniz et al., 2018, 2018; Nabil and Samman, 2012). No entanto, até o presente momento, essas hipóteses não foram validadas em *overdentures* sobre implantes.

Portanto, para fornecer informações adicionais à literatura, (#Capítulo nº 02) este estudo tem como objetivo avaliar individualmente a associação da (i) média de citação e (ii) fator de impacto JCR com parâmetros bibliométricos (renda do país, continente, desenho do estudo, tópico do estudo, sistema de retenção, local da intervenção, número de instituições, número de disciplinas, rede internacional, suporte financeiro, *índice-h*) ao longo dos anos em publicações com *overdentures* sobre implantes.

Diante dos dados previamente apresentados é possível classificar a reabilitação do tipo *overdenture*, especificamente em mandíbula, como um protocolo clínico historicamente consolidado (Borges et al., 2021; Brennan et al., 2010; M. A. ELsyad et al., 2019; Feine et al., 1994; Müller et al., 2012; Nagay et al., 2021). Além disso, essa modalidade de tratamento está entre as duas opções (removível e fixa) de reabilitação sobre implante para pacientes edêntulos. Considerando o atual estado da arte, ambas próteses (*overdenture* e prótese total fixa) apresentam efetividade clínica (Ayna et al., 2018; De Kok et al., 2011a; M. ELsyad et al., 2019; Tinsley et al., 2001). Entretanto, financeiramente *overdentures* apresentam custo inicial duas vezes menor que próteses totais fixas (Attard et al., 2003; Hartmann et al., 2020), além da requererem um número inferior de implantes/componentes, consequentemente demandando menor tempo clínico (Passia et al., 2019; Passia and Kern, 2014; Thomason et al., 2009).

Em contrapartida, próteses totais fixas fornecem ao paciente maior força máxima de mordida e o benefício de requererem número reduzido de manutenções protéticas ao longo do tempo, quando comparadas a *overdentures* (Ayna et al., 2018; Beresford and Klineberg, 2018; Müller et al., 2012). Ademais, ambas reabilitações, sejam fixas ou removíveis, apresentam benefícios clínicos bem documentados e seguros, como alta taxa de sobrevivência implantar (>98%) e reabsorção óssea aceitável a longo prazo (Ayna et al., 2018; De Kok et al., 2011b; M. ELsyad et al., 2019; Zarb and Albrektsson, 1998). No entanto, a percepção dos pacientes sobre o tratamento pode não estar de alinhada com os dados clínicos previamente reportados (Feine et al., 2018a; Gallardo et al., 2018; Wittneben et al., 2018).

Em prótese sobre implante, parâmetros clínicos implantares (e.g., sobrevivência/ sucesso de implantes, estabilidade primária/secundária) e peri-implantares (e.g., profundidade de sondagem, sangramento a sondagem, índice de placa, perda óssea marginal) são aplicados com objetivo de avaliar a efetividade das reabilitações em relação a dados tecnicamente coletáveis (Alfadda et al., 2019; Ayna et al., 2018; Balshi et al., 2014; Borges et al., 2020; De Kok et al., 2011b; M. ELsyad et al., 2019; Elsyad and Khirallah, 2016; Niedermaier et al., 2017; Passia et al., 2019; Patzelt et al., 2014; Turkyilmaz et al., 2012; Zarb and Albrektsson, 1998). Entretanto, essas variáveis devem ser complementadas com a percepção subjetiva autorrelatada, utilizando medidas de desfechos relatadas pelo paciente (PROMs), como qualidade de vida relacionada à saúde bucal (QVRS) e satisfação, visando complementar e compreender a autoavaliação dos pacientes sobre a sua condição oral (Feine et al., 2018a; Gallardo et al., 2018; Wittneben et al., 2018). Posto isso, destaca-se a ausência de dados na literatura avaliando a autopercepção do paciente somada a dados clínicos, especialmente considerando arcos mandibulares edêntulos. Torna-se assim plausível (#Capítulo nº 03) a avaliação sistemática de forma quantitativa (meta-análises) dos PROMs (qualidade de vida relacionada à saúde bucal e satisfação) e parâmetros clínicos implantares/ peri-implantares (sobrevivência, profundidade de sondagem e perda óssea marginal) em *overdentures* e próteses totais fixas para reabilitações mandibulares, visto que ambos grupos de dados podem subsidiar clínicos e pesquisadores em um melhor plano de tratamento.

O conceito de reabilitações sobre implante, sejam fixas ou removíveis, sustenta-se devido o principio da osseointegração inicialmente proposto por Brånemark (Brånemark et al., 1969). Posto isso, uma vez que o implante-dentário esteja devidamente ancorado (adesão osso-implante), ele deve sequencialmente ser associado a *abutments*, os quais penetram no tecido peri-implantar na zona de transição entre o tecido ósseo adjacente ao implante e a prótese dentária (Guo et al., 2021; Laleman and Lambert, 2023). Esses pilares possuem papel fundamental na reabilitação e resistência ao ambiente oral hostil assim que instalados (Guo et al., 2021). Dessa forma, a implementação de materiais mecanicamente resistentes em *abutments* é necessária diante da realidade clínica (Beline et al., 2020; Pantaroto et al., 2021; Souza et al., 2020a).

Dentre as possibilidades comerciais, o Titânio Grau IV (TiGrIV) é um metal usual com aplicabilidade em componentes protéticos devido à sua biocompatibilidade e vantagens mecânicas (Mishnaevsky et al., 2014). Além disso, o biomaterial a base de titânio (*abutment*) assim que conectado ao implante e exposto aos componentes da cavidade oral (e.g., oxigênio e água), fornece benefícios adicionais devido a formação de uma fina camada de dióxido de titânio, consequentemente melhorando a resistência à corrosão (Wang et al., 2016). Entretanto, durante atividades funcionais (e.g., mastigação, métodos mecânicos de higienizacao), forças contínuas na cavidade oral podem romper a estabilidade da camada de dióxido de titânio e sua integridade (Mints et al., 2014). Vale ressaltar que a degradação da camada de óxido também pode ser iniciada por íons corrosivos (e.g., Cl^-, F^- e H^-) presentes no biofilme oral e saliva (Nagay et al., 2022). Consequentemente, subprodutos de titânio resultantes do processo de corrosão podem ser liberados na forma de íons ou partículas metálicas, desencadeando reações pró-inflamatórias adversas ao tecido peri-implantar (Nagay et al., 2022; Noronha Oliveira et al., 2018). Logo, tecnologias voltadas para tratamentos de superfície, especialmente centradas em filmes protetivos tornam-se necessárias para superar os problemas mencionados, otimizando a resistência a corrosão e ao desgaste de pilares. No entanto, é necessário modificar as propriedades de superfície dos componentes implantáveis sem adversamente afetar sua resposta biológica, para estender a usabilidade e reduzir a degradação quando aplicados em ambiente oral (Beline et al., 2020).

O carbono tipo diamante (DLC), um material hidrogenado amorfo composto essencialmente por carbono, tem impulsionado grande interesse no campo biomédico devido às suas propriedades protetoras (e.g., resistência mecânica, anticorrosão, inércia química e biocompatibilidade) (Guo et al., 2017; Kasiorowski et al., 2020; Kuznetsova et al., 2023). No entanto, essas características biomecânicas do DLC estão diretamente associadas com a rede química tridimensional das hibridizações do carbono sp^2 e sp^3 (Casiraghi et al., 2005; Ferrari, 2002; Ferrari and Robertson, 2000). Em detalhes, a ligação sp^2 (atribuição relacionada ao grafite) é modulada pela quantidade de hidrogênio, favorecendo um maior comportamento lubrificante (Casiraghi et al., 2005; Ferrari and Robertson, 2000). Enquanto que filmes com densidade considerável (estrutura compacta) e alta rigidez (alta dureza e módulo de elasticidade) são obtidos pela hibridização sp^3 de átomos de carbono (Zajikova, 2003). Entretanto, materiais a base de DLC com elevadas quantidades de carbono sp^3 exibem alta tensão residual, consequentemente apresentando defeitos estruturais na interface filme-substrato, dificultando assim sua aplicação prática (Li et al., 2020). Para superar tais problemas, estratégias foram revisadas para desenvolver um filme DLC funcional com equilíbrio nas hibridações de carbono (Vetter, 2014). Por exemplo, aumento do teor de hidrogênio, associação de componentes intercamada (e.g., silício) e processo de deposição (e.g., plasma de vapor químico utilizando corrente direta pulsada: DC-PECVD) têm sido consideradas alternativas promissoras; juntas, elas poderiam diminuir não apenas as tensões residuais internas, mas também promover resistência ao material desenvolvido (Kasiorowski et al., 2020; Vetter, 2014; Wei et al., 2020; Wu et al., 2016). Essas alternativas podem determinar a integridade durante a deposição dos filmes de DLC, entretanto devido a redução de hibridizações sp^3, as propriedades mecânicas são consequentemente alteradas favorecendo a ductilidade (Li et al., 2020). Dados pregressos descreveram que filmes de DLC com alto teor de sp^3 ($\geq$50%) apresentam valores de dureza de até 80 GPa, porém aumentando a tensão compressiva e favorecendo a delaminação (Kamiya et al., 2008; Robertson, 2003). Enquanto isso, filmes com intercamada de silício e 20% de hibridação sp^3 apresentaram dureza reduzida (~ 20 GPa), mas superando desvantagens particulares de filmes de carbono puro, como baixa resistência ao desgaste em metais e alta tensão interna (Vetter, 2014). Deve-se considerar que, embora as propriedades mecânicas do DLC possam ser reduzidas a partir da estratégia selecionada, esse material ainda assim supera as características do Ti (e.g., dureza e módulo de elasticidade) (Wei et al., 2022).

Nesta perspectiva, a motivação para usar materiais a base de DLC em pilares de implantes-dentários reside na sua característica protetiva (robustez mecânica e excelente resistência à corrosão), como já discutido. No entanto, existem questões à espera de respostas que precisam ser solucionadas (#Capítulo nº 04), como: (*i*) Podemos superar os problemas típicos de resistência ao desgaste (delaminação do substrato metálico) do filme DLC pela combinação da metodologia DC-PECVD e intercamada de silício para otimizar propriedades materiais?; (*ii*) A atividade eletroquímica e as propriedades mecânicas do filme DLC obtido são altas o suficiente em comparação com o TiGrIV?; (*iii*) Do ponto de vista da aplicabilidade clínica, a citocompatibilidade biológica do filme DLC em relação às células hospedeiras (fibroblastos gengivais humanos) é semelhante ao material comercial (TiGrIV)?; (*iv*) Considerando um colonizador inicial (*Streptococcus sanguinis*) para formação de biofilme, o material é propenso ou não à adesão microbiana? Como essas questões não foram totalmente estudadas antes, torna-se assim viável desenvolver um estudo com objetivo de sintetizar um filme DLC em um substrato de TiGrIV, considerando que tal pesquisa seria altamente interessante para o aprimoramento da superfície de pilares em implantes-dentários.

2. ARTIGOS

2.1 Funding assistance and global productivity in the field of implant overdentures: A bibliometric analysis of 35 years#

Supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, finance code 001; Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), grant/ award number: 2020/05234-3; and Conselho Nacional de Desenvolvimento Científico e Tecnológico, grant/award number: 304853/2018-6.

Guilherme Almeida Borges, DDS, MSc,[a] Caroline Dini, DDS, MSc,[b] Mariana Marinho Davino de Medeiros, DDS, MSc,[c] Renata Cunha Matheus Rodrigues Garcia, DDS, MSc, PhD,[d] Valentim Adelino Ricardo Barão, DDS, MSc, PhD,[e] and Marcelo Ferraz Mesquita, DDS, MSc, PhD[f]

[a]PhD student, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.
[b]PhD student, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.
[c]PhD student, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.
[d]Full Professor, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.
[e]Associate Professor, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.
[f]Full Professor, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.

Corresponding author:
Dr. Marcelo Ferraz Mesquita
University of Campinas (UNICAMP)
Piracicaba Dental School
Av Limeira, 901, Piracicaba
São Paulo, 13414-903
BRAZIL
Email: mesquita@unicamp.br

#Artigo publicado na revista *Journal of Prosthetic Dentistry* (Fator de impacto = 4.6).

ABSTRACT

Statement of problem. Implant overdentures have been widely used as a treatment option for edentulous patients. However, the development of implants, aside from commercial growth, requires funding assistance to determine scientific reliability and clinical applications. Nonetheless, bibliometric studies in the implant overdenture field are lacking.

Purpose. The purpose of this bibliometric analysis was to evaluate the prevalence of funding and its bibliometric associated parameters according to the financial assistance granted and the implant overdenture documentation over time.

Material and methods. Six databases were assessed, and 12 bibliometric parameters related to the economy, geographical origin, publication details, and corresponding author metrics were recorded. An incidence rate ratio was applied by using a multiple Poisson regression model (α=.05) to assess the association between funding and each bibliometric parameter.

Results. In total, 1369 studies published between 1986 and 2021 were assessed bibliometrically. The prevalence of funded studies was 34.8% (n=477). The parameter associated with the presence of funding was country income (P<.01), with those having a high and upper-middle income being more funded than those with a lower-middle and low income. Oceania and South America were the continents more frequently funded (P<.05), with Africa being the least frequent. Randomized and nonrandomized controlled trials, in vitro studies, and in silico studies were more funded (P<.001) than case reports and series. Stud and ball attachment systems were more funded (P<.01) than studies with more than 1 retention system. Funding increased over time (P<.01), and corresponding authors with a higher h-index had more studies funded (P<.05).

Conclusions. The number of funded studies on implant overdentures increased over the years. Other bibliometric parameters such as country income, continent, study design, retention system,

and corresponding author h-index were associated with the frequency of funded studies published.

CLINICAL IMPLICATIONS

Funding assistance for implant-retained overdenture studies has grown remarkably over the past 35 years (1986 to 2021). However, financial support still needs to reach lower-middle and low income countries. To be eligible for funding, researchers must seek expertise in the area and in randomized or nonrandomized clinical trials, in silico studies, or in vitro studies. Also, funding assistance was mainly granted for unsplinted systems (stud and ball) that are more straightforward to maintain in daily practice.

INTRODUCTION

Studies on dental implants have increased remarkably over the years, including on implant-retained overdentures.[1-5] Since 2002, two-implant overdentures have been recommended over complete conventional den- tures as the first treatment choice for patients with mandibular edentulism,[6] and a large number of publi- cations are available on the procedure.[5,7-10] Bibliometric parameters allow the understanding of scientific production by identifying its evolution, important topics to be addressed, and dissemination of research findings to the scientific community.[2,11] Clustering studies also provide information to assess the clinical data, the most researched areas, the most frequently used study designs, and the journals referenced.[12,13] Such scientific evidence represents the progress in dental implantology to assist in determining further studies for clinicians and stakeholdersd authors.[14,15] Other parameters include the h-index, described as an important outcome to quantify an individual's scientific contribution.[16]

Among implantology studies, the number of authors, international network, and funding assistance have increased over time.[1,3] Bibliometric studies assessing the dental implant field have also reported a growth in studies with public or private funding.[3,17] At the same time, funded studies have been reported to be cited more frequently and published in journals with high impact factors.[1] Thus, financial support might be related to the relevance of a scientific field and its improvements over the years. Industry funding is frequently present and at the same time complemented by additional sources.[3] However, a bibliometric assessment is required to evaluate the frequency of funding and scientific production in the literature related to implant overdentures. Therefore, this study aimed to evaluate the prevalence of bibliometric parameters (country income, continent, study design, study topic, retention system, intervention location, number of institutions, number of disciplines, international network, year, h-index, and mean citation per article) associated with funding assistance and the implant overdenture literature over time. The null hypothesis was that funding would not affect bibliometric outcomes.

MATERIAL AND METHODS

To acquire articles in the implant-retained overdenture field, an extensive search without geographic or timeline filters was conducted in April 2021 among 9 core collections (Supplemental Table 1, available online). After eliminating duplicate entries, the titles and abstracts were screened by 2 independent reviewers (G.A.B., C.D.). The article was deemed eligible for bibliometric evaluation if it was a randomized (RCT) or nonrandomized (N-RCT) controlled clinical trial, retrospective study, case reports or series, in vitro study, in silico study, or a systematic review. Two independent reviewers (G.A.B., C.D.) extracted the data. A calibration before final data population was performed with 100 eligible articles to ensure interinvestigator reliability. The entries were randomly selected (https://www.randomizer.org), and the results were assessed by using the Cohen kappa coefficient (k). The output presented almost perfect agreement (k=0.868). Thereafter, bibliometric indicators were divided and collected individually according to the financial support, country income, continent, study design, study topic (Supplemental Table 2, available online), retention system, intervention location, number of institutions, number of disciplines, international network, year, h-index, and mean citation per article (Supplemental Table 3, available online). The financial support was classified as "funded" whether the study received support from the foundation, the government, a donation, a company or industry, a research institute, or a university. When the study did not provide information or lacked a description by which to classify the funding, it was noted as "unfunded". Thereafter, the incidence rate ratio (IRR) was applied by using multiple Poisson regression analysis with a statistical software program (IBM SPSS Statistics, v20.0; IBM Corp) to evaluate the association between funding and the bibliometric parameters (Supplemental Table 4, available online).

RESULTS

In total, 12 025 entries were identified from all databases, and 1369 remained for assessment after the removal of duplicates and screening as seen in Figure 1. Regarding the bibliometric descriptions (Table 1) that have been published to date, countries of the corresponding author classified as high income (n=913, 67.5%) presented the highest number of publications. Studies with a single retention system represented 76% of the sample, and the most chosen system was the bar (n=361, 31.9%). Although collaborations with different institutions (n=690, 51.1%) and disciplines (n=718, 53.9%) within the same study occurred more often than those without, international networking among countries (n=289, 21.3%) was less frequent than studies within a single country (n=1065, 78.8%). Among the included studies, the publication period ranged from 1986 to 2021. Approximately one-third of the studies were classified as funded (n=477, 34.8%), and most of them (n=292, 61.2%) had only 1 source of funding (Table 2). The number of funding agencies reported in the funded studies was 774, and the majority were allocated to the industry (n=271, 35%) followed by the government (n=206, 26.6%) (Table 2). When those most supportive funding agencies were organized according to the number of studies, the top 10 sources were determined (Table 3). The largest group was composed of private companies, who financed 35.6% of the studies. In the first and second place were the European companies Nobel Biocare (n=56, 11.7%) and Straumann (n=51, 10.7%). Additionally, another cluster of funding was obtained by governmental bodies, including 3 from Brazil that composed 14.3% of all funded studies, with the São Paulo Research Foundation (FAPESP) contributing the most (n=28, 5.9%).

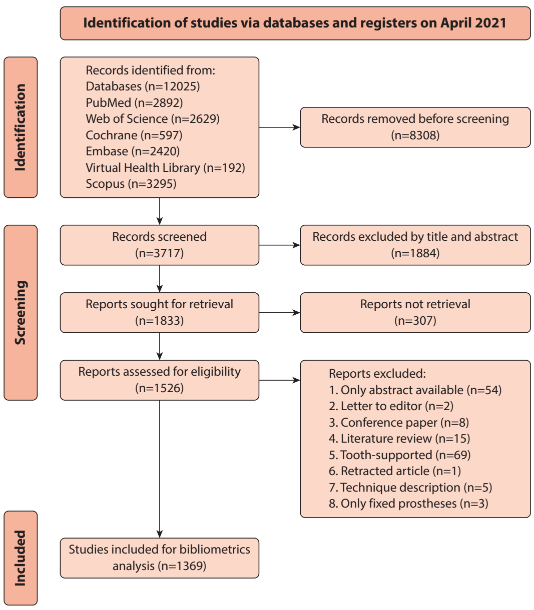


Figure 1. Flowchart of articles included in bibliometric study.

Table 1. Bibliometric parameter distribution in implant overdenture studies during last 35 years (1986 to 2021)

Variables	n	%
I. Country income		
High	913	67.5
Upper-middle	301	22.3
Lower-middle	137	10.1
Low	1	0.1
II. Continent		
Europe	531	39.2
Asia	338	25.0
North America	227	16.8
South America	136	10.1
Africa	81	6.0
Oceania	40	3.0
III. Study design		
N-RCT	479	35.0
RCT	287	21.0
Case reports and series	224	16.4
In vitro	134	9.8
In silico	89	6.5
Retrospective	82	6.0
Systematic review	74	5.4
IV. Topic		
Rehabilitation method	347	25.4
Retention system	311	22.7
Complications	176	12.9
Loading protocol	126	9.2
Implant macrodesign	121	8.8
Anatomical and surgical	113	8.3
Implant setting	109	8.0
Surface treatment	37	2.7
Others	29	2.1
V. Retention system		
Bar	361	31.9
Ball	288	25.5
Stud	181	16.0
Magnetic	25	2.2
ERA	4	0.4
> 1 retention system	271	24.0
VI. Intervention location		
Mandible	1062	78.3
Maxilla	174	12.8
Mandible and maxilla	120	8.8
VII. Institution		
> 1 Institution	690	51.1
1 institution	661	48.9
VIII. Discipline		
> 1 discipline	718	53.9
1 discipline	613	46.1
IX. International network		
> 1 country	289	21.3
1 country	1065	78.7
Variables	**Mean**	**Standard deviation**
X. Year	2011	8
XI. h-index	16.4	15.4
XII. Mean citations	2.2	2.5

N-RCT, nonrandomized controlled clinical trial; RCT, randomized controlled clinical trial.

Table 2. Funding distribution according to presence, number of sources, and description of implant overdenture studies during last 35 years (1986 to 2021)

Funding	n	%
I. Funded and unfunded studies		
Funded	477	34.8
Unfunded	892	65.2
II. Number of funding sources[a]		
1	292	61.2
2	121	25.4
3	40	8.4
4	13	2.7
5-9	5	2.3
III. Funding description[b]		
Industry	271	35.0
Government	206	26.6
Research institute and university	166	21.5
Foundation	71	9.2
Donation	60	7.8

[a]Number and percentage based on 477 funded studies. [b]Number and percentage based on 774 counted sources of funding within 477 funded studies.

Table 3. Ten most supportive funding sources

Rank	Funding organization	Funding source	n	%
1	Nobel Biocare	Industry	56	11.7
2	Straumann	Industry	51	10.7
3	International Team for Implantology (ITI)	Foundation	43	9.0
4	Southern Implants	Industry	32	6.7
5	São Paulo Research Foundation (FAPESP)	Government	28	5.9
6	Coordination for the Improvement of Higher Education Personnel (CAPES)	Government	24	5.0
7	Canadian Institutes of Health Research	Government	22	4.6
8	Dentsply Sirona	Industry	16	3.4
9	National Council for Scientific and Technological Development (CNPq)	Government	16	3.4
10	Astra Tech	Industry	15	3.1

Percentage based on 477 funded studies.

A total of 1369 studies were analyzed and accepted in 219 different journals, while only 94 journals published funded studies. The 10 journals with the most studies, headed by Clinical Oral Implants Research (COIR), are listed in Table 4 for funded studies (n=78, 16.4%) with the second-highest impact factor (IF=5.977). When all studies were evaluated, COIR had an increased number of studies (n=162, 11.8%) but fewer than the *International Journal of Oral and Maxillofacial Implants* (n=165, 12.1%). The *Journal of Prosthetic Dentistry* was among the top 4 journals in both lists.

Table 4. Ten journals with higher number of publications in implant overdenture according to presence of funding and overall studies evaluated

Rank	Funded studies – publishing journals[a]	Impact factor[c]	n	%
1	Clinical Oral Implants Research	5.977	78	16.4
2	International Journal of Prosthodontics	1.681	53	11.1
3	International Journal of Oral & Maxillofacial Implants	2.804	43	9.1
4	Journal of Prosthetic Dentistry	3.426	41	8.6
5	Clinical Implant Dentistry and Related Research	3.932	32	6.7
6	Journal of Oral Rehabilitation	3.837	21	4.4
7	Journal of Dental Research	6.116	19	3.9
8	Journal of Dentistry	4.379	17	3.6
9	Journal of Prosthodontics	1.681	16	3.4
10	Quintessence International	1.677	9	1.9
	Overall studies - publishing journals[b]			
1	International Journal of Oral & Maxillofacial Implants	2.804	165	12.1
2	Clinical Oral Implants Research	5.977	162	11.8
3	Journal of Prosthetic Dentistry	3.426	127	9.3
4	International Journal of Prosthodontics	1.681	108	7.9
5	Clinical Implant Dentistry and Related Research	3.932	70	5.1
6	Journal of Oral Rehabilitation	3.837	50	3.7
7	Journal of Oral Implantology	1.779	46	3.4
8	Journal of Prosthodontics	1.681	37	2.7
9	Implant Dentistry	2.454	35	2.6
10	Journal of Dentistry	4.379	24	1.8

[a]Number and percentage based on the 477 funded studies. [b]Number and percentage based on the 1369 studies evaluated. [c]Impact factor recorded on 2020 Journal Citation Reports-Clarivate.

The most productive countries were predominantly European (Table 5). Brazil led the funded list (n=70, 5.1%), being the only South American country in both the funded and overall lists and the only one in the funded rank with an upper-middle income. Canada (n=65, 4.75%) and the United States of America (n=62, 4.53%) were the next countries in the funded list.

In a timeline assessment, Figure 2 showed that even though the lowest amount of publication was observed in Oceania, the continent had more funded than unfunded studies. Meanwhile, Europe had the highest volume of publications, and Asia was second with a remarkable increase over the years. The study design is presented in Figure 3: Systematic reviews started to be published in this field around 2006, and prospective trials (RCT and N-RCT) represented the highest number of funded publications. Figure 4 shows all retention systems. The stud attachment was the most recent component, and the bar attachment has been present the longest. After 2002, the number of studies on the mandible increased (Fig. 5), and this was responsible for the highest body of documentation, regardless (n=1062, 78.3%) of whether financing was present or not.

Table 5. Ten countries with higher number of publications in implant overdenture according to presence of funding and overall studies evaluated

Rank	Funded studies – countries[a]	Income classification[c]	n	%
1	Brazil	Upper-middle	70	5.11
2	Canada	High	65	4.75
3	United States	High	62	4.53
4	Netherlands	High	54	3.94
5	Japan	High	35	2.56
6	Germany	High	35	2.56
7	Switzerland	High	34	2.48
8	United Kingdom	High	28	2.05
9	New Zealand	High	27	1.97
10	Belgium	High	21	1.53
	Overall studies – countries[b]			
1	United States of America	High	187	13.66
2	Netherlands	High	148	10.81
3	Brazil	Upper-middle	135	9.86
4	Egypt	Lower-middle	98	7.16
5	Canada	High	93	6.79
6	Turkey	Upper-middle	86	6.28
7	Japan	High	82	5.99
8	Germany	High	82	5.99
9	Switzerland	High	74	5.41
10	Italy	High	71	5.19

[a]Number and percentage based on 477 funded studies. [b]Number and percentage based on 1369 studies evaluated. [c]Income classification recorded on 2021 World Bank Country and Lending Groups (https://data.worldbank.org).

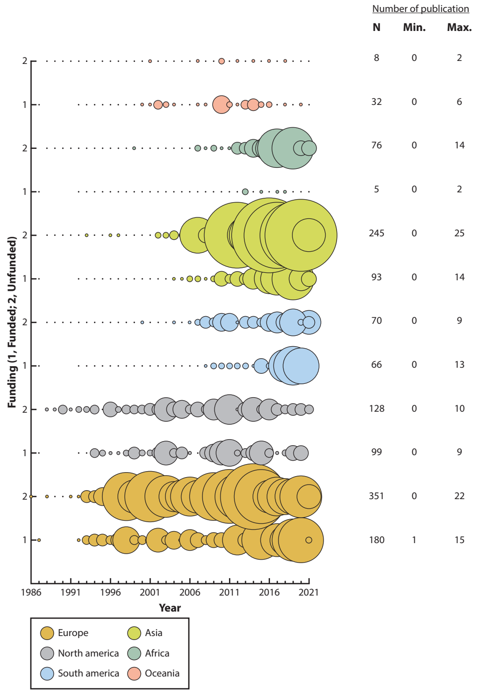


Figure 2. Continental trends and number of publications (graphically represented by bubble size) over time according to financial assistance (funded and unfunded).

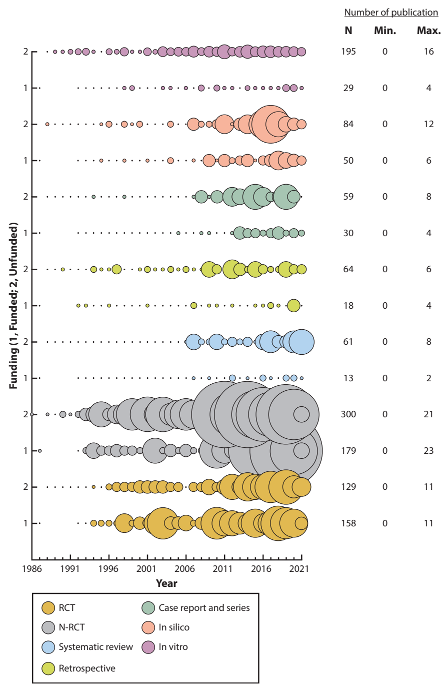


Figure 3. Study design trends and number of publications (graphically represented by bubble size) over time according to financial assistance (funded and unfunded).

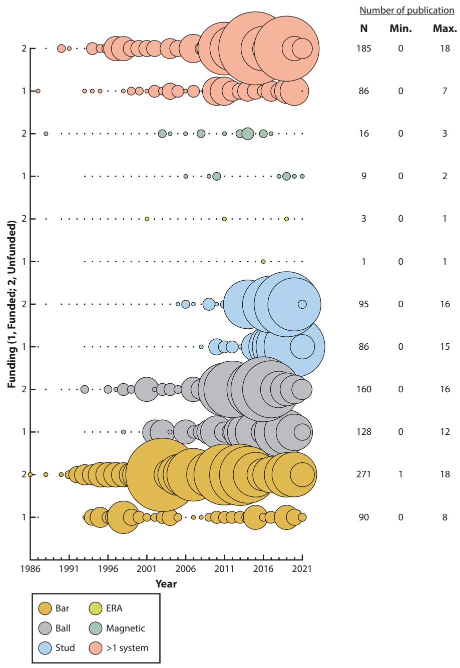


Figure 4. Retention system trends and number of publications (graphically represented by bubble size) over time according to financial assistance (funded and unfunded).

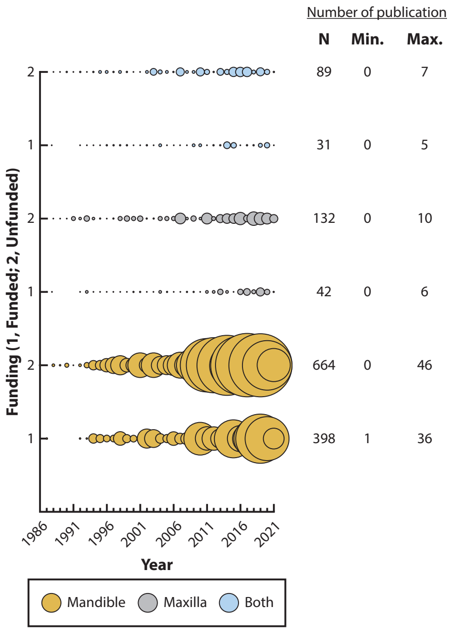


Figure 5. Location assessed and number of publications (graphically represented by bubble size) over time according to financial assistance (funded and unfunded).

The overall Poisson regression results regarding the fit of the model was R square=0.147, F ratio=22.213, degree of freedom=1005, collinearity statistics (tolerance>0.448, VIF<2.230), and omnibus test<0.001. Thereafter, the multiple Poisson regression showed an association between the presence of funding and bibliometric parameters (Table 6). High (IRR=4.355, 95% CI=1.778, 10.665, P=.001) and upper-middle (IRR=3.081, 95% CI=1.259, 7.539, P=.014) income countries compared with lower-middle income and low income countries presented an increased number of funded studies by 4.355- and 3.081- fold, respectively. Two continents were more likely to be funded, Oceania (IRR=4.537, 95% CI=1.333, 15.443, P=.016) and South America (IRR=4.025, 95% CI=1.209, 13.404, P=.023), which presented an increase in articles from funded studies of 4.537- and 4.025-fold, respectively. When the study designs were assessed, RCTs, compared with case reports and series, showed the biggest increase in funded studies (IRR=4.011, 95% CI=2.608, 6.170, P<.001), but in vitro, in silico, and N- RCT studies have also presented an increase in funded studies by 3.252-, 2.752-, and 2.819-fold, respectively, over case reports and series (P<.001). Regarding the retention system, stud attachments (IRR=1.605, 95% CI=1.266, 2.034, P<.001) and ball (IRR=1.326, 95% CI=1.079, 1.630, P=.007) had an increased number of funded studies compared with those with more than 1 system. Thereafter, the number of funded studies was also associated with the continuous variables (P<.05), year of publication, and h-index. Specifically, as the year and h-index score increased, the number of funded studies also increased by 1.021- and 1.005-fold, respectively.

Table 6. Crude and adjusted multiple Poisson regression to determine independent parameters associated with funding classification into implant overdenture studies during last 35 years (1986 to 2021)

		Crude model				Adjusted model*			
				95% CI				95% CI	
Variables	**Funded n (%) [Mean ± SD]**	***P***	**IRR**	**Lower**	**Upper**	***P***	**IRR**	**Lower**	**Upper**
I. Country income									
High	357 (26.4)	.001	4.29	1.75	10.51	**.001**	4.355	1.778	10.665
Upper-middle	109 (8.1)	.015	3.05	1.25	7.48		3.081	1.259	7.539
Low-middle and low	9 (0.7)	-	Ref.	-	-	-	Ref.	-	-
II. Continent									
Europe	180 (13.3)	.19	2.26	0.668	7.642	.189	2.258	0.671	7.601
North America	99 (7.3)	.071	3.046	0.909	10.204	.073	3.030	0.903	10.170
South America	66 (4.9)	.024	4.013	1.199	13.43	**.023**	4.025	1.209	13.404
Asia	93 (6.9)	.153	2.376	0.725	7.785	.149	2.389	0.732	7.800
Oceania	32 (2.4)	.017	4.513	1.309	15.559	**.016**	4.537	1.333	15.443
Africa	5 (0.4)	-	Ref.	-	-	-	Ref.	-	-
III. Study design									
RCT	158 (11.5)	<.001	3.638	2.311	5.728	**<.001**	4.011	2.608	6.170
N-RCT	179 (13.1)	<.001	2.577	1.657	4.006	**<.001**	2.819	1.839	4.321
Retrospective	18 (1.3)	.196	1.551	0.797	3.018	.134	1.660	0.855	3.221
In silico	30 (2.2)	<.001	2.557	1.518	4.305	**<.001**	2.752	1.666	4.546
In vitro	50 (3.7)	<.001	2.996	1.838	4.882	**<.001**	3.252	2.037	5.191
Case reports and series	29 (2.1)		Ref.	-	-	-	Ref.	-	-
IV. Topic									
Retention system	95 (6.9)	.331	1.224	0.814	1.842	-	-	-	-
Others	14 (1)	.178	1.495	0.833	2.684	-	-	-	-
Implant setting	40 (2.9)	.352	1.215	0.806	1.831	-	-	-	-
Loading protocol	52 (3.8)	.264	1.254	0.843	1.867	-	-	-	-
Rehabilitation method	138 (10.1)	.153	1.307	0.905	1.889	-	-	-	-
Macrodesign	59 (4.3)	.114	1.372	0.927	2.031	-	-	-	-
Anatomic and surgical	26 (1.9)	.63	1.12	0.705	1.781	-	-	-	-
Surface treatment	18 (1.3)	.374	1.268	0.752	2.138	-	-	-	-
Complications	35 (2.6)	-	Ref.	-	-	-	-	-	-
V. Retention system									
Bar	90 (8)	.641	0.939	0.722	1.222	.631	0.941	0.734	1.206
Ball	128 (11.3)	.054	1.275	0.996	1.633	**.007**	1.326	1.079	1.630
Stud	86 (7.6)	.001	1.578	1.204	2.069	**<.001**	1.605	1.266	2.034
ERA	1 (0.1)	.927	0.914	0.13	6.403	.910	0.896	0.135	5.949
Magnetic	9 (0.8)	.293	1.343	0.775	2.328	.282	1.342	0.785	2.292
> 1 Retention system	86 (7.6)	-	Ref.	-	-	-	Ref.	-	-
VI. Intervention location									
Maxilla and mandible	31 (2.3)	.879	1.036	0.657	1.632	-	-	-	-
Mandible	398 (29.4)	.690	1.060	0.796	1.411	-	-	-	-
Maxilla	42 (3.1)	-	Ref.	-	-	-	-	-	-
VII. Institution									
> 1 institution	270 (20)	.447	0.935	0.785	1.113	-	-	-	-
1 institution	204 (15.1)	-	Ref.	-	-	-	-	-	-
VIII. Discipline									
> 1 discipline	301 (22.6)	.166	1.127	0.952	1.334	.165	1.119	0.955	1.311
1 discipline	165 (12.4)	-	Ref.	-	-	-	Ref.	-	-
IX. International network									
> 1 country	143 (10.6)	.413	1.079	0.900	1.293	-	-	-	-
1 country	332 (24.5)	-	Ref.	-	-	-	-	-	-
X. Year	[2012 ± 8]	.008	1.021	1.005	1.036	**.005**	1.021	1.006	1.035
XI. h-index	[19.9 ± 16.2]	.044	1.005	1.000	1.011	**.025**	1.005	1.001	1.010
XII. Mean citations	[2.6 ± 2.6]	.141	1.023	0.993	1.054	.085	1.026	0.996	1.056

CI, confidence interval; IRR, incidence rate ratio; N-RCT, nonrandomized controlled clinical trial; RCT, randomized controlled clinical trial; Ref., reference category used; SD, standard deviation. Bold values in adjusted model inform statistically significant difference. *Included variables with P<.2 for crude model. In sequence, intervention location, topic, number of institutions, and international network drawn from crude model.

DISCUSSION

The development of dental implants, aside from commercial growth, requires funding to achieve scientific reliability and to allow clinicians and researchers to recognize what is available for implant-supported overdentures. The authors are unaware of a previous biblio- metric article in this field that provides such information. Parameters including country income, continent, study design, retention system assessed, year, and author h-index were associated with the frequency of funded studies. Therefore, the null hypothesis that funding assistance would not affect bibliometric parameters was rejected.

The present data demonstrated that funding has increased over the years. Companies have frequently improved their products, including implants and components, and providing financial support has marketing and economic benefits, as previously observed for implant dentistry.[1,3] The majority of the highest ranked companies (Nobel Biocare, Straumann, Dentsply Sirona) have supported research activities to test the benefits of their products by using online incentive programs so that researchers can submit potential projects. These companies are located in high income countries, are recognized worldwide, are committed to improve their products with cutting-edge innovations, and have an extensive catalog for clinicians. Governmental institutions have also provided extensive support (São Paulo Research Foundation, Coordination for the Improvement of Higher Education Personnel, Canadian Institutes of Health Research, National Council for Scientific and Technological Development). This extensive support might be explained by well-developed research projects designed with the collaboration of experts and by the critical evaluation of reviewers before a research grant is awarded. However, it must be mentioned that the Coordination for the Improvement of Higher Education Personnel (CAPES) listed in this study and in a previous bibliometric article1 is mainly directed toward supporting human resource scholarships. Thus, further explanations are required before drawing any conclusions. The Coordination for the Improvement of Higher Education Personnel (CAPES) in Brazil provides financial support to all Brazilian graduate programs. However, the financial support is destined primarily for the maintenance of the scholarship holder. The research is not directly funded although it is frequently reported in the study under the finance code 001. Conversely, governmental funding from Brazil (São Paulo Research Foundation, National Council for Scientific and Technological Development), despite investing in human resource scholarships, also finances research projects.

As expected, authors in countries with high and upper-middle income were more frequently funded, indicating that research funding and economic progress might be related. Also, as the income increases, the countries present similar research structures and form strong networks with identifiable geographical, linguistic, commercial, and geopolitical areas.[11] In this study, Europe was the most productive continent, based on the corresponding author. The same pattern had been previously noted in a bibliometric study in the implantology field.[2] Even though Europe did not show a statistical difference in funding, most European countries (except Italy) do have a high income and were responsible for the most funded studies.

The only continents that presented a higher frequency of funded studies were Oceania and South America. Those geographic locations have seen increased productivity over the last 2 decades, and Oceania was the only continent with more funded than unfunded studies. A possible explanation might be related to a settled source of funding. Regarding Oceania, most of the publications had industry assistance from multiple sources, including 1 study with 9 different connections. Additionally, of the 40 published studies, 30 were from New Zealand, 18 presented the same senior author (Dr Alan G. T. Payne), and only 3 of those 18 were not funded.

Meanwhile, most of the studies in South America were from Brazil, and this country presented the highest number of funded studies. Such data might also be related to the recognized governmental assistance throughout the graduate programs previously reported. It must be highlighted that implant-retained overdentures, especially in Brazil, can be up to 2.4 times less expensive than implant-supported fixed prostheses and even less expensive than those in countries such as Switzerland when considering purchasing power parities to convert the costs into other currencies.[7,8] Altogether, the rehabilitation price simplifies the assessment, requires additional research, and can explain the number of publications in Brazil.

Regarding the metrics associated with funding, only the h-index was statistically significantly associated. Corresponding authors with a higher h-index were more likely to publish funded studies. The h-index parameter accounts for previous citations with implant overdenture studies and other specific research fields. Therefore, the main reasons assumed for the result obtained are an understanding of the subject, well-established work environments, access to different equipment to comply with methodological steps, and the successful completion of previously awarded grants. Even though the h-index is a classic metric parameter, it still requires improvement so that it is not inflated by excessive self-citations.[4] For this study, it was expected that the intellectual contribution of authors from different institutions, disciplines, and countries would also impact funding assistance. However, those parameters might be more related to the diffusion of the study across the globe (citation) rather than the financial support. Additionally, the highest volume of publication, considering funded and unfunded studies, is found in consolidated journals (COIR, International Journal of Prosthodontics, International Journal of Oral and Maxillofacial Implants, and Journal of Prosthetic Dentistry). These journals mainly address prosthetic and restorative dentistry areas, indicating a reliable source when seeking implant overdenture studies.

Higher methodological quality trials, such as prospective trials (RCT and N-RCT), were more frequently funded than in vitro and in silico studies. In many instances, those different study designs might be complementary, as different companies often launch new products to improve treatment. Those alternative methods, including variation into implant macrodesign, surface treatment, and component design, might require laboratory investigation before assessment with clinical trials. However, although RCTs and N-RCTs cannot explain all research questions, those designs are the best choice when evaluating rehabilitation effectiveness and might explain the highest amount of publication since 1986. Interestingly, the number of studies increased considerably after the McGill Consensus Statement as indicated by the funding relationship among study design and publication over the years; the same was true for the location being assessed.[6] The similarity might be related to the change from conventional complete dentures to mandibular 2-implant overdentures as the standard rehabilitation plan for mandibular edentulous patients.

The historical evaluation of the attachment described in the publications showed that the ball and stud retention systems were more frequently funded. Additionally, the number of studies using an unsplinted single system, either ball or stud, increased remarkably in the last decade. This might be related to the recent development and mechanical features of the stud system and its benefits for edentulous patients.[9,10] Meanwhile, according to the manufacturer, the ball attachment has spherical variations to enhance its mechanical properties.[9] Both systems are considered straightforward, even though more maintenance is required than the bar attachment, might be why the authors of such studies apply for funds. Additionally, improvements in those attachments (angulation, nylon retention, housing material) might also explain more funding assistance, especially from the company responsible for marketing those products.

Even though several bibliometric parameters were noted to be associated with funding in implant overdenture documentation, this study had limitations. The h-index metric is an exceptional tool to inform the dissemination of science; however, it does not represent entire author documentation, and bias in citation analysis is inevitable.[1,2,4] Some documents were not available for further assessment in Scopus (total citations to calculate the mean citations). Nevertheless, it was represented by the minority (n=69, 5.04%) part of the entire sample. Notably, there are shortfalls in the information on funding in some published works. For example, in the case of Coordination for the Improvement of Higher Education Personnel (CAPES), it is unclear whether funding is extended to grant the project or only to support human resources with scholarships, which leads to data inaccuracy. Finally, authors should be encouraged to collect and report findings irrespective of the industry, government, foundation, size of company, research institute, or university.

CONCLUSIONS

Based on the findings of this bibliometric study, the following conclusions were drawn:

1. Studies on implant overdentures have increased remarkably over the past 35 years (1986 to 2021). The frequency of funded studies was also higher according to country economy, especially those with high and upper-middle income. The same trend was observed for 2 continents, Oceania and South America.
2. Bibliometric parameters were associated with funding, including study design (randomized and nonrandomized controlled clinical trials and in silico and in vitro studies) and retention systems (ball and stud). Finally, those authors with a higher h-index had more funded studies.

REFERENCES

1. Alonso-Arroyo A, Tarazona-Alvarez B, Lucas-Dominguez R, Peñarrocha- Oltra D, Vidal-Infer A. The funding sources of implantology research in the period 2008-2017: a bibliometric analysis. Clin Implant Dent Relat Res 2019;21:708-14.

2. Chiang HS, Huang RY, Weng PW, Mau LP, Tsai YC, Chung MP, et al. Prominence of scientific publications towards peri-implant complications in implantology: a bibliometric analysis using the H-classics method. J Oral Rehabil 2018;45:240-9.

3. Barão VA, Shyamsunder N, Yuan JC, Lee DJ, Assunção WG, Sukotjo C. Authorship, collaboration, and funding trends in implantology literature: analysis of five journals from 2005 to 2009. Implant Dent 2011;20:68-75.

4. Heneberg P. From excessive journal self-cites to citation stacking: analysis of journal self-citation kinetics in search for journals, which boost their scien- tometric indicators. PLoS One 2016;11:e0153730.

5. Alhajj MN, Al-Sanabani FA, Alkheraif AA, Smran A, Alqerban A, Samran A. Bibliometric analysis and evaluation of the Journal of Prosthetic Dentistry from 1970 to 2019. J Prosthet Dent 24 June 2021. https://doi:10.1016/ j.prosdent.2021.05.013. [Epub ahead of print].

6. Feine JS, Carlsson GE, Awad MA, Chehade A, Duncan WJ, Gizani S, et al. The McGill consensus statement on overdentures. Mandibular two-implant overdentures as first choice standard of care for edentulous patients. Mon- treal, Quebec, May 24-25, 2002. Int J Oral Maxillofac Implants 2002;17:601-2.

7. Zitzmann NU, Marinello CP, Sendi P. A cost-effectiveness analysis of implant overdentures. J Dent Res 2006;85:717-21.

8. Hartmann R, de Menezes Bandeira ACF, de Araújo SC, McKenna G, Brägger U, Schimmel

M, et al. Cost-effectiveness of three different concepts for the rehabilitation of edentulous mandibles: overdentures with 1 or 2 implant attachments and hybrid prosthesis on four implants. J Oral Rehabil 2020;47:1394-402.

9. Alsabeeha NH, Payne AG, Swain MV. Attachment systems for mandibular two-implant overdentures: a review of in vitro investigations on retention and wear features. Int J Prosthodont 2009;22:429-40.

10. Marcello-Machado RM, Faot F, Schuster AJ, Bielemann AM, Chagas Júnior OL, Del Bel Cury AA. One-year clinical outcomes of locking taper Equator attachments retaining mandibular overdentures to narrow diameter implants. Clin Implant Dent Relat Res 2018;20:483-92.

11. Jaffe K, Ter Horst E, Gunn LH, Zambrano JD, Molina G. A network analysis of research productivity by country, discipline, and wealth. PLoS One 2020;15:e0232458.

12. Alarcón MA, Esparza D, Montoya C, Monje A, Faggion CM Jr. The 300 most- cited articles in implant dentistry. Int J Oral Maxillofac Implants 2017;32:e1-8.

13. Kassebaum NJ, Bernabé E, Dahiya M, Bhandari B, Murray CJ, Marcenes W. Global burden of severe tooth loss: a systematic review and meta-analysis. J Dent Res 2014;93:20S-8S.

14. Buser D, Sennerby L, De Bruyn H. Modern implant dentistry based on osseointegration: 50 years of progress, current trends and open questions. Periodontol 2000 2017;73:7-21.

15. Tarazona B, Vidal-Infer A, Alonso-Arroyo A. Bibliometric analysis of the scientific production in implantology (2009-2013). Clin Oral Implants Res 2017;28:864-70.

16. Hirsch JE. An index to quantify an individual's scientific research output. Proc Natl Acad Sci U S A 2005;102:16569-72.

17. Tarazona-Álvarez B, López-Roldan A, Vidal-Infer A, López-Padilla D, Alonso-Arroyo A. Bibliometric analysis of the scientific production of literature on peri-implant diseases in the

Web of Science. Clin Implant Dent Relat Res 2021;23:625-34.

SUPPLEMENTARY MATERIAL

Supplementary Table 1. Electronic bibliometric search strategies

PubMed

#1:
Denture, Overlay[MeSH Terms] OR Overlay*[Title/Abstract] OR Overdenture*[Title/Abstract] OR Removable[Title/Abstract]
#2:
Mandible[MeSH Terms] OR Maxilla[MeSH Terms] OR Maxilla*[Title/Abstract] OR Mylohyoid*[Title/Abstract] OR Ridge*[Title/Abstract] OR Mandib*[Title/Abstract]
#3:
Dental Implants[MeSH Terms] OR Implant*[Title/Abstract]

#1 AND #2 AND #3

Scopus

#1:
TITLE-ABS-KEY("Denture, Overlay") OR TITLE-ABS-KEY(Overlay*) OR TITLE-ABS-KEY(Overdenture*) OR TITLE-ABS-KEY(Removable)
#2:
TITLE-ABS-KEY(Mandible) OR TITLE-ABS-KEY(Maxilla) OR TITLE-ABS-KEY(Maxilla*) OR TITLE-ABS-KEY(Mylohyoid*) OR TITLE-ABS-KEY(Ridge*) OR TITLE-ABS-KEY(Mandib*)
#3:
TITLE-ABS-KEY("Dental Implants") OR TITLE-ABS-KEY(Implant*)

#1 AND #2 AND #3

Web of Science

#1:
TS=("Denture, Overlay") OR TS=(Overlay*) OR TS=(Overdenture*) OR TS=(Removable)
#2:
TS=(Mandible) OR TS=(Maxilla) OR TS=(Maxilla*) OR TS=(Mylohyoid*) OR TS=(Ridge*) OR TS=(Mandib*)
#3:
TS=("Dental Implants") OR TS=(Implant*)

#1 AND #2 AND #3

Embase

#1:
'Denture, Overlay':ab,ti OR Overlay*:ab,ti OR Overdenture*:ab,ti OR Removable:ab,ti
#2:
Mandible:ab,ti OR Maxilla:ab,ti OR Maxilla*:ab,ti OR Mylohyoid*:ab,ti OR Ridge*:ab,ti OR Mandib*:ab,ti

#3:
‘Dental Implants’:ab,ti OR Implant*:ab,ti

#1 AND #2 AND #3

Cochrane Library

#1
MeSH descriptor: [Denture, Overlay] explode all trees or (Overlay*):ti,ab,kw OR (Overdenture*):ti,ab,kw OR (Removable):ti,ab,kw
#2
MeSH descriptor: [Mandible] explode all trees or MeSH descriptor: [Maxilla] explode all trees or (Maxilla*):ti,ab,kw OR (Mylohyoid*):ti,ab,kw OR (Ridge*):ti,ab,kw OR (Mandib*):ti,ab,kw
#3
MeSH descriptor: [Dental Implants] explode all trees or (Implant*):ti,ab,kw

#1 AND #2 AND #3

Virtual Health Library

#1:
(mh:(“Denture, Overlay”)) OR (tw:(Overlay$)) OR (tw:(Overdenture$)) OR (tw:(Removable))
#2:
(mh:(Mandible)) OR (mh:(Maxilla)) OR (tw:(Maxilla$)) OR (tw:(Mylohyoid$)) OR (tw:(Ridge$)) OR (tw:(Mandib$))
#3:
(mh:(“Dental Implants”)) OR (tw:(Implant$))

#1 AND #2 AND #3

Supplementary Table 2. Subdivision of topics according to broad thematic described in included studies

Topic	Included content
Retention system	Unsplinted systems, different bar levels, prefabricated system, abutment designs, splinted systems, bar extensions, attachment incorporation techniques (direct and indirect), attachment high, bar length, bars manufacturing, CAD CAM bars.
Complications	Diabetic patients, late implant failure, mandibular cancer, syndromes (Papillon Lefevre, Sjögren, Moebius, Down), hypohidrotic ectodermal dysplasia, reconstruction of hemimandibular and condylar defect, osteoporotic patients, HIV patients, fractured mandibular bone, unrepaired complete cleft, patients with temporomandibular disorders, macroglossia, rheumatoid polyarthritis, maxillofacial reconstruction.
Implant setting	Implant positions, angulation, or number.
Loading protocol	Immediate, early, conventional.
Rehabilitation method	Different methods of rehabilitation compared with implant supported overdentures (complete conventional dentures, fixed rehabilitations, tooth supported overdentures, partial fixed prosthesis).
Implant macrodesign	Implant diameter, and length, one piece implants, zygomatic implants.
Anatomical or surgical	Implant placement after extraction, augmentation, free autograft of connective tissue, computer assisted implant surgery, flapless implant surgery, expanded mandibular knife edge ridge, limited inter arch space, reduced bone mineral density, changes in width of maxillary residual ridge, arch form, arch size, inter foraminal distance, severely resorbed edentulous jaw.
Surface treatment	Porous coating, hydroxyapatite coating, bilayer bioactive surface coating, plasma sprayed, machine surfaced, rough surfaced, anodized surface, microthreaded, TiOblast, titanium dioxide grit blasted, fluoride, TiUnite, acid etched.
Others	Occlusion design, hygiene protocol, palatal coverage, base thicknesses, base reinforcement, teeth design (cusped and cuspless), neutral zone.

Supplementary Table 3. Methodological details of bibliometric parameters collection

Outcomes description
Regarding bibliometric parameters, first publication descriptions (year, journal name, number of institutions, number of disciplines, number of countries, study design) recorded. When 1 listed author had 2 or even more affiliations in different institutions, only first mentioned institution remained noted. Disciplines within same listed description of authors remained collected. When disciplines presented with more than 2 areas (Department of Prosthodontics and Periodontology), 2 disciplines remained counted. Also, when authors had multiple affiliations with different disciplines, only first listed affiliation with its disciplines descriptions kept noted. Additionally, study design criteria for articles with multiple classifications (nonrandomized controlled clinical trial and in vitro study) first mentioned into objective remained noted to avoid overlapping data. Second, geographic details (continent from corresponding author, total number of countries from listed authors) assessment based on first mentioned category. Economy description from corresponding author country (income classification), further evaluated in 'low', 'lower-middle', 'upper-middle', or 'high', according to World Bank Country and Lending Groups (https://data.worldbank.org). Forth, corresponding author metrics collected in May 2021 in Scopus by Elsevier (h-index, mean citations), value used into mean citations per article based on following equation $\frac{\text{Total number of citations}}{2021 - \text{Year of publication}}$. Overdenture features (location assessed, retention system) also noted and corresponding jaw under evaluation kept reported as 'mandible', 'maxilla', or 'both'; while for retention system, this section categorized in 'ball', 'stud', 'ERA', 'bar', or 'magnetic', according to component design. Meanwhile, studies with additional retention systems clustered as '> 1 retention system'. Article main objective (study topic) divided into a)

retention system, b) complications, c) implant setting, d) loading protocol, e) rehabilitation method, f) implant macrodesign, g) anatomical or surgical, h) surface treatment, i) others (Supplementary Table 2, available online). Moreover, whether study had multiple topics, first one mentioned in objective considered and noted.

Supplementary Table 4. Methodological details of multiple Poisson regression analysis

Poisson regression analysis
Statistical assay conducted with appropriate software (IBM SPSS Statistics, v20.0; IBM Corp). Initially, bibliometric parameters properly described, according to data set in categorical and continuous outcomes. Incidence rate ratio (IRR) applied, using multiple Poisson regression analysis, evaluating association between funding (dependent variable) and bibliometric parameters (country income, continent, study design, study topic, retention system, intervention location, number of institutions, number of disciplines, international network, year, h-index, mean citations). Thereafter, crude and adjusted *P* value, IRR, and its 95% confidence intervals values plotted. To acquire appropriate fit into regression model Backward-Wald method selected and independent variables with $P > .2$ progressively removed from unadjusted model. Thereafter, all outcomes with $P < .05$ into adjusted model considered statistically significant. Optimum fit throughout model established with Omnibus tests ($P < .05$). It withdrawn from crude model intervention location, topic, number of institutions, and international network. Therefore, remaining outcomes kept into adjusted model. Out of 12 independent variables, 'country income' needed adjustment, and 'systematic review' subtopic could not be carried out in statistical assessment. Specifically, 'low' income classification noted in only 1 study (0.1%), and it moved to 'lower-middle' category to avoid unrepresentative evaluations. One of study topics 'systematic review'; however, information related to retention system not applicable and not reported for this study design. Thereafter due to missing information, statistical assessment did not consider this subtopic. Moreover, dichotomization applied for number of institutions (1 or > 1 institution), disciplines (1 or > 1 discipline), and international network (1 or > 1 country).

2.2 Bibliometric assessment in implant-retained overdenture articles: Mapping citation and journal impact factor trends#

Supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), finance code 001; Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), grant/award number: 2020/05234-3, 2021/02463-4; and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), grant/award number: 304853/2018-6.

Guilherme Almeida Borges, DDS, MSc,[a] Caroline Dini, DDS, MSc,[b] Mariana Marinho Davino de Medeiros, DDS, MSc,[c] Renata Cunha Matheus Rodrigues Garcia, DDS, MSc, PhD,[d] Valentim Adelino Ricardo Barão, DDS, MSc, PhD,[e] and Marcelo Ferraz Mesquita, DDS, MSc, PhD[f]

[a]PhD student, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.
[b]PhD student, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.
[c]PhD student, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.
[d]Full Professor, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.
[e]Associate Professor, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.
[f]Full Professor, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.

Corresponding author:
Dr. Marcelo Ferraz Mesquita
University of Campinas (UNICAMP)
Piracicaba Dental School
Av Limeira, 901, Piracicaba
São Paulo, 13414-903
BRAZIL
Email: mesquita@unicamp.br

#Artigo publicado na revista *Journal of Prosthetic Dentistry* (Fator de impacto = 4.6).

ABSTRACT

Statement of problem. Implant-retained overdentures are a recognized treatment option. However, a comprehensive assessment of all articles on implant-retained overdentures to identify publication standards such as mean citation and the Journal Citation Reports (JCR) impact factor is lacking.

Purpose. The purpose of this bibliometric assessment was to evaluate the association of mean citation and JCR impact factor with bibliometric parameters in articles on implant-retained overdentures.

Material and methods. Articles reporting randomized controlled clinical trials (RCTs) and nonrandomized controlled clinical trials (N-RCTs); case reports and series; retrospective studies; and in silico, in vitro, or systematic reviews in 6 databases were included. Data were extracted, and 2 multiple Poisson regressions analyses were applied (α=.05). The dependent variables were mean citation and JCR impact factor, which were evaluated to identify their association with bibliometric parameters by using prevalence ratio (PR) values.

Results. A total of 1369 articles published from 1986 to 2021 were included. The data revealed a high mean citation and high JCR impact factor for RCT, N-RCT, retrospective, and in vitro studies (P<.05). In silico studies presented a high mean citation (P<.001). Senior researchers with a high h-index were more likely to have a high mean citation and publications with a high JCR impact factor (P<.001). Also, senior authors associated with an international network were more likely to have a high mean citation (P=.001). High-income countries had more studies with a high mean citation and JCR impact factor (P<.05). Higher JCR impact factors were associated with articles evaluating only the maxilla or mandible (P<.05). The topics “implant setting” and “macrodesign” were associated with a high mean citation (P<.05).

Conclusions. The publication trends suggest a high mean citation and a high JCR impact factor for clinical designs (RCT, N-RCT, retrospective) and in vitro studies. The same pattern was also displayed for researchers with a high h-index and located in high-income countries.

CLINICAL IMPLICATIONS

The bibliometric analysis revealed a favorable publishing environment in terms of a high JCR impact factor and a high mean citation in implant-retained overdenture studies (1986-2021) according to the study design (RCT, N-RCT, retrospective, and in vitro studies) and senior authors' country income and h-index. Also, researchers and clinicians should be aware that data related to the study topic may change as industries launch new products and improve implants and components, leading to changes in the topics studied in implant-retained overdenture articles.

INTRODUCTION

The scientific evolution in the field of implant-retained overdentures has been demonstrated by an outstanding development in academic research on implantology and prosthodontics.[1-10] This information has been supported by a high survival rate of prostheses, number of publications, citation count, journal impact factor, and even funding to support researchers evaluating novel concepts.[1,3,4,7,9-14] With such scientific growth, progress in treatment with implant-retained overdentures continues to increase, with knowledge from prospective trials, laboratory research, and in silico studies.[15-21]

Publishing has been important in spreading technical information and raising important topics to be addressed by the scientific community.[22-24] These data can be better understood by clustering articles and assessing publication standards such as mean citation and the Journal Citation Reports (JCR) impact factor.[9,11,25-28] The mean citation is a numerical parameter that might represent an influential publication in a field, in addition to being a suitable tool for quantifying the impact of a publication, journal, topic of discussion, author, and trends over time.[29] In dentistry, few studies have assessed citation patterns.[1,11,24-26] Previous bibliometric analyses on citation count have provided information on dominant areas of a research field (global burden of severe tooth loss), historical inequalities related to geographical location (Middle East, Africa), methodological study design with least citations (case reports or series), and journals with exceptional citation counts.[1,5,25,26,30] That information might have an important role when assessing the literature for relevant studies in the field.[20,30]

The JCR impact factor has been frequently used to assess the quality of specific journals in a specific area and remains the most established bibliometric indicator at the journal level.[25] However, excessive self-citations can inflate the impact factor.[29] Nevertheless, an overall decrease in JCR impact factor over time and a nonsignificant correlation between the self-citation report and the impact factor display a reliable publishing environment in dentistry, oral surgery, and medicine.[11] Therefore, both parameters (mean citation and JCR impact factor) may have an individual association with other bibliometric indicators (international network, study design, topic, funding assistance, senior researcher data).[1,5,11,25-27] Additionally, the mean citation and JCR impact factor may provide useful information or guidelines for future authors, clinicians, researchers, peer re- viewers, journal editors, and publishers. This study aimed to evaluate the association of mean citation and JCR impact factor with bibliometric parameters (country income, study design, study topic, retention system, intervention location, number of institutions, number of disciplines, international network, funding assistance, h- index) over the years in publications on implant-retained overdentures. The research hypothesis was that both dependent variables (mean citation and impact factor) would be influenced by bibliometric outcomes.

MATERIAL AND METHODS

An electronic literature search was carried out in April 2021 using 6 core collections and included proper adaptations (Supplemental Table 1, available online). The subject being tracked was articles about implant-retained overdentures. Articles were deemed eligible for bibliometric evaluation if they were classified as randomized controlled clinical trials (RCTs) or nonrandomized controlled clinical trials (N-RCTs); case reports or series; retrospective studies; and in silico, in vitro, or systematic reviews. The bibliometric parameters of each article were recorded, including article mean citation per year, senior author's (corresponding author) information (name, country income, and h-index), study design, main topic (Supplemental Table 2, available online), implant-retained overdenture data included in the article (location being assessed, retention system), total number of institutions, disciplines, countries, funding assistance, and JCR impact factor (Supplemental Table 3, available online). A network analysis of international interactions among countries and authors was conducted with a software program (Gephi, v0.9.2; GNU General Public License) (Supplemental Table 4, available online). Thereafter, a statistical software program (IBM SPSS Statistics, v20.0; IBM Corp) was used to calculate multiple Poisson regressions analyses to determine the association between the dependent variables (mean citation and JCR impact factor) and each independent variable (country income, study design, topic, retention system, intervention location, institution number, discipline number, international network, funding, h-index). Measurement of the association between variables was verified through regression prevalence ration (PR) values and 95% confidence interval (α=.05).

RESULTS

A total of 1369 articles published between 1986 and 2021 on implant-retained overdentures were identified. The mean ±standard deviation citations per article was 2.2 ±2.5, and the median was 1.5. The JCR impact factor ranged from 0 to 8.728, with a mean ±standard deviation of 3.243 ±1.708, and the median was 2.8. The distribution of other bibliometric parameters was reported by Borges et al.[2] The network interaction of articles having more than 1 country is displayed in Figure 1. Canada and the United States of America had the widest network among countries, but interactions with the United States of America (n=67) were mainly bidirectional and included Brazil, Canada, China, Italy, Japan, Sweden, Switzerland, and the United Kingdom. However, of the 71 interactions with Canada, 54 had Canada as an original source, and 17 were from senior authors elsewhere collaborating with those in Canada, principally Brazil, Japan, the United Kingdom, the United Arab Emirates, and the United States of America. Figure 2 presents an additional network with the major interactions of senior authors with international contributions, with individual clusters around de Souza R.F., ELsyad M.A., and Awad M.A. Although some authors, including Schincaglia G.P., Alfadda S.A., and Alqutaibi A.Y. did not have grade 2 connections (2 or more interactions), they are displayed in the graph because of the high number of single connections established. Bilateral contributions were observed between Feine J.S. and Awad M.A., Matthys C. and de Bruyn H., and Swain M.V. and Osman R.B. The pooled interactions of all authors are displayed in Supplementary Figure 1, available online.

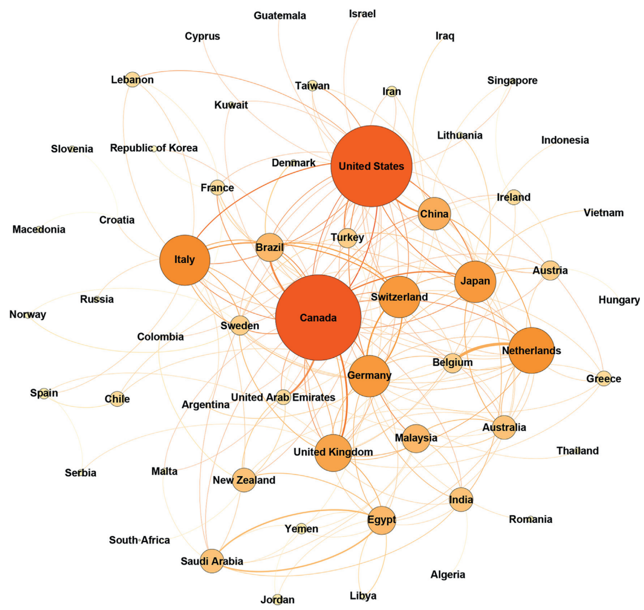


Figure 1. Collaboration networks among countries in articles related to implant-retained overdentures. Note: As color and bubble size intensify, number of collaborations (articles) increases; as line thickens, number of collaborations (articles) among countries increases.

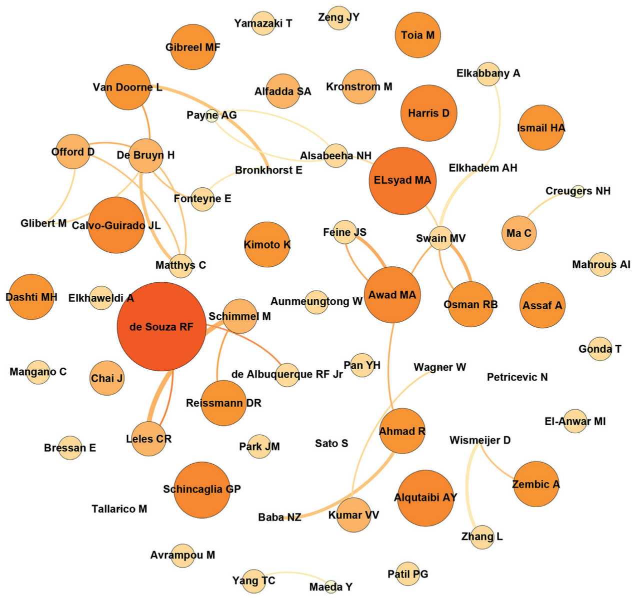


Figure 2. Collaboration networks among authors in articles related to implant-retained overdentures. Note: As color and bubble size intensify, number of collaborations (articles) increases; as line thickens, number of collaborations (articles) among authors increases. Filtration applied for authors displaying international collaboration; thus, authors with grade 2 (two or more interaction) connections further assessed.

The multiple Poison regression model (Table 1) displayed a high mean citation for high-income countries (P=.017) compared with lower-middle income and low-income countries. When the study designs were assessed, RCTs, compared with case reports and series, showed the highest mean citation (P<.001), but N-RCT, in vitro, retrospective, and in silico studies also had an increased mean citation of 3.84-, 3.02-, 3-, and 2.95-fold, respectively, over case reports and series (P<.001). The topics with a high mean citation were implant setting (P=.037) and macrodesign (P=.041) when compared with complications by 1.4- and 1.36-fold, respectively. The data also indicated a higher mean citation for articles with senior authors with international collaboration than for articles from a single country (P=.001). A higher mean citation was also associated with senior authors having a high h-index (P<.001). Regarding the multiple Poisson regression for JCR impact factor (Table 2), a high JCR impact factor was associated with studies from countries with a high income (P=.001) compared with those countries with a lower-middle and low income. Additionally, high-impact-factor journals published studies more frequently with the following designs, RCT (P<.001), N-RCT (P<.001), retrospective (P=.01), and in vitro (P=.02) than case reports and series. Articles with data for only mandibular implant-retained overdentures (P=.043) or only maxillary (P=.01) were more frequently published in high-impact journals than studies having both maxillary and mandibular implant-retained over- dentures. Journals with high JCR impact factors were more likely to publish articles by senior researchers with a high h-index (P<.001).

Table 1. Crude and adjusted Poisson regression models to determine bibliometric parameters associated with mean citation in implant-retained overdenture studies from 1986 to 2021

	Mean citation[a]		Crude model				Adjusted model[b]			
	Low	High			95% CI				95% CI	
Variables	n; % (Mean ±SD)	n; % (Mean ±SD)	*P*	PR[3]	Lower	Upper	*P*	PR[c]	Lower	Upper
I. Country income										
High	411; 46.7	473; 53.3	.031	1.34	1.03	1.76	**.017**	1.37	1.059	1.780
Upper-middle	158; 58.5	112; 41.5	.213	1.2	0.9	1.59	.176	1.21	0.917	1.608
Lower-middle and low	81; 64.3	45; 35.7%	-	Ref.		-	-	Ref.	-	-
II. Study design										
RCT	91;32.7	187; 67.3	<.001	4.26	2.84	6.4	**<.001**	4.32	2.9	6.45
N-RCT	197; 43.2	259; 56.8	<.001	3.83	2.56	5.72	**<.001**	3.84	2.57	5.74
Retrospective	42; 54.5	35; 45.5	<.001	3.02	1.88	4.84	**<.001**	3	1.87	4.82
In silico	52; 61.2	33; 38.8	<.001	2.94	1.82	4.75	**<.001**	2.95	1.83	4.76
In vitro	75; 59.1	52; 40.9	<.001	3.01	1.92	4.72	**<.001**	3.02	1.93	4.72
Case report and series	179; 87.3	26; 12.7	-	Ref.	-	-	-	Ref.	-	-
III. Topic										
Retention system	155;51.8	144; 48.2	.306	1.16	0.87	1.54	.298	1.16	0.87	1.55
Others	17; 70.8	7;29.2	.832	0.94	0.52	1.69	.834	0.94	0.52	1.69
Implant setting	45; 43.7	58; 56.3	.038	1.4	1.02	1.91	**.037**	1.4	1.02	1.92
Loading protocol	49; 40.8	71; 59.2	.108	1.27	0.95	1.71	.105	1.28	0.95	1.71
Rehabilitation method	139; 41.9	193; 58.1	.081	1.28	0.97	1.68	.081	1.28	0.97	1.68
Macrodesign	51; 44.3	64; 55.7	.041	1.36	1.01	1.82	**.041**	1.36	1.01	1.82
Anatomic and surgical	67; 62.6	40; 37.4	.711	1.07	0.75	1.53	.691	1.07	0.75	1.54
Surface treatment	19; 54.3	16; 45.7	.682	1.1	0.7	1.73	.677	1.1	0.7	1.73
Complications	118; 71.5	47; 28.5	-	Ref.	-	-	-	Ref.	-	-
IV. Retention system										
Bar	177; 50.3	175; 49.7	.128	1.82	0.84	3.93	.136	1.8	0.83	3.9
Ball	130; 49.8	131; 50.2	.183	1.69	0.78	3.65	.185	1.69	0.78	3.66
> 1 Retention system	110; 42	152; 58	.063	2.07	0.96	4.44	.065	2.06	0.96	4.45
Stud	107; 61.5	67; 38.5	.251	1.58	0.72	3.48	.249	1.59	0.72	3.5
Magnetic	19; 79.2	5; 20.8	-	Ref.	-	-	-	Ref.	-	-
V. Intervention location										
Mandible	500; 49.8	505; 50.2	.912	1.01	0.79	1.3	-	-	-	-
Maxilla	91; 54.5	76; 45.5	.994	1	0.75	1.34	-	-	-	-
Maxilla and mandible	61; 53	54; 47	-	Ref.	-	-	-	-	-	-
VI. Institution							-	-	-	-
> 1 Institution	307; 47.2	343; 52.8	.405	0.94	0.82	1.08	-	-	-	-
1 Institution	343; 54.3	289; 45.7	-	Ref.	-	-	-	-	-	-
VII. Discipline							-	-	-	-
> 1 Discipline	307; 45.5	368; 54.5	.601	1.03	0.92	1.16	-	-	-	-
1 Discipline	332; 56.5	256; 43.5	-	Ref.	-	-	-	-	-	-
VIII. International network										
Yes	98; 35.9	175; 64.1	.002	1.249	1.08	1.44	**.001**	1.22	1.09	1.36
No	555; 54.8	457; 45.2	-	Ref.	-	-	-	Ref.	-	-
IX. Funding										
Yes	188; 41	270; 59	.698	1.024	0.91	1.15	-	-	-	-
No	472; 56.1	370; 43.9	-	Ref.	-	-	-	-	-	-
X. h-index	(12 ±12)	(21 ±17)	<.001	1.010	1.01	1.01	**<.001**	1.01	1.01	1.01

95% CI, 95% confidence interval; N-RCT, nonrandomized controlled clinical trial; PR, prevalence ratio; RCT, randomized controlled clinical trial; Ref., reference category used to interpret prevalence ratio output in regression model; SD, standard deviation. Bold values in adjusted model show statistically significant difference. [a]Dichotomization in low or high categories based on median (1.50). [b]Included variables with P<.2 in crude model. According to Backward-Wald procedure, in sequence, withdrawn from crude model: intervention location, funding, discipline, institution. [c]PR calculated based on ratio between prevalence among exposed (articles with high mean citation) and prevalence among unexposed (articles with low mean citation), interpreted based on reference.

Table 2. Crude and adjusted Poisson regression models to determine bibliometric parameters associated with Journal Citation Reports impact factor classi!cation in implant-retained overdenture studies from 1986 to 2021

	Impact factor[a]		Crude Model				Adjusted Model[b]			
	Low	High			95% CI				95% CI	
Variables	n; % (Mean ±SD)	n; % (Mean ±SD)	*P*	PR[c]	Lower	Upper	*P*	PR[3]	Lower	Upper
I. Country income										
High	273; 32.5	568; 67.5	.004	1.5	1.14	1.97	**.001**	1.57	1.2	2.06
Upper-middle	118;48.8	124; 51.2	.142	1.24	0.93	1.67	.104	1.27	0.95	1.7
Lower-middle and low	55; 61.8	34; 38.2		Ref.	-	-	-	Ref.	-	-
II. Study design										
RCT	76; 29.1	185; 70.9	<.001	1.58	1.28	1.95	**<.001**	1.62	1.32	1.98
N-RCT	124; 28.9	305; 71.1	<.001	1.57	1.3	1.91	**<.001**	1.6	1.32	1.93
Retrospective	24; 30.8	54; 69.2	.01	1.41	1.08	1.82	**.01**	1.42	1.1	1.83
In silico	43; 64.2	24; 35.8	.668	0.92	0.65	1.32	.707	0.93	0.65	1.33
In vitro	57; 48.7	60; 51.3	.022	1.36	1.05	1.77	**.02**	1.37	1.06	1.78
Case report and series	100; 58.1	72; 41.9	-	Ref.	-	-	-	Ref.	-	-
III. Topic										
Retention system	124; 46.1	145; 53.9	.066	0.82	0.67	1.01	.06	0.82	0.67	1.01
Others	9; 37.5	15; 62.5	.925	1.02	0.71	1.46	.975	1.01	0.7	1.44
Implant setting	33; 36.3	58; 63.7	.654	1.05	0.84	1.32	.697	1.05	0.83	1.31
Loading protocol	38; 32.5	79; 67.5	.36	0.9	0.73	1.12	.323	0.9	0.72	1.11
Rehabilitation method	97; 31.8	208; 68.2	.404	0.92	0.77	1.11	.373	0.92	0.76	1.11
Macrodesign	40; 37.4	67; 62.6	.534	0.93	0.75	1.16	.415	0.91	0.73	1.14
Anatomic and surgical	28; 30.8	63; 69.2	.7	1.04	0.85	1.28	.573	1.06	0.86	1.3
Surface treatment	10; 27.8	26; 72.2	.547	1.08	0.84	1.38	.661	1.06	0.82	1.35
Complications	67; 45.3	81; 54.7	-	Ref.	-	-	-	Ref.	-	-
IV. Retention system										
Bar	89; 27.7	232; 72.3	.492	1.15	0.77	1.74	-	-	-	-
Ball	95; 40.3	141; 59.7	.856	0.96	0.63	1.46	-	-	-	-
> 1 Retention system	99; 40.7	144; 59.3	.847	1.04	0.69	1.58	-	-	-	-
Stud and ERA	68; 43.3	89; 56.7	.859	1.04	0.68	1.59				
Magnetic	11; 50	11; 50	-	Ref.	-	-	-	-	-	-
V. Intervention location										
Mandible	344; 37.6	572; 62.4	.031	1.31	1.02	1.68	**.043**	1.29	1.01	1.66
Maxilla	52; 33.5	103; 66.5	.008	1.44	1.1	1.89	**.01**	1.46	1.11	1.92
Maxilla and mandible	46; 43	61; 57	-	Ref.	-	-	-	Ref.	-	-
VI. Institution										
> 1 Institution	224; 37.2	378; 62.8	.102	0.91	0.81	1.02	-	-	-	-
1 Institution	220; 38.6	350; 61.4	-	Ref.	-	-	-	Ref.	-	-
VII. Discipline										
> 1 Discipline	214; 33.9	418; 66.1	.414	1.04	0.94	1.15	-	-	-	-
1 Discipline	223; 42.7	299; 57.3	-	Ref.	-	-	-	Ref.	-	-
VIII. International network										
Yes	86; 31.9	184; 68.1	.068	1.13	0.99	1.28	.102	1.11	0.98	1.26
No	360; 39.8	544; 60.2	-	Ref.	-	-	-	Ref.	-	-
IX. Funding										
Yes	142; 31.9	303; 68.1	.316	1.05	0.95	1.16	.153	0.92	0.82	1.03
No	304; 40.9	439; 59.1	-	Ref.	-	-	-	Ref.	-	-
X. h-index	(13 ±11)	(21 ±17)	<.001	1.01	1	1.01	**<.001**	1.01	1	1.01

95% CI, 95% confidence interval; N-RCT, nonrandomized controlled clinical trial; PR, prevalence ratio; RCT, randomized controlled clinical trial; Ref., reference category used to interpret prevalence ratio output in regression model; SD, standard deviation. Bold values in adjusted model show statistically significant difference. [a]Dichotomization in low or high categories based on the median (2.80). [b]Included variables with P<.2 in crude model. According to Backward-Wald procedure, in sequence, withdrawn from crude model: retention system, funding, discipline. [c]PR calculated based on ratio between prevalence among exposed (articles with high impact factor) and prevalence among unexposed (articles with low impact factor), interpreted based on reference.

DISCUSSION

Dentistry journals have followed an upward trend in citation counts and JCR impact factor,[11] and the growth of those metrics can be related to the increased number of articles, especially original publications addressing relevant clinical topics.[1,26,30] The data obtained in this 35- year cross-sectional study led to acceptance of the research hypothesis and identified parameters that might be associated with the increase in citation and impact factor of articles. Those parameters were country income, study design, topic, intervention location, international network, and researcher h-index. A high mean citation and JCR impact factor were both associated with country income, study design, and senior authors' h-index. In addition, the mean citation increased according to the study's topic and international network. The JCR impact factor was also associated with the location of the study authors.

High-income countries were found more likely to have an increased mean citation and number of publications in journals having a high impact factor. Those geographical locations (the United States of America, the Netherlands, Switzerland, Canada, Germany, Japan, Italy) accounted for 42% of the total sample of articles included in this study and had been previously reported to have had a high number of publications in bibliometric studies related to implantology[1,9,10,12,24] or in the most established journals[3,26] (*Journal of Prosthetic Dentistry*, *Journal of Dental Research*). The finding might be explained by the presence of sufficient funds to develop research and an extensive community of active researchers in high-income countries.[2,9,10]

Additionally, the location (the United States of America, Japan, the Netherlands, Denmark, the United Kingdom) of leading journals (*Journal of Prosthetic Dentistry*, *Clinical Oral Implants Research*, *Journal of Prosthodontic Research*) might also be associated with a high impact factor, particularly when researchers located in those high-income regions are pursuing publication. The network connections of high-income countries (the United States of America, Japan, the United Kingdom) may be increased by well-established collaboration,[9] industry financed studies,[2,10] and probably a higher rate of acceptance when submitting to high-impact journals. The multiple Poisson regressions identified an association between the impact factor and the h-index. Therefore, well-recognized researchers might be more likely to publish their studies in high-impact-factor journals. Altogether, the knowledge of the methodological aspects related to researchers with a high h-index and the benefits of grants frequently present in high- income countries may account for publishing standards, especially a high mean citation and a higher number of studies in well-recognized journals in the field.[2,9,10]

Research has been driven by clinical problems, funding agencies, preceding literature, improved ways to extend previous research, and the translation of laboratory research to the clinic or community.[22] This bibliometric study demonstrated that the study's design could influence publication standards (mean citation and JCR impact factor). All clinical studies (RCT, N-RCT, and retrospective) displayed a higher prevalence ratio to be published in high-impact-factor journals and to have a high mean citation. The result might be explained by a direct association of the subject with the journal scope, readers seeking reliable information to apply in daily practice, and also researchers exploring practical ways to improve patients' quality of life. Another JCR impact factor association demonstrated that articles individually investigating maxillary or mandibular implant-retained overdentures might be more attractive for journals with a high impact factor, possibly because, even though the rehabilitation is mainly provided for the mandible,[8] patients with maxillary implant-retained overdentures will receive additional benefits, especially those with advanced alveolar atrophy or other causes of decreased retention and stability of conventional maxillary dentures.[21]

In vitro and in silico study designs also had a higher mean citation than case reports and series. The higher mean citation might be related to limitations in analyzing some dependent variables (biomechanical outcomes) clinically, the need for investigation of newly launched products before clinical trials, and also identifying a mechanical explanation for clinical outcomes. Implant-retained overdenture treatments may include a number of alternatives that can be evaluated in vitro to determine their suitability according to implant and component variations. Biomechanical studies have been used to predict occurrences (implant failure, possible locations of bone resorption, overall stress in ductile and nonductile structures) in challenging rehabilitation plans.[17] Only in silico studies did not present an association with the JCR impact factor, possibly because of the lower number of articles in the field, fewer journals that accept in silico analyses, and discrepancies among the results of in silico studies. A higher mean citation was found for areas covering macrodesign and implant location, possibly related to the frequency with which private companies improve their products (implants or components) and the search for alternative treatment plans for patients (number of implants placed, location, angulation).[15,17,19] Improvements or comprehension of outcomes in implant-retained overdenture research, according to the topic, might still be required to justify a high mean citation based on what has been established.

Implant-retained overdenture studies with authors from more than 1 country had a higher mean citation, possibly because when authors establish international networks, a more comprehensive understanding of the subject can be provided, either by sharing knowledge or experience, assisting with complementary methodologies, or adding data with multicentric studies. Additionally, because citation reflects dissemination and relevant findings among researchers, this concept might be more inflated when researchers from different countries combine with the mutual objective of spreading scientific knowledge. Even though only abstracts are freely available for many studies because the authors have not paid for open-access, researchers without university or society access might still be able to access the full text via digital platforms such as ResearchGate that might increase the number of mean citations. An author's h-index is associated with the mean citation and JCR impact factor. However, the association should be evaluated with caution because the h-index not only accounts for metrics related to implant-retained overdenture articles but also the author's publications in other fields.

Limitations of this study included that about 14% of articles could not be further assessed because of lack of information about the journal's impact factor on the JCR website. The JCR database includes only 4% of the available journals worldwide.[27] Some documents (less than 6%) were not available for calculating the mean citations based on the total citation when further assessed in the Scopus. The total citation count did not exclude self-citation, which might have changed the statistical results. Self-citation also affects the JCR impact factor but to a lesser extent, as a reduction in self-citation has been reported over the years in dentistry.[11] The h- index could be improved as self-citation and year of publication are not considered.[29] The h-index does not represent the entire author output, and bias in the citation analysis occurs.[29] The "systematic review" subtopic could not be carried out in the analysis because information related to the "retention system" was not applicable and the statistical assessment could not include this study design. The results should also be analyzed with caution because the data in this study represent publication trends in a timeline fraction of all implant-retained overdenture articles. It is not possible to measure and consequently ensure whether bibliometric metrics (JCR impact factor and mean citation) have a direct influence by publishing policies or whether there is a conflict of interest between and among authors, peer reviewers, journal editors, and journal editorial board. These issues need to be taken into consideration while evaluating the data reported, and future research should expand the understanding of the factors affecting publication biases.

CONCLUSIONS

Based on the findings of this bibliometric study, the following conclusions were drawn:

1. The bibliometric trends of the implant-retained overdenture articles revealed a high JCR impact factor and a high mean citation for RCT, N-RCT, retrospective studies, and in vitro studies. In silico studies only presented a high mean citation. A high JCR impact factor and a high mean citation were also noted for researchers presenting expertise in the field (identified by the h-index) and located in high-income countries. A high JCR impact factor was associated with studies evaluating the maxilla or mandible.
2. A high mean citation was seen for studies considering specific topics (implant setting and macrodesign) and senior researchers with international collaborations. However, authors should be aware that data related to the topic might change as industry continues to enhance implants and components.

REFERENCES

1. Alarcón MA, Esparza D, Montoya C, Monje A, Faggion Jr CM. The 300 Most- Cited Articles in Implant Dentistry. Int J Oral Maxillofac Implants. 2017;32: e1ee8.

2. Borges GA, Dini C, Medeiros MMD, Rodrigues Garcia RCM, Barão VAR, Mesquita MF. Funding assistance and global productivity in the field of implant overdentures: a bibliometric analysis of 35 years. J Prosthet Dent. 13 December 2021. https://doi.org/10.1016/j.prosdent.2021.11.002 [Epub ahead of print.].

3. Alhajj MN, Al-Sanabani FA, Alkheraif AA, Smran A, Alqerban A, Samran A. Bibliometric analysis and evaluation of the journal of prosthetic dentistry from 1970 to 2019. J Prosthet Dent. 23 June 2021. https://doi.org/10.1016/j. prosdent.2021.05.013 [Epub ahead of print.].

4. Barão VA, Shyamsunder N, Yuan JC, Lee DJ, Assunção WG, Sukotjo C. Authorship, collaboration, and funding trends in implantology literature: analysis of five journals from 2005 to 2009. Implant Dent. 2011;20:68e75.

5. Nabil S, Samman N. The impact of case reports in oral and maxillofacial surgery. Int J Oral Maxillofac Surg. 2012;41:789e796.

6. Tipton PA. The milled bar-retained removable bridge implant-supported prosthesis: a treatment alternative for the edentulous maxilla. J Esthet Restor Dent. 2002;14:208e216.

7. Winkler S, Piermatti J, Rothman A, Siamos G. An overview of the O-ring implant overdenture attachment: clinical reports. J Oral Implantol. 2002;28:82e86. 8. Feine JS, Carlsson GE, Awad MA, et al. The McGill consensus statement on overdentures. Mandibular two-implant overdentures as first choice standard of care for edentulous patients. Montreal, Quebec, May 24-25, 2002. Int J Oral Maxillofac Implants. 2002;17:601e602.

9. Dini C, Pereira MMA, Souza JGS, Shibli JA, de Avila ED, Barão VAR. Association between

industry support and the reporting of study outcomes in randomized clinical trials of dental implant research from the past 20 years. Clin Implant Dent Relat Res. 2022;24:94e104.

10. Pereira MMA, Dini C, Souza JGS, Barão VAR, de Avila ED. Industry support for dental implant research: A metatrend study of industry partnership in the development of new technologies. J Prosthet Dent. 7 July 2022. https://doi.org/ 10.1016/j.prosdent.2022.05.026 [Epub ahead of print.].

11. Livas C, Delli K. Journal self-citation rates and impact factors in dentistry, oral surgery, and medicine: a 3-year bibliometric analysis. J Evid Based Dent Pract. 2018;18:269e274.

12. Tarazona B, Vidal-Infer A, Alonso-Arroyo A. Bibliometric analysis of the scientific production in implantology (2009-2013). Clin Oral Implants Res. 2017;28:864e870.

13. Alonso-Arroyo A, Tarazona-Alvarez B, Lucas-Dominguez R, Peñarrocha- Oltra D, Vidal-Infer A. The funding sources of implantology research in the period 2008-2017: a bibliometric analysis. Clin Implant Dent Relat Res. 2019;21:708e714.

14. Chiang HS, Huang RY, Weng PW, et al. Prominence of scientific publications towards peri-implant complications in implantology: a bibliometric analysis using the H-classics method. J Oral Rehabil. 2018;45:240e249.

15. Hartmann R, de Menezes Bandeira ACF, de Araújo SC, et al. Cost-effectiveness of three different concepts for the rehabilitation of edentulous mandibles: overdentures with 1 or 2 implant attachments and hybrid pros- thesis on four implants. J Oral Rehabil. 2020;47:1394e1402.

16. Fonteyne E, Burms E, Matthys C, Van Lierde K, De Bruyn H. Four-implant- supported overdenture treatment in the maxilla. Part II: Speech- and oral health-related quality of life in patients with implant-supported overdentures in the maxilla-A prospective 3-year follow-up.

Clin Implant Dent Relat Res. 2021;23:680e691.

17. Borges GA, Presotto AGC, Caldas RA, Pisani MX, Mesquita MF. Is one dental mini-implant biomechanically appropriate for the retention of a mandibular overdenture? A comparison with Morse taper and external hexagon plat- forms. J Prosthet Dent. 2021;125:491e499.

18. Maniewicz S, Badoud I, Herrmann FR, et al. In vitro retention force changes during cyclic dislodging of three novel attachment systems for implant overdentures with different implant angulations. Clin Oral Implants Res. 2020;31:315e327.

19. Abdraboh AE, Elsyad MA, Mourad SI, Alameldeen HE. Milled bar with PEEK and metal housings for inclined implants supporting mandibular over- dentures: 1-year clinical, prosthetic, and patient-based outcomes. Int J Oral Maxillofac Implants. 2020;35:982e989.

20. Clarke M, Alderson P, Chalmers I. Discussion sections in reports of controlled trials published in general medical journals. JAMA. 2002;287:2799e2801.

21. Klemetti E. Is there a certain number of implants needed to retain an overdenture? J Oral Rehabil. 2008;35:80e84.

22. Ioannidis JP, Greenland S, Hlatky MA, et al. Increasing value and reducing waste in research design, conduct, and analysis. Lancet. 2014;383:166e175. 23. Mulrow CD. The medical review article: state of the science. Ann Intern Med. 1987;106:485e488.

24. Geminiani A, Ercoli C, Feng C, Caton JG. Bibliometrics study on authorship trends in periodontal literature from 1995 to 2010. J Periodontol. 2014;85:e136ee143.

25. Muniz FWMG, Celeste RK, Oballe HJR, Rösing CK. Citation analysis and
trends in review articles in dentistry. J Evid Based Dent Pract. 2018;18:110e118. 26. Ahmad P, Alam MK, Jakubovics NS, Schwendicke F, Asif JA. 100 years of the journal of dental research: a bibliometric analysis. J Dent Res. 2019;98:1425e1436. 27. Kurmis AP. Understanding the

limitations of the journal impact factor. J Bone Joint Surg Am. 2003;85:2449e2454.

28. Ibrahim GM, Snead 3rd OC, Rutka JT, Lozano AM. The most cited works in epilepsy: trends in the "Citation Classics". Epilepsia. 2012;53:765e770.

29. Heneberg P. From excessive journal self-cites to citation stacking: analysis of journal self-citation kinetics in search for journals, which boost their scientometric indicators. PLoS One. 2016;11:e0153730.

30. Kassebaum NJ, Bernabé E, Dahiya M, Bhandari B, Murray CJ, Marcenes W. Global burden of severe tooth loss: a systematic review and meta-analysis. J Dent Res. 2014;93:20Se28S.

Supplementary Table 1. Electronic bibliometric search strategies

Database	Search strategy
PubMed	#1: Denture, Overlay[MeSH Terms] OR Overlay*[Title/Abstract] OR Overdenture*[Title/Abstract] OR Removable[Title/Abstract] #2: Mandible[MeSH Terms] OR Maxilla[MeSH Terms] OR Maxilla*[Title/Abstract] OR Mylohyoid*[Title/Abstract] OR Ridge*[Title/Abstract] OR Mandib*[Title/Abstract] #3: Dental Implants[MeSH Terms] OR Implant*[Title/Abstract] #1 AND #2 AND #3
Scopus	#1: TITLE-ABS-KEY("Denture, Overlay") OR TITLE-ABS-KEY(Overlay*) OR TITLE-ABS-KEY(Overdenture*) OR TITLE-ABS-KEY(Removable) #2: TITLE-ABS-KEY(Mandible) OR TITLE-ABS-KEY(Maxilla) OR TITLE-ABS-KEY(Maxilla*) OR TITLE-ABS-KEY(Mylohyoid*) OR TITLE-ABS-KEY(Ridge*) OR TITLE-ABS-KEY(Mandib*) #3: TITLE-ABS-KEY("Dental Implants") OR TITLE-ABS-KEY(Implant*) #1 AND #2 AND #3
Web of Science	#1: TS=("Denture, Overlay") OR TS=(Overlay*) OR TS=(Overdenture*) OR TS=(Removable) #2: TS=(Mandible) OR TS=(Maxilla) OR TS=(Maxilla*) OR TS=(Mylohyoid*) OR TS=(Ridge*) OR TS=(Mandib*) #3: TS=("Dental Implants") OR TS=(Implant*) #1 AND #2 AND #3
Embase	#1: 'Denture, Overlay':ab,ti OR Overlay*:ab,ti OR Overdenture*:ab,ti OR Removable:ab,ti #2: Mandible:ab,ti OR Maxilla:ab,ti OR Maxilla*:ab,ti OR Mylohyoid*:ab,ti OR Ridge*:ab,ti OR Mandib*:ab,ti #3: 'Dental Implants':ab,ti OR Implant*:ab,ti #1 AND #2 AND #3
Cochrane Library	#1 MeSH descriptor: [Denture, Overlay] explode all trees or (Overlay*):ti,ab,kw OR (Overdenture*):ti,ab,kw OR (Removable):ti,ab,kw #2 MeSH descriptor: [Mandible] explode all trees or MeSH descriptor: [Maxilla] explode all trees or (Maxilla*):ti,ab,kw OR (Mylohyoid*):ti,ab,kw OR (Ridge*):ti,ab,kw OR (Mandib*):ti,ab,kw #3 MeSH descriptor: [Dental Implants] explode all trees or (Implant*):ti,ab,kw #1 AND #2 AND #3
Virtual Health Library	#1: (mh:("Denture, Overlay")) OR (tw:(Overlay$)) OR (tw:(Overdenture$)) OR (tw:(Removable)) #2: (mh:(Mandible)) OR (mh:(Maxilla)) OR (tw:(Maxilla$)) OR (tw:(Mylohyoid$)) OR (tw:(Ridge$)) OR (tw:(Mandib$)) #3: (mh:("Dental Implants")) OR (tw:(Implant$)) #1 AND #2 AND #3

Supplementary Table 2. Topics according to broad thematic described in included studies

Topic	Included content
Retention system	Unsplinted systems, different bar levels, prefabricated system, abutment designs, splinted systems, bar extensions, attachment incorporation techniques (direct and indirect), attachment high, bar length, bars manufacturing, CAD CAM bars.
Complications	Diabetic patients, late implant failure, mandibular cancer, syndromes (Papillon Lefevre, Sjögren, Moebius, Down), hypohidrotic ectodermal dysplasia, reconstruction of hemimandibular and condylar defect, osteoporotic patients, HIV patients, fractured mandibular bone, unrepaired complete cleft, patients with temporomandibular disorders, macroglossia, rheumatoid polyarthritis, maxillofacial reconstruction.
Implant setting	Implant positions, angulation, or number.
Loading protocol	Immediate, early, conventional.
Rehabilitation method	Different methods of rehabilitation compared with implant-retained overdenture (complete conventional dentures, fixed rehabilitations, tooth supported overdentures, partial fixed prosthesis).
Implant macrodesign	Implant diameter, and length, one piece implants, zygomatic implants.
Anatomical or surgical	Implant placement after extraction, augmentation, free autograft of connective tissue, computer assisted implant surgery, flapless implant surgery, expanded mandibular knife edge ridge, limited inter arch space, reduced bone mineral density, changes in width of maxillary residual ridge, arch form, arch size, inter foraminal distance, severely resorbed edentulous jaw.
Surface treatment	Porous coating, hydroxyapatite coating, bilayer bioactive surface coating, plasma sprayed, machine surfaced, rough surfaced, anodized surface, microthreaded, TiOblast, titanium dioxide grit blasted, fluoride, TiUnite, acid etched.
Others	Occlusion design, hygiene protocol, palatal coverage, base thicknesses, base reinforcement, teeth design (cusped and cuspless), neutral zone.

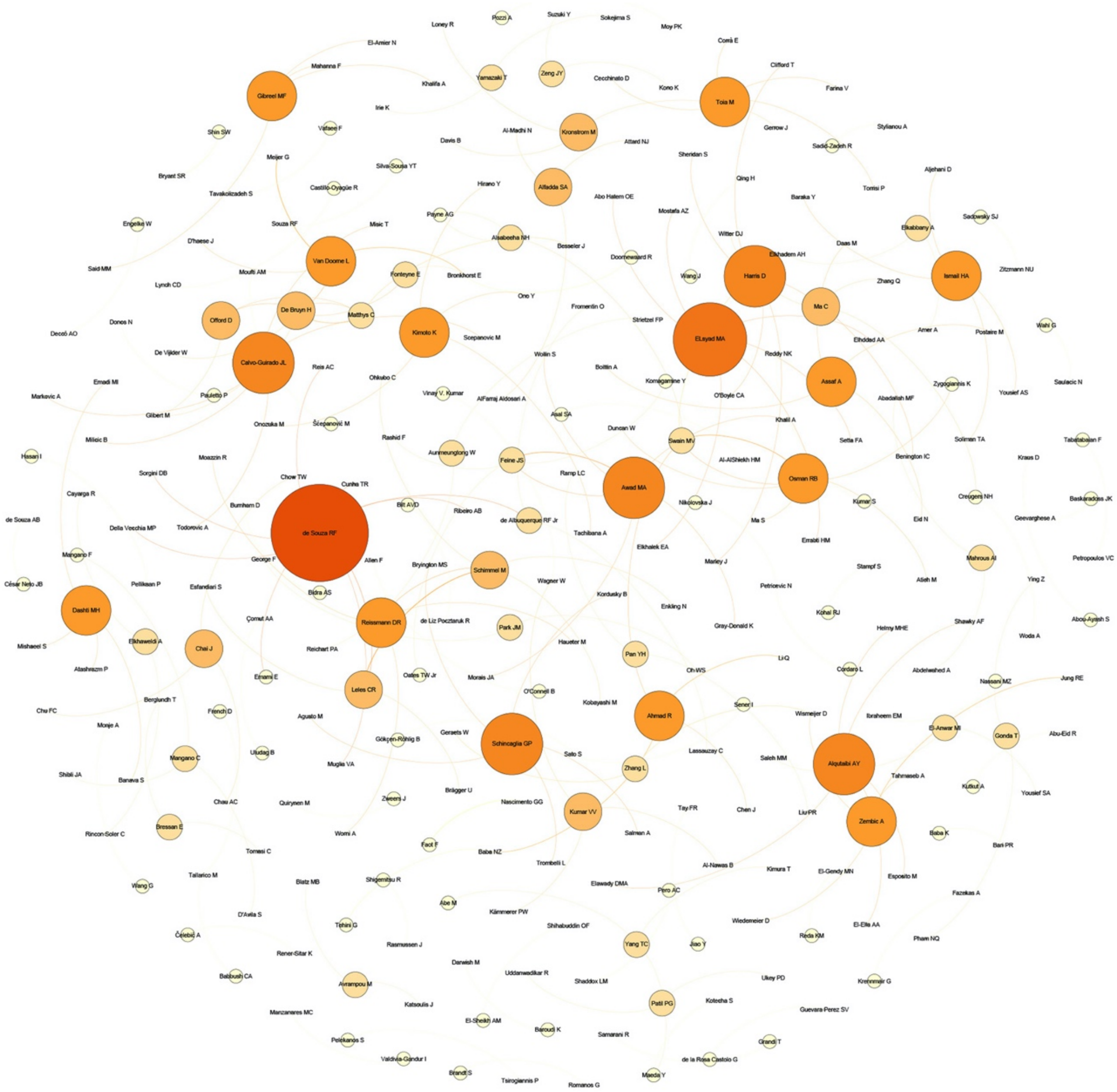
Supplementary Table 3. Bibliometric parameters collection

Outcomes description
After gathering all articles and having duplicated entries removed, titles and abstracts of studies initially screened by 2 independent reviewers (G.A.B., C.D.). Thereafter, all included articles had their data populated by two independent reviewers (G.A.B., C.D.) using an Excel spreadsheet form (Microsoft Office). Calibration prior to final data extraction conducted with 100 eligible articles to ensure interinvestigator reliability. Entries randomly selected (https://www.randomizer.org) and results input into appropriate software (IBM SPSS Statistics, v20.0; IBM Corp) to calculate Cohen's kappa coefficient ($\varkappa$). Afterwards, output registered an almost perfect agreement ($\varkappa$=0.87). Regarding bibliometric parameters, first publication descriptions (year, journal name, number of institutions, number of disciplines, number of countries, study design) recorded. When 1 listed author had 2 or even more affiliations in different institutions, only first mentioned institution remained noted. Disciplines within same listed description of authors remained collected. When disciplines presented with more than 2 areas (Department of Prosthodontics and Periodontology), 2 disciplines remained counted. Also, when authors had multiple affiliations with different disciplines, only first listed affiliation with its discipline's descriptions kept noted. Additionally, study design criteria for articles with multiple classifications (nonrandomized controlled clinical trial and in vitro study) first mentioned into objective remained noted to avoid overlapping data. Second, geographic details (total number of countries from listed authors) assessment based on first mentioned category. Economy description from corresponding author country (income classification), further evaluated in 'low', 'lower-middle', 'upper-middle', or 'high', according to World Bank Country and Lending Groups (https://data.worldbank.org). Fourth, corresponding author metrics collected in May 2021 in Scopus by Elsevier (h-index, mean citations), value used into mean citations per article based on following equation (Total number of citations)/(2021 - Year of publication). Implant-retained overdenture features (location assessed, retention system) also noted and corresponding jaw under evaluation kept reported as 'mandible', 'maxilla', or 'both'; while for retention system, this section categorized in 'ball', 'stud', 'bar', or 'magnetic', according to component design. Meanwhile, studies with additional retention systems clustered as '> 1 retention system'. Article main objective (study topic) divided into a) retention system, b) complications, c) implant setting, d) loading protocol, e) rehabilitation method, f) implant macrodesign, g) anatomical or surgical, h) surface treatment, i) others (Supplementary Table 2, available online). Moreover, whether study had multiple topics, first one mentioned in objective considered and noted.

Supplementary Table 4. Network analyses for countries and authors displaying international collaboration

Outcomes description
Visualization of international interactions among countries and authors conducted individually with an open-source software for graph and network analysis (Gephi, v0.9.2; GNU General Public License). From original nodes (total number of countries and authors), countries (n=59) and authors (n=285), it displayed the interactions individually according to the network. Two parameters (diameter and modularity) used to set graph, network diameter represented output degree according to the established collaborations as well as color intensity of bubbles. Whilst network modularity represented output degree for bubble diameter instead of modularity. Filtration only used for authors displaying international collaboration; thus, authors with grade 2 (two or more interaction) connections were further assessed. Network layout established using Fruchterman Reinfolg (gravity=10, speed=1) design for all 3 graphs, only variation among them: area used. For network of countries, area was 100.000, while for 2 networks of authors (one with filtration and another without) area was 70.000.

Supplementary Figure 1. Collaboration networks among authors within papers related to implant-retained overdenture. Note: as color and bubble size intensify, number of collaborations (articles) increase; as line thickens number of collaborations (articles) between authors increases.



2.3 Patient-reported outcome measures and clinical assessment of implant-supported overdentures and fixed prostheses in mandibular edentulous patients: A systematic review and meta-analysis#

Guilherme Almeida Borges, DDS, MSc,[a] Thaís Barbin, DDS, MSc,[b] Caroline Dini, DDS, MSc,[c] Lucianne Cople Maia, DDS, MSc, PhD,[d] Marcela Baraúna Magno, DDS, MSc, PhD,[e] Valentim Adelino Ricardo Barão, DDS, MSc, PhD,[f] and Marcelo Ferraz Mesquita, DDS, MSc, PhD[g]

Supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES), [grant number 001]; Conselho Nacional de Desenvolvimento Científico e Tecnológico, Grant/Award Number: 140387/2020-0.

[a]PhD student, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.
[b]PhD student, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.
[c]PhD student, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.
[d]Full Professor, Department of Pediatric Dentistry and Orthodontics, School of Dentistry, Federal University of Rio de Janeiro (UFRJ), Rio de Janeiro, RJ, Brazil.
[e]Postdoctoral Research Fellow, Department of Pediatric Dentistry and Orthodontics, School of Dentistry, Federal University of Rio de Janeiro (UFRJ), Rio de Janeiro, RJ, Brazil.
[f]Assistant Professor, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.
[g]Full Professor, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Piracicaba, SP, Brazil.

Corresponding author:
Dr. Marcelo Ferraz Mesquita
University of Campinas (UNICAMP)
Piracicaba Dental School
Av Limeira, 901, Piracicaba
São Paulo, 13414-903
BRAZIL
Email: mesquita@unicamp.br

#Artigo publicado na revista *Journal of Prosthetic Dentistry* (Fator de impacto = 4.6).

ABSTRACT

Statement of problem. A consensus based on the patients' perceptions as to whether to use overdentures or fixed prostheses to rehabilitate mandibular edentulous arches is limited.

Purpose. The purpose of this systematic review and meta-analysis was to compare the patient-reported outcome measures (PROMs) and clinical outcomes associated with implant-supported overdentures and fixed prostheses in edentulous mandibles.

Material and methods. Nine electronic databases were searched for randomized clinical trials (RCTs) and nonrandomized clinical trials (N-RCTs). The risk-of-bias was assessed by the revised Cochrane risk-of-bias tool for RCTs (RoB 2) and N-RCT (ROBINS-I). Data sets for oral health-related quality of life (OHRQoL), satisfaction, survival rate, implant probing depth, and marginal bone loss were plotted, and the appropriate analyses were applied by using the Rev Man 5.3 software program. Certainty of evidence was also evaluated by means of the grading of recommendations assessment, development and evaluation (GRADE) approach.

Results. Ten eligible trials were included and evaluated quantitatively. For 3 domains of OHRQoL, fixed prostheses showed significantly higher quality of life when compared with overdentures regarding functional limitation ($P<.001$), physical disability ($P=.001$), and physical pain ($P=.003$). Fixed prostheses also improved satisfaction, when compared with overdentures for comfort ($P=.02$), ease of chewing ($P<.001$), retention ($P<.001$), and stability ($P<.001$). The same pattern was observed for overall OHRQoL ($P=.01$) and satisfaction ($P=.01$), in which fixed prostheses improved patient satisfaction. Only ease of cleaning presented greater satisfaction for the overdenture group. Clinical parameters did not differ statistically ($P>.05$) between both types of prosthesis.

Conclusions. Fixed rehabilitations for mandibular edentulous patients seem to be a well-

accepted treatment from the patients' oral health perspective. However, mandibular overdentures are no less efficient than fixed prostheses in terms of clinical outcomes.

CLINICAL IMPLICATIONS

Clinicians should be aware that the treatment choice of patients might not be aligned with the protocol planned. Even though the clinical parameters evaluated in this study have reported equality between fixed and overdenture treatments, patient-reported outcome measures indicated a better oral health status with fixed rehabilitations.

INTRODUCTION

The rehabilitation of edentulous arches with conventional complete dentures has functional shortcomings, and the use of implant-supported or implant-retained prostheses has been reported to improve treatment outcomes.[1-9] Overdentures have been demonstrated to be more cost-effective than fixed restorations,[10] and, with fewer implants and components, they can also be less surgically demanding.[11-13] However fixed restorations provide higher maximum occlusal force and a reduced need for prosthetic maintenance.[2,14,15] Either overdenture or fixed rehabilitations present well-documented clinical advantages, including high implant survival rate (>98%) and acceptable long-term bone resorption.[14,16-18] However, the patients' perception of the treatment might not be consistent with the clinical findings.

The success of implant-supported treatment has mainly been evaluated by means of the assessment of clinical parameters such as survival, marginal bone loss (MBL), and probing depth (PD).[11,14,16-26] However, those variables must be gathered with patient perception of the treatment by means of patient-reported outcome measures (PROMs), such as oral health-related quality of life (OHRQoL)[27-29] and patient satisfaction, to supplement clinical parameters with measurements of the patient's oral condition.[30,31] The PROM outcome has become prevalent in dental outcomes research.[30,32,33] However, the authors are unaware of a quantitative evaluation of PROMs and clinical parameters in both fixed and overdenture prostheses for mandibular rehabilitations. Therefore, the aim of this systematic review and meta-analysis was to evaluate the PROMs (OHRQoL and satisfaction) and clinical outcomes (survival, probing depth, and marginal bone loss) of fixed prostheses compared with overdentures. The null hypothesis was that the patients receiving fixed prostheses or overdentures would not affect PROMs (OHRQoL and satisfaction) or clinical outcomes (survival, probing depth, and marginal bone loss).

MATERIAL AND METHODS

This systematic review was conducted following the recommendation of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement[34] and was registered in the International Prospective Register of Systematic Reviews (PROSPERO) (protocol #CRD42020187905).[35] It was structured, as per the Population, Intervention, Comparison, Outcome (PICO) elements (Table 1). The literature search was performed in September 2020 and combined 9 databases (Supplemental Table 1 available online). The studies were added if they met the specific inclusion and exclusion criteria (Table 2). After duplicate removal, 2 reviewers (G.A.B., T.B.) independently screened the title and abstract of the articles. Whenever the title or abstract could not be definitively assessed for relevance, the articles were maintained for further evaluation. Potential articles were further accessed in full text by the same investigators individually for eligibility. Disagreements between examiners, at any stage, were solved by a third author (M.F.M.).

Table 1. Population, Intervention, Comparison, Outcome (PICO) elements

Element	Contents
Population	Mandibular edentulous patients with osseointegrated dental implants.
Intervention and Comparison	Rehabilitation with implant-supported mandibular overdentures and fixed dental prostheses.
Outcomes	Primary outcomes: patient-reported outcome measures: oral health-related quality of life, and the satisfaction profile. Secondary clinical outcomes: survival rate, probing depth, and marginal bone loss.

Table 2. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
• Human studies • Studies comparing implant- supported overdentures and fixed prostheses in mandibular edentulous patients • Studies evaluating quality of life, satisfaction, implant survival rate, probing depth, marginal bone loss	• Animal studies • Retrospective studies • Letters to editor • Case report and case series • In vitro and in silico studies Narrative and systematic reviews Articles not available online Articles evaluating only rehabilitations in maxilla • Articles mixing upper and lower rehabilitations • Articles involving postextraction implants • Articles comparing one- and two- pieces implants • Implants placed in augmented bone

The risk of methodological bias was independently assessed by 2 reviewers (G.A.B., C.D.). Randomized clinical trials (RCTs) were evaluated based on the revised Cochrane risk of bias tool for RCTs (RoB 2).[36] As blinding of the patient and those delivering the interventions was not possible for these studies, this section was described as not applicable in the intended intervention domain. However, although for measurement of the outcome, the examiner could be someone outside the study context, for this domain, the blinding was evaluated to avoid any further bias. Nonrandomized clinical trials (N-RCTs) were evalu- ated with the risk of bias in nonrandomized studies e of interventions (ROBINS-I scoring system).[37] The final risk of bias was based on the judgment for each domain. Throughout the risk of bias evaluation, any disagreements between reviewers were resolved by a third reviewer (L.C.M.).

A data extraction spreadsheet for the included arti- cles was populated with the main features of each study. For data available only in graphs, a Web-based tool for extracting numerical data (WebPlotDigitizer; Ankit Rohatgi) was used, which has been considered a reliable tool for data extraction.[38,39] To avoid overlapping, data were collected based on the most recent publication for studies carried out with the same sample population.

Data analyses were performed by using a software program (RevMan v5.3; The Cochrane Collaboration) to evaluate PROMs, as well as clinical parameters between overdentures and fixed prostheses. The OHRQoL and satisfaction analyses were assessed based on the mean difference (MD) between rehabilitations (MD fixed-MD overdentures). A 95% confidence interval and standard errors were calculated for all articles included in this analysis to combine data from parallel and crossover studies.[40] In the design of crossover studies, an intra-participant correlation coefficient of 0.5 was assumed.[41] The pooled effect size was calculated by the generic inverse variance standardized MD (SMD). For satisfaction, individual analyses were performed for each parameter (comfort, esthetics, ease of mastication, ease of speaking, ease of cleaning, stability, and retention) and for overall assay. For the OHRQoL, the common questionnaire domains for the Oral Health Impact Profile (OHIP)-14 and OHIP-49 (functional limitation, physical pain, psychological discomfort, physical disability, psychological disability, social disability, and handicap) were evaluated and also for overall evaluation.

Risk ratio was used for survival rate as per the dichotomous feature of the variable. The MD was applied for PD and MBL as per the mean and standard deviation in millimeters and the number of implants evaluated. The MD was selected because the studies included used similar methods and ranges units. A 95% confidence interval was calculated in each parameter.

When necessary, the effect estimates were converted with the help of RevMan software tools. A fixed effect model was applied when 3 or fewer studies were included, and the random effect model was applied when 4 or more studies were included in the meta-analysis.[42] Heterogeneity was tested with the I^2 index, and the prediction interval was calculated into the analyses in which the random effect was applied. The certainty of the evidence (certainty in the estimates of effect) was determined for each outcome by means of Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach.[43]

RESULTS

The process of literature identification and selection is outlined in the PRISMA flowchart (Fig. 1). The search yielded a total of 1528 unique records; of which, 10[1,3,14-17,44-47] studies were included in the quantitative and qualitative synthesis. The main reason for exclusion of articles during full-text review was lack of compatibility with the inclusion criteria. The details of the articles included are reported in Table 3 and were obtained from 5 RCTs[1,3,16,17,47] and 5 N-

RCTs.[14,15,44-46] The detailed inclusion and exclusion criteria for all articles[1,3,14-17,44-47] in the study sample are described in Supplemental Table 2 (available online). The quality assessment for RCTs (Fig. 2) revealed a high risk of bias in 4[1,3,16,47] of 5[1,3,16,17,47] studies evaluated, and the main reason was related to 2 domains. The randomization process and washout period for 3 articles[3,30,47] were the main problems and led to some concerns as the final classification. Regarding the measurement of the outcome, as blinding of outcome assessors was not possible and an examiner outside the trial context was not included, additional bias was added to 4 studies.[1,16,17,47] The Cochrane criteria indicate that the assessment of PROMs are potentially influenced by knowledge of the intervention received, and this was present in 3 studies,[1,3,16] including those with a high risk of bias for this domain.

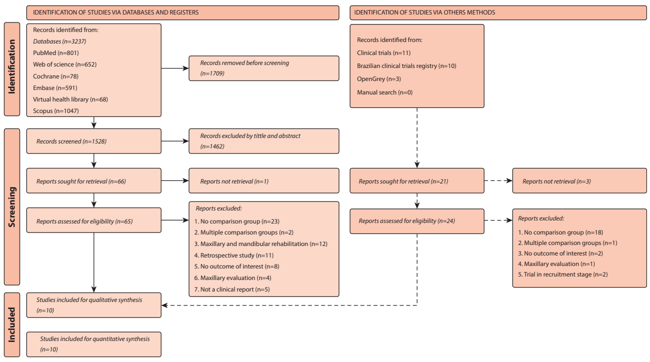


Figure 1. Flow diagram for study selection process.

Risk of bias to NRCTs revealed a critical quality in 3 and a moderate quality in 2 studies (Fig. 3). Generally, the problems were related to cofounders either in the participant selection process or inequality among participants. Deviation from the intended intervention arose for all studies[14,15,44-46] because of the study design and expectations for intervention and comparator (overdentures compared with fixed prostheses), and participants might have felt unlucky to have been assigned to the comparison group and therefore sought a different intervention.

Table 3. Summary data from included studies e author (citation), study design; study setting; follow-up; comparison; attachment; N. of patients; age; mandibular residual ridge; timing of loading; implant features; implants per patient; implant surface

Author (Citation)	Study design	Study setting	Follow -up	Comparison	Attachment	N. of patients	Age in Y (Mean ± Stand. Dev.)	Mandibular residual ridge	Timing of loading	Implant			Implants per patient	Implant surface
										Length (mm)	Diameter (mm)	Brand		
Ayna et al, 2018[14]	Prospective (N-RCT)	Center for Dental Implantology	7 Ys	G1; Overdenture G2; Fixed Prosthesis	G1; Mixed: bar with ball G2; *	G1; 16 G2; 16	G1; 71.50 ± 3.86 G2; 72.06 ± 4.35	Bone width ≥5 mm and bone height ≥8 mm	3 mo	13-15	4	Nobel Speedy	G1; 4 G2; 4	NR
Beresford et al 2018[15]	Prospective Within -subjct (N-RCT)	Private practice	4 mo	G1; Overdenture G2; Fixed Prosthesis	G1; Locator G2; *	G1 and G2; 12	G1 and G2; 69 ± 6.46	Adequate bone quality and volume to place dental implants with a minimum length of 10 mm and diameter of 4 mm	4 mo	10-16	4-4.3	Nobel Biocare	G1; 2 G2; 3	Anodized
De Kok et al 2011[16]	Prospective (RCT)	University	1 y	G1; Overdenture G2; Fixed Prosthesis	G1; Ball G2; *	G1; 10 G2; 10	G1; 62.6 ± 7.31 G2; 62.4 ± 9.88	Bone with at least 10 mm high	2 mo	11-13	4	Astra Tech	G1; 2 G2; 3	NR
Elsyad et al 2019 A[17]	Prospective (RCT)	University	1 y	G1; Overdenture G2; Fixed Prosthesis	G1; Bar G2; *	G1; 17 G2; 17	NR	Bone volume (classes IV to VI, Cawood and Howell) and density (classes 1 to 3, Lekholm and Zarb)	3 mo	11	3.75	TioLogic	G1; 4 G2; 4	Airborne-particle abraded or Etched Surface
Elsyad et al 2019 B[3]	Prospective Within -subjct (RCT)	University	3 mo	G1; Overdenture G2; Fixed Prosthesis	G1; Bar G2; *	G1 and G2; 16	G1 and G2; 58.4 ± NR	Bone volume (classes IV to VI, Cawood and Howell) and density (classes 1 to 3, Lekholm and Zarb)	3 mo	11	3.75	TioLogic	G1; 4 G2; 4	Airborne-particle abraded or Etched Surface
Feine et al 1994[1]	Prospective Within -subjct (RCT)	NR	2 mo	G1; Overdenture G2; Fixed Prosthesis	G1; Bar G2; *	G1 and G2; 16	G1 and G2; 53.8 ± NR	NR	4 mo	NR	NR	Brånemark System	G1; 4 G2; 4	NR
Makkonen et al 1997[44]	Prospective (N-RCT)	University	5 y	G1; Overdenture G2; Fixed Prosthesis	G1; Bar G2; *	G1; 20 G2; 13	G1; 58 ± 9 G2; 50 ± 10	Bone high with at least 8 mm	3-4 mo	7.5-17	3.5 to 4	Astra Tech	G1; 4 G2; 5-6	Machined

Table 3. (Continued)

Author (Citation)	Study design	Study setting	Follow -up	Comparison	Attachm ent	N. of patient s	Age in years (Mean ± Stand. Dev.)	Residual ridge	Timing of loading	Implant			Implants per patient	Implant surface
										Length (mm)	Diameter (mm)	Brand		
Quirynen et al 2005[45]	Prospe ctive (N-RCT)	University	10 y	G1; Overdenture G2; Fixed Prosthesis	G1; Mixed: bar, ball, magnetic G2; *	G1; 25 G2; 12	G1; 63.7 ± NR G2; 54.9 ± 10	Bone volume adequate to install two implants with a minimum length of 10 mm	NR	NR	NR	Nobel Biocare	G1; 2 G2; NR	Anodized
Raghoebar et al 2003[46]	Prospe ctive (N-RCT)	Multicenter	3 y	G1; Overdenture G2; Fixed Prosthesis	G1; Bar G2; *	G1; 30 G2; 10	G1 and G2; 56 ± NR	Bone quality (1-4) and quantity (A-E) according to Adell.	6 wk	10-18	3.75	Brånema rk System	G1; 4 G2; 5	Machined
Tinsley et al 2001[47]	Prospe ctive (RCT)	NR	6 y	G1; Overdenture G2; Fixed Prosthesis	G1; NR G2; *	G1; 27 G2; 21	NR	Bone height greater than 8 mm and width greater than 5 mm.	3 mo	NR	NR	Calcitek Integral dental implant	G1; 2-3 G2; 5	Hydroxylapatite

G1, overdenture; G2, fixed prosthesis; N-RCT, nonrandomized clinical trial; NR, not reported; RCT, randomized clinical trial. *Data not applied.

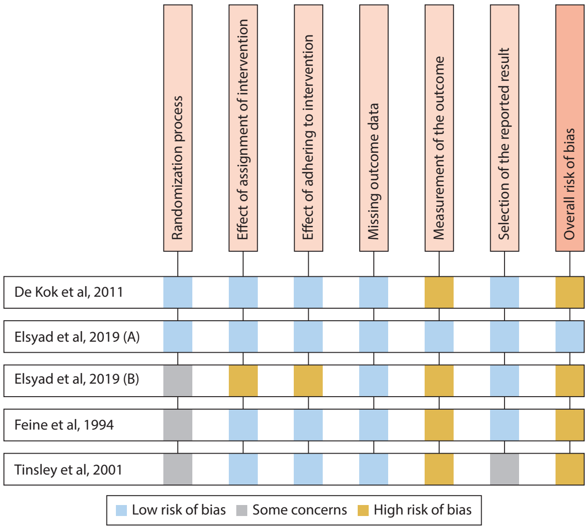


Figure 2. Quality assessment for RCTs based on Revised Cochrane risk-of-bias tool for randomized trials (RoB 2). RCT, Randomized Clinical Trial.

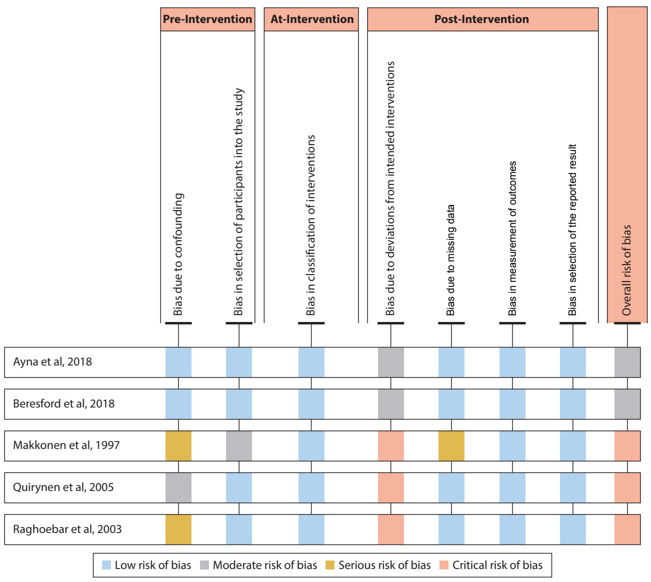


Figure 3. Quality assessment for N-RCTs based on ROBINS-I tool (Risk-of-Bias in Non-randomized Studies - of Interventions). N-RCT, Non-Randomized Clinical Trial.

The OHRQoL was evaluated by using the OHIP-49[15,16] and its short version the OHIP-14.[3,14] Meta-analyses were possible for 6 domains and the overall assay related to OHRQoL. Participants provided with overdentures presented greater scores than participants provided with fixed prostheses for functional limitation (SMD: -0.76 [-1.18, -0.34], P<.001,

I^2=0%), physical disability (SMD: -0.70 [-1.12, -0.28], P=.001, I^2=0%), and physical pain (SMD: -0.62 [-1.02, -0.21], P=.003, I^2=0%) (Fig. 4A), representing significantly lower OHRQoL for participants with overdentures for these parameters. However, for handicap (SMD: -0.30 [-0.68, 0.09], P=.13, I^2=0%), psychological disability (SMD: -0.20 [-0.58, 0.19], P=.31, I^2=0%), and social disability (SMD: 0.04 [-0.33, 0.42], P=.82, I^2=0%), participants rehabilitated with overdentures and fixed prostheses presented similar mean scores (Fig. 4A). For the OHRQoL overall score, participants provided with overdentures presented greater scores than participants provided with fixed protheses, representing significantly lower OHRQoL (SMD: -0.61 [-1.08, -0.13], P=.01, I^2=39%) (Fig. 4B). The certainty of evidence for OHRQoL parameters and overall assay ranged from very low to moderate (Supplemental Table 3 available online).

Satisfaction was evaluated only by using the visual analog scale.[1,3,15,16] Seven variables and an overall assessment related to this outcome were further analyzed by means of meta-analyses. Participants provided with fixed prostheses presented a greater mean of satisfaction than did participants provided with overdentures for comfort (SMD: 0.72 [0.10, 1.34], P=.02, I^2=85%), ease of mastication (SMD: 0.94 [0.41, 1.47], P<.001, I^2=51%), retention (SMD: 0.93 [0.50, 1.36], P<.001, I^2=24%), and stability (SMD: 0.99 [0.50, 1.47], P<.001, I^2=33%, prediction interval: [-0.61, 2.60]) (Fig. 5A). In addition, participants provided with overdentures judged greater satisfaction for ease of cleaning than participants provided with fixed protheses (SMD: -0.91 [-1.29, -0.52], P<.001, I^2=0% - prediction interval [-1.74, 0.07]) (Fig. 5A).

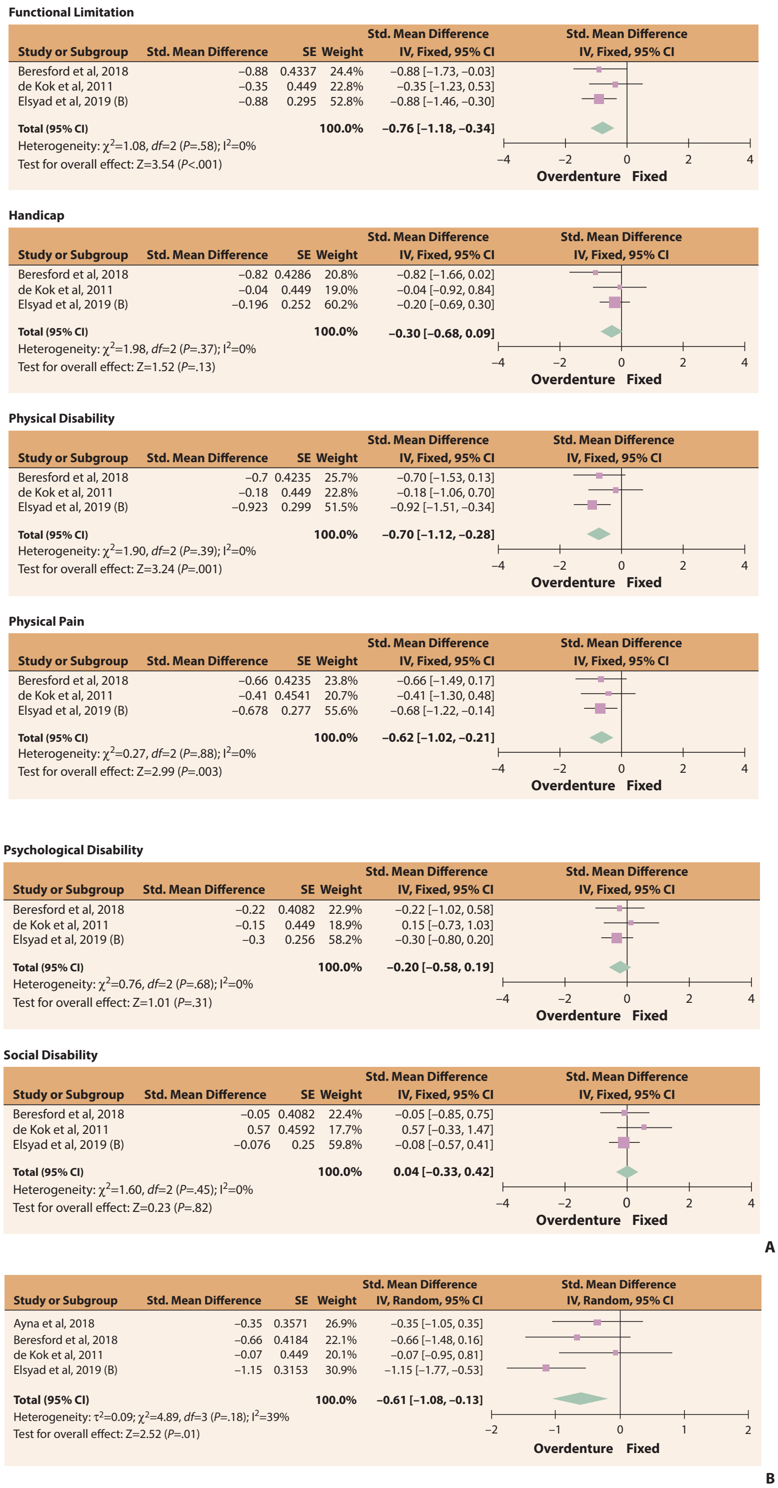


Figure 4. Meta-analyses for comparison of oral health-related quality of life (individual and overall domains) between overdentures and fixed prostheses. A, Individual domains. B, Overall quality of life.

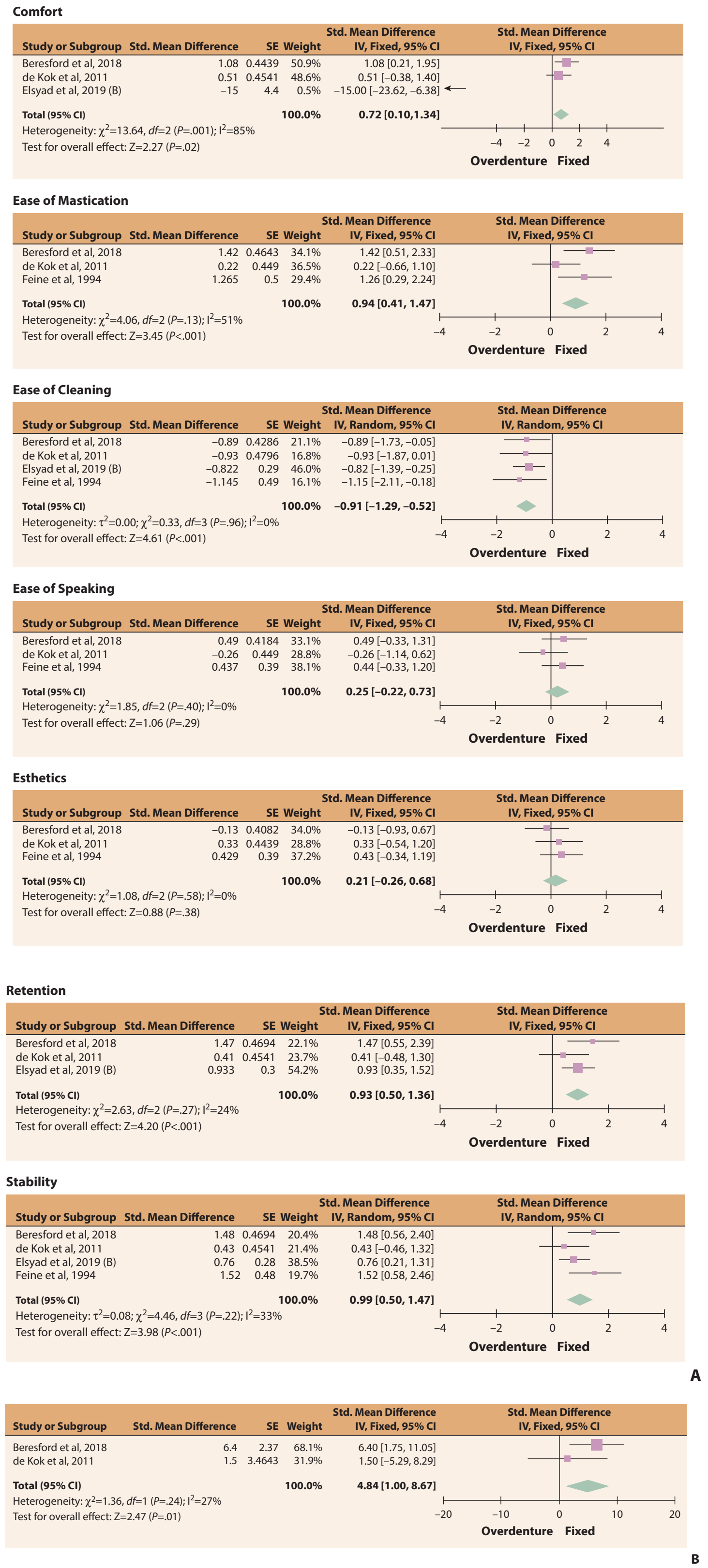


Figure 5. Meta-analyses for comparison of satisfaction (individual and overall domains) between overdentures and fixed prostheses. A, Individual domains. B, Overall satisfaction.

However, for ease of speaking (SMD: 0.25 [-0.22, 0.73], P=.29, I^2=0%) and esthetics (SMD: 0.21 [-0.26, 0.68], P=.38, I^2=0%), mean satisfaction values were similar among participants provided with overdentures and fixed prostheses (Fig. 5A). Satisfaction overall mean scores were greater in participants provided with fixed protheses compared with those with overdentures (SMD: 4.84 [1.00, 8.67], P=.01, I^2=27%) (Fig. 5B). The certainty of evidence for satisfaction parameters and overall assessment ranged from very low to low (Supplemental Table 4 available online).

The survival rate forest plot shows 829 implants being evaluated, and the proportion of implants that survived with overdentures (n=416 of 427) and with fixed prostheses (n=399 of 402) was similar (risk ratio: 1.00 [0.98, 1.01], P=.66, I^2=0%) (Fig. 6A). The certainty of evidence was moderate (Supplemental Table 5 available online). The PD evaluation included 66 implants. One year after implant placement, the data showed similar results (MD: -0.20 [-0.48, 0.09], P=.17, I^2=94%) between implants supporting overdentures (n=33) and fixed prostheses (n=33) (Fig. 6B), with very low certainty of evidence (Supplemental Table 5 available online). Finally, 4 studies[14,17,44,45] were included for time point (1, 3, 5, and 6 to 10 years) analysis of the MBL. The MD between implants that supported overdentures and fixed prostheses was similar after 1 year (MD: 0.01 [-0.07, 0.09], P=.78, I^2=65%), after 3 years (MD: 0.05 [-0.03, 0.12], P=.2, I^2=79%), after 5 years (MD: 0.05 [-0.04, 0.13], P=.27, I^2=30%), and 6 to 10 years after implant installation (MD: 0.03 [-0.06, 0.11], P=.56, I^2=0%) (Fig. 7). Certainty of evidence ranged from moderate to high (Supplemental Table 5 available online).

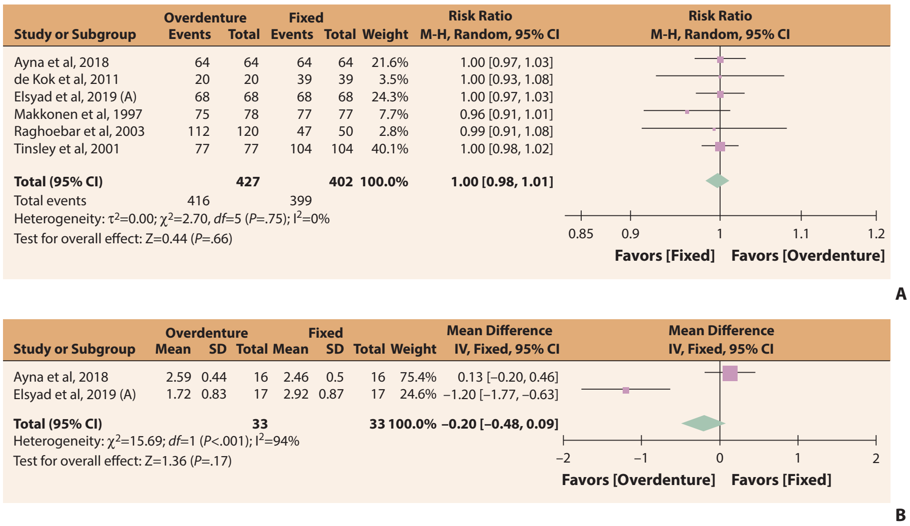


Figure 6. Meta-analyses for clinical parameters (survival rate and probing depth) comparing overdentures and fixed rehabilitation. A, Survival rate. B, Probing depth.

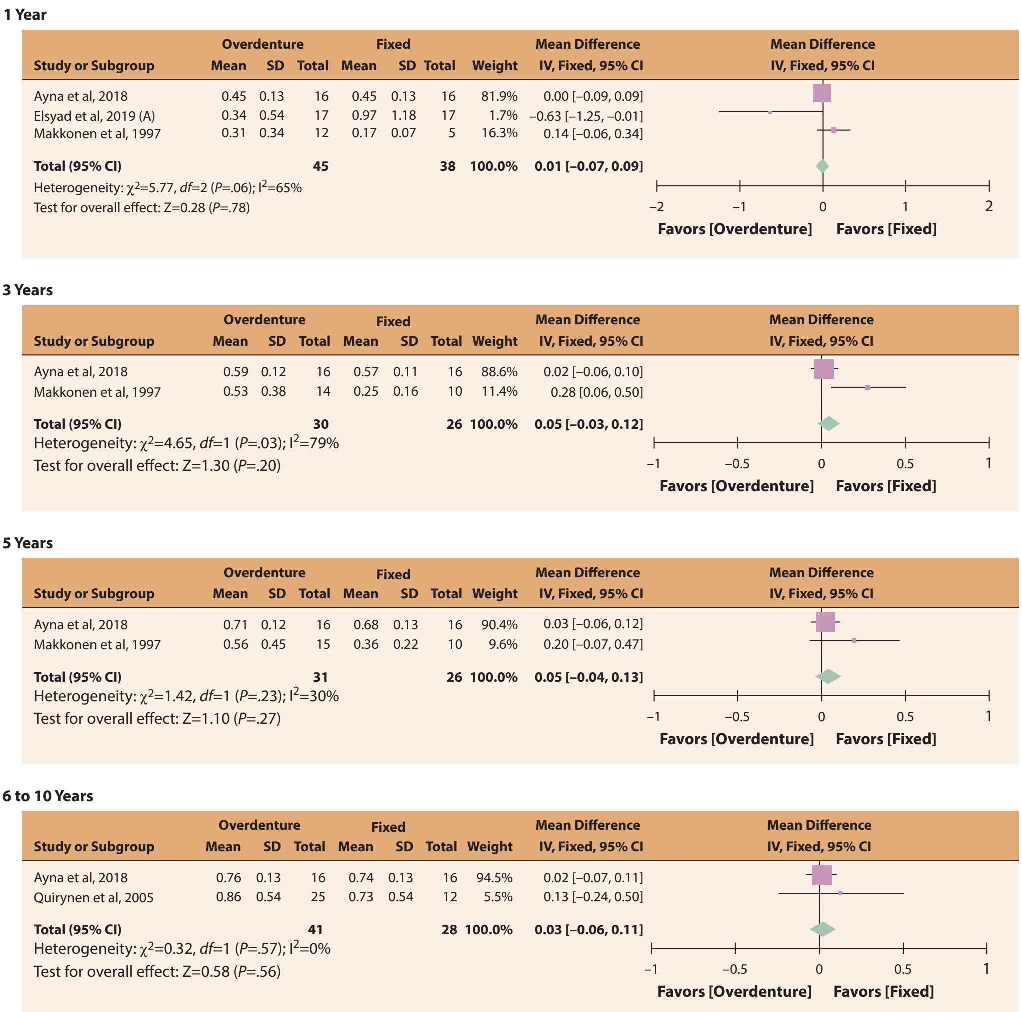


Figure 7. Meta-analyses for marginal bone loss according to different time points (1, 3, 5 and 6-10 years) between overdentures and fixed rehabilitation.

DISCUSSION

Although several clinical studies have prospectively evaluated the clinical outcomes of implant-supported overdentures and fixed prostheses, data systematically documenting PROMs are lacking, in particular for OHRQoL and satisfaction. However, patient perceptions of implant therapy have recently gained considerable attention, especially for prospective trials. The ITI Consensus established that the choice of either fixed or removable implant-supported prostheses for edentulous patients must not be guided only by clinical parameters but also by patients' subjective perspective of their treatment.[30] Thus, this systematic review sought to answer the following question: What are the PROMs and clinical influence of mandibular edentulous patients rehabilitated with either overdentures or fixed prostheses? The null hypothesis that patients receiving fixed prostheses or overdentures would not affect PROMs was rejected. However, for the clinical outcomes (survival, PD, and MBL), no differences were found between the fixed and overdenture prostheses, and the null hypothesis was accepted.

The assessment of the OHRQoL was conducted either with the OHIP-49 or its short version the OHIP-14 to estimate patient awareness of the oral condition on well-being.[27] Both questionnaires have been validated and reported to have similar multivariate models for oral condition and social impact related to sociodemographic variables.[28,29] Quantitative measurement of the OHRQoL was possible for 6 of 7 domains from the OHIP. Only psychological discomfort lacked numerical data to be included in a forest plot. Satisfaction scores were also evaluated covering clinical and functional aspects based on 7 domains. The findings of the OHRQoL meta-analyses showed lower scores for functional limitation, physical disability, and physical pain for the overdenture group. Similarly, the overdenture also recorded lower satisfaction for comfort and ease of mastication, as well as lower retention and stability compared with fixed prostheses. The inferior results in the overdenture groups could be associated with clinical aspects of the prostheses, including rotation and lateral movements, lower maximum occlusal force, mucosa contact, fewer number of implants, and greater number of maintenance appointments.[2,3,5,6,8]

The rotation and lateral movements in the overdenture group might have played an important role, especially for 2 studies[15,16] that included unsplinted attachments, which might limit the stability of the prostheses during function.[5,6] Hence, the lack of stability can compromise the sense of taste and the ability to pronounce sounds. The lower maximum occlusal force for the overdenture group might also be an explanation because those patients present a closer contact between the denture base with the underlying mucosa and higher peripheral input when compared with fixed prostheses.[2,8] Therefore, those overdentures wearers can have nutritional restriction because the food needs to be masticated for the action of saliva and to enhance taste perception.[31] Those effects can lead to functional limitations of overdentures, physical disability, physical pain, as well as less comfort and ease of mastication.

Satisfaction with implant-supported prostheses depends mainly on how well the rehabilitation restores patients' oral function and how often complications occur. The current findings display improved satisfaction with the retention and stability of fixed prostheses compared with overdentures. These results might be because of the number of implants in the overdenture rehabilitation because 2[15,16] studies had 2 implants as retainers, while for the fixed prostheses, the number of implants was either 3[15,16] or 4.[1,3] In addition, the screw retention used with the fixed rehabilitation might have contributed to the feeling that the prosthesis is part of the patient.[3]

Ease of cleaning recorded significantly higher satisfaction for the overdenture group, consistent with previous clinical studies.[3,7,9] Even so, edentulous patients who receive implant therapy are well motivated and instructed to perform acceptable oral hygiene; being able to remove the prosthesis and clean underneath might lead to patients choosing the overdenture over the fixed prosthesis.[7] However, the majority of the participants included into this systematic review were elderly. Further studies should evaluate patient dexterity and ability to keep the prostheses clean to avoid bias.

The forest plot for overall OHRQoL and satisfaction exhibited a positive tendency by participants toward fixed rehabilitations, possibly because the fixed prostheses were based on the all-on-four concept in 2[3,14] included studies in comparison with 2[15,16] studies that used overdentures supported by 2 implants. Another explanation can be related to the higher number of maintenance appointments for the overdenture prostheses.[14-16,46,47] In addition, the sequence that patients received the prostheses in crossover studies should be further investigated to evaluate whether bias affected prosthesis choice.

The clinical assessment of both prosthesis types is essential to predict the success of the rehabilitation. The present systematic review displayed comparable results for implant survival rate, PD, and MBL in the fixed and overdenture groups. Previous clinical trials and systematic reviews have yielded a high long-term survival rate in fixed and overdenture prostheses, irrespective of loading protocol.[19-25] Those studies are consistent with the meta-analysis for survival that included 6[14,16,17,44,46,47] studies in this review. In addition, the MBL results in all follow-up periods evaluated (1, 3, 5, and 6-10 years) also corroborate with the survival rate findings. In addition, the values obtained by all included articles[14,17,44,45] remained in a typical range (<1 mm for the first year and 0.2 mm in the following years) for the successful classification of the implants, irrespective of the group.[18,26] Finally, PD had different results between the 2[14,17] articles included, one favoring the fixed group and other the overdenture rehabilitation, indicating that more studies are needed.

Limitations of this study include the lack of information regarding the randomization process for 2[9,47] studies and absence of washout period in 1[3] study. In addition, measurement of the outcome also increased the risk of bias because of the inevitable participant knowledge of the intervention being received, especially for PROMs. Those criteria should be included in future prospective studies because patient choice and the cost-effectiveness of both treatments might play an important role in choosing a fixed or overdenture rehabilitation. Thus, the OHRQoL and satisfaction results should be evaluated with caution once the certainty of evidence ranged from low to moderate because of the heterogenicity among studies. For clinical parameters, except for survival rate, the need for an examiner outside the study background limited the methodological quality of 5[14,16,44,45,47] studies. In addition, imbalance between sample size hindered adequate evaluation in 3[44-46] articles and should be considered in future studies. Finally, variables related to the implant location (posterior or anterior) and bleeding on probing might play an important role in evaluating the PD and should also be investigated.

CONCLUSIONS

Based on the findings of this systematic review and meta-analysis, the following conclusions were drawn:

1. PROMs results for OHRQoL and satisfaction demonstrated a tendency by participants toward implant-supported fixed prostheses when compared with overdentures.

2. Clinical assessment based on the survival rate, MBL, and PD indicated that overdentures

were no less efficient than fixed prostheses.

REFERENCES

1. Feine JS, de Grandmont P, Boudrias P, Brien N, LaMarche C, Taché R, et al. Within-subject comparisons of implant-supported mandibular prostheses: choice of prosthesis. J Dent Res 1994;73:1105-11.

2. Müller F, Hernandez M, Grütter L, Aracil-Kessler L, Weingart D, Schimmel M. Masseter muscle thickness, chewing efficiency and bite force in edentulous patients with fixed and removable implant-supported prostheses: a cross-sectional multicenter study. Clin Oral Implants Res 2012;23:144-50.

3. ELsyad MA, Elgamal M, Mohammed Askar O, Youssef Al-Tonbary G. Patient satisfaction and oral health-related quality of life (OHRQoL) of conventional denture, fixed prosthesis and milled bar overdenture for All-on-4 implant rehabilitation. A crossover study. Clin Oral Implants Res 2019;30:1107-17.

4. Brennan M, Houston F, O'Sullivan M, O'Connell B. Patient satisfaction and oral health-related quality of life outcomes of implant overdentures and fixed complete dentures. Int J Oral Maxillofac Implants 2010;25:791-800.

5. Yoda N, Matsudate Y, Abue M, Hong G, Sasaki K. Effect of attachment type on load distribution to implant abutments and the residual ridge in mandibular implant-supported overdentures. J Dent Biomech 2015;6. 1758736015576009.

6. Dudic A, Mericske-Stern R. Retention mechanisms and prosthetic complications of implant-supported mandibular overdentures: long-term results. Clin Implant Dent Relat Res 2002;4:212-9.

7. Heydecke G, Boudrias P, Awad MA, De Albuquerque RF, Lund JP, Feine JS. Within-subject comparisons of maxillary fixed and removable implant pros- theses: Patient satisfaction and choice of prosthesis. Clin Oral Implants Res 2003;14:125-30.

8. Haraldson T. Comparisons of chewing patterns in patients with bridges supported on

osseointegrated implants and subjects with natural dentitions. Acta Odontol Scand 1983;41:203-8.

9. Feine JS, Dufresne E, Boudrias P, Lund JP. Outcome assessment of implant- supported prostheses. J Prosthet Dent 1998;79:575-9.

10. Attard N, Wei X, Laporte A, Zarb GA, Ungar WJ. A cost minimization analysis of implant treatment in mandibular edentulous patients. Int J Prosthodont 2003;16:271-6.

11. Passia N, Wolfart S, Kern M. Ten-year clinical outcome of single implant- supported mandibular overdentures-A prospective pilot study. J Dent 2019;82:63-5.

12. Passia N, Kern M. The single midline implant in the edentulous mandible: a systematic review. Clin Oral Investig 2014;18:1719-24.

13. Thomason JM, Feine J, Exley C, Moynihan P, Müller F, Naert I, et al. Mandibular two implant-supported overdentures as the first choice standard of care for edentulous patients– the York Consensus Statement. Br Dent J 2009;207:185-6.

14. Ayna M, Gülses A, Acil Y. A comparative study on 7-year results of "All-on- FourTM" immediate-function concept for completely edentulous mandibles: metal-ceramic vs. bar-supported superstructures. Odontology 2018;106: 73-82.

15. Beresford D, Klineberg I. A within-subject comparison of patient satisfaction and quality of life between a two-implant overdenture and a three-implant- supported fixed dental prosthesis in the mandible. Int J Oral Maxillofac Implants 2018;33:1374-82.

16. De Kok IJ, Chang KH, Lu TS, Cooper LF. Comparison of three-implant- supported fixed dentures and two-implant-supported overdentures in the edentulous mandible: a pilot study of treatment efficacy and patient satis- faction. Int J Oral Maxillofac Implants 2011;26:415-26.

17. Elsyad MA, Alameldeen HE, Elsaih EA. Four-implant-supported fixed prosthesis and milled bar overdentures for rehabilitation of the edentulous mandible: A 1-year randomized controlled clinical and radiographic study. Int J Oral Maxillofac Implants 2019;34:1493-503.

18. Zarb GA, Albrektsson T. Consensus report: towards optimized treatment outcomes for dental implants. J Prosthet Dent 1998;80:641.

19. Borges GA, Costa RC, Nagay BE, Magno MB, Maia LC, Barão VAR, et al. Long-term outcomes of different loading protocols for implant-supported mandibular overdentures: A systematic review and meta-analysis. J Prosthet Dent 2021;125:732-45.

20. Elsyad MA, Khirallah AS. Circumferential bone loss around splinted and nonsplinted immediately loaded implants retaining mandibular over- dentures: A randomized controlled clinical trial using cone beam computed tomography. J Prosthet Dent 2016;116:741-8.

21. Alfadda SA, Chvartszaid D, AlFarraj Aldosari A. Clinical outcomes of immediately loaded implant-supported overdentures: A long-term prospec- tive clinical trial. J Prosthet Dent 2019;121:911-5.

22. Turkyilmaz I, Tozum TF, Fuhrmann DM, Tumer C. Seven-year follow-up re- sults of TiUnite implants supporting mandibular overdentures: early versus delayed loading. Clin Implant Dent Relat Res 2012;14(Suppl 1):e83-90.

23. Niedermaier R, Stelzle F, Riemann M, Bolz W, Schuh P, Wachtel H. Implant- supported immediately loaded fixed full-arch dentures: evaluation of implant survival rates in a case cohort of up to 7 years. Clin Implant Dent Relat Res 2017;19:4-19.

24. Balshi TJ, Wolfinger GJ, Slauch RW, Balshi SF. A retrospective analysis of 800 Brånemark System implants following the All-on-Four protocol. J Prosthodont 2014;23:83-8.

25. Patzelt SB, Bahat O, Reynolds MA, Strub JR. The all-on-four treatment concept: a systematic review. Clin Implant Dent Relat Res 2014;16:836-55.

26. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: a review and proposed criteria of success. Int J Oral Maxillofac Implants 1986;1:11-25.

27. Slade GD, Spencer AJ. Development and evaluation of the Oral Health Impact Profile.

Community Dent Health 1994;11:3-11.

28. Slade GD. Derivation and validation of a short-form oral health impact profile. Community Dent Oral Epidemiol 1997;25:284-90.

29. Awad M, Al-Shamrany M, Locker D, Allen F, Feine J. Effect of reducing the number of items of the Oral Health Impact Profile on responsiveness, validity and reliability in edentulous populations. Community Dent Oral Epidemiol 2008;36:12-20.

30. Feine J, Abou-Ayash S, Al Mardini M, de Santana RB, Bjelke-Holtermann T, Bornstein MM, et al. Group 3 ITI Consensus Report: Patient-reported outcome measures associated with implant dentistry. Clin Oral Implants Res 2018;29(Suppl 16):270-5.

31. Liu D, Deng Y, Sha L, Abul Hashem M, Gai S. Impact of oral processing on texture attributes and taste perception. J Food Sci Technol 2017;54:2585-93.

32. Wittneben JG, Wismeijer D, Brägger U, Joda T, Abou-Ayash S. Patient-re- ported outcome measures focusing on aesthetics of implant- and tooth- supported fixed dental prostheses: A systematic review and meta-analysis. Clin Oral Implants Res 2018;29(Suppl 16):224-40.

33. Gallardo YR, Bohner L, Tortamano P, Pigozzo MN, Laganá DC, Sesma N. Patient outcomes and procedure working time for digital versus conventional impressions: A systematic review. J Prosthet Dent 2018;119:214-9.

34. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 2009;7:e1000097.

35. Booth A, Clarke M, Dooley G, Ghersi D, Moher D, Petticrew M, et al. The nuts and bolts of PROSPERO: an international prospective register of sys- tematic reviews. Syst Rev 2012;1:2.

36. Sterne JAC, Savovic J, Page MJ, Elbers RG, Blencowe NS, Boutron I, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ 2019;366:l4898.

37. Sterne JA, Hernán MA, Reeves BC, Savovic J, Berkman ND, Viswanathan M, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. BMJ 2016;355:i4919.

38. Burda BU, O'Connor EA, Webber EM, Redmond N, Perdue LA. Estimating data from figures with a Web-based program: Considerations for a systematic review. Res Synth Methods 2017;8:258-62.

39. Drevon D, Fursa SR, Malcolm AL. Intercoder reliability and validity of WebPlotDigitizer in extracting graphed data. Behav Modif 2017;41:323-39.

40. Borenstein M, Hedges LV, Higgins JPT, Rothstein HR. Introduction to meta- analysis. 1st ed. Chichester: John Wiley & Sons; 2009. p. 59-86.

41. Higgins JP, Green S. Cochrane handbook for systematic reviews of in- terventions. Oxford: The Cochrane Collaboration; 2019. p. 165-6.

42. Borenstein M. Common mistakes in meta-analysis. New Jersey: Biostat Inc.; 2019. p. 13-41.

43. Ryan R, Hills S. How to grade the quality of the evidence. Cochrane Con- sumers and Communication Group. Available at: http://cccrgcochraneorg/ author-resources Version 30 December 2016. Accessed September 7, 2020.

44. Makkonen TA, Holmberg S, Niemi L, Olsson C, Tammisalo T, Peltola J. A 5- year prospective clinical study of Astra Tech dental implants supporting fixed bridges or overdentures in the edentulous mandible. Clin Oral Implants Res 1997;8:469-75.

45. Quirynen M, Alsaadi G, Pauwels M, Haffajee A, van Steenberghe D, Naert I. Microbiological and clinical outcomes and patient satisfaction for two treat- ment options in the edentulous lower jaw after 10 years of function. Clin Oral Implants Res 2005;16:277-87.

46. Raghoebar GM, Friberg B, Grunert I, Hobkirk JA, Tepper G, Wendelhag I. 3- year prospective multicenter study on one-stage implant surgery and early loading in the edentulous mandible. Clin Implant Dent Relat Res 2003;5:39-46.

47. Tinsley D, Watson CJ, Russell JL. A comparison of hydroxylapatite coated implant supported fixed and removable mandibular prostheses over 4 to 6 years. Clin Oral Implants Res 2001;12:159-66.

Supplementary Table 1. Electronic search strategies.

PubMed
#1:
Mouth, Edentulous[MeSH Terms] OR Mouth, Edentulous[Title/Abstract] OR Edentul*[Title/Abstract] OR Complete edentulism[Title/Abstract] OR Toothless[Title/Abstract]
#2:
Denture, Overlay[MeSH Terms] OR Implant overdenture[Title/Abstract] OR Implant Overdentures[Title/Abstract] OR Mandibular overdenture[Title/Abstract] OR Mandibular overdentures[Title/Abstract] OR Removable[Title/Abstract] OR Dentures, Overlay[Title/Abstract] OR Overlay Denture[Title/Abstract] OR Overlay Dentures[Title/Abstract] OR Overdenture*[Title/Abstract] OR Denture, Overlay[Title/Abstract]
#3:
Fixed[Title/Abstract] OR Full-arch[Title/Abstract] OR All-on-4[Title/Abstract] OR All-on-four[Title/Abstract] OR Fixed prosthesis[Title/Abstract] OR Fixed prostheses[Title/Abstract] OR Fixed full prosthesis[Title/Abstract] OR Fixed full prostheses[Title/Abstract] OR Fixed denture[Title/Abstract] OR Fixed dentures[Title/Abstract] OR Fixed bridges[Title/Abstract] OR Fixed bridge[Title/Abstract] OR Fixed dental prosthesis[Title/Abstract] OR Fixed dental prostheses[Title/Abstract]
#1 AND #2 AND #3
Scopus
#1:
TITLE-ABS-KEY("Mouth, Edentulous") OR TITLE-ABS-KEY(Edentul*) OR TITLE-ABS-KEY("Complete edentulism") OR TITLE-ABS-KEY(Toothless)
#2:
TITLE-ABS-KEY("Implant overdenture") OR TITLE-ABS-KEY("Implant overdentures") OR TITLE-ABS-KEY("Mandibular overdenture") OR TITLE-ABS-KEY("Mandibular overdentures") OR TITLE-ABS-KEY(Removable) OR TITLE-ABS-KEY("Dentures, Overlay") OR TITLE-ABS-KEY("Overlay Denture") OR TITLE-ABS-KEY("Overlay Dentures") OR TITLE-ABS-KEY(Overdenture*) OR TITLE-ABS-KEY("Denture, Overlay")
#3:
TITLE-ABS-KEY(Fixed) OR TITLE-ABS-KEY("Full-arch") OR TITLE-ABS-KEY("All-on-4") OR TITLE-ABS-KEY("All-on-four") OR TITLE-ABS-KEY("Fixed prosthesis") OR TITLE-ABS-KEY("Fixed prostheses") OR TITLE-ABS-KEY("Fixed full prosthesis") OR TITLE-ABS-KEY("Fixed full prostheses") OR TITLE-ABS-KEY("Fixed denture") OR TITLE-ABS-KEY("Fixed dentures") OR TITLE-ABS-KEY("Fixed bridges") OR TITLE-ABS-KEY("Fixed bridge") OR TITLE-ABS-KEY("Fixed dental prostheses") OR TITLE-ABS-KEY("Fixed dental prosthesis")
#1 AND #2 AND #3
Web of Science
#1:
TS=("Mouth, Edentulous") OR TS=(Edentul*) OR TS=("Complete edentulism") OR TS=(Toothless)
#2:
TS=("Implant overdenture") OR TS=("Implant overdentures") OR TS=("Mandibular overdenture") OR TS=("Mandibular overdentures") OR TS=(Removable) OR TS=("Dentures, Overlay") OR TS=("Overlay Denture") OR TS=("Overlay Dentures") OR TS=(Overdenture*) OR TS=("Denture, Overlay")
#3:
TS=(Fixed) OR TS=("Full-arch") OR TS=("All-on-4") OR TS=("All-on-four") OR TS=("Fixed

prosthesis”) OR TS=(“Fixed prostheses”) OR TS=(“Fixed full prosthesis”) OR TS=(“Fixed full prostheses”) OR TS=(“Fixed denture”) OR TS=(“Fixed dentures”) OR TS=(“Fixed bridges”) OR TS=(“Fixed bridge”) OR TS=(“Fixed dental prostheses”) OR TS=(“Fixed dental prosthesis”)
#1 AND #2 AND #3

Embase

#1:
‘mouth, edentulous':ab,ti OR edentul*:ab,ti OR 'complete edentulism':ab,ti OR toothless:ab,ti
#2:
‘implant overdenture':ab,ti OR 'implant overdentures':ab,ti OR 'mandibular overdenture':ab,ti OR 'mandibular overdentures':ab,ti OR removable:ab,ti OR 'dentures, overlay':ab,ti OR 'overlay denture':ab,ti OR 'overlay dentures':ab,ti OR overdenture*:ab,ti OR 'denture, overlay':ab,ti
#3:
fixed:ab,ti OR 'full-arch':ab,ti OR 'all-on-4':ab,ti OR 'all-on-four':ab,ti OR 'fixed prosthesis':ab,ti OR 'fixed prostheses':ab,ti OR 'fixed full prosthesis':ab,ti OR 'fixed full prostheses':ab,ti OR 'fixed denture':ab,ti OR 'fixed dentures':ab,ti OR 'fixed bridges':ab,ti OR 'fixed bridge':ab,ti OR 'fixed dental prostheses':ab,ti OR 'fixed dental prosthesis':ab,ti
#1 AND #2 AND #3

Cochrane Library

#1
MeSH descriptor: [Mouth, Edentulous] explode all trees OR (Mouth, Edentulous):ti,ab,kw OR (Edentul*):ti,ab,kw OR (Complete edentulism):ti,ab,kw OR (Toothless):ti,ab,kw
#2
MeSH descriptor: [Denture, Overlay] explode all trees OR (Implant overdenture):ti,ab,kw OR (Implant overdentures):ti,ab,kw OR (Mandibular overdenture):ti,ab,kw OR (Mandibular overdentures):ti,ab,kw OR (Removable):ti,ab,kw OR (Dentures, Overlay):ti,ab,kw OR (Overlay Denture):ti,ab,kw OR (Overlay Dentures):ti,ab,kw OR (Overdenture*):ti,ab,kw OR (Denture, Overlay):ti,ab,kw
#3
(Fixed):ti,ab,kw OR (Full-arch):ti,ab,kw OR (All-on-4):ti,ab,kw OR (All-on-four):ti,ab,kw OR (Fixed prosthesis):ti,ab,kw OR (Fixed prostheses):ti,ab,kw OR (Fixed full prosthesis):ti,ab,kw OR (Fixed full prostheses):ti,ab,kw OR (Fixed denture):ti,ab,kw OR (Fixed dentures):ti,ab,kw OR (Fixed bridges):ti,ab,kw OR (Fixed bridge):ti,ab,kw OR (Fixed dental prostheses):ti,ab,kw OR (Fixed dental prosthesIs):ti,ab,kw
#1 AND #2 AND #3

Virtual Health Library

#1:
(mh:(“Mouth, Edentulous”)) OR (tw:(“Mouth, Edentulous”)) OR (tw:("Complete edentulism")) OR (tw:(Toothless)) OR (tw:(Edentul$))
#2:
(mh:(“Denture, Overlay”)) OR (tw:(“Dentures, Overlay”)) OR (tw:("Overlay Denture")) OR (tw:(“Overlay Dentures”)) OR (tw:(Overdenture$)) OR (tw:(“Denture, Overlay”)) OR (tw:(“Implant overdenture”)) OR (tw:(“Implant overdentures”)) OR (tw:(“Mandibular overdenture”)) OR (tw:(“Mandibular overdentures”)) OR (tw:(Removable))
#3:
(tw:(Fixed)) OR (tw:(“Full-arch”)) OR (tw:("All-on-4")) OR (tw:(“All-on-four”)) OR (tw:(“Fixed prosthesis”)) OR (tw:(“Fixed prostheses”)) OR (tw:(“Fixed full prosthesis”)) OR (tw:(“Fixed full prostheses”)) OR (tw:(“Fixed denture”)) OR (tw:(“Fixed dentures”)) OR (tw:(“Fixed bridges”)) OR (tw:(“Fixed bridge”)) OR (tw:(“Fixed dental prosthesis”)) OR (tw:(“Fixed dental prostheses”))

#1 AND #2 AND #3
OpenGrey
(“Mouth, Edentulous” OR Edentul* OR “Complete edentulism” OR Toothless) AND (“Implant overdenture” OR “Implant overdentures” OR “Mandibular overdenture” OR “Mandibular overdentures” OR Removable OR “Dentures, Overlay” OR “Overlay Denture” OR “Overlay Dentures” OR Overdenture* OR “Denture, Overlay”) AND (Fixed OR Full-arch OR “All-on-4” OR “All-on-four” OR “Fixed prosthesis” OR “Fixed prostheses” OR “Fixed full prosthesis” OR “Fixed full prostheses” OR “Fixed denture” OR “Fixed dentures” OR “Fixed bridges” OR “Fixed bridge Fixed dental prosthesis” OR “Fixed dental prostheses” OR “Fixed dental prosthesis”)

Supplementary Table 2. Inclusion and exclusion criteria of studies included.

Author (Citation)	Inclusion criteria	Exclusion criteria
Ayna et al, 2018[14]	(1) Atrophy of the edentulous mandible (class C and D according to Misch and Judy); (2) Opposing natural dentition or implant-based prosthesis; (3) An interforaminal bone width ≥5 mm and bone height ≥8 mm; (4) Completely healed, at least 6 months postextraction socket(s).	(1) General systemic contraindications against implant surgery (psychiatric disorders, pregnancy, metabolic bone diseases, etc.); (2) The presence of systemic diseases which may jeopardize the success of implant integration (uncontrolled diabetes, osteoporosis, etc.); (3) The use of drugs which may negatively affect the osseointegration process (bisphosphonates, corticosteroids, etc.); (4) Active inflammation or neighboring pathologies in the areas intended for implant placement; (5) Radiation therapy to the head and/or neck region in the preceding 12 months; (6) Requirement of bone augmentation during implant placement; (7) Clinically significant parafunction; (8) Poor oral hygiene and/or compliance.
Beresford et al 2018[15]	(1) Fluent in English; (2) Above the age of 18; (3) Willingness to provide informed consent; (4) Good physical health –ASA Class I or II; (5) Edentulous in the mandible or presenting with few mandibular teeth with a poor prognosis; (6) Adequate quality and sufficient volume of bone in the parasymphysis region of mandible to place; (7) three dental implants with a minimum length of 10 mm and diameter of 4 mm.	(1) Pregnancy or a desire to become pregnant during the expected duration of the study; (2) Bad physical health – ASA Class III, IV, V or VI; (3) Uncontrolled diabetes; (4) Subjected to irradiation in the head or neck region; (5) Substance abuse; (6) Smoking habit; (7) Severe bruxism; (8) Unrealistic expectations; (9) Psychologic problems for accepting a RDP (such as a severe gag reflux); (10) Medications that may impair normal healing ability (such as coagulation; (11) Any other condition that may contraindicate dental implant therapy.
De Kok et al 2011[49]	(1) Age between 18 and 80 years old; (2) Good physical health (ASA class 1 or 2); (3) Complete edentulism for at least 3 months; (4) Mandibular bone height of at least 10 mm in parasymphysis area; (5) Willingness to give informed consent.	(1) History of radiotherapy in head and neck region; (2) Smoking habit; (3) Severe Angle Class II or III arch relationship; (4) Psychologic problems in accepting a removable prosthesis (eg, unwilling to wear dentures, severe gag reflex); (5) Current pregnancy; (6) Current steroid use; (7) ASA class 3 or 4 status; (8) Uncontrolled diabetes; (9) Known alcohol and/or drug abuse; (10) Bruxism; (11) Unrealistic esthetic expectations; (12) Current medication that might interfere with coagulation (eg, aspirin, coumadin) and/or subjects with bleeding disorders (eg, liver disease); (13) Any condition that would contraindicate dental implant therapy.
Elsyad et al 2019 A[17]	(1) Adequate bone volume (classes IV to VI, Cawood and Howell) and density (classes 1 to 3, Lekholm and Zarb) in the interforaminal area of the mandible to insert implants of at least 11 mm lenght and 3.75 mm in diameter as verified by preoperative cone beam computered tomography; (2) Sufficient restorative space (class I according to Ahuja and Cagna) to accomodate the fixed and milled bar prostheses.	(1) Patients with any contraindications to implant surgery such as liver disease, bleeding disorders, radiation therapy to the head and neck region, and immunosuppressive therapy were excluded; (2) Patients with metabolic diseases that may affect osseointegration such as diabetes mellitus and osteoporosis were also excluded.

Supplementary Table 2. (Continued)

Author (Citation)	Inclusion criteria	Exclusion criteria
Elsyad et al 2019 B[3]	(1) Insufficient retention and stability of conventional mandibular dentures; (2) Sufficient bone quantity (class IV-VI) according to Cawood and Howell and quality (classes 1–3) according to Lekholm and Zarb in the mandibular interforaminal region to install standard implants of at least 11 mm length and 3.7 mm diameter; (3) At least 15 mm restorative space (class I) according to Ahuja and Cagna to accommodate all types of tested prosthesis.	(1) Metabolic disorders that affect osseointegration such as diabetes mellitus, hepatic disorders, and osteoporosis; (2) History of radiation therapy in the head and neck region; (3) Smoking habit.
Feine et al 1994[1]	(1) Male or Female; (2) Ages 30-65 years; (3) Completely edentulous for at least 10 years and having significant problems with the existing mandibular prosthesis; (4) Possessing an adequate understanding of written and spoken French; (5) Able to understand and respond to scales used in the study; (6) Willing to accept the conditions of the study and to give informed consent.	(1) Insufficient bone to place a minimum of 4 implants in the mandible; (2) Acute or chronic symptoms of temporomandibular disorders; (4) History of radiation therapy to the orofacial region; (4) Systemic or neurologic disease (dyskinesia, etc.); (5) Other health conditions that jeopardize surgical treatment (obesity, cardiovascular disease, etc.); (6) Psychological or psychiatric conditions that could influence the subject's reaction to treatment.
Makkonen et al 1997[45]	(1) Be in good general health with no history of mental illness; (2) No chronic alcoholism; (3) No uncontrolled diabetes mellitus; (4) Edentulous in the lower jaw for at least 1 year; (5) Upper jaw had to have a removable complete denture; (6) Sufficient height of jawbone (at least 8 mm) had to be available at the sites of the implant.	NR
Quirynen et al 2005[46]	NR	(1) Patients who for medical reasons might not be a candidate for recall; (2) Current known alcohol abuse, drug or medication abuse; (3) Insufficient bone volume to harbour two implants with a minimum length of 10mm; (4) Psychological problems with the acceptance of a removable denture; (5) Gagging reflexes; (6) Multiple medication intake.
Raghoebar et al 2003[47]	(1) Mandibular edentulism of at least 3 to 4 months; (2) Age limit from 18 to 70 years.	(1) Drug or alcohol abuse; (2) Psychiatric or administrative problems, which were anticipated to lead to a disruption of the planned follow-up period of 5years; (3) Patients with a history of radiotherapy in the head and neck region of bone grafting, or of oral implantology were excluded.
Tinsley et al 2001[48]	(1) Inability to wear a removable lower complete prosthesis.	(1) Medically compromised patients; (2) Identification of poor oral hygiene; (3) Heavy smokers; (4) Severe psychiatric disorders.

ASA, American Society of Anesthesiologists; NR, not reported.

Supplementary Table 3. Certainty of evidence for oral health-related quality of life domains and overall score.

Certainty assessment							Summary of findings			
Prothesis (studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Overall certainty of evidence	Study event rates (%)		Anticipated absolute effects	
							Fixed	Overdenture	Risk with Fixed	Risk difference with Overdenture
Functional limitation										
76 (1 N-RCT and 2 RCTs)	serious [a]	not serious	serious [b,c]	very serious [d,e]	none	⊕◯◯◯ VERY LOW	38	38	-	SMD **0.76 lower** (1.18 lower to 0.34 lower)
Physical pain										
76 (1 N-RCT and 2 RCTs)	serious [a]	not serious	serious [b,c]	serious [d]	none	⊕◯◯◯ VERY LOW	38	38	-	SMD **0.62 lower** (1.02 lower to 0.21 lower)
Psychologic discomfort										
76 (1 N-RCT and 2 RCTs)	serious [a]	not serious	serious [b,c]	serious [d]	very strong association	⊕⊕⊕◯ MODERATE	38	38	-	SMD **0.11 higher** (0.27 lower to 0.48 higher)
Physical disability										
76 (1 N-RCT and 2 RCTs)	serious [a]	not serious	serious [b,c]	serious [d]	none	⊕◯◯◯ VERY LOW	38	38	-	SMD **0.7 lower** (1.12 lower to 0.28 lower)
Psychologic disability										
76 (1 N-RCT and 2 RCTs)	serious [a]	not serious	serious [b,c]	serious [d]	strong association	⊕⊕◯◯ LOW	38	38	-	SMD **0.2 lower** (0.58 lower to 0.19 higher)
Social disability										
76 (1 N-RCT and 2 RCTs)	serious [a]	not serious	serious [b,c]	serious [d]	very strong association	⊕⊕⊕◯ MODERATE	38	38	-	SMD **0.04 higher** (0.33 lower to 0.42 higher)
Handicap										
76 (1 N-RCT and 2 RCTs)	serious [a]	not serious	serious [b,c]	serious [d]	strong association	⊕⊕◯◯ LOW	38	38	-	SMD **0.3 lower** (0.68 lower to 0.09 higher)
Overall oral health-related quality of life										
108 (2 N-RCTs and 2 RCTs)	not serious	not serious	very serious [b,c,f]	serious [d]	none	⊕◯◯◯ VERY LOW	54	54	-	SMD **0.61 lower** (1.08 lower to 0.13 lower)

CI, Confidence interval; SMD, standardized mean difference. Explanations: (a) All studies included in this analysis presented some type of risk of bias; (b) Included studies did not included all-on-5 or all-on-6 fixed prothesis; (c) None of the included studies used immediate loading in implants; (d) Total number of participants is less than 400; (e) Upper or lower confidence limit crosses the effect size is greater than 0.5 in either direction; (f) Included studies did not used bar attachment in overdenture.

Supplementary Table 4. Certainty of evidence for satisfaction domains and overall score.

Certainty assessment							Summary of findings			
							Study event rates (%)		Anticipated absolute effects	
Prothesis (studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	Overall certainty of evidence	Fixed	Overdenture	Risk with Fixed	Risk difference with Overdenture
Comfort										
76 (1 N-RCT and 2 RCTs)	serious [a]	very serious [b,c]	serious [d,e]	very serious [f,g]	none	⊕◯◯◯ VERY LOW	38	38	-	SMD **0.72 higher** (0.1 higher to 1.34 higher)
Esthetics										
59 (1 N-RCT and 2 RCTs)	serious [a]	not serious	serious [d,e]	serious [f]	strong association	⊕⊕◯◯ LOW	30	29	-	SMD **0.21 higher** (0.26 lower to 0.68 higher)
Ease of chewing										
59 (1 N-RCT and 2 RCTs)	serious [a]	not serious	serious [d,e]	serious [f]	none	⊕◯◯◯ VERY LOW	30	29	-	SMD **0.94 higher** (0.41 higher to 1.47 higher)
Ease of speaking										
59 (1 N-RCT and 2 RCTs)	serious [a]	not serious	serious [d,e]	serious [f]	strong association	⊕⊕◯◯ LOW	30	29	-	SMD **0.25 higher** (0.22 lower to 0.73 higher)
Ease of cleaning										
91 (1 N-RCT and 3 RCTs)	serious [a]	very serious [b,h]	serious [d,e]	very serious [f,g]	none	⊕◯◯◯ VERY LOW	46	45	-	SMD **0.91 lower** (1.29 lower to 0.52 lower)
Stability										
91 (1 N-RCT and 3 RCTs)	serious [a]	not serious	serious [d,e]	serious [f]	none	⊕◯◯◯ VERY LOW	46	45	-	SMD **0.99 higher** (0.5 higher to 1.47 higher)
Retention										
76 (1 N-RCT and 2 RCTs)	serious [a]	not serious	serious [d,e]	serious [f]	none	⊕◯◯◯ VERY LOW	38	38	-	SMD **0.93 higher** (0.5 higher to 1.36 higher)
Overall satisfaction										
44 (1 N-RCT and 1 RCT)	serious [a]	not serious	very serious [d,e,i]	very serious [f,g]	strong association	⊕◯◯◯ VERY LOW	22	22	-	SMD **4.84 higher** (1.00 higher to 8.67 higher)

CI, Confidence interval; SMD, standardized mean difference. Explanations: (a) All studies included in this analysis presented some type of risk of bias; (b) Considerable heterogeneity; (c) Some variation in the effect estimates across studies and little overlap of confidence intervals associated with the effect estimates; (d) Included studies did not included all-on-5 ou all-on-6 fixed prothesis; (e) None of the included studies used immediate loading in implants; (f) Total number of participants is less than 400; (g) Upper or lower confidence limit crosses the effect size is greater than 0.5 in either direction.

Supplementary Table 5. Certainty of evidence for clinical parameters: survival, probing depth, and marginal bone loss.

Certainty assessment							Summary of findings				
Implants (studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Other consideratinos	Overall certainty of evidence	Study event rates (%)		Relative effect (95% CI)	Anticipated absolute effects	
							Fixed	Overdenture		Risk with Fixed	Risk difference with Overdenture
Survival											
829 (3 N-RCTs and 3 RCTs)	not serious	not serious	serious [a]	not serious	none	⊕⊕⊕◯ MODERATE	399/402 (99.3%)	416/427 (97.4%)	**RR 1.00** (0.98 to 1.01)	993 per 1.000	**0 fewer per 1.000** (from 20 fewer to 10 more)
Probing depth											
66 (1 N-RCT and 1 RCT)	not serious	very serious [b,c]	very serious [a,d,e]	serious [f]	very strong association	⊕◯◯◯ VERY LOW	33	33	-	The mean probing depth was **0**	MD **0.2 lower** (0.48 lower to 0.09 higher)
Marginal bone loss - 1 year											
83 (2 N-RCTs and 1 RCT)	not serious	serious [c]	serious [a,d]	serious [f]	very strong association	⊕⊕⊕◯ MODERATE	38	45	-	The mean marginal bone loss - 1 year was **0**	MD **0.01 higher** (0.07 lower to 0.09 higher)
Marginal bone loss - 3 years											
56 (2 N-RCTs)	not serious	serious [c]	serious [a,d]	serious [f]	very strong association	⊕⊕⊕◯ MODERATE	26	30	-	The mean marginal bone loss - 3 years was **0**	MD **0.05 higher** (0.03 lower to 0.12 higher)
Marginal bone loss - 5 years											
57 (2 N-RCTs)	not serious	not serious	serious [a,d]	serious [f]	very strong association	⊕⊕⊕⊕ HIGH	26	31	-	The mean marginal bone loss - 5 years was **0**	MD **0.05 higher** (0.04 lower to 0.13 higher)
Marginal bone loss - 6 to 10 years											
69 (2 N-RCTs)	not serious	not serious	serious [a]	serious [f]	very strong association	⊕⊕⊕⊕ HIGH	28	41	-	The mean marginal bone loss - 6 years or more was **0**	MD **0.03 higher** (0.06 lower to 0.11 higher)

CI, Confidence interval; RR, Risk ratio; MD, Mean difference. Explanations: (a) None of the included studies used immediate loading in implants; (b) wide variation in the effect estimates across studies and no overlap of confidence intervals associated with the effect estimates; (c) Considerable heterogeneity; (d) Included studies did not used ball attachment in overdenture; (e) Included studies did not included all-on-5 or all-on-6 fixed prothesis; (f) Total number of participants is less than 400.

2.4 Targeting biomechanical endurance of dental-implant abutments using a diamond-like carbon coating#

Guilherme Almeida Borges[a], Raphael Cavalcante Costa[a], Bruna Egumi Nagay[a], Catharina Marques Sacramento[a], Karina Gonzales Silverio Ruiz[a], Larissa Solano Almeida[b], Luciana Sgarbi Rossino[b], Carlos Alberto Fortulan[c], Elidiane Cipriano Rangel[d], Valentim A. R. Barão[a], Marcelo Ferraz Mesquita[a,*]

[a] University of Campinas (UNICAMP), Piracicaba Dental School, Department of Prosthodontics and Periodontics, Av. Limeira, 901, Piracicaba, São Paulo 13414-903, Brazil

[b] Federal University of São Carlos (UFSCar) – Campus Sorocaba, Postgraduate Program in Materials Science, Rodovia João Leme dos Santos, Km 110, Sorocaba, São Paulo 18052-780, Brazil

[c] University of São Paulo (USP), Department of Mechanical Engineering, Trabalhador São Carlense 400, São Carlos, São Paulo 13566-590, Brazil

[d] São Paulo State University (UNESP), Institute of Science and Technology, Laboratory of Technological Plasmas, Av. Três de Março, 511, Sorocaba, São Paulo 18087-180, Brazil

[*] Corresponding author at University of Campinas (UNICAMP), Piracicaba Dental School, Department of Prosthodontics and Periodontology, Av. Limeira, 901, Piracicaba, São Paulo, 13414-903, Brazil.

E-mail address: mesquita@unicamp.br (M.F. Mesquita)

#Artigo submetido e aceito na revista *ACS Applied Bio Materials* (Fator de impacto = 4.7).

ABSTRACT

Abutment components (i.e., fixtures associated with oral implants) are essentially made of titanium (Ti), which is continuously exposed to the hash oral environment, resulting in scratching. Thus, such components need to be protected, and surface treatments are viable methods for overcoming long-term damage. Diamond-like carbon (DLC), an excellent protective material, is an alternative surface-treatment material for Ti abutments. Here, we demonstrate that a silicon interlayer for DLC film growth and pulsed-direct current plasma-enhanced chemical vapor deposition (DC-PECVD) method enables the deposition of an enhanced protective DLC film. As a result, the DLC film demonstrated a smooth topography with a compact surface. Furthermore, the DLC film enhanced the mechanical (load displacement, hardness, and elastic modulus) and tribological properties of Ti as well as increased its corrosion resistance (16-fold), which surpassed that of a bare Ti substrate. The biofilm formed (*Streptococcus sanguinis*) after 24 h exhibited an equal bacterial load (~7 Log colony-forming units) for both the groups (Ti and DLC). In addition, the DLC film exhibited good cytocompatibility owing to its noncytotoxicity toward human gingival fibroblast cells. Therefore, DLC deposition via DC-PECVD can be considered a promising protective and cytocompatible alternative for developing implant abutments with enhanced mechanical, tribological, and electrochemical properties.

Keywords: Titanium; Dental implants; DLC film; Corrosion; Biomaterials.

1. Introduction

Dental implantology relies on the biocompatibility of the designed material (Titanium; Ti), which facilitates osseointegration with the host bone,[1] thus providing sufficient anchorage (bone-implant bonding) for functional dental reconstruction.[2] Once the implant is properly set up, it has to be adequately connected with the abutments, which are components that penetrate the soft tissue (oral mucosa) in the transitional zone between the anchoring bone and dental prosthesis/crown.[2,3] Because the abutment is an individual transmucosal structure that resists the harsh oral environment, considerable strategies have been developed for designing and implementing surface treatments to increase the mechanical endurance of these components.[4–6] Nonetheless, it is necessary to modify the surface properties of implantable components without adversely affecting their biological response to extend their usability and reduce degradation in the oral environment.[4,7]

As a commercial implant material, Ti Grade-IV (TiGrIV) is used for developing abutments for dental implants because of its suitable mechanical strength and adequate biocompatibility.[8] Furthermore, as the Ti abutment is connected to the implant and exposed in the oral cavity, a thin Ti dioxide layer is formed due to the presence of oxygen and water, and this layer increases the corrosion resistance.[9] However, during functional activities (e.g., mastication, mechanical hygiene), continuous forces in the oral cavity can disrupt the oxide layer's stability and surface integrity.[10] Notably, Ti dioxide layer degradation may also be initiated by corrosive ions (e.g., Cl^-, F^-, and H^-) present within the oral biofilm and saliva.[11] Ultimately, Ti subproducts resulting from the corrosion process might be released as metallic ions or particles, adversely triggering proinflammatory reactions in the peri-implant tissue.[7,11,12] Therefore, an effective approach to overcome the aforementioned drawbacks is to develop a protective film with wear/corrosion resistance and biological cytocompatibility.

Diamond-like carbon (DLC), an amorphous hydrogenated material mainly composed of carbon, is extensively used in the biomedical field because of its protective properties (mechanical resistance, anticorrosion, chemical inertness, and biocompatibility).[13–15] However, DLC properties are directly associated with the three-dimensional chemical network of sp^2 and sp^3 hybridized carbon.[16–18] In detail, the sp^2 bonding (graphite-like behavior) is modulated by the amount of hydrogen, favoring a strong lubricating behavior.[17,18] Moreover, coatings with considerable density (compact structure) and rigidity (high hardness and elastic modulus) are obtained by the sp^3 hybridization of carbon atoms.[19] Hence, DLC materials with higher amounts of sp^3 carbon atoms display elevated residual stress, allowing the intrinsic bucking defect at the film–substrate interface, which also hinder their practical application.[20] To overcome these shortcomings, various strategies have been developed to obtain functional DLC films with carbon hybridization balance.[21] For instance, hydrogen content increase, interlayer components (e.g., silicon), and deposition process (e.g., pulsed-direct current plasma-enhanced chemical vapor deposition; DC-PECVD) have been considered promising alternatives;

altogether, they could lessen not only the intern residual stresses, but also promote wear resistance.[13,21–23] These alternatives can determine the integrity of the DLC film during its growth as well as degrade its mechanical properties to achieve ductility.[20] DLC films with a high sp^3 content (≥50%) present hardness values up to 80 GPa; nevertheless, increasing the compressive stress results in delamination.[24,25] Moreover, films with a silicon interlayer and 20% sp^3 hybridization present a reduced hardness (~20 GPa) but overcome the particular disadvantages of pure carbon films, such as wear resistance in metals and high internal stress.[21] Thus, even though the mechanical properties of DLC films deteriorate as the internal stress diminishes, these films still outperform pure Ti-based materials (e.g., hardness and elastic modulus).[26]

DLC interlayers containing silicon are commonly employed to improve the adhesion in metallic alloys owing to its chemical stability.[14,19,26–28] The inner stress of the DLC material is responsible for the initiation/propagation of cracks at the tail between the contact zone on the surface or at the base of the coating and finally cause delamination from its substrate.[29] Thus, adding a silicon interlayer increases adherence with the metallic substrates and consequently decreases the shear stress as a crack barrier shielding to increase material applicability.[30] Moreover, another methodology that can tackle the DLC inner stress drawbacks is the deposition process. A previous study has outlined that DLC films prepared using the DC-PECVD process exhibit small carbon clusters and low roughness, unlike those prepared by magnetron sputtering. Consequently, the DLC films prepared by DC-PECVD display high densities and outstanding mechanical properties.[13] In addition, the DC-PECVD presents a stable deposition process with controllable glow discharges in short pulses, also contributing to a high electron density, temperature, and ion bombardment.[31] Interestingly, the combination of both methodologies (silicon interlayer and DC-PECVD) has not been previously carried out, especially considering implant-abutment materials, including the TiGrIV, as proposed herein.

As already discussed, the motivation to use DLC materials in implant abutments is owing to their protective characteristics (mechanical robustness and excellent corrosion resistance). However, there are open questions that need to be settled, as follows: (*i*) Can we overcome the typically occurring wear resistance problems (delamination from the metallic substrate) of the DLC films by combining DC-PECVD methodology and silicon interlayer to achieve excellent material properties? (*ii*) Are the electrochemical activity and mechanical properties of the obtained DLC film better than those of bare substrates (TiGrIV)? (*iii*) Is the biological cytocompatibility of DLC films toward host cells (human gingival fibroblasts) similar to that of the commercial material (TiGrIV) for clinical applications? (*iv*) Considering an early colonizer (*Streptococcus sanguinis*) for biofilm formation, is the material prone or not for microbial adhesion? Because these questions have not been studied before, it would be feasible to synthesize a DLC film on a TiGrIV substrate, considering that such a study would be highly interesting for surface enhancement of implant abutments.

2. MATERIAL AND METHODS

2.1. Sample preparation. Commercially pure TiGrIV milled disks, with 10 mm diameter and 1.2 mm thickness (Realum Industria e Comercio de Metais Puros e Ligas Ltd., Brazil), were sequentially polished using SiC sandpapers of #320, #400, and #600 grit sizes (Carbimet 2; Buehler, USA) in an automatic polisher (EcoMet/AutoMet 250 Pro; Buehler, USA). Then, the samples were cleaned in an ultrasonic bath with enzymatic detergent, deionized water, and 70% propanol for 10 min in each solution, and subsequently, hot-air-dried [6].

2.2. DLC surface coating. The DLC coating was deposited using the DC-PECVD technique at a fixed frequency of 20 Hz and pulse modulation power of 48 ms on-time and 2 ms off-time.[32] The plasma system was composed of a reactor chamber (anode) with an internal circular plate (cathode) (made of AISI 316 stainless steel), which was operated in combination with a thermocouple, pressure sensor, vacuum system, and air gas mass flow meter.[32,33] Deposition of the samples was conducted using a continuous three-step process: ablation,[33] silicon interlayer deposition,[34] and the outermost DLC coating (Figure 1). Initially, the samples were positioned inside the vacuum chamber in the electrode, subsequentially closing the system (to limit air contaminants), and pressure was pumped down to 3×10^{-3} Torr. The ablation process was then established with 2.1×10^{0} Torr (80% argon and 20% hydrogen) to eliminate contaminants in the target surface for 60 min, 250 W, 0.8 A, 290 V, and 350ºC. The second deposition step was conducted with a new pressure in the chamber of 7.4×10^{-2} Torr (70% hexamethyldisiloxane and 30% argon) to enhance coating adhesiveness to the TiGrIV substrate, all along 25 min, 100W, 0.1 A, 500 V, 160ºC. Thereafter, for the preparation of the DLC film, the plasma was ignited with a working pressure of 1.1×10^{-1} Torr (90% argon and 10% acetylene); the deposition was conducted for 60 min at 130 W, 0.2 A, 500 V, and 135ºC. Notably, the total pressure of the gases, voltage, current, and power applied to the electrode were maintained constant in all the three steps of deposition for all the samples included in the DLC group. The noncoated TiGrIV samples (disks polished, cleaned, and not treated by plasma) were included as the control group.

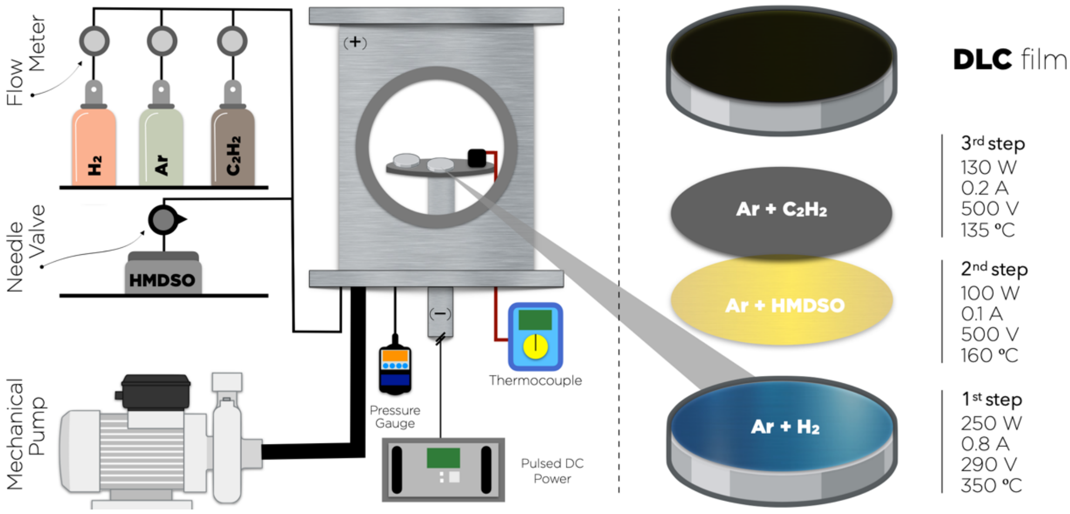


Figure 1. Schematic representation of the pulsed-direct current plasma-enhanced chemical vapor deposition method used to grow diamond-like carbon (DLC) films.

2.3. Surface characterization. *2.3.1. Roughness and wettability*. The average roughness (Ra) of the specimens (n = 5) was obtained by contact profilometry (Dektak 150-d; Veeco, USA), presenting a tip of 12.5 μm radius. Repeatability errors were minimized by the selected tip which dominate measurement if the chord rise is less than 100Å for scans longer than 1 mm. Measurements in three prespecified regions (upper, center, and lower section) for each specimen were acquired and averaged with a cut-off of 0.25 mm at 0.05 mm/s for 12 s at controllable temperature (23ºC ± 1ºC) and according to the description provided in International Organization for Standardization (ISO) 4288:1997.[35] The water wettability was measured by contact angle using an automated goniometer (Ramé-Hart 100–00; Ramé-Hart Instrument Co., USA) (n = 5). The sessile drop technique using deionized water droplets (5 μL) and appropriate software (DROPimage Standard; Ramé-Hart Instrument Co., USA) were applied, at controllable temperature (23ºC ± 1ºC).[36] To minimize experimental error sample calibration at 0% ± 0.1% tilt was accomplished and a total of 10 readings per sample were obtained.

2.3.2. Structural morphology and topography. Surface morphology and top-view characteristics were investigated by scanning electron microscopy (SEM) (JEOL JSM-5600; Peabody, USA) at controllable temperature (23ºC ± 1ºC). For the cross-sectional analysis, the DLC-treated disks (n = 1) were placed in a dual-beam focused ion beam-SEM (FIB-SEM) (FEI Helios Nanolab 600; Thermo Fisher Scientific, USA). Initially a 1.0 ± 0.1 μm thick platinum protective layer was deposited at the center of the disk in the area of interest (DLC coating) using the ion beam (30 kV, 93 pA). Sequentially, a trench was cut directly adjacent to the area of interest, afterward, the cross-section lamella was cleaned up at a voltage of 30 kV. The sample was then tilted to observe the cross-section features using the electron beam at an incident angle of 45 ˚. Afterward, to obtain the coating thickness, 10 measurements in randomly selected areas were dimensioned using SEM. The surface profile was also assessed by atomic force microscopy (AFM) with a scanning microscope (Park NX10; Park System, USA) with a silicon probe, within a chamber presenting a controllable temperature (25ºC ± 1ºC) and humidity (5% ± 1%) to identify the three-dimensional surface topography in tapping mode, using intermittent contact technique (n = 1). Areas of 40 µm × 40 µm were scanned, each image (521 pixels X 512 pixels) displayed 512 profile lines within each line 512 points, to obtain the arithmetic average roughness and the total surface area, these outputs were calculated via Gwyddion software (GNU General Public License, Czech Republic).

2.3.3. Carbon chemical structure and composition. The chemical compositions of the control and DLC coating layers were analyzed by energy-dispersive spectroscopy (EDS) (JEOL JSM-5600; Peabody, USA) (n = 1) on three different areas of each sample at a controlled temperature (23ºC ± 1ºC).[36] The Raman spectra (n = 1) were measured using a confocal Raman microscope (Horiba Jobin Yvon) for characterizing the carbon content (D and G bands). An argon laser was applied with a 5 µm diameter spot, wavelength of 633 nm, and power of 5%, and the corresponding spectra was collected at a controlled temperature (20ºC ± 1ºC). The resulting data were deconvoluted using the Fityk 1.3.1 software; specifically, Lorentzian (D-peak) and Gaussian (G-peak) curves were applied to identify the stretching vibration of sp^2-C in the carbon chains and aromatic rings (D-peak) as well as the symmetric breathing vibration of sp^2-C only in the rings (G-peak).[37] Thereafter, the hydrogen content in the DLC film was determined from the Raman spectra output using the following equation reported by Casiraghi et al. in 2005:

$$H[\%] = 21.7 + 16.6 \log \frac{m}{I(G)[\mu m]}$$

where m is the inclination of spectra between 1000 and 1800 cm^{-1}, and $I(G)$ is the intensity of the G-band.[18] The surface chemical composition of the outermost oxide layer was analyzed with K-Alpha X-ray Photoelectron Spectrometer (XPS) from Thermo Fisher Scientific Inc., using monochromatic Al Kα X-rays (1486.6 eV) (n = 1) at 25ºC ± 1ºC. The survey spectra were obtained by running the scans in the 0–1350 eV range at three different areas for each sample, with 300 µm spot size, using a pass energy of 200 eV, and dwell time of 10 ms. The high-resolution spectra were recorded in the bonding energy ranges of C 1s, O 1s, and Ti 2p signals, using a 300 µm spot size, pass energy 50 eV, and dwell time of 50 ms. The deconvolution and background subtraction were carried out by fitting the peaks on Avantage 5.89 software (Thermos Scientific).

2.4. Mechanical and tribological assays. *2.4.1. Nanomechanical properties.* The nanoindentation mechanical performances were measured using a TriboIndentator device (TI 950TriboIndente; Hysitron Inc., USA) equipped with a Berkovich diamond tip (100 nm diameter). Indentation tests were operated in a controllable displacement mode. The displacement excitation was applied to the sample according to a programmed loading function (range: 0 µN to 5000 µN) while the force response was continuously monitored. The loading function in this work consisted of a 5 s linear loading and 5 s unloading segments with a 10 s force dwelling at the peak load to reduce the influence of creeping effects. A total of 10 indents with lateral spacings of 15 μm were taken, and the Oliver–Pharr model was applied to explore the loading–unloading curves and estimate the hardness and elastic modulus of the control and TiGrIV samples coated with DLC.[38]

2.4.2. Tribological characterization. The friction coefficient (n = 5) was evaluated using custom-made tribological equipment (pin-on-disk tribometer-Faculty of Mechanical Engineering, University of São Paulo, São Carlos, SP, Brazil), previously described.[35] The assay was conducted under constant vertical normal load (5 N), track diameter (7.6 mm), sliding velocity (0.01 m/s), and sliding duration (300 s). The sample was standardly positioned in the machine, and zirconia (Y-TPZ; ø = 5 mm) ball was positioned as a counterbody. The assembly was immersed in 100 mL of artificial saliva (37°C) at pH 6.5 to mimic the intraoral environment.[39] At the end of each test, the zirconia ball and artificial saliva solution were replaced before moving forward to the upcoming sample. Moreover the assay, the evolution of surface wear was monitored via LabViews software (National Instruments, Brazil), and the friction coefficient average was determined (μ).

After tribological tests, the morphology of the wear track was investigated by SEM. For calculation of the wear volume of the samples, an optical microscope with 1.0 μm precision and 120× magnification (VMM-100-BT; Walter UHL, Germany) equipped with a digital camera (KC-512NT; Kodo BR Eletrônica Ltd., Brazil) and analyzer unit (QC 220-HH Quadra-Check 200; Metronics Inc., USA) was applied.[35] The total area worn by the tribological test was calculated based on measurements made on the horizontal and vertical axis by a trained operator (GAB). These data were obtained to subtract the circular areas not affected by the assay, and the final surface adherence was analyzed from the wear-track area (mm^2).

2.4.3. Electrochemical assay. The electrochemical tests (n = 5) were performed in a potentiostat (Interface 1000; Gamry Instruments, USA).[40] All measurements were obtained by a three-electrode cell standardized method which was set following the American Society for Testing of Materials instructions (G61-86 and G31-72).[4,35] The AFM data were used to estimate the exposed surface area (TiGrIV = 0.80 cm^2; DLC = 0.85 cm^2) and used as a working electrode. Additionally, it was operated with a saturated calomel electrode as a reference electrode and a graphite rod as the counter electrode. For each corrosion test, the assembly (working electrode, reference electrode, graphite rod) was immersed in 5 mL of electrolyte solution (artificial saliva at pH 6.5) with a constant temperature maintained at 37ºC ± 1ºC.[6,39]

The assay provided quantitative dependent variables. First, a cathodic potential (−0.9 V *vs*. SCE) was applied for 600 s.[4,35] Afterward, the open-circuit potential (OCP; to obtain the measurement when no current is flowing) was scanned for 3600 s followed by performing electrochemical impedance spectroscopy (EIS; to investigate the formation and growth of the Ti oxide layer) assay, which was conducted at a frequency range of 100 kHz to 5 mHz with a sinusoidal amplitude curve of 10 mV applied at the electrode at its corrosion potential.[6] For EIS, the constant phase elements (CPE; equivalent circuit model) were better fitted and applied to estimate the real (Z_{real}) and imaginary (Z_{imag}) components of the impedance, which were presented as Nyquist plot, impedance (|Z|) and phase angle.[4] Subsequently, to draw the potentiodynamic polarization curves, the samples were polarized from −0.8 V to 1.8 V (scan rate of 2 mV/s).[4,6] The polarization curves by the Tafel extrapolation method provided electrochemical parameters: corrosion potential (E_{corr}), corrosion current density (i_{corr}), and corrosion rate. Electrochemical software (Echem Analyst; Gamry Instruments) was applied thereafter for the analysis for data assessment.[35]

2.5. Biological assessments. *2.5.1. Cellular Viability.* Cellular metabolic activity of primary human gingival fibroblasts (Approved by the Local Research and Ethics Committee: 64309522.4.0000.5418) on the control and DLC surfaces was determined at 1 and 3 days by using 3-[4,5-dimethylthiazol-2yl]-2,5-diphenyl tetrazolium bromide (MTT; Sigma-Aldrich, St. Louis, MO, USA) assay.[36] The cells were seeded into separate wells of 48-well plates (1.5×10^4 cells/well) in standard medium for 24 h for cell attachment. After the experimental periods, cells were washed with PBS, and the culture medium was replaced by α-MEM with MTT (0.5 mg/mL) (trypsin-ethylenediaminetetraacetic acid; Gibco) and incubated at 37°C and 5% CO_2 atmosphere conditions for 4h following the manufacturer's recommendation. Subsequently, ethanol 100% (Sigma-Aldrich) was used to dissolve the formazan crystals. Next, the optical density was verified (VersaMax; Molecular Devices, USA) at a 570 nm wavelength.[40] MTT assays were performed in triplicate to guarantee reproducibility.

Immunohistochemical staining was used in order to quantify the cells on the surfaces. Accordingly, human gingival fibroblasts were cultivated as described before. At days 1 and 3, the samples were washed once with PBS (Gibco, Life Technologies), fixed with 4% paraformaldehyde in PBS (PFA; Sigma-Aldrich), and permeabilized using 0.1% Triton X-100 solution in PBS (Carl Roth). After blocking with 1% bovine serum albumin in PBS (BSA; Sigma-Aldrich), the cells were covered with ProLong® Gold antifade reagent including 4′-6-Diamidino-2-phenylindole (DAPI; Sigma) for nuclear counterstaining.[41] The nuclear assessment was further determined by confocal imaging (LSM 800; Carl Zeiss, Germany).

Cell morphology, adhesion, and spreading were also verified by SEM analysis.[40,41] Briefly, cells were cultured as described above, and after 1 and 3 days, cells were washed with PBS and fixed with 2.5% glutaraldehyde for 12 h. Next, cells were dehydrated in ethanol (50, 70, 90, and 100%) at 37°C for 10 min in each concentration, critical-point dried (mod. DCP-1; Denton Vacuum, USA) and sputtered with gold (mod. SCD 050; Bal-Tec, USA).[4]

2.5.2. Microbiologic assay. Streptococcus sanguinis (IAL 1832) stationary-phase cultures, a usual initial colonizer in implant surfaces, were grown overnight in brain heart infusion (BHI) to reach exponential growth.[42] Subsequently, the optical density was adjusted to $OD_{600} = 1.00 \pm 0.02$ using a spectrophotometer (Multiskan; Thermo Scientific, Finland), representing a final suspension of 10^7 cells/mL.[36] For the acquired saliva pellicle formation (Approved by the Local Research and Ethics Committee: 64309522.4.0000.5418), human saliva stimulated by a chewable flexible film (Parafilm M; American Can Co., USA) was collected from 3 healthy volunteers selected by inclusion criteria previously determined.[43] The collected saliva was centrifuged (6,000 *g* for 10 min at 4°C), and the supernatant was filtered through a 0.22-µm membrane filter (K15–1500, Kasvi, São José dos Pinhais, Paraná, Brazil) and used immediately. Before the acquired pellicle formation, disks were sterilized in an autoclave at 121°C (1.8 kgf cm^{-3} for 15 min) (Vitale 21, Cristófoli, Brazil). Thereafter, disks were transferred individually to a 24-well polystyrene cell culture plate, covered with 1 mL of saliva, and incubated under agitation for 30 min at 37°C.

After pellicle formation, the saliva coated-disks were transferred to new wells and covered with 100 µL of *S. sanguinis* cell suspension and 900 µL of BHI medium.[36] Then, the disks were incubated under 10% CO_2 at 37°C for 24 h. For nonadherent cell removal, disks were washed in 0.9% NaCl and then transferred to cryogenic tubes containing 1 mL of 0.9% NaCl. The tube was vortexed for 10 s and then sonicated (7 W for 30 s) to disaggregate the bacterial cells, and an aliquot of 100 µL was 7-fold serially diluted in 0.9% NaCl and plated in BHI agar. Then, the plates were incubated (10% CO_2, at 37°C for 24 hours). The obtained counts of colony-forming units (CFU) were expressed as the log of the colony-forming units per mL (log CFU/mL). Live and dead cells were stained with 1 µM SYTO-9 green fluorescent nucleic acid (485–498 nm; Thermo Scientific, USA) and 1.0 mg/mL propidium iodide solution (490–635 nm; Thermo Scientific, USA) in the dark at room temperature for 20 min.[44] A confocal scanning fluorescence microscope (CARLS ZEISS LSM 800 Airyscan with GaAsp detector, Germany) was used to visualize the distribution of live and dead bacteria throughout the biofilm. The images were further assessed by ZEN Blue software (version 2.3) for reconstruction.[45] Region of interest had the same area to standardize comparison. Arbitrary units were used to estimate fluorescence intensity.

2.6. Statistical analysis. The output data were assessed with IBM SPSS Statistics using Windows (IBM SPSS Statistics for Windows, v.21.0., IBM Corp., USA). The normality of all response variables was tested by the Shapiro–Wilk method. Surface properties (roughness and wettability), mechanical assessments (hardness and elastic modulus), tribological behavior (friction coefficients and wear track), electrochemical parameters (OCP, polarization resistance, capacitance, corrosion potential, corrosion current density, and corrosion rate) and microbiological properties (quantification of CFU) were analyzed using a Bonferroni *t*-test. Moreover, the microbiological live/dead staining and biological properties (MTT absorbance and DAPI nuclei count) were assessed by two-way ANOVA (factor 1 = surface treatment and factor 2 = time). Tukey honestly significant difference test was applied as a post hoc technique for multiple comparisons with significance set at $p < 0.05$. The Graph-Pad Prism software (GraphPad, USA) was applied for graphical reconstruction.

3. RESULTS AND DISCUSSION

3.1. Compact and smooth DLC film coated on a TiGrIV substate via pulsed DC-PECVD. A successfully deposited film has been produced and characterized in terms of surface topography, roughness, wettability, and chemical composition, as such features play important roles in the biological response of dental-implant components. Figure 2a shows the Raman spectra, which provide information on the microstructure of the fabricated film. Notably, a nonsymmetric and wide peak observed at 1000–1800 cm^{-1} was deconvoluted into two peaks (D- and G-peak), which validated the successful deposition of the DLC structure.[16] The D-peak (1311 cm^{-1}), G-peak (1515 cm^{-1}), full width at half maximum for the G-band ($FWHM_G$; 198 cm^{-1}), I_D/I_G ratio (0.61), and hydrogen content (22.66%), were obtained to assess the sp^2 bonding structure. The G-peak center position obtained was lower than that reported in previous studies, either using the same DC-PECVD method (1540–1544 cm^{-1}) or the same deposition chemical components (1549–1589 cm^{-1}),[13,14,28,33] indicating a low internal stress in the DLC film in our study. In detail, the G-peak wavenumber indirectly reflects the degree of carbon disorder and structure order of the sp^2 sites of the DLC film.[18,46] Since the bond disorder of sp^2 clusters decreases with the addition of hydrogen or silicon to the system.[46] When it comes to silicon, it only increases the sp^3 content, consequently the stress felt by sp^2 tends to decrease due to increased bonding with Si atoms, shifting the position of the G-band toward lower wavenumbers.[14] Thus, this reduction can be ascribed to the underlying silicon layer (70% hexamethyldisiloxane and 30% argon), which was formed before the DLC deposition. Further, the reduced internal stress in the DLC film can be attributed to the film's wear resistance, which is further described in the tribological analysis section.

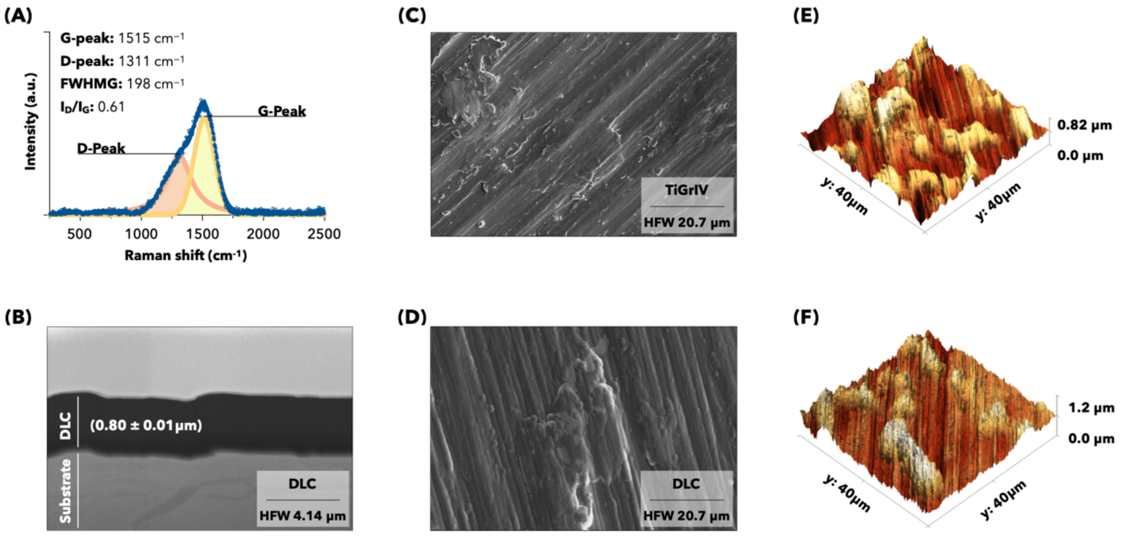


Figure 2. Surface chemical composition determined from the Raman spectra (A); morphology obtained from a cross-sectional focused ion beam-scanning electron microscope (FIB-SEM) micrograph and the thickness (mean ± standard deviation) of the DLC film deposited onto the TiGrIV substrate (B); top-view SEM micrographs of TiGrIV (C) and DLC (D); atomic force microscopy (AFM) 3D topography obtained for the TiGrIV (E) and DLC (F) surfaces (n = 1/group). HFW, horizontal field width; (mean ± standard deviation).

The obtained I_D/I_G (0.61) ratio indirectly represents the defectiveness degree of the coating.[16,18] Values less than 1 characterize increased carbon disorder (D band), boosting the sp^3 carbon hybridization.[14,27] Thus, the G-band located at a lower wavenumber might be attributed to the strengthening of the sp^3 bond in the material, as described previously.[22] Based on obtained results, the presence of silicon used as an interlayer in our study probably replaces the carbon atoms (sp^2 bonded clusters), leading to the formation of sp^3 bonds since Si does not form π bonds, only σ.[47,48] In agreement with previous data,[16–18,26] the developed film also presented a high $FWHM_G$, accounting for the observed high carbon disorder degree. The Raman slope between 1000 and 1800 cm^{-1} was also used to determine the hydrogen content (atomic %), which was 22.66% within the range of the DLC materials usually obtained using the PECVD methodology.[18]

Delamination or crack initiation/defects, well-known disadvantages of DLC coatings, are mainly caused by high-stress levels in the film or islands of trapped gas formed during the deposition process.[21] A cross-sectional image (Figure 2b) obtained by a FIB-SEM exhibited a uniform sectional morphology. Further, microscopic cracks or defect propagation are not observed. The thicknesses (mean ± standard deviation) of the DLC film deposited over the TiGrIV substrate were uniform (0.80

± 0.01 μm) all along the surface. In an external approach (top-view), Figure 2c and 2d show the SEM images of the TiGrIV and DLC samples, respectively. Both the surfaces display longitudinal grooves due to the polishing process; however, it is possible to identify a granular profile in the DLC surface. The mentioned DLC topography is more noticeable in the AFM image (Figure 2f). Additionally, the deposition process did not modify ($p < 0.05$) the surface roughness, and a similar average roughness (Ra) was observed between the TiGrIV (0.12 ± 0.01 μm) and DLC (0.11 ± 0.01 μm) groups. The obtained result can be attributed to the compact DLC thin film deposited on the Ti surfaces, which acquired the microgeometry of the polished sample in addition to the small size of the granular profile throughout the surface. These features are expected for the deposition methodology applied, mainly because the size and morphology of the carbon clusters are expected to be smaller and more uniform in DC-PECVD deposition; further, a lower thickness is expected when compared to high-power impulse magnetron sputtering and plasma ion immersion deposition. Therefore, mimicking the subtract underneath and justifying a nonsignificant result for the roughness output.[13] Considering the wettability, the water contact angle of the DLC ($p < 0.0001$) was higher (Θw = 62.7° ± 1.4°) than that of TiGrIV (Θw = 33.6° ± 4.1°). The result might be related to the reduction in the oxygen vacancies and, consequently, the occupation of water molecules,[49] resulting in a reduction of adsorbed hydroxyl groups, which makes the surface more hydrophobic.

The high-resolution XPS spectra revealed the chemical compositions of the DLC surface and pure TiGrIV sample. Two main peaks (C 1s and O 1s) are observed in the XPS profile of the DLC film, which exhibits a dominant C 1s peak as shown in Figure 3a at a binding energy of 284.4 eV and a less dominant O 1s peak at approximately 532.5 eV (Figure 3b). The atomic percent of carbon in the DLC film was determined to be 92.4%, and the remaining amount was attributed to oxygen (7.6%). Because XPS is a technique surface sensitive, and the TiGrIV substrate was covered by the DLC layer, no clear peak of Ti was observed in the profile, similar to a previously study.[50] Moreover, in the Ti 2p spectrum (Figure 3c), doublets can be seen only for the TiGrIV sample at 459.1 and 464.7 eV. In the control sample, the atomic percentage of the oxide layer was composed of oxygen (45.4%), carbon (36.7%), and titanium (17.9%). The deconvoluted C 1s spectrum (Figure 3d) of DLC film showed three Gaussian peaks at 284.4, 285.5, and 287.9 eV, corresponding to sp^2 C=C (78.6%), sp^3 C–C/ C–H, and C=O (21.4%), respectively, indicating the different bonding states of the carbon atom.[15,23,51] Additionally, the high-intensity peak at the binding energy corresponding to the sp^2 hybridization was related to the G-band obtained in the Raman assessment. Notably, the DLC film is susceptible to oxidation outside the deposition chamber. The formation of C–O bonds was mainly due to the contamination of the film's surface due to air exposure [6]. Figure 3e shows that the O1s spectra are deconvolution into two subpeaks at binding energies of 532.1 eV for C=O and 532.9 eV for C–O, suggesting the different bonding states of oxygen.[52] It is important to highlight that the lower concentration of C–O bonds imply that the C atoms in the acquired films are not easily oxidized.[53] Additionally, the formed oxide layer of the DLC film acted protectively during the diffusion of the active ions or water molecules, thus hindering the disarrangement of the crosslinked carbon network structure; the details are provided in the corrosion performance analysis section. Additionally, the amounts of C, O, and Ti determined by the XPS analysis agreed with the elemental ratios of each group obtained by EDS chemical mapping (Table 1).

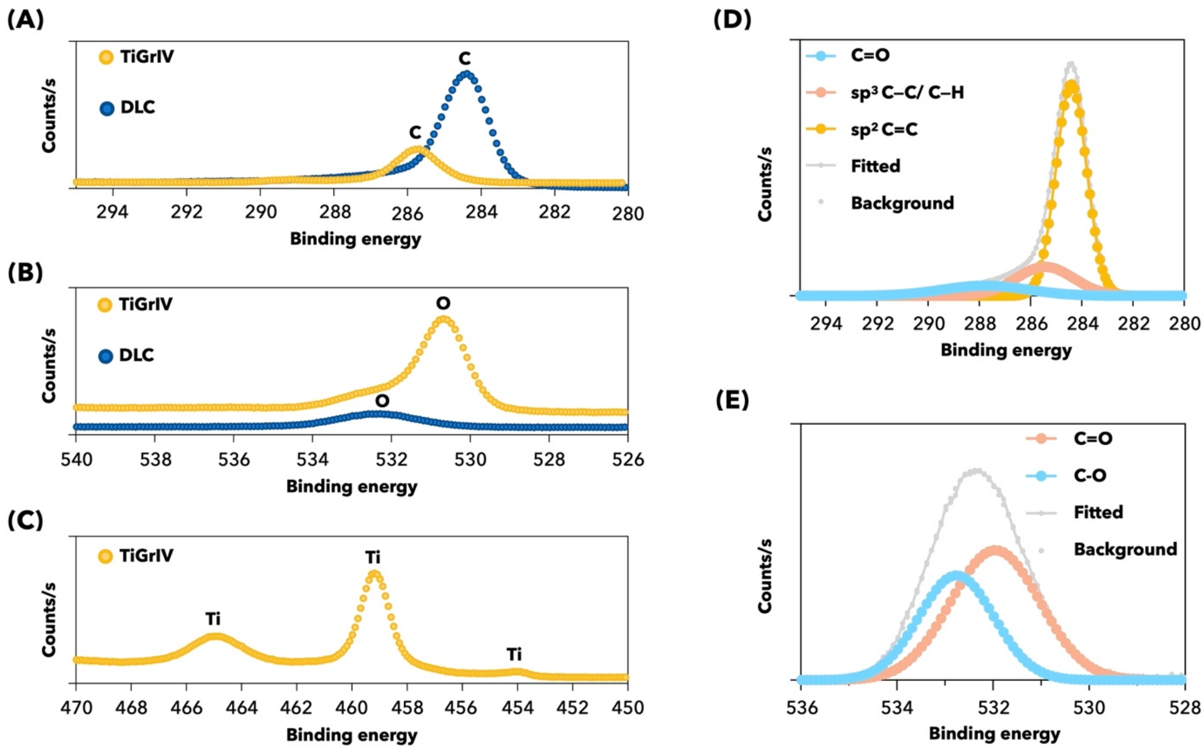


Figure 3. X-ray photoelectron spectroscopy (XPS) high-resolution spectra of C 1s (A), O 1s (B), and Ti 2p (C) for TiGrIV and DLC. Deconvoluted curves of C 1s (D) and O 1s (E) for the deposited DLC film (n = 1/group).

Table 1. Elementary spectrum (atomic %) of the DLC and TiGrIV surfaces acquired via EDS analysis.

Groups	C	O	Ti	Si	Ar
TiGrIV	7.3	3.8	88.9	-	-
DLC	95.2	2.5	1.1	0.9	0.3

3.2. Optimizing electrochemical resistance with an anticorrosive DLC film. Human saliva is an electrolytic solution in which implant components are exposed in clinical conditions.[3] Additionally, it is composed of a large variability of major corrosive anions, including chloride and phosphate.[54] These anions jeopardize the passivation of metals, in which they are protected from corrosion.[11] Figure 4a exhibits the OCP evolution as a function of time (1 h of immersion in artificial saliva). The DLC group exhibited the most positive OCP values (31.9 ± 16.2 mV) ($p < 0.0001$) (Table 2), thus indicating excellent stability in artificial saliva and low corrosion tendency in the surrounding environment; these features indicate that the DLC film outperforms TiGrIV because more positive OCP values indicate nobler behavior of the material.

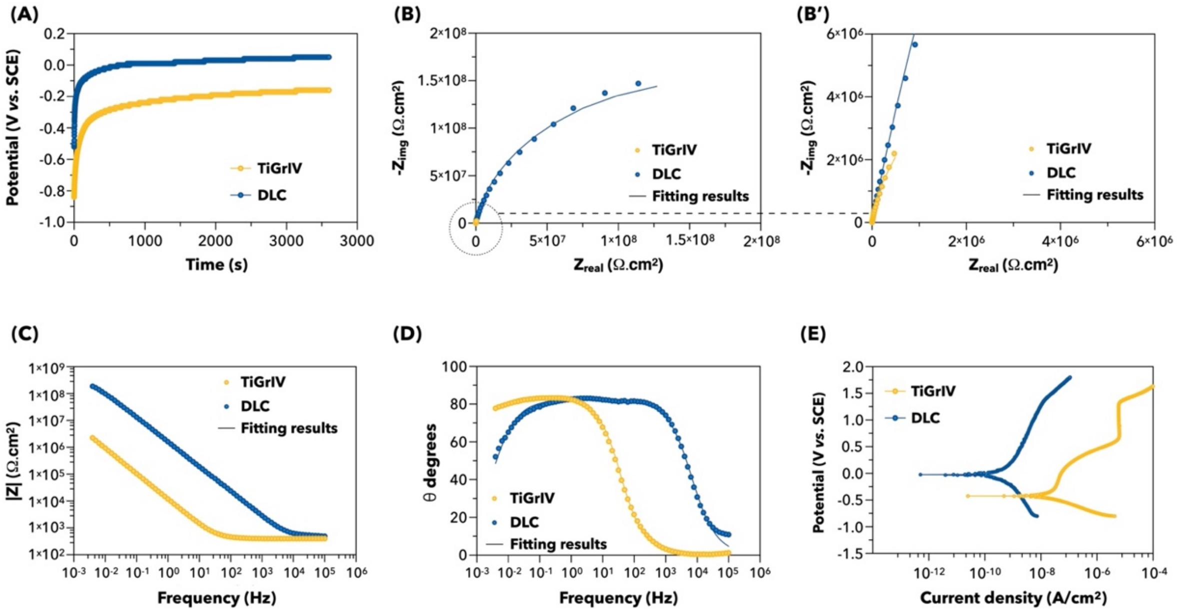


Figure 4. Representative open-circuit potential (OCP) evolution curve (in V *vs*. SCE) for TiGrIV and DLC surfaces exposed to artificial saliva solution for 3600 s (A); Nyquist diagrams (B and B'); impedance modulus (C); phase angles of electrochemical impedance spectroscopy (EIS) responses (D); potentiodynamic polarization curves (E). Curves in yellow are related to the TiGrIV surface, and blue for the DLC film (n = 5/group).

Table 2. Means and standard deviations of the electrical parameters determined using the equivalent circuit model for the control TiGrIV and DLC surfaces.

Groups	OCP (mV)	R_p ($M\Omega \cdot cm^2$)	Q ($S \cdot s^n \cdot cm^{-2}$)	η	$X^2 \cdot 10^{-3}$
TiGrIV	−161.1 ± 21.5^A	10.3 ± 4.2^A	15420 ± 334.7^A	0.9 ± 0.002	0.5 ± 0.05
DLC	31.9 ± 16.2^B	315.2 ± 54.9^B	85.6 ± 18.1^B	0.9 ± 0.01	3.1 ± 2.1

Note: Different superscript upper-case letters indicate statistically significant differences ($P < 0.05$, using the Bonferroni t-test) between both groups (TiGrIV *vs*. DLC). OCP, open-circuit potential; R_p, polarization resistance; Q, capacitance ($S\ s^n\ cm^{-2}$; unit of measurement in nanoohm and cm^{-2} represents the division by the exposed surface area); η, alpha; $X^2 \cdot 10^{-3}$, goodness-of-fit on the order of 10^{-3} obtained from electrochemical impedance spectroscopy.

Corrosion properties of the assessed materials were evaluated by EIS, on analyzing the Nyquist (Figures 4b and 4b') and Bode plot, specifically the impedance (Figures 4c) and phase angle (Figures 4d). Figures 4b and 4b' represent the Nyquist plot, specifically the evolution of the resultant impedance as a function of Z_{real} and Z_{imag}. It has been established, that as the semicircular loop increases, the film stability also increases, indicating a reduction in charge transfer reaction from the sample surface to the electrolyte.[4] The DLC group exhibited the highest semicircular diameter (on the order of 10^8), indicating an improved corrosion resistance. The variation in the impedance (|Z|) as a function of frequency (Hz) is displayed by the Bode plot in Figure 4c, which shows high impedance values for the developed DLC surface. The mentioned output indicates that the DLC film has a superior electrochemical resistance because high impedance values at low frequencies suggest the formation of a stable oxide layer on a surface and this layer might be more resistant to dissolution.[26] The phase angle data (Figure 4d) displayed crescent values for the DLC group, especially in medium (10^{-3} to 10^{-1}) to high (10^0 to 10^3) frequencies; meanwhile the control group presented a decrescent phase angle values as the frequency increased. Even though the DLC group exhibited a decreasing slope at higher frequencies (10^4 to 10^5), it still surpassed the phase angle value of the control group, indicating overall electrochemical stability. These last data might be related to the fact that during the assessment of the coating in a corrosive environment, the electrolyte solution gradually permeates into the coating, and the coating resistance decreases but not as much as the control group, as a result, the current flowing through the resistance gradually increases and the phase angle gradually decreases with immersion time, reaching the substrate.[55] Quantitative parameters (Rp: polarization resistance and Q: capacitance) were obtained by fitting the curves with a simple circuit, presenting a single resistance–capacitance pair with a CPE for the capacitance (Table 2). Those data showed excellent agreement between the experimental and simulated EIS data, according to the chi-square evaluation ($X^2 \cdot 10^{-3}$). Table 2 shows that the DLC film displayed the highest polarization resistance and lowest capacitance outputs ($p < 0.0001$), confirming that a more resistant and protective oxide film for ion transfer was obtained.

The polarization curves of both the groups (DLC and TiGrIV) are represented in Figure 4e. Evidently, the DLC group exhibited high potential values (upper region of the graph) and low current densities (left region of the graph). Therefore, shifting the electrode potential to more positive values ensures a less active behavior in ion exchange and better corrosion resistance of the DLC surface compared with that of TiGrIV. The electrochemical parameters (E_{corr}, i_{corr}, and corrosion rate) obtained from the potentiodynamic polarization curves are described in Table 3, which demonstrates an enhanced corrosion potential of the DLC film to nobler values ($p < 0.0001$). In fact, DLC decreased the corrosion potential (E_{corr}) (TiGrIV: −389.2 ± 36.3 mV; DLC: −86.8 ± 39.1 mV), corrosion current density (i_{corr}; unit: $nA \cdot cm^{-2}$) (TiGrIV: 20 ± 2.1 $nA \cdot cm^{-2}$; DLC: 1.2 ± 1 $nA \cdot cm^{-2}$), and corrosion rate (unit: $mpy \cdot 10^{-4}$) (TiGrIV: 73.2 ± 7.7 $mpy \cdot 10^{-4}$; DLC: 4.5 ± 4.2 $mpy \cdot 10^{-4}$), suggesting that the obtained film is a reliable protective option for the simulated environment (artificial saliva).

Table 3. Mean and standard deviation values of the electrochemical parameters obtained from the potentiodynamic polarization curves of the control TiGrIV and DLC surfaces.

Groups	**E_{corr} (mV)**	**i_{corr} ($nA \cdot cm^{-2}$)**	**Corrosion rate (mpy)$\cdot 10^{-4}$**
TiGrIV	-389.2 ± 36.3^A	20 ± 2.1^A	73.2 ± 7.7^A
DLC	-86.8 ± 39.1^B	1.2 ± 1^B	4.5 ± 4.2^B

Note: Different superscript upper-case letters indicate statistically significant differences ($P < 0.05$, using the Bonferroni t-test) between both groups (TiGrIV *vs.* DLC). E_{corr}, corrosion potential; i_{corr}, corrosion current density.

The mechanism that justifies the DLC corrosion resistance might be related to its film structure, specifically its homogeneity, compactness, and reduced internal stress because delamination was not observed after the deposition process. These characteristics can be better understood via FIB-SEM cross-sectional analyses (Figure 2b). Further, corrosion processes occur in a complex biological environment (e.g., an oral cavity containing saliva as the main electrolyte), and the passageways for ion transportation to remote organs are inherent. However, the developed DLC film may provide a protective and long-lasting smooth surface, thereby reducing the Ti wear debris (particle and ion release) and restraining the inflammatory reaction induced by Ti subproducts penetrating through the film, leading to electrochemical degradation and potential systemic cytotoxic effects (Figure 5).[7,11] Thus, the data are consistent with the concept that the DLC film provides a protective chemically inert layer.[15,23,27] Another explanation for the obtained output is the greater elemental distribution in the film (mainly composed by carbon arrangement), which may also add to a better corrosion resistance obtained due to the lack of pinholes (e.g., imperfections), improved stability and durability of the passive film formed on the substrate.[11]

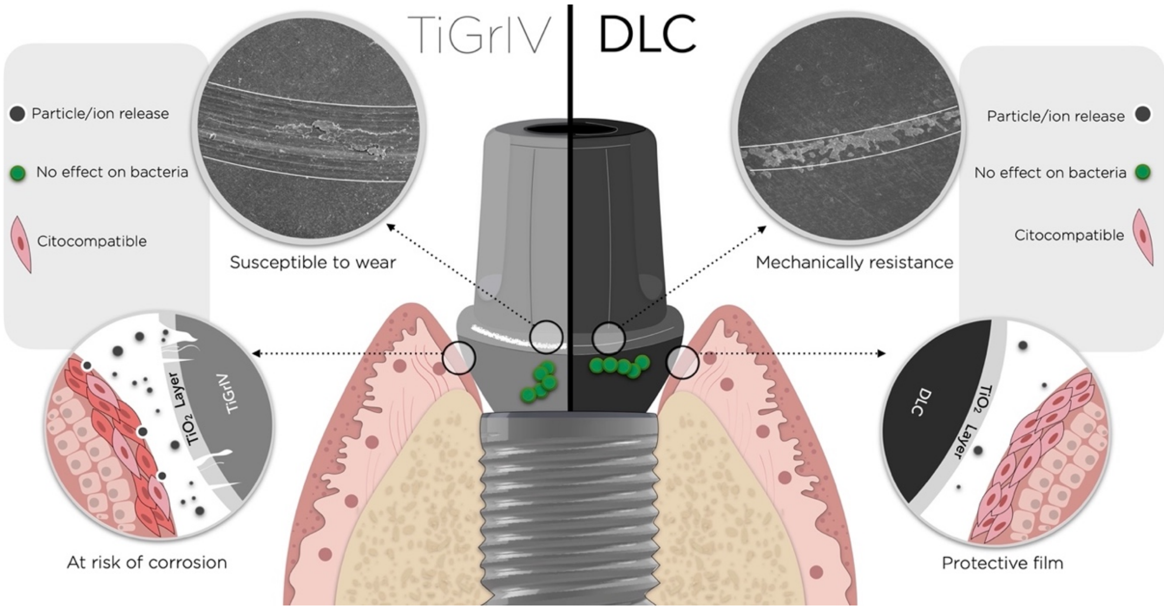


Figure 5. Schematic representation of hypothesized biochemical mechanisms for dental implant abutments with and without DLC film coverage. Abutment surface in the oral environment is prone to sliding forces against materials related to the daily hygiene methods, solid foods, or even the upcoming prosthesis, ultimately resulting in scratched material. In a close look, a lower susceptibility to wear in the abutment recovered by the DLC material (right side) is noticeable, owing to its protective layer. As a consequence, there is a reduced amount of titanium particles/ions released due to the mechanical resistance and stability of the DLC material. Also, the corrosion process is enhanced compared to the abutment only composed of Titanium Grade-IV (left side), in which the protective oxide passive layer (TiO_2) and the TiGrIV substrate are attacked electrochemically by the reactive oral environment disrupting the material integrity. It should be noted that even though the cytotoxicity assessment for human gingival fibroblasts displayed mitochondrial metabolism over 80% in both materials (TiGrIV and DLC), once those titanium subproducts, either particles or ions, are released, it may induce an inflammatory process in soft tissue cells over time, especially for the material without the protective DLC film. Additionally, to the benefits mentioned, the as-developed DLC surface did not negatively influence bacterial proliferation and hence was not considered at risk for developing mucositis and further failure of the dental implant system.

3.3. DLC enhances the TiGrIV mechanical resistance. The mechanical properties of both the groups (DLC and TiGrIV), such as hardness (response of a material flow resistance) and elastic modulus (material stiffness as the stress required to create a unit of elastic deformation), were evaluated via nanoindentation (Figure 6) to assess the applicability of the deposited film in biological fields.[38] The typical loading–unloading curves are shown for the TiGrIV (Figure 6a) and DLC surfaces (Figure 6b) according to the load–penetration depth. During the nanoindentation assessment, the penetration depth increased until ~1600 nm with the increasing applied load (μN) for the TiGrIV group (Figure 6a), and permanent plastic deformation occurred in the bare substrate, which was indicated by the difference between the maximum displacement and residual displacement after load removal (usually observed in metals).[26] In contrast, a predominant elastic recovery of the curve can be observed for the DLC group due to the relaxation of the elastic strain within the film structure, indicating a typically hard and adherent film.[56] The mentioned profile has been previously identified and related to the data of our study.[50] Moreover, the DLC group outperformed the bare substrate ~12 times, reaching a penetration depth of ~130 nm (Figure 6b), the mentioned result indicates a higher resistance to the diamond Berkovich tip, considering the identical loading value when compared to TiGrIV. The exploitation of these curves (loading–unloading) by applying the Oliver–Pharr model allowed us to estimate the mechanical parameters.[38] For hardness and elastic modulus, the maximum depths for the TiGrIV and DLC surfaces were ~610 (Figures 6c and 6e) and ~100 nm (Figures 6d and 6f), respectively. Indeed, the hardness (mean ± standard deviation) increased from TiGrIV (1.83 ± 0.03 GPa) to the DLC (11.81 ± 1.312 GPa) group by ~10 fold ($p < 0.0001$, Bonferroni *t*-test), and the elastic modulus increased from 3.50 ± 0.19 GPa (TiGrIV) to 90.25 ± 11.15 GPa (DLC) ($p < 0.0001$), indicating that the coating was beneficial for environments that require mechanical resistance, such as the oral cavity. Therefore, the DLC surpassed the TiGrIV as a hard protective layer and presented important information for tribological assessment. Additionally, the mechanical properties of the DLC film were directly influenced by the I_D/I_G ratio obtained from the Raman spectra. The sp^3 content enhanced the hardness and elastic modulus of the film without the inclusion of dopants to boost these mechanical parameters, similar to the results obtained in previous studies.[26]

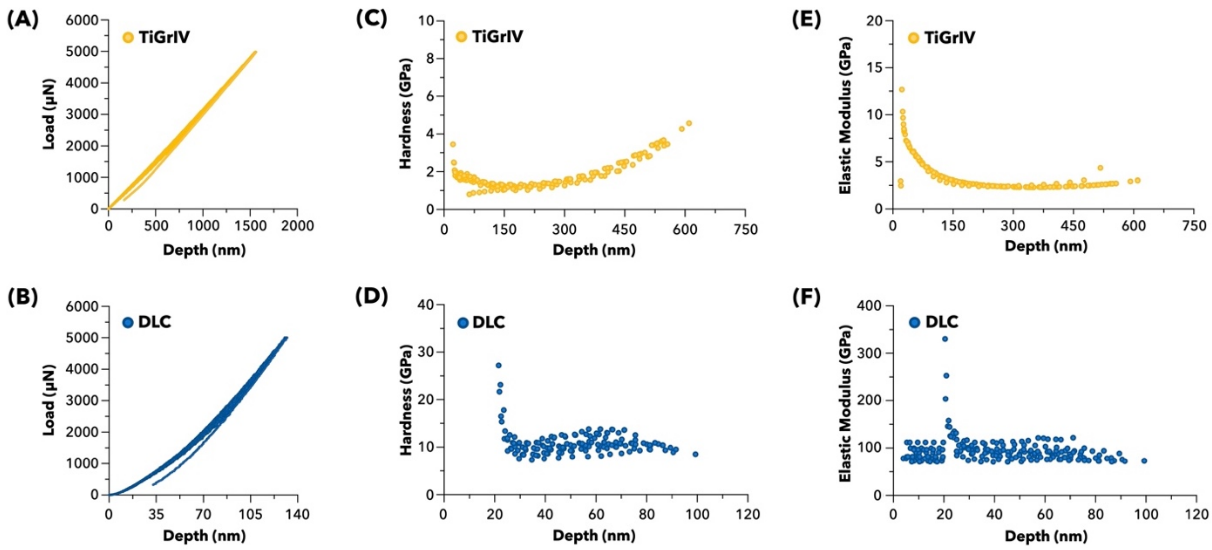


Figure 6. Representative load–displacement curves for TiGrIV (A) and DLC (B); hardness–depth curves for TiGrIV (C) and DLC (D); elastic modulus-depth curve for TiGrIV (E) and DLC (F). Curves in yellow are related to the TiGrIV surface, and blue for the DLC film (*n* = 1/group with 10 scanning within the sample).

Figure 7 exhibits the friction coefficient curves (Figure 7a), friction coefficient value (Figure 7b), and wear track (Figure 7c) of the TiGrIV and DLC groups sliding against zirconia Y-TPZ balls in the artificial saliva. Interestingly, the curve exhibited by the TiGrIV group showed signal fluctuations unlike that shown by the DLC group, which exhibited a steady and almost linear geometry (Figure 7a). The result might be related to sample/counter body contact in which the higher the debris generated into the friction process, the higher the pitch noise. The friction coefficient of the DLC film ($0.04 \pm 0.01\ \mu$) was lower than that of the control group ($0.20 \pm 0.01\ \mu$) (Figure 7b). The result can be justified by the higher sp^2 carbon amount and, consequently, a lubricating graphite-like behavior.[13,21] Further, the wear-track (Figure 7c) and diameter observed in the sample after removal from the pin-on-disk tribometer was wider for the TiGrIV (Figure 7d) than for the DLC (Figure 7e). When this data were further visualized using SEM, it was possible to ensure that the counter body generated furrows but could not remove the entire DLC film, impaling resistance to spalling and adherence. Further, the wear-track diameter of the TiGrIV group (409.4 ± 17.4 μm) was larger than that of the DLC (157.7 ± 26.6 μm) group. These results demonstrate that the DLC layer can serve as a viable lubrication film for dental-implant components.

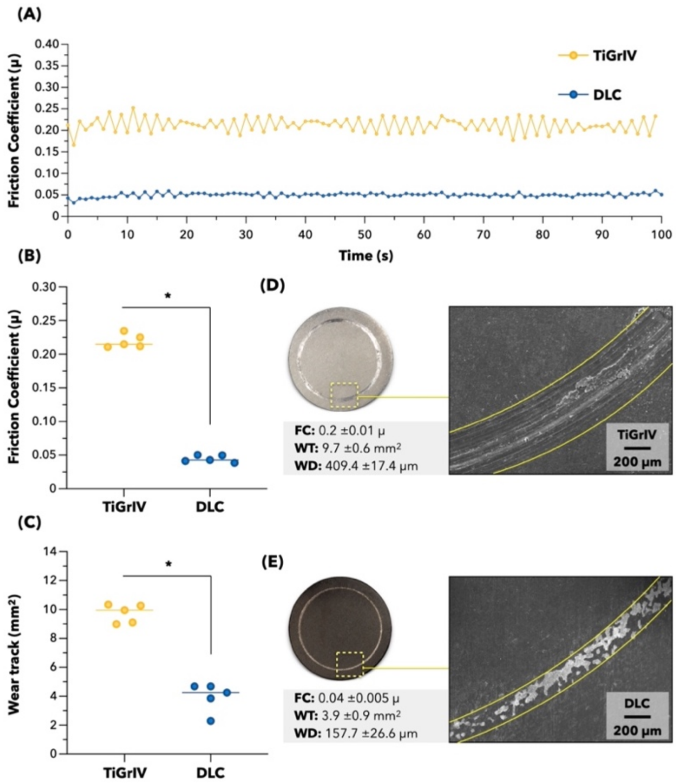


Figure 7. Tribological behavior determined from the friction coefficient curves (A); average of friction coefficients during sliding (B); wear-track area based on the counter body profile after friction (C); disk surfaces after tribological assessment and the respective morphological SEM image obtained at 75× magnification for TiGrIV (D) and DLC (E). FC = friction coefficient, WT = wear track, WD = wear diameter. *$p < 0.001$, by Bonferroni t-test ($n = 5$/group).

Exchanging the previous mechanical information to a practical clinical scenario, the film application for dental-implant abutments might be feasible, offering resistance for components that require mechanical reinforcement, considering challenging oral environments (e.g., solids in the diet, hygiene protocols, or mechanical retention devices). When the DLC film is used in these dental-implant components, two close surfaces slide against each other, and debris may be obtained. Subsequently, the scratched material released into the human body may contaminate the medium. Considering that DLC may suppress those problems due to the optimum resistance (such as hardness) it might also avoid mechanical instabilities related to the release of titanium particles in the peri-implant tissue and prevent severe immune toxicity.[3]

3.4. Newly developed DLC film exhibits cytocompatibility with human gingival fibroblasts. The feasibility of dental-implant components depends on previous osseointegration at the bone-implant level and robust soft-tissue viability/sealing at the transmucosal region.[3] Thus, considering that assessing cell viability is essential for determining the metabolic activity of biomaterials toward host cells, the MTT assay was carried out to determine the impact of the DLC film on the TiGrIV substrate. The absorbance of primary human gingival fibroblast cell metabolism after one and three days of culturing is presented in Figure 8a. The control group (TiGrIV) presented an increased metabolism over time (~15%). Further, after three days, the absorbance of the TiGrIV samples was higher than that of the DLC samples as well as independent of time. Notably, it is possible to identify a minimum increase in mitochondrial metabolism over time (~8%) for the DLC group, however without statistical difference. In the present study, both the groups displayed well-spread morphologies in all the experimental periods (Figure 8b). Even though the DAPI-stained cell nuclei count increased with time (Figure 8c), both the dependent variables (time and surface) were statistically similar ($P < 0.05$). Moreover, the nuclei adhered to the samples for the DAPI fluorescence in each group presented the same pattern (Figure 8d). Therefore, both the groups did not exhibit cytotoxic effects, according to the biological description provided in the International Organization for Standardization (ISO) 10993-5: 2009.

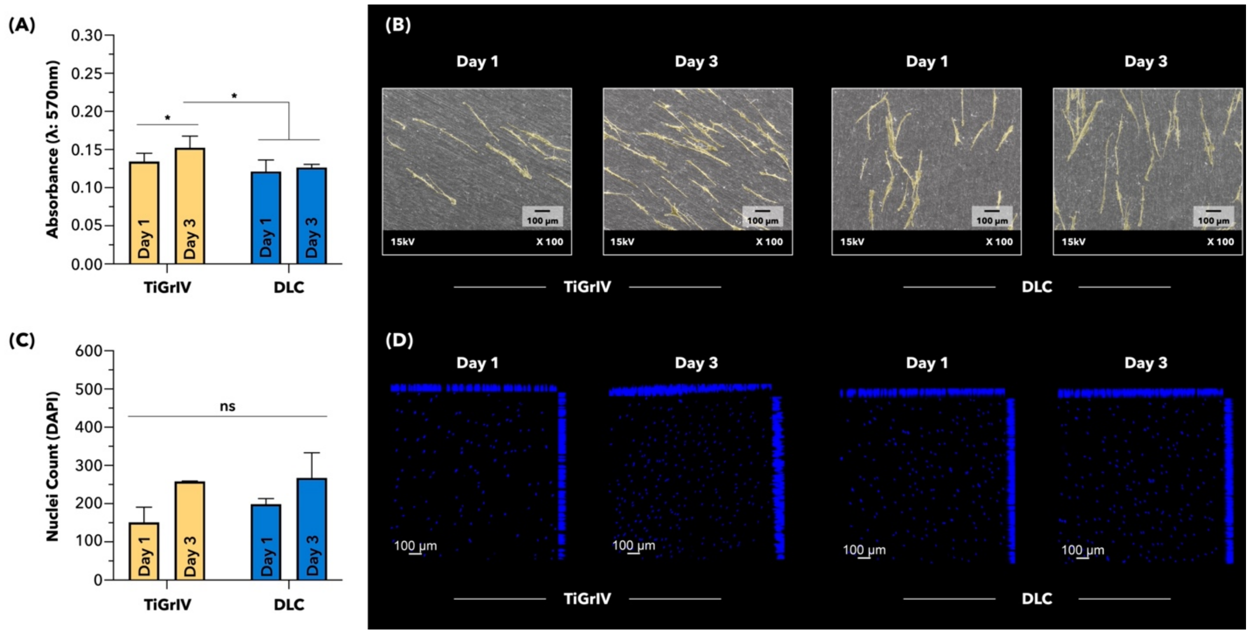


Figure 8. Cytocompatibility assay on human gingival fibroblasts (HGF). Absorbance is expressed as a measure of cell metabolism for HGFs cells cultured in control (TiGrIV) and experimental group (DLC) at 1 and 3 days (A). Representative HGFs cells distribution by SEM on TiGrIV and DLC surface after 1 and 3 days (B). Nuclei counts based on DAPI fluorescence staining (C). Representative confocal laser scanning microscopy (CLSM) images for nuclei observation with DAPI-staining (cells were labeled for nuclei in blue), HGFs were cultured on the TiGrIV and DLC surfaces for 1 and 3 days (D). The scale bar corresponds to 100 µm. * $p < 0.01$, ns = not significant by two-way ANOVA and the Tukey test (n = 3/group).

3.5. DLC film does not increase biofilm formation. Peri-implant diseases are multifactorial inflammatory reactions triggered by polymicrobial biofilm formation, which is modulated by the interaction between bacterial cells and immune system response.[1,6,57] Thus, dental-implant surfaces should avoid bacterial accumulation either via adhesion or biofilm formation.[1] Early colonizers such as *Streptococcus sanguinis* play an essential role in complex biofilm formation as well as affect the predominant bacterium found on implant materials.[58,59] In this study, the *S. sanguinis* biofilm load was similar for both the groups (TiGrIV and DLC). The previous data were supported by similar bacterial adhesion data based on colony-forming units (Figure 9a) as functions of the control and experimental group (~7 log CFU). The same profile was observed in the live/ dead count (Figure 9b) and also in the CSLM reconstructed images of biofilms, which suggested similarity for the live (green fluorescence) and dead (red fluorescence) bacteria (Figure 9c). Moreover, corroborating with the SEM micrographs of 24 h biofilms that presented an organized aggregate of structures suggestive of *S. sanguinis* (green) for all surfaces (Figure 9d). Although the water contact angle of the DLC sample (62.7° ± 1.4°) was higher than that of the control group (33.6° ± 4.1°), biofilm accumulation occurred owing to additional factors such as roughness.[60] The absence of a statistical difference in the roughness for DLC compared to the commercialized material used as control (TiGrIV: 0.12 ± 0.01 µm; DLC: 0.11 ± 0.01 µm) can justify the equal biofilm load. These results indicate that the film does not boost bacterial proliferation on its surface and thus does not disrupt microbiota balance and prevents possible risk of developing peri-implantitis.[61]

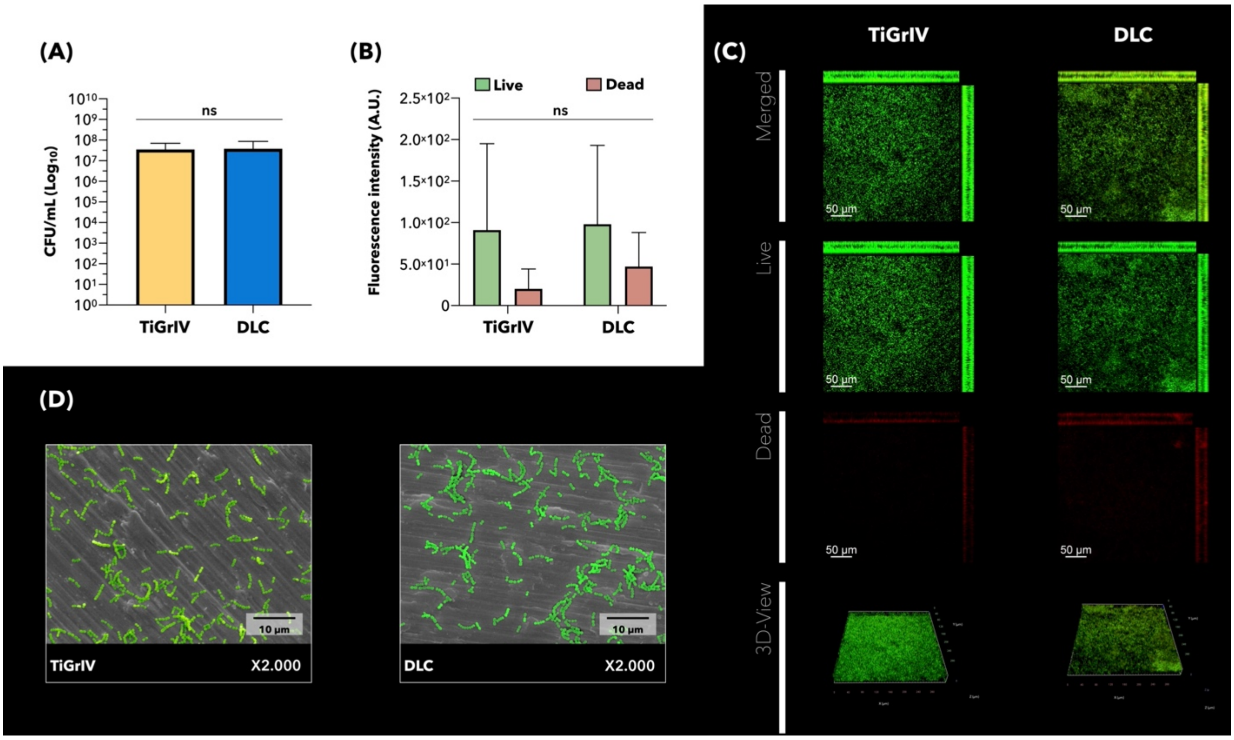


Figure 9. Microbiological assay using *Streptococcus sanguinis*. Total bacterial counts (CFU/mL) (A). Individual bacteria count for live and dead based on live/dead confocal laser scanning microscopy (CLSM) images (B). Representative CLSM images of fluorescence staining, illustrating merged (live and dead), individual (live/dead), and three-dimensional reconstruction for the bacteria distribution on the TiGrIV and DLC groups (green represents live bacteria and red relates to dead bacteria) (C). The scale bar corresponds to 50 µm. Representative scanning electron microscope (SEM) micrographs illustrating the colonization of bacteria on the surfaces (D). ns = not significant by Bonferroni *t*-test (CFU/mL) and two-way ANOVA (live/dead fluorescence intensity).

3.6. Future applications of the as-developed DLC film. Coating layers play a vital role in daily implantology owing to their ability to improve the operational characteristics of implantable structures, such as abutments, either by inhibiting biofilm formation or via cytocompatibility.[6] However, upfront resistance requirements must be met, considering that once the implantable abutment is exposed to the oral environment, mechanical and chemical degradation (i.e., corrosion and wear) occur, which lead to the release/accumulation of metallic particles in the peri-implant tissue,[7,11,12] thus contributing to microbiological dysbiosis and ultimately causing peri-implantitis.[7] To overcome those limitations, we developed a biomechanical solution, in which a protective film of DLC was successfully deposited on a TiGrIV substrate. The fabricated film could respond the following open questions: (*i*) the often problem of DLC films related to delamination from metallic substrate, using a combination of pulsed DC-PECVD and silicon interlayer, was overcome and guaranteed according to our results in the tribological assessment; (*ii*) mechanically, the DLC film optimized the resistance (hardness and elastic modulus) of the substrate, ensured optimum tribological parameters, and exhibited an anticorrosive pattern; (*iii*) a cytocompatible property with HGF is demonstrated by a mitochondrial metabolism over 80% (ISO) 10993-5: 2009; (*iv*) the DLC film does not overexpress biofilm formation compared to the TiGrIV group. Altogether, those data indicate in a potential candidate in dental-implant abutments. It should be assumed that our *in vitro* study was carried out using TiGrIV machined disks, which can be a limitation considering the different geometry of components, according to the manufacture and the protheses design. To extent applicability upcoming alternatives using antibacterial agents should be engineered to improve the benefits already provided in our study because implant abutments are intended for temporary or permanent application in the human body.

4. CONCLUSION

A 0.8-µm-thick DLC film was successfully deposited on the surface of TiGrIV for implant abutments using the DC-PECVD process. The cross-sectional and surface morphologies of the deposited DLC film were uniform and compact without microcrack propagation. The hardness of the DLC film was 11.81 GPa, which was much higher than that of TiGrIV (1.83 GPa), and the DLC film showed the best resistance to plastic deformation as revealed by loading–unloading curve analysis. Moreover, the elastic modulus of the DLC film (90.25 GPa) was more than 30-fold higher than that of TiGrIV (3.50 GPa), ensuring that the mechanical properties of the obtained DLC film were better than those of the bare substrate. When assessed in an artificial saliva solution, the DLC film exhibited excellent tribological properties, specifically for wear resistance, considering the wear-track diameter (3.95 mm^2), compared to the TiGrIV (9.7 mm^2), and this feature is a prerequisite for service in liquid environments. Similar to previous results, the friction coefficient of the DLC film was significantly lower than that of TiGrIV, indicating that the as-deposited film played a protective role for application in implant abutments. The DLC film showed the minimum friction coefficient (0.04 μ) in the artificial saliva; in other words, the DLC film possessed the best tribological properties. The film also showed high electrochemical stability, with high values of charge transfer resistance, nobler corrosion potential, and lower capacitance values, corrosion current density, and corrosion rate. Moreover, the results of the cytocompatibility test for HGF indicated that the DLC film was not cytotoxic. Further, the DLC film did not favor bacterial (*Streptococcus sanguinis*) adherence compared to TiGrIV. The findings of this study collectively indicate that the DLC film can be considered a promising option when targeting long-term durability for implant abutments, specifically to enhance the electrochemical and mechanical properties of dental implants.

Declaration of Competing Interest

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

This study was funded by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Finance code 001; Fundo de Apoio ao Ensino, à Pesquisa e Extensão (FAEPEX), Grant/Award number: 2021/2501; Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), Grant/Award numbers: 2020/10436-4, 2019/17238-6; Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Grant/Award number: 304853/2018-6; and the Latin American Oral Health Association (LAOHA). The authors express their gratitude to the Brazilian Nanotechnology National Laboratory (LNNano) for the use of AFM, XPS, EDS, FIB, and SEM facilities.

CRediT authorship contribution statement

Guilherme Almeida Borges: Conceptualization; Methodology; Data curation; Visualization; Writing-original draft. **Raphael Cavalcante Costa:** Methodology; Visualization; Writing-review & editing. **Bruna Egumi Nagay:** Methodology; Visualization; Writing-review & editing. **Catharina Marques Sacramento:** Methodology; Writing-review & editing. **Karina Gonzales Silverio Ruiz:** Methodology; Resources; Writing-review & editing. **Larissa Solano Almeida:** Methodology; Writing-review & editing. **Luciana Sgarbi Rossino:** Methodology; Resources; Writing-review & editing. **Carlos Alberto Fortulan:** Resources; Writing-review & editing. **Elidiane Cipriano Rangel:** Resources; Writing-review & editing. **Valentim Adelino Ricardo Barão:** Project administration; Writing-review & editing. **Marcelo Ferraz Mesquita:** Project administration; Supervision; Writing-review & editing.

REFERENCES

(1) Costa, R. C.; Nagay, B. E.; Bertolini, M.; Costa-Oliveira, B. E.; Sampaio, A. A.; Retamal-Valdes, B.; Shibli, J. A.; Feres, M.; Barão, V. A. R.; Souza, J. G. S. Fitting Pieces into the Puzzle: The Impact of Titanium-Based Dental Implant Surface Modifications on Bacterial Accumulation and Polymicrobial Infections. *Advances in Colloid and Interface Science* **2021**, 298, 102551.

(2) Laleman, I.; Lambert, F. Implant Connection and Abutment Selection as a Predisposing and/or Precipitating Factor for Peri-implant Diseases: A Review. *Clin Implant Dent Rel Res* **2023**, cid.13185.

(3) Guo, T.; Gulati, K.; Arora, H.; Han, P.; Fournier, B.; Ivanovski, S. Race to Invade: Understanding Soft Tissue Integration at the Transmucosal Region of Titanium Dental Implants. *Dental Materials* **2021**, 37 (5), 816–831.

(4) Beline, T.; de Almeida, A. B.; Azevedo Neto, N. F.; Matos, A. O.; Ricomini-Filho, A. P.; Sukotjo, C.; Smeets, P. J. M.; da Silva, J. H. D.; Nociti, F. H.; Barão, V. A. R. β-Ta2O5 Thin Film for Implant Surface Modification Triggers Superior Anti-Corrosion Performance and Cytocompatibility of Titanium. *Applied Surface Science* **2020**, 520, 146326.

(5) Pantaroto, H. N.; Cordeiro, J. M.; Pereira, L. T.; de Almeida, A. B.; Nociti Junior, F. H.; Rangel, E. C.; Azevedo Neto, N. F.; da Silva, J. H. D.; Barão, V. A. R. Sputtered Crystalline TiO2 Film Drives Improved Surface Properties of Titanium-Based Biomedical Implants. *Materials Science and Engineering: C* **2021**, 119, 111638.

(6) Souza, J. G. S.; Bertolini, M.; Costa, R. C.; Cordeiro, J. M.; Nagay, B. E.; de Almeida, A. B.; Retamal-Valdes, B.; Nociti, F. H.; Feres, M.; Rangel, E. C.; Barão, V. A. R. Targeting Pathogenic Biofilms: Newly Developed Superhydrophobic Coating Favors a Host-Compatible Microbial Profile on the Titanium Surface. ACS Appl. *Mater. Interfaces* **2020**, 12 (9), 10118–10129.

(7) Souza, J. G. S.; Costa Oliveira, B. E.; Bertolini, M.; Lima, C. V.; Retamal-Valdes, B.; Faveri, M.; Feres, M.; Barão, V. A. R. Titanium Particles and Ions Favor Dysbiosis in Oral Biofilms. *J Periodont Res* **2020**, 55 (2), 258–266.

(8) Mishnaevsky, L.; Levashov, E.; Valiev, R. Z.; Segurado, J.; Sabirov, I.; Enikeev, N.; Prokoshkin, S.; Solov'yov, A. V.; Korotitskiy, A.; Gutmanas, E.; Gotman, I.; Rabkin, E.; Psakh'e, S.; Dluhoš, L.; Seefeldt, M.; Smolin, A. Nanostructured Titanium-Based Materials for Medical Implants: Modeling and Development. *Materials Science and Engineering: R: Reports* **2014**, 81, 1–19.

(9) Wang, L.; Yu, H.; Wang, K.; Xu, H.; Wang, S.; Sun, D. Local Fine Structural Insight into Mechanism of Electrochemical Passivation of Titanium. *ACS Appl. Mater. Interfaces* **2016**, 8 (28), 18608–18619.

(10) Mints, D.; Elias, C.; Funkenbusch, P.; Meirelles, L. Integrity of Implant Surface Modifications After Insertion. *Int J Oral Maxillofac Implants* **2014**, 29 (1), 97–104.

(11) Nagay, B. E.; Cordeiro, J. M.; Barao, V. A. R. Insight Into Corrosion of Dental Implants: From Biochemical Mechanisms to Designing Corrosion-Resistant Materials. *Curr Oral Health Rep* **2022**, 9 (2), 7–21.

(12) Noronha Oliveira, M.; Schunemann, W. V. H.; Mathew, M. T.; Henriques, B.; Magini, R. S.; Teughels, W.; Souza, J. C. M. Can Degradation Products Released from Dental Implants Affect Peri-implant Tissues? *J Periodont Res* **2018**, 53 (1), 1–11.

(13) Kasiorowski, T.; Lin, J.; Soares, P.; Lepienski, C. M.; Neitzke, C. A.; de Souza, G. B.; Torres, R. D. Microstructural and Tribological Characterization of DLC Coatings Deposited by Plasma

Enhanced Techniques on Steel Substrates. *Surface and Coatings Technology* **2020**, 389, 125615.

(14) Kuznetsova, T.; Lapitskaya, V.; Khabarava, A.; Trukhan, R.; Chizhik, S.; Torskaya, E.; Mezrin, A.; Fedorov, S.; Rogachev, A.; Warcholinski, B. Silicon Addition as a Way to Control Properties of Tribofilms and Friction of DLC Coatings. *Applied Surface Science* **2023**, 608, 155115.

(15) Guo, T.; Kong, C.; Li, X.; Guo, P.; Wang, Z.; Wang, A. Microstructure and Mechanical Properties of Ti/Al Co-Doped DLC Films: Dependence on Sputtering Current, Source Gas, and Substrate Bias. *Applied Surface Science* **2017**, 410, 51–59.

(16) Ferrari, A. C. Determination of Bonding in Diamond-like Carbon by Raman Spectroscopy. *Diamond and Related Materials* **2002**, 11 (3–6), 1053–1061.

(17) Ferrari, A. C.; Robertson, J. Interpretation of Raman Spectra of Disordered and Amorphous Carbon. *Phys. Rev. B* **2000**, 61 (20), 14095–14107.

(18) Casiraghi, C.; Ferrari, A. C.; Robertson, J. Raman Spectroscopy of Hydrogenated Amorphous Carbons. *Phys. Rev. B* **2005**, 72 (8), 085401.

(19) Zajikova, L. Correlation between SiOx Content and Properties of DLC:SiOx Films Prepared by PECVD. *Surface and Coatings Technology* **2003**, 174–175, 281–285.

(20) Li, C.; Huang, L.; Yuan, J. Effect of Sp3 Content on Adhesion and Tribological Properties of Non-Hydrogenated DLC Films. *Materials* **2020**, 13 (8), 1911.

(21) Vetter, J. 60 Years of DLC Coatings: Historical Highlights and Technical Review of Cathodic Arc Processes to Synthesize Various DLC Types, and Their Evolution for Industrial Applications. *Surface and Coatings Technology* **2014**, 257, 213–240.

(22) Wu, M.; Tian, X.; Li, M.; Gong, C.; Wei, R. Effect of Additional Sample Bias in Meshed Plasma Immersion Ion Deposition (MPIID) on Microstructural, Surface and Mechanical Properties of Si-DLC Films. *Applied Surface Science* **2016**, 376, 26–33.

(23) Wei, X.; Chen, L.; Zhang, M.; Lu, Z.; Zhang, G. Effect of Dopants (F, Si) Material on the Structure and Properties of Hydrogenated DLC Film by Plane Cathode PECVD. *Diamond and Related Materials* **2020**, 110, 108102.

(24) Robertson, J. Requirements of Ultrathin Carbon Coatings for Magnetic Storage Technology. *Tribology International* **2003**, 36 (4–6), 405–415.

(25) Kamiya, M.; Tanoue, H.; Takikawa, H.; Taki, M.; Hasegawa, Y.; Kumagai, M. Preparation of Various DLC Films by T-Shaped Filtered Arc Deposition and the Effect of Heat Treatment on Film

Properties. *Vacuum* **2008**, 83 (3), 510–514.

(26) Wei, X.; Zhang, Y.; Feng, H.; Cao, X.; Ding, Q.; Lu, Z.; Zhang, G. Bio-Tribology and Corrosion Behaviors of a Si- and N-Incorporated Diamond-like Carbon Film: A New Class of Protective Film for Ti6Al4V Artificial Implants. *ACS Biomater. Sci. Eng.* **2022**, 8 (3), 1166–1180.

(27) Bociaga, D.; Sobczyk-Guzenda, A.; Szymanski, W.; Jedrzejczak, A.; Jastrzebska, A.; Olejnik, A.; Jastrzebski, K. Mechanical Properties, Chemical Analysis and Evaluation of Antimicrobial Response of Si-DLC Coatings Fabricated on AISI 316 LVM Substrate by a Multi-Target DC-RF Magnetron Sputtering Method for Potential Biomedical Applications. *Applied Surface Science* **2017**, 417, 23–33.

(28) de Campos, L. de A. P.; de Almeida, L. S.; da Silva, B. P.; Danelon, M. R.; Aoki, I. V.; Manfrinato, M. D.; Rossino, L. S. Evaluation of Nitriding, Nitrocarburizing, Organosilicon Interlayer, Diamond-Like Carbon Film and Duplex Plasma Treatment in the Wear and Corrosion Resistance of AISI 4340 Steel. *J. of Materi Eng and Perform* **2020**, 29 (12), 8107–8121.

(29) Wang, T.; Wang, L.; Gu, L.; Zheng, D. Stress Analysis of Elastic Coated Solids in Point Contact. *Tribology International* **2015**, 86, 52–61.

(30) Cemin, F.; Boeira, C. D.; Figueroa, C. A. On the Understanding of the Silicon-Containing Adhesion Interlayer in DLC Deposited on Steel. *Tribology International* **2016**, 94, 464–469.

(31) Corbella, C.; Portal, S.; Kundrapu, M. N.; Keidar, M. Nanosynthesis by Atmospheric Arc Discharges Excited with Pulsed-DC Power: A Review. *Nanotechnology* **2022**, 33 (34), 342001.

(32) Danelon, M. R.; De Almeida, L. S.; Manfrinato, M. D.; Rossino, L. S. Study of the Influence of a Gradient Gas Flow as an Alternative to Improve the Adhesion of Diamond-Like Carbon Film in the Wear and Corrosion Resistance on the Nitrided AISI 4340 Steel. *Surfaces and Interfaces* **2023**, 36, 102352.

(33) Almeida, L. S.; Souza, A. R. M.; Costa, L. H.; Rangel, E. C.; Manfrinato, M. D.; Rossino, L. S. Effect of Nitrogen in the Properties of Diamond-like Carbon (DLC) Coating on Ti 6 Al 4 V Substrate. *Mater. Res. Express* **2020**, 7 (6), 065601.

(34) Dalibon, E. L.; Pecina, J. N.; Cabo, A.; Trava-Airoldi, V. J.; Brühl, S. P. Fretting Wear Resistance of DLC Hard Coatings Deposited on Nitrided Martensitic Stainless Steel. *Journal of Materials Research and Technology* **2019**, 8 (1), 259–266.

(35) Costa, R. C.; Souza, J. G. S.; Cordeiro, J. M.; Bertolini, M.; de Avila, E. D.; Landers, R.; Rangel, E. C.; Fortulan, C. A.; Retamal-Valdes, B.; da Cruz, N. C.; Feres, M.; Barão, V. A. R. Synthesis of

Bioactive Glass-Based Coating by Plasma Electrolytic Oxidation: Untangling a New Deposition Pathway toward Titanium Implant Surfaces. *Journal of Colloid and Interface Science* **2020**, 579, 680–698.

(36) Nagay, B. E.; Dini, C.; Cordeiro, J. M.; Ricomini-Filho, A. P.; de Avila, E. D.; Rangel, E. C.; da Cruz, N. C.; Barão, V. A. R. Visible-Light-Induced Photocatalytic and Antibacterial Activity of TiO 2 Codoped with Nitrogen and Bismuth: New Perspectives to Control Implant-Biofilm-Related Diseases. *ACS Appl. Mater. Interfaces* **2019**, 11 (20), 18186–18202.

(37) Almeida, L. S.; Souza, A. R. M.; Costa, L. H.; Rangel, E. C.; Manfrinato, M. D.; Rossino, L. S. Effect of Nitrogen in the Properties of Diamond-like Carbon (DLC) Coating on Ti 6 Al 4 V Substrate. *Mater. Res. Express* **2020**, 7 (6), 065601.

(38) Oliver, W. C.; Pharr, G. M. An Improved Technique for Determining Hardness and Elastic Modulus Using Load and Displacement Sensing Indentation Experiments. *J. Mater. Res.* **1992**, 7 (6), 1564–1583.

(39) Beline, T.; Marques, I. da S. V.; Matos, A. O.; Ogawa, E. S.; Ricomini-Filho, A. P.; Rangel, E. C.; da Cruz, N. C.; Sukotjo, C.; Mathew, M. T.; Landers, R.; Consani, R. L. X.; Mesquita, M. F.; Barão, V. A. R. Production of a Biofunctional Titanium Surface Using Plasma Electrolytic Oxidation and Glow-Discharge Plasma for Biomedical Applications. *Biointerphases* **2016**, 11 (1), 011013.

(40) Borges, M. H. R.; Nagay, B. E.; Costa, R. C.; Sacramento, C. M.; Ruiz, K. G.; Landers, R.; Van Den Beucken, J. J. J. P.; Fortulan, C. A.; Rangel, E. C.; Da Cruz, N. C.; Barão, V. A. R. A Tattoo-Inspired Electrosynthesized Polypyrrole Film: Crossing the Line toward a Highly Adherent Film for Biomedical Implant Applications. *Materials Today Chemistry* **2022**, 26, 101095.

(41) Cordeiro, J. M.; Nagay, B. E.; Dini, C.; Souza, J. G. S.; Rangel, E. C.; Da Cruz, N. C.; Yang, F.; Van Den Beucken, J. J. J. P.; Barão, V. A. R. Copper Source Determines Chemistry and Topography of Implant Coatings to Optimally Couple Cellular Responses and Antibacterial Activity. *Biomaterials Advances* **2022**, 134, 112550.

(42) Beline, T.; da Silva, J. H. D.; Matos, A. O.; Azevedo Neto, N. F.; de Almeida, A. B.; Nociti Júnior, F. H.; Leite, D. M. G.; Rangel, E. C.; Barão, V. A. R. Tailoring the Synthesis of Tantalum-Based Thin Films for Biomedical Application: Characterization and Biological Response. *Materials Science and Engineering: C* **2019**, 101, 111–119.

(43) Pantaroto, H. N.; Amorim, K. P.; Matozinho Cordeiro, J.; Souza, J. G. S.; Ricomini-Filho, A. P.; Rangel, E. C.; Ribeiro, A. L. R.; Vaz, L. G.; Barão, V. A. R. Proteome Analysis of the Salivary Pellicle Formed on Titanium Alloys Containing Niobium and Zirconium. *Biofouling* **2019**, 35 (2), 173–

186.

(44) Costa, R. C.; Souza, J. G. S.; Bertolini, M.; Retamal-Valdes, B.; Feres, M.; Barão, V. A. R. Extracellular Biofilm Matrix Leads to Microbial Dysbiosis and Reduces Biofilm Susceptibility to Antimicrobials on Titanium Biomaterial: An in Vitro and in Situ Study. *Clin Oral Impl Res* **2020**, 31 (12), 1173–1186.

(45) Souza, J. G. S.; Costa Oliveira, B. E.; Costa, R. C.; Bechara, K.; Cardoso-Filho, O.; Benso, B.; Shibli, J. A.; Bertolini, M.; Barão, V. A. R. Bacterial-Derived Extracellular Polysaccharides Reduce Antimicrobial Susceptibility on Biotic and Abiotic Surfaces. *Archives of Oral Biology* **2022**, 142, 105521.

(46) Cui, W. G.; Lai, Q. B.; Zhang, L.; Wang, F. M. Quantitative Measurements of Sp3 Content in DLC Films with Raman Spectroscopy. *Surface and Coatings Technology* **2010**, 205 (7), 1995–1999.

(47) Baba, K.; Hatada, R.; Flege, S.; Ensinger, W. Deposition of Silicon-Containing Diamond-like Carbon Films by Plasma-Enhanced Chemical Vapour Deposition. *Surface and Coatings Technology* **2009**, 203 (17–18), 2747–2750.

(48) Bertóti, I.; Tóth, A.; Mohai, M.; Szépvölgyi, J. Chemical Structure and Mechanical Properties of Si-Containing a-C:H and a-C Thin Films and Their Cr- and W-Containing Derivatives. *Surface and Coatings Technology* **2011**, 206 (4), 630–639.

(49) Garlisi, C.; Lai, C.-Y.; George, L.; Chiesa, M.; Palmisano, G. Relating Photoelectrochemistry and Wettability of Sputtered Cu- and N-Doped TiO 2 Thin Films via an Integrated Approach. *J. Phys. Chem. C* **2018**, 122 (23), 12369–12376.

(50) Konkhunthot, N.; Photongkam, P.; Wongpanya, P. Improvement of Thermal Stability, Adhesion Strength and Corrosion Performance of Diamond-like Carbon Films with Titanium Doping. *Applied Surface Science* **2019**, 469, 471–486.

(51) Viswanathan, S.; Manjunath Reddy, M.; Mohan, L.; Bera, P.; Barshilia, H. C.; Anandan, C. Corrosion and Wear Properties of Ti/Tetrahedral Amorphous Carbon Multilayered Coating. *J Bio Tribo Corros* **2017**, 3 (3), 39.

(52) Hang, R.; Zhang, M.; Ma, S.; Chu, P. K. Biological Response of Endothelial Cells to Diamond-like Carbon-Coated NiTi Alloy. *J. Biomed. Mater. Res.* **2012**, 100A (2), 496–506.

(53) Su, Z.; Jie, X.; Li, W.; Liao, Z.; Li, Y.; Zhu, W. Effect of C2H2 Flow Rate and a Ti/TiN/TiCN Interlayer on the Structure, Mechanical and Tribological Properties of a-C:H Films Deposited Using a Hybrid PVD/PECVD Process with an Anode-Layer Ion Source. *Vacuum* **2023**, 209, 111753.

(54) Chen, Z.-F.; Darvell, B. W.; Leung, V. W.-H. Human Salivary Anionic Analysis Using Ion Chromatography. *Archives of Oral Biology* **2004**, 49 (11), 863–869.

(55) Zuo, Y.; Pang, R.; Li, W.; Xiong, J. P.; Tang, Y. M. The Evaluation of Coating Performance by the Variations of Phase Angles in Middle and High Frequency Domains of EIS. *Corrosion Science* **2008**, 50 (12), 3322–3328.

(56) Coll, B. F.; Chhowalla, M. Amorphous Diamond Film by Enhanced Arc Deposition. *Surface and Coatings Technology* **1996**, 79 (1–3), 76–86.

(57) Berglundh, T.; Armitage, G.; Araujo, M. G.; Avila-Ortiz, G.; Blanco, J.; Camargo, P. M.; Chen, S.; Cochran, D.; Derks, J.; Figuero, E.; Hämmerle, C. H. F.; Heitz-Mayfield, L. J. A.; Huynh-Ba, G.; Iacono, V.; Koo, K.-T.; Lambert, F.; McCauley, L.; Quirynen, M.; Renvert, S.; Salvi, G. E.; Schwarz, F.; Tarnow, D.; Tomasi, C.; Wang, H.-L.; Zitzmann, N. Peri-Implant Diseases and Conditions: Consensus Report of Workgroup 4 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. *J Clin Periodontol* **2018**, 45, S286–S291.

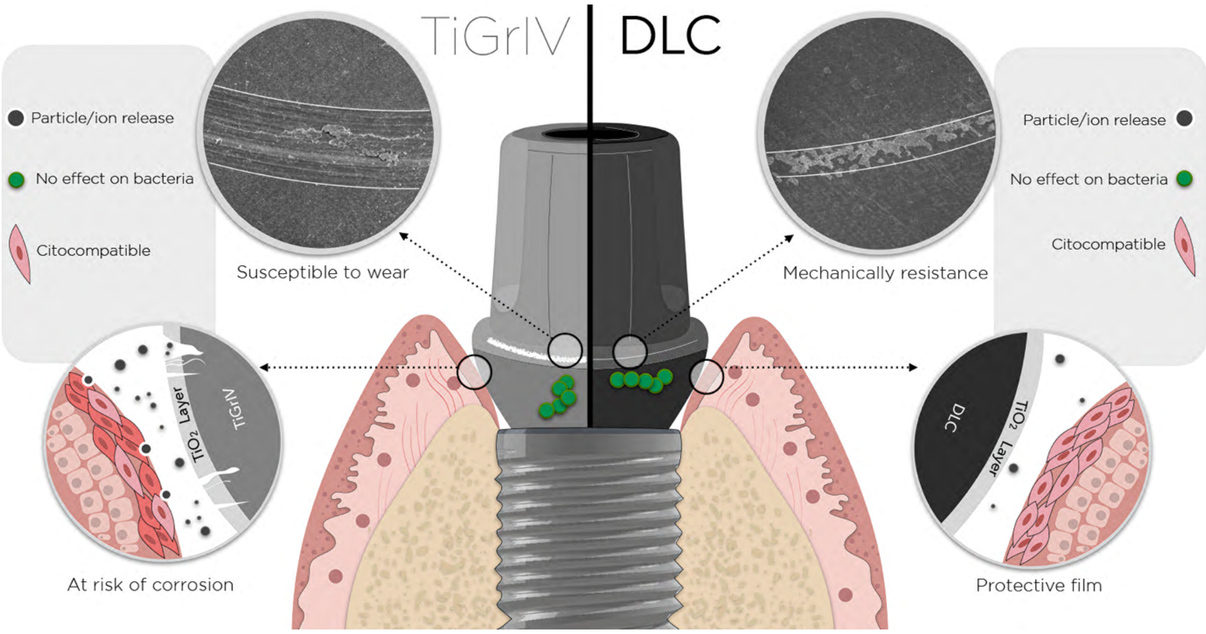
(58) Nakazato, G.; Tsuchiya, H.; Sato, M.; Yamauchi, M. In Vivo Plaque Formation on Implant Materials. *Int J Oral Maxillofac Implants* **1989**, 4 (4), 321–326.

(59) Kolenbrander, P. E.; Palmer, R. J.; Periasamy, S.; Jakubovics, N. S. Oral Multispecies Biofilm Development and the Key Role of Cell–Cell Distance. *Nat Rev Microbiol* **2010**, 8 (7), 471–480.

(60) Al-Ahmad, A.; Wiedmann-Al-Ahmad, M.; Fackler, A.; Follo, M.; Hellwig, E.; Bächle, M.; Hannig, C.; Han, J.-S.; Wolkewitz, M.; Kohal, R. In Vivo Study of the Initial Bacterial Adhesion on Different Implant Materials. *Archives of Oral Biology* **2013**, 58 (9), 1139–1147.

(61) Albrektsson, T.; Buser, D.; Chen, S. T.; Cochran, D.; DeBruyn, H.; Jemt, T.; Koka, S.; Nevins, M.; Sennerby, L.; Simion, M.; Taylor, T. D.; Wennerberg, A. Statements from the Estepona Consensus Meeting on Peri-implantitis, F Ebruary 2–4, 2012. *Clin Implant Dent Rel Res* **2012**, 14 (6), 781–782.

Graphical Abstract



3. DISCUSSÃO

Ao acessar a complexa experiência de severa perda dentária (i.e., edentulismo) mundialmente, as taxas de incidência e prevalência diminuíram em 45% entre 1990-2010. No entanto, foi postulado que em 2010 cerca de 158 milhões (2,3%) de indivíduos da população ainda eram edêntulos (Kassebaum et al., 2014). O primeiro padrão de tratamento protético para esses pacientes, especialmente edêntulos na mandíbula desde 2002, não são mais próteses totais convencionais, mas sim *overdentures* retidas por implantes (Feine et al., 2002b). Em paralelo a esse contexto, a implantodontia está em constante evolução, seja em aspectos protéticos ou comerciais (Alhajj et al., 2021), destacando que a validação das propostas de mercado (i.e., componentes angulados, diferentes materiais para pilares/ sistemas retenção em *overdenture*) requer assistência financeira para reconhecer cientificamente novos protocolos para dentistas/ pesquisadores, quando utilizam *overdentures* sobre implantes. Alternativamente a esse plano historicamente consolidado (*overdentures*), pacientes ainda dispõem de reabilitações totais fixas, as quais são clinicamente efetivas (Feine et al., 2018a). Entretanto, a percepção subjetiva dos pacientes frente as opções (*overdenture* e prótese total fixa) ofertadas requer entendimento para estabelecer o protocolo de atendimento correto (Feine et al., 2018a; Gallardo et al., 2018; Wittneben et al., 2018). Ademais, a otimização clínica de ambas reabilitações (*overdenture* e prótese total fixa) pode ser obtida através do desenvolvimento de um tratamento de superfície mecanicamente resistente em pilares de prótese sobre implante de forma a aumentar a longevidade e a saúde peri-implantar das reabilitações citadas.

Em relação ao estado da arte na área de *overdentures*, observou-se no estudo 1 que o número de estudos financiados aumentou notavelmente nos últimos 35 anos. Acredita-se que essa associação se deve ao fato que as empresas privadas estão frequentemente otimizando seus produtos, incluindo implantes e componentes. Destacando também o fato que há um crescente interesse econômico/marketing em fornecer apoio financeiro no intuito de expandir a efetividade de protocolos de tratamento (Alonso-Arroyo et al., 2019b). A frequência de artigos financiados também foi maior segundo a economia do país, especialmente aqueles com renda alta (RP = 4,36) e média-alta (RP = 3,08). Esses dados entrelaçam o conceito de que o campo da ciência e o progresso econômico podem ser relacionáveis, além do fato de que à medida que a renda aumenta, os países apresentam estruturas de pesquisa reconhecidas, formando fortes redes com áreas geográficas, linguísticas, comerciais e geopolíticas semelhantes (Jaffe et al., 2020). Ademais, a maioria das empresas mundialmente reconhecidas (i.g., Nobel Biocare, Straumann, Dentsply) apresentam programas para apoiar e testar os benefícios dos seus produtos através de aplicações em editais online, visando aquisição de suporte financeiro. Além disso, essas empresas estão localizadas em países de alta renda, reconhecidas mundialmente. A mesma tendência de maior financiamento foi observada para dois continentes, Oceania (RP = 4,54) e América do Sul (RP = 4,03). Ao mesmo tempo, o apoio financeiro ainda precisa ser difundido em países de baixa renda e em continentes que apresentam expressiva produção científica na área, como Europa, Ásia e América do Norte. Parâmetros bibliométricos adicionais também foram associados ao financiamento, incluindo ensaios clínicos controlados randomizados (RP = 4,01)/não randomizados (RP = 2,82), *in silico* (RP = 2,75) e *in vitro* (RP = 3,25); sistema de retenção tipo bola (RP = 1,33) e *stud* (RP = 1,61). Os achados desse estudo evidenciam que esses diferentes desenhos metodológicos podem ser complementares, uma vez que a investigação laboratorial precede estudos clínicos, destacando que cada método responde questões específicas seja laboratorial (i.e., avaliações biomecânicas) ou clínicas (i.e., efetividade de protocolos de tratamento).

Em uma abordagem pós-publicação no estudo 2, avaliando métricas de difusão de dados publicados, em específico fator de impacto JCR e média de citação, observou-se um ambiente de publicação favorável em termos de um alto fator de impacto JCR e alta citação média para ensaios clínicos (RCT, N-RCT, retrospectivos) e estudos *in vitro*. Ao mesmo tempo, os estudos *in silico* apresentaram apenas uma média de citação elevada, portanto, os autores da área de *overdenture* sobre implantes podem considerar parcerias especializadas com especialistas na área de engenharia com conhecimento adequado em análises biomecânicas para ter sucesso ao buscar revistas de alto fator de impacto. Para ter um fator de impacto JCR alto e uma média de citação alta, os pesquisadores devem buscar experiência na área (retratada pelo índice h). Enquanto isso, os periódicos com alto fator de impacto JCR eram mais propensos a publicar estudos de países de renda alta. Deve-se mencionar que ainda é necessário espalhar oportunidades em países de renda baixa e média-baixa para aumentar o número de pesquisas que serão publicadas como artigos. Além disso, os estudos devem considerar colaborações internacionais e tópicos específicos (configuração do implante e *macrodesign*) para terem uma média de citação elevada. Ademais, os autores-interessados devem estar cientes de que os dados relacionados ao tópico e ao sistema de retenção podem mudar à medida que as indústrias melhoram os implantes e os componentes ao longo dos anos. Essas descobertas também podem envolver pesquisas futuras para rastrear desigualdades e auxiliar na conceituação de novos estudos.

Comprovada a efetividade clínica e histórica das reabilitações com próteses removíveis retidas por implantes (*overdentures*), questionou-se no estudo 3 se essas reabilitações poderiam ser efetivamente similares com próteses totais fixas, considerando a perspectiva do paciente. Além disso, faltam dados que documentem sistematicamente os PROMs, em particular para QVRSB e satisfação. O Consenso do ITI estabeleceu que a escolha de próteses implanto-suportadas fixas ou removíveis para pacientes edêntulos não deve ser guiada apenas por parâmetros clínicos, mas também pela perspectiva subjetiva do tratamento obtida pelo paciente (Feine et al., 2018b). A avaliação da QVRSB foi realizada com o OHIP-49 e sua versão curta, o OHIP-14, para estimar a consciência do paciente sobre a condição bucal em relação ao bem-estar (Slade and Spencer, 1994). Ambos os questionários foram validados e relatados como tendo modelos multivariados semelhantes para condição bucal e impacto social relacionado a variáveis sociodemográficas (Awad et al., 2007; Slade, 1997). A avaliação quantitativa da QVRSB foi possível para 6 dos 7 domínios do OHIP. Apenas o desconforto psicológico não apresentou dados numéricos para serem incluídos. Também foram avaliados escores de satisfação abrangendo aspectos clínicos e funcionais com base em 7 domínios. Os resultados das meta-análises de QVRSB mostraram escores mais baixos para limitação funcional, incapacidade física e dor física para o grupo de overdentures. Da mesma forma, a *overdenture* também registrou menor satisfação quanto ao conforto e facilidade de mastigação, bem como menor retenção e estabilidade em comparação com as próteses fixas. Os resultados inferiores nos grupos de overdentures podem estar associados aos aspectos clínicos das próteses, incluindo rotação e movimentos laterais, menor força oclusal máxima, contato com mucosa, menor número de implantes e maior número de consultas de manutenção (Dudic and Mericske-Stern, 2002; M. A. ELsyad et al., 2019; Haraldson, 1983; Müller et al., 2012).

Diante das reabilitações revisadas nos capítulos anteriores (#1, #2 e #3) identificou-se que pilares de prótese sobre implantes são estruturas expostas ininterruptamente ao ambiente oral hostil. Consequentemente, pré-requisitos devem ser atendidos, especificamente resistência mecânica e a degradação química (e.g., corrosão e desgaste) os quais, se ausentes, podem levar à liberação/acúmulo de partículas metálicas no tecido peri-implantar (Nagay et al., 2022; Noronha Oliveira et al., 2018; Souza et al., 2020b). Contribuindo assim para a disbiose microbiológica e, em última instância peri-implantite (Souza et al., 2020b). Diante desse contexto, nosso estudo foi direcionado em desenvolver um tratamento de superfície a base de DLC para *abutments* biomecanicamente resistente e protetor, o qual foi depositado com sucesso em substrato de TiGrIV. Assim, respondendo às questões em aberto no atual estado-da-arte inicialmente apresentado, (*i*) o problema frequente dos filmes DLC relacionados à delaminação do substrato metálico, usando uma combinação de DC-PECVD pulsado e intercamada de silício, pode ser superado e garantido de acordo com nossos resultados na avaliação tribológica; (*ii*) mecanicamente, o filme DLC otimiza a resistência do substrato e em alinhamento com os dados tribológicos e sua estrutura estável fornece um material anticorrosivo; (*iii*) uma propriedade citocompatível com fibroblastos gengivais humanos é demonstrada por um metabolismo mitocondrial superior a 80% (ISO) 10993-5:2009; (*iv*) o filme DLC não aumenta a formação de biofilme em comparação com o TiGrIV. Em conjunto, esses dados podem ser traduzidos num potencial candidato em pilares para implantes-dentários. Deve-se presumir que nosso estudo in vitro foi realizado utilizando discos usinados TiGrIV, o que pode ser uma limitação considerando as diferentes geometrias dos componentes, a depender do fabricante e o tipo de prótese. Para ampliar a aplicabilidade, as futuras alternativas que utilizam agentes antibacterianos devem ser projetadas para melhorar os benefícios já fornecidos em nosso estudo, uma vez que os componentes de implantes são destinados à aplicação temporária ou permanente no corpo humano.

4. CONCLUSÃO

Baseado no estudo bibliométrico #01, os dados adquiridos demonstraram que o número de estudos financiados na área de overdentures sobre implantes aumentou notavelmente nos últimos 35 anos. A frequência de artigos financiados também foi maior segundo a economia do país, especialmente aqueles com renda alta (RP = 4,36) e média-alta (RP = 3,08). A mesma tendência foi observada para dois continentes, Oceania (RP = 4,54) e América do Sul (RP = 4,03). Ao mesmo tempo, o apoio financeiro ainda precisa ser distribuído em países de baixa renda e em continentes que apresentam expressiva produção científica na área, como Europa, Ásia e América do Norte. Parâmetros bibliométricos adicionais também foram associados ao financiamento, incluindo ensaios clínicos randomizados (RP = 4,01)/não-randomizados (RP = 2,82), in silico (RP = 2,75) e in vitro (RP = 3,25); sistema de retenção, bola (RP = 1,33) e *stud* (RP = 1,61); por último, a métrica do índice-h também foi associada à variável dependente, aqueles autores com maior índice-h tiveram mais artigos financiados.

Nessa mesma perspectiva bibliométrica, entretanto avaliando métricas de publicação #02, observou-se um alto fator de impacto JCR e uma alta média de citação para RCT, N-RCT, estudos retrospectivos e estudos in vitro. Os estudos in silico apresentaram apenas média de citação elevada. Um alto fator de impacto do JCR e uma alta média de citações também foram observados para pesquisadores com expertise na área (identificado pelo índice-h) e localizados em países de alta renda. Um alto fator de impacto do JCR foi associado a estudos que avaliaram a maxila ou a mandíbula. Uma média de citação elevada foi observada para estudos que consideraram tópicos específicos (configuração do implante e macrodesign) e pesquisadores seniores com colaborações internacionais.

Quando se comparou reabilitações mandibulares do tipo *overdenture* com próteses totais fixas #03 concluiu-se que os resultados das medidas relatados pelos pacientes (PROMs), especificamente para qualidade de vida e satisfação relacionadas à saúde bucal, demonstraram uma tendência de melhores índices para próteses fixas retidas por implantes. Já a avaliação clínica baseada na taxa de sobrevivência do implante, perda óssea marginal e profundidade de sondagem indicou que as *overdentures* madibulares eram igualmente eficientes que próteses totais fixas. Ademais concluiu-se que benefícios podem ser estendidos a essas modalidades reabilitadoras, utilizando um tratamento mecanicamente resistente a base de DLC #04 sobre componentes a base de TiGrIV. O filme de DLC obtido demonstrou uma topografia lisa (rugosidade média: 0,11 ± 0,01 μm) com uma superfície compacta/uniforme (medição da seção transversal: 0,80 ± 0,01 μm). Além disso, tal filme melhorou as propriedades mecânicas (cargadescarga, dureza e módulo de elasticidade) do substrato de TiGrIV puro. Quando avaliados em saliva artificial, o coeficiente de atrito e as trilhas de desgaste foram menores para o DLC (0,04 ±0,005 μ e 157,7 ±26,6 μm, respectivamente) em comparação ao Ti (0,2 ±0,01 μ e 409,4 ±17,6 μm, respectivamente), apresentando propriedades tribológicas superiores. Os parâmetros eletroquímicos obtidos para filmes DLC em saliva artificial aumentaram significativamente a resistência à polarização (30 vezes) e o potencial de corrosão (4 vezes), ao mesmo tempo que diminuíram a capacitância (180 vezes), a densidade da corrente de corrosão (17 vezes) e a taxa de corrosão (16 vezes), em comparação com o substrato de TiGrIV. A formação de biofilme (Streptococcus sanguinis) após 24 h apresentou carga bacteriana igual (~7 Log unidades formadoras de colônias) para ambos os grupos (TiGrIV e DLC). Além disso, o filme DLC apresentou citocompatibilidade por apresentar efeito não citotóxico sobre células de fibroblastos gengivais humanos.

REFERÊNCIAS*

Ahmad P, Alam MK, Jakubovics NS, Schwendicke F, Asif JA. 100 Years of the Journal of Dental Research: A Bibliometric Analysis. J Dent Res 2019;98:1425–36.

Alarcón MA, Esparza D, Montoya C, Monje A, Faggion CM. The 300 Most-Cited Articles in Implant Dentistry. Int J Oral Maxillofac Implants 2017;32:e1–8.

Alfadda SA, Chvartszaid D, AlFarraj Aldosari A. Clinical outcomes of immediately loaded implant-supported overdentures: A long-term prospective clinical trial. The Journal of Prosthetic Dentistry 2019;121:911–5.

Alhajj MN, Al-Sanabani FA, Alkheraif AA, Smran A, Alqerban A, Samran A. Bibliometric analysis and evaluation of the Journal of Prosthetic Dentistry from 1970 to 2019. The Journal of Prosthetic Dentistry 2021:S0022391321002791.

Alonso-Arroyo A, Tarazona-Alvarez B, Lucas-Dominguez R, Peñarrocha-Oltra D, Vidal-Infer A. The funding sources of implantology research in the period 2008-2017: A bibliometric analysis. Clin Implant Dent Relat Res 2019a;21:708–14.

Alonso-Arroyo A, Tarazona-Alvarez B, Lucas-Dominguez R, Peñarrocha-Oltra D, Vidal-Infer A. The funding sources of implantology research in the period 2008-2017: A bibliometric analysis. Clin Implant Dent Relat Res 2019b;21:708–14.

Attard N, Wei X, Laporte A, Zarb GA, Ungar WJ. A cost minimization analysis of implant treatment in mandibular edentulous patients. Int J Prosthodont 2003;16:271–6.

Awad M, Al-Shamrany M, Locker D, Allen F, Feine J. Effect of reducing the number of items of the Oral Health Impact Profile on responsiveness, validity and reliability in edentulous populations. Commun Dent Oral Epidemiol 2008; 36:12-20.

Ayna M, Gülses A, Acil Y. A comparative study on 7-year results of “All-on-FourTM” immediate-function concept for completely edentulous mandibles: metal-ceramic vs. bar-retained superstructures. Odontology 2018;106:73–82.

* De acordo com as normas da UNICAMP/FOP, baseadas na padronização do International Committee of Medical Journal Editors - Vancouver Group. Abreviatura dos periódicos em conformidade com o PubMed.

Balshi TJ, Wolfinger GJ, Slauch RW, Balshi SF. A Retrospective Analysis of 800 Brånemark System Implants Following the All-on-FourTM Protocol: All-on-Four Retrospective Analysis. Journal of Prosthodontics 2014;23:83–8.

Barão VAR, Shyamsunder N, Yuan JC-C, Lee DJ, Assunção WG, Sukotjo C. Authorship, Collaboration, and Funding Trends in Implantology Literature: Analysis of Five Journals From 2005 to 2009. Implant Dentistry 2011;20:68–75.

Beline T, de Almeida AB, Azevedo Neto NF, Matos AO, Ricomini-Filho AP, Sukotjo C, et al. β-Ta2O5 thin film for implant surface modification triggers superior anti-corrosion performance and cytocompatibility of titanium. Applied Surface Science 2020;520:146326.

Beresford D, Klineberg I. A Within-Subject Comparison of Patient Satisfaction and Quality of Life Between a Two-Implant Overdenture and a Three-Implant–Supported Fixed Dental Prosthesis in the Mandible. Int J Oral Maxillofac Implants 2018;33:1374–82.

Borges GA, Costa RC, Nagay BE, Magno MB, Maia LC, Barão VAR, et al. Long-term outcomes of different loading protocols for implant-supported mandibular overdentures: A systematic review and meta-analysis. The Journal of Prosthetic Dentistry 2021;125:732–45.

Borges GA, Costa RC, Nagay BE, Magno MB, Maia LC, Barão VAR, et al. Long-term outcomes of different loading protocols for implant-supported mandibular overdentures: A systematic review and meta-analysis. J Prosthet Dent 2020.

Brånemark P-I, Breine U, Adell R, Hansson BO, Lindström J, Ohlsson Å. Intra-Osseous Anchorage of Dental Prostheses: I. Experimental Studies. Scandinavian Journal of Plastic and Reconstructive Surgery 1969;3:81–100.

Brennan M, Houston F, O'Sullivan M, O'Connell B. Patient satisfaction and oral health-related quality of life outcomes of implant overdentures and fixed complete dentures. Int J Oral Maxillofac Implants 2010;25:791–800.

Buser D, Sennerby L, De Bruyn H. Modern implant dentistry based on osseointegration: 50 years of progress, current trends and open questions. Periodontol 2000 2017;73:7–21.

Casiraghi C, Ferrari AC, Robertson J. Raman spectroscopy of hydrogenated amorphous carbons. Phys Rev B 2005;72:085401.

Chiang H-S, Huang R-Y, Weng P-W, Mau L-P, Tsai Y-WC, Chung M-P, et al. Prominence of scientific publications towards peri-implant complications in implantology: A bibliometric analysis using the H-classics method. J Oral Rehabil 2018;45:240–9.

Clarke M. Discussion Sections in Reports of Controlled Trials Published in General Medical Journals. JAMA 2002;287:2799.

De Kok IJ, Chang K-H, Lu T-S, Cooper LF. Comparison of three-implant-supported fixed dentures and two-implant-retained overdentures in the edentulous mandible: a pilot study of treatment efficacy and patient satisfaction. Int J Oral Maxillofac Implants 2011a;26:415–26.

De Kok IJ, Chang K-H, Lu T-S, Cooper LF. Comparison of three-implant-supported fixed dentures and two-implant-retained overdentures in the edentulous mandible: a pilot study of treatment efficacy and patient satisfaction. Int J Oral Maxillofac Implants 2011b;26:415–26.

Dini C, Pereira MMA, Souza JGS, De Avila ED, Barão VAR. Mapping the trends and impact of research collaboration between countries in oral implantology publications: A bibliometric analysis from 1999 to 2019. The Journal of Prosthetic Dentistry 2022a:S0022391322006539.

Dini C, Pereira MMA, Souza JGS, Shibli JA, de Avila ED, Barão VAR. Association between industry support and the reporting of study outcomes in randomized clinical trials of dental implant research from the past 20 years. Clin Implant Dent Relat Res 2022b;24:94–104.

Dudic A, Mericske-Stern R. Retention Mechanisms and Prosthetic Complications of Implant-Supported Mandibular Overdentures: Long-Term Results. Clin Implant Dent Rel Res 2002;4:212–9.

ELsyad M, Alameldeen H, Elsaih E. Four-Implant–Supported Fixed Prosthesis and Milled Bar Overdentures for Rehabilitation of the Edentulous Mandible: A 1-Year Randomized Controlled Clinical and Radiographic Study. Int J Oral Maxillofac Implants 2019;34:1493–503.

ELsyad MA, Elgamal M, Mohammed Askar O, Youssef Al-Tonbary G. Patient satisfaction and oral health-related quality of life (OHRQoL) of conventional denture, fixed prosthesis and milled bar overdenture for All-on-4 implant rehabilitation. A crossover study. Clin Oral Impl Res 2019;30:1107–17.

Elsyad MA, Khirallah AS. Circumferential bone loss around splinted and nonsplinted immediately loaded implants retaining mandibular overdentures: A randomized controlled clinical trial using cone beam computed tomography. The Journal of Prosthetic Dentistry 2016;116:741–8.

Feine J, Abou-Ayash S, Al Mardini M, Santana RB, Bjelke-Holtermann T, Bornstein MM, et al. Group 3 ITI Consensus Report: Patient-reported outcome measures associated with implant dentistry. Clin Oral Impl Res 2018a;29:270–5.

Feine J, Abou-Ayash S, Al Mardini M, Santana RB, Bjelke-Holtermann T, Bornstein MM, et al. Group 3 ITI Consensus Report: Patient-reported outcome measures associated with implant dentistry. Clin Oral Impl Res 2018b;29:270–5.

Feine JS, Carlsson GE, Awad MA, Chehade A, Duncan WJ, Gizani S, et al. The McGill consensus statement on overdentures. Mandibular two-implant overdentures as first choice standard of care for edentulous patients. Gerodontology 2002a;19:3–4.

Feine JS, Carlsson GE, Awad MA, Chehade A, Duncan WJ, Gizani S, et al. The McGill consensus statement on overdentures. Mandibular two-implant overdentures as first choice standard of care for edentulous patients. Montreal, Quebec, May 24-25, 2002. Int J Oral Maxillofac Implants 2002b;17:601–2.

Feine JS, de Grandmont P, Boudrias P, Brien N, LaMarche C, Taché R, et al. Within-subject Comparisons of Implant-supported Mandibular Prostheses: Choice of Prosthesis. J Dent Res 1994;73:1105–11.

Ferrari AC. Determination of bonding in diamond-like carbon by Raman spectroscopy. Diamond and Related Materials 2002;11:1053–61.

Ferrari AC, Robertson J. Interpretation of Raman spectra of disordered and amorphous carbon. Phys Rev B 2000;61:14095–107.

Gallardo YR, Bohner L, Tortamano P, Pigozzo MN, Laganá DC, Sesma N. Patient outcomes and procedure working time for digital versus conventional impressions: A systematic review. The Journal of Prosthetic Dentistry 2018;119:214–9.

Guo T, Gulati K, Arora H, Han P, Fournier B, Ivanovski S. Race to invade: Understanding soft tissue integration at the transmucosal region of titanium dental implants. Dental Materials 2021;37:816–31.

Guo T, Kong C, Li X, Guo P, Wang Z, Wang A. Microstructure and mechanical properties of Ti/Al co-doped DLC films: Dependence on sputtering current, source gas, and substrate bias. Applied Surface Science 2017;410:51–9.

Haraldson T. Comparisons of chewing patterns in patients with bridges supported on osseointegrated implants and subjects with natural dentitions. Acta Odontologica Scandinavica 1983;41:203–8.

Hartmann R, de Menezes Bandeira ACF, de Araújo SC, McKenna G, Brägger U, Schimmel M, et al. Cost-effectiveness of three different concepts for the rehabilitation of edentulous mandibles: Overdentures with 1 or 2 implant attachments and hybrid prosthesis on four implants. J Oral Rehabil 2020;47:1394–402.

Heneberg P. From Excessive Journal Self-Cites to Citation Stacking: Analysis of Journal Self-Citation Kinetics in Search for Journals, Which Boost Their Scientometric Indicators. PLoS ONE 2016;11:e0153730.

Ibrahim GM, Carter Snead O, Rutka JT, Lozano AM. The most cited works in epilepsy: Trends in the “Citation Classics”: Most Cited Works in Epilepsy. Epilepsia 2012;53:765–70.

Jaffe K, Ter Horst E, Gunn LH, Zambrano JD, Molina G. A network analysis of research productivity by country, discipline, and wealth. PLoS ONE 2020;15:e0232458.

Kamiya M, Tanoue H, Takikawa H, Taki M, Hasegawa Y, Kumagai M. Preparation of various DLC films by T-shaped filtered arc deposition and the effect of heat treatment on film properties. Vacuum 2008;83:510–4.

Kasiorowski T, Lin J, Soares P, Lepienski CM, Neitzke CA, de Souza GB, et al. Microstructural and tribological characterization of DLC coatings deposited by plasma enhanced techniques on steel substrates. Surface and Coatings Technology 2020;389:125615.

Kassebaum NJ, Bernabé E, Dahiya M, Bhandari B, Murray CJL, Marcenes W. Global Burden of Severe Tooth Loss: A Systematic Review and Meta-analysis. J Dent Res 2014;93:20S-28S.

Kurmis AP. Understanding the limitations of the journal impact factor. J Bone Joint Surg Am

2003;85:2449–54.

Kuznetsova T, Lapitskaya V, Khabarava A, Trukhan R, Chizhik S, Torskaya E, et al. Silicon addition as a way to control properties of tribofilms and friction of DLC coatings. Applied Surface Science 2023;608:155115.

Laleman I, Lambert F. Implant connection and abutment selection as a predisposing and/or precipitating factor for peri-implant diseases: A review. Clin Implant Dent Rel Res 2023:cid.13185.

Li C, Huang L, Yuan J. Effect of sp3 Content on Adhesion and Tribological Properties of Non-Hydrogenated DLC Films. Materials 2020;13:1911.

Livas C, Delli K. Journal Self-Citation Rates and Impact Factors in Dentistry, Oral Surgery, and Medicine: A 3-year Bibliometric Analysis. J Evid Based Dent Pract 2018;18:269–74.

Mints D, Elias C, Funkenbusch P, Meirelles L. Integrity of Implant Surface Modifications After Insertion. Int J Oral Maxillofac Implants 2014;29:97–104.

Mishnaevsky L, Levashov E, Valiev RZ, Segurado J, Sabirov I, Enikeev N, et al. Nanostructured titanium-based materials for medical implants: Modeling and development. Materials Science and Engineering: R: Reports 2014;81:1–19.

Müller F, Hernandez M, Grütter L, Aracil-Kessler L, Weingart D, Schimmel M. Masseter muscle thickness, chewing efficiency and bite force in edentulous patients with fixed and removable implant-supported prostheses: a cross-sectional multicenter study: Masseter muscle thickness and bite force. Clinical Oral Implants Research 2012;23:144–50.

Muniz FWMG, Celeste RK, Oballe HJR, Rösing CK. Citation Analysis and Trends in review articles in dentistry. Journal of Evidence Based Dental Practice 2018;18:110–8.

Nabil S, Samman N. The impact of case reports in oral and maxillofacial surgery. International Journal of Oral and Maxillofacial Surgery 2012;41:789–96.

Nagay BE, Cordeiro JM, Barao VAR. Insight Into Corrosion of Dental Implants: From Biochemical Mechanisms to Designing Corrosion-Resistant Materials. Curr Oral Health Rep 2022;9:7–21.

Nagay BE, Dini C, Borges GA, Mesquita MF, Cavalcanti YW, Magno MB, et al. Clinical efficacy of anodized dental implants for implant-supported prostheses after different loading protocols: A systematic review and meta-analysis. Clinical Oral Implants Res 2021;32:1021–40.

Niedermaier R, Stelzle F, Riemann M, Bolz W, Schuh P, Wachtel H. Implant-Supported Immediately Loaded Fixed Full-Arch Dentures: Evaluation of Implant Survival Rates in a Case Cohort of up to 7 Years: Immediately Loaded Fixed Full-Arch Dentures. Clinical Implant Dentistry and Related Research 2017;19:4–19.

Noronha Oliveira M, Schunemann WVH, Mathew MT, Henriques B, Magini RS, Teughels W, et al. Can degradation products released from dental implants affect peri-implant tissues? J Periodont Res 2018;53:1–11.

Pantaroto HN, Cordeiro JM, Pereira LT, de Almeida AB, Nociti Junior FH, Rangel EC, et al. Sputtered crystalline TiO2 film drives improved surface properties of titanium-based biomedical implants. Materials Science and Engineering: C 2021;119:111638.

Passia N, Kern M. The single midline implant in the edentulous mandible: a systematic review. Clin Oral Invest 2014;18:1719–24.

Passia N, Wolfart S, Kern M. Ten-year clinical outcome of single implant-retained mandibular overdentures—A prospective pilot study. Journal of Dentistry 2019;82:63–5.

Patzelt SBM, Bahat O, Reynolds MA, Strub JR. The All-on-Four Treatment Concept: A Systematic Review: All-on-4. Clinical Implant Dentistry and Related Research 2014;16:836–55.

Pereira MMA, Dini C, Souza JGS, Barão VAR, De Avila ED. Industry support for dental implant research: A metatrend study of industry partnership in the development of new technologies. The Journal of Prosthetic Dentistry 2022:S0022391322003559.

Robertson J. Requirements of ultrathin carbon coatings for magnetic storage technology. Tribology International 2003;36:405–15.

Slade GD. Derivation and validation of a short-form oral health impact profile. Commun Dent Oral Epidemiol 1997;25:284–90.

Slade GD, Spencer AJ. Development and evaluation of the Oral Health Impact Profile. Community Dent Health 1994;11:3–11.

Souza JGS, Bertolini M, Costa RC, Cordeiro JM, Nagay BE, de Almeida AB, et al. Targeting Pathogenic Biofilms: Newly Developed Superhydrophobic Coating Favors a Host-Compatible Microbial Profile on the Titanium Surface. ACS Appl Mater Interfaces 2020a;12:10118–29.

Souza JGS, Costa Oliveira BE, Bertolini M, Lima CV, Retamal-Valdes B, Faveri M, et al. Titanium particles and ions favor dysbiosis in oral biofilms. J Periodont Res 2020b;55:258–66.

Tarazona B, Vidal-Infer A, Alonso-Arroyo A. Bibliometric analysis of the scientific production in implantology (2009-2013). Clin Oral Implants Res 2017;28:864–70.

Tarazona-Álvarez B, López-Roldan A, Vidal-Infer A, López-Padilla D, Alonso-Arroyo A. Bibliometric analysis of the scientific production of literature on peri-implant diseases in the Web of Science. Clin Implant Dent Relat Res 2021:cid.13024.

Thomason JM, Feine J, Exley C, Moynihan P, Müller F, Naert I, et al. Mandibular two implant-supported overdentures as the first choice standard of care for edentulous patients - the York Consensus Statement. Br Dent J 2009;207:185–6.

Tinsley D, Watson CJ, Russell JL. A comparison of hydroxylapatite coated implant retained fixed and removable mandibular prostheses over 4 to 6 years. Clin Oral Implants Res 2001;12:159–66.

Turkyilmaz I, Tozum TF, Fuhrmann DM, Tumer C. Seven-Year Follow-Up Results of TiUnite Implants Supporting Mandibular Overdentures: Early versus Delayed Loading: Implant Overdentures. Clinical Implant Dentistry and Related Research 2012;14:e83–90.

Vetter J. 60 years of DLC coatings: Historical highlights and technical review of cathodic arc processes to synthesize various DLC types, and their evolution for industrial applications. Surface and Coatings Technology 2014;257:213–40.

Wang L, Yu H, Wang K, Xu H, Wang S, Sun D. Local Fine Structural Insight into Mechanism of Electrochemical Passivation of Titanium. ACS Appl Mater Interfaces 2016;8:18608–19.

Wei X, Chen L, Zhang M, Lu Z, Zhang G. Effect of dopants (F, Si) material on the structure and properties of hydrogenated DLC film by plane cathode PECVD. Diamond and Related

Materials 2020;110:108102.

Wittneben J, Wismeijer D, Brägger U, Joda T, Abou-Ayash S. Patient-reported outcome measures focusing on aesthetics of implant- and tooth-supported fixed dental prostheses: A systematic review and meta-analysis. Clin Oral Impl Res 2018;29:224–40.

Wu M, Tian X, Li M, Gong C, Wei R. Effect of additional sample bias in Meshed Plasma Immersion Ion Deposition (MPIID) on microstructural, surface and mechanical properties of Si-DLC films. Applied Surface Science 2016;376:26–33.

Zajikova L. Correlation between SiOx content and properties of DLC:SiOx films prepared by PECVD. Surface and Coatings Technology 2003;174–175:281–5.

Zarb GA, Albrektsson T. Consensus report: towards optimized treatment outcomes for dental implants. J Prosthet Dent 1998;80:641.

ANEXOS

ANEXO 1: Verificação de originalidade e prevenção de plágio

Tese

RELATÓRIO DE ORIGINALIDADE

22%	15%	20%	2%
ÍNDICE DE SEMELHANÇA	FONTES DA INTERNET	PUBLICAÇÕES	DOCUMENTOS DOS ALUNOS

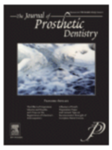
FONTES PRIMÁRIAS

1	repositorio.unicamp.br Fonte da Internet	4%
2	www.researchgate.net Fonte da Internet	2%
3	Xubing Wei, Yujue Zhang, Haiyan Feng, Xueqian Cao, Qi Ding, Zhibin Lu, Guangan Zhang. "Bio-Tribology and Corrosion Behaviors of a Si- and N-Incorporated Diamond-like Carbon Film: A New Class of Protective Film for Ti6Al4V Artificial Implants", ACS Biomaterials Science & Engineering, 2022 Publicação	1%
4	Thamara Beline, Amanda B. de Almeida, Nilton F. Azevedo Neto, Adaias O. Matos et al. "β-Ta2O5 thin film for implant surface modification triggers superior anti-corrosion performance and cytocompatibility of titanium", Applied Surface Science, 2020 Publicação	1%
5	pubs.rsc.org Fonte da Internet	

ANEXO 2: Liberação da revista quanto aos direitos e conteúdo do #Capítulo 01

RightsLink

Home | Help | Live Chat | Sign in | Create Account



Funding assistance and global productivity in the field of implant overdentures: A bibliometric analysis of 35 years

Author:
Guilherme Almeida Borges,Caroline Dini,Mariana Marinho Davino de Medeiros,Renata Cunha Matheus Rodrigues Garcia,Valentim Adelino Ricardo Barão,Marcelo Ferraz Mesquita

Publication: The Journal of Prosthetic Dentistry

Publisher: Elsevier

Date: Available online 13 December 2021

Journal Author Rights

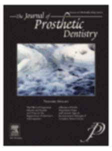
Please note that, as the author of this Elsevier article, you retain the right to include it in a thesis or dissertation, provided it is not published commercially. Permission is not required, but please ensure that you reference the journal as the original source. For more information on this and on your other retained rights, please visit: https://www.elsevier.com/about/our-business/policies/copyright#Author-rights

BACK | CLOSE WINDOW

ANEXO 3: Liberação da revista quanto aos direitos e conteúdo do #Capítulo 02

CCC | RightsLink

Home | Help | Live Chat | Sign in | Create Account



Bibliometric assessment in implant-retained overdenture articles: Mapping citation and journal impact factor trends

Author:
Guilherme Almeida Borges,Caroline Dini,Mariana Marinho Davino de Medeiros,Renata Cunha Matheus Rodrigues Garcia,Valentim Adelino Ricardo Barão,Marcelo Ferraz Mesquita

Publication: The Journal of Prosthetic Dentistry

Publisher: Elsevier

Date: Available online 11 December 2022

Journal Author Rights

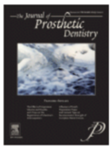
Please note that, as the author of this Elsevier article, you retain the right to include it in a thesis or dissertation, provided it is not published commercially. Permission is not required, but please ensure that you reference the journal as the original source. For more information on this and on your other retained rights, please visit: https://www.elsevier.com/about/our-business/policies/copyright#Author-rights

BACK | CLOSE WINDOW

ANEXO 4: Liberação da revista quanto aos direitos e conteúdo do #Capítulo 03

RightsLink

Home | Help | Live Chat | Sign in | Create Account



Patient-reported outcome measures and clinical assessment of implant-supported overdentures and fixed prostheses in mandibular edentulous patients: A systematic review and meta-analysis

Author:
Guilherme Almeida Borges,Thaís Barbin,Caroline Dini,Lucianne Cople Maia,Marcela Baraúna Magno,Valentim Adelino Ricardo Barão,Marcelo Ferraz Mesquita

Publication: The Journal of Prosthetic Dentistry

Publisher: Elsevier

Date: April 2022

Journal Author Rights

Please note that, as the author of this Elsevier article, you retain the right to include it in a thesis or dissertation, provided it is not published commercially. Permission is not required, but please ensure that you reference the journal as the original source. For more information on this and on your other retained rights, please visit: https://www.elsevier.com/about/our-business/policies/copyright#Author-rights

BACK | CLOSE WINDOW

ANEXO 5: Liberação da revista quanto aos direitos e conteúdo do #Capítulo 04

CCC RightsLink

Sign in/Register

ACS Publications
Most Trusted. Most Cited. Most Read.

Targeting Biomechanical Endurance of Dental-Implant Abutments Using a Diamond-Like Carbon Coating

Author: Guilherme Almeida Borges, Raphael Cavalcante Costa, Bruna Egumi Nagay, et al

Publication: ACS Applied Bio Materials

Publisher: American Chemical Society

Date: Dec 1, 2023

PERMISSION/LICENSE IS GRANTED FOR YOUR ORDER AT NO CHARGE

This type of permission/license, instead of the standard Terms and Conditions, is sent to you because no fee is being charged for your order. Please note the following:

- Permission is granted for your request in both print and electronic formats, and translations.
- If figures and/or tables were requested, they may be adapted or used in part.
- Please print this page for your records and send a copy of it to your publisher/graduate school.
- Appropriate credit for the requested material should be given as follows: "Reprinted (adapted) with permission from {COMPLETE REFERENCE CITATION}. Copyright {YEAR} American Chemical Society." Insert appropriate information in place of the capitalized words.
- One-time permission is granted only for the use specified in your RightsLink request. No additional uses are granted (such as derivative works or other editions). For any uses, please submit a new request.

If credit is given to another source for the material you requested from RightsLink, permission must be obtained from that source.

BACK

CLOSE WINDOW

ANEXO 6: Comitê de Ética em Pesquisa para execução do #Capítulo 04

CERTIFICADO CEP nº 5/2023

COMITÊ DE ÉTICA EM PESQUISA
FACULDADE DE ODONTOLOGIA DE PIRACICABA
UNIVERSIDADE ESTADUAL DE CAMPINAS

CERTIFICADO

O Comitê de Ética em Pesquisa da FOP-UNICAMP certifica que o projeto de pesquisa "**Filme de carbono tipo diamante depositado por plasma de vapor químico para pilares de overdentures**", CAAE **64309522.4.0000.5418**, dos pesquisadores **Guilherme Almeida Borges** e **Marcelo Ferraz Mesquita**, satisfaz as exigências das resoluções específicas sobre ética em pesquisa com seres humanos do Conselho Nacional de Saúde – Ministério da Saúde e foi aprovado por este comitê em 28/11/2022.

The Research Ethics Committee of the Piracicaba Dental School of the University of Campinas (FOP-UNICAMP) certifies that research project "**Diamond-like Carbon film obtained by plasma enhanced chemical vapour deposition for overdenture abutments**", CAAE **64309522.4.0000.5418**, of the researcher's **Guilherme Almeida Borges** and **Marcelo Ferraz Mesquita**, meets the requirements of the specific resolutions on ethics in research with human beings of the National Health Council - Ministry of Health, and was approved by this committee on November, 28, 2022.

Prof. Jacks Jorge Junior
Coordenador
CEP/FOP/UNICAMP

Nota: O título do protocolo e a lista de autores aparecem como fornecidos pelos pesquisadores, sem qualquer edição.
Notice: The title and the list of researchers of the project appears as provided by the authors, without editing.