UNICAMP

UNIVERSIDADE ESTADUAL DE CAMPINAS
FACULDADE DE ODONTOLOGIA DE PIRACICABA

RAFAEL PINO VITTI

INFLUÊNCIA DO TRATAMENTO DE SUPERFÍCIE DO POLIETERETERCETONA (PEEK) NA RESISTÊNCIA DA UNIÃO À RESINA COMPOSTA: REVISÃO SISTEMÁTICA COM METANÁLISE EM REDE

INFLUENCE OF SURFACE TREATMENT OF POLYETHERETHERKETONE (PEEK) ON BOND STRENGTH TO RESIN COMPOSITE: SYSTEMATIC REVIEW WITH NETWORK META-ANALYSIS

Piracicaba

2025

RAFAEL PINO VITTI

INFLUÊNCIA DO TRATAMENTO DE SUPERFÍCIE DO POLIETERETERCETONA (PEEK) NA RESISTÊNCIA DA UNIÃO À RESINA COMPOSTA: REVISÃO SISTEMÁTICA COM METANÁLISE EM REDE

INFLUENCE OF SURFACE TREATMENT OF POLYETHERETHERKETONE (PEEK) ON BOND STRENGTH TO RESIN COMPOSITE: SYSTEMATIC REVIEW WITH NETWORK META-ANALYSIS

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 Dentística.

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 Restorative Dentistry area.

Orientador: Prof. Dr. Flavio Henrique Baggio Aguiar

ESTE TRABALHO CORRESPONDE À VERSÃO FINAL DA TESE DEFENDIDA PELO ALUNO RAFAEL PINO VITTI E ORIENTADA PELO PROF. DR. FLAVIO HENRIQUE BAGGIO AGUIAR.

Piracicaba
2025

Ficha catalográfica
Universidade Estadual de Campinas (UNICAMP)
Biblioteca da Faculdade de Odontologia de Piracicaba
Heloisa Maria Ceccotti - CRB 8/6403

V835i

Vitti, Rafael Pino, 1984-
Influência do tratamento de superfície do polieteretercetona (PEEK) na resistência da união à resina composta : revisão sistemática com metanálise em rede / Rafael Pino Vitti. – Piracicaba, SP : [s.n.], 2025.

Orientador: Flavio Henrique Baggio Aguiar.
Tese (doutorado) – Universidade Estadual de Campinas (UNICAMP), Faculdade de Odontologia de Piracicaba (FOP).

1. Adesivos dentinários. 2. Resinas compostas. 3. Revisão sistemática. I. Aguiar, Flavio Henrique Baggio, 1977-. II. Universidade Estadual de Campinas (UNICAMP). Faculdade de Odontologia de Piracicaba (FOP). III. Título.

Informações complementares

Título em outro idioma: Influence of surface treatment of polyetheretherketone (PEEK) on bond strength to resin composite : systematic review with network meta-analysis
Palavras-chave em inglês:
Dentin-bonding agents
Composite resins
Systematic review
Área de concentração: Dentística
Titulação: Doutor em Clínica Odontológica
Banca examinadora:
Flavio Henrique Baggio Aguiar [Orientador]
Rafael Rocha Pacheco
Maria do Carmo Aguiar Jordão Mainardi
Luís Roberto Marcondes Martins
Giselle Maria Marchi
Data de defesa: 07-07-2025
Programa de Pós-Graduação: Clínica Odontológica

Objetivos de Desenvolvimento Sustentável (ODS)
ODS: 3. Saúde e bem-estar

Identificação e informações acadêmicas do(a) aluno(a)
- ORCID do autor: https://orcid.org/0000-0001-6366-5868
- Currículo Lattes do autor: http://lattes.cnpq.br/6177430284440545

PROF. DR. FLAVIO HENRIQUE BAGGIO AGUIAR

PROF. DR. RAFAEL ROCHA PACHECO

PROFA. DRA. MARIA DO CARMO AGUIAR JORDÃO MAINARDI

PROF. DR. LUÍS ROBERTO MARCONDES MARTINS

PROFA. DRA. GISELLE MARIA MARCHI

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

Ao meu **filho,** Lorenzo Ranzani Vitti, por, em tão pouco tempo, me ensinar muita coisa e me proporcionar o sentimento do puro amor. Obrigado por me incentivar na realização desta tese.

À minha **esposa**, Liza Furlan Ranzani Vitti, ao meu **pai** (*in memoriam*), José Urbano Vitti, minha **mãe**, Maria Helena Pino Vitti, minha **irmã**, Fernanda Pino Vitti, aos meus **sogros**, Godofredo Barbosa Ranzani e Lia Marta Furlan Ranzani, e ao meu **cunhado**, Gabriel Furlan Ranzani, por constituírem a minha base familiar, por todo carinho, amor, paciência e dedicação.

AGRADECIMENTOS

A **Deus**, por sempre estar ao meu lado, orientando e guiando meus passos, colocando sempre em meu caminho pessoas corretas, tornando possível mais uma conquista pessoal e profissional.

À direção da Faculdade de Odontologia de Piracicaba, da Universidade Estadual de Campinas, nas pessoas de sua Diretora **Profa. Dra. Karina Gonzales Silvério Ruiz** e de seu Diretor Associado **Prof. Dr. Márcio de Moraes**, por todos os momentos vividos na faculdade e por toda estrutura física e técnico-administrativa que permitem o desenvolvimento de trabalhos acadêmicos.

À coordenadoria geral de Pós-Graduação da Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas na pessoa do seu coordenador **Prof. Dr. Valentim Adelino Ricardo Barão**, e da coordenadora do Programa de Pós-Graduação em Clínica Odontológica **Profa. Dra. Débora Alves Nunes Leite Lima**.

Ao **Prof. Dr. Flávio Henrique Baggio Aguiar**, da Área de Dentística, do Departamento de Odontologia Restauradora, da Faculdade de Odontologia de Piracicaba, Universidade Estadual de Campinas, pelo apoio, dedicação, confiança e paciência a mim dispensados durante a orientação e principalmente pela amizade, transformando as horas de trabalho em momentos de agradável convivência.

Aos Professores Doutores **Débora Alves Nunes Leite Lima**, **Giselle Maria Marchi Baron**, **Luis Roberto Marcondes Martins**, **Marcelo Giannini**, **Vanessa Cavalli Gobbo** e **Waldemir Francisco Vieira Junior**, da Área de Dentística, do Departamento de Odontologia Restauradora, da Faculdade de Odontologia de Piracicaba, Universidade Estadual de Campinas, pela dedicação durante o curso e pela contribuição em meu crescimento científico e pessoal, sempre incentivando a busca pelo conhecimento, além dos agradáveis momentos vividos durante o curso.

Aos Professores Doutores **William Custodio**, **Marina Amaral** e **Anderson Catelan** pela disponibilidade em participar da banca de qualificação e pelas valiosas contribuições para esta tese.

Ao técnico especializado do laboratório da Área Dentística, da Faculdade de Odontologia de Piracicaba, **Wanderlei Francisco Vieira**, pelo trabalho, paciência e convívio.

Aos meus **colegas** e **amigos** de Pós-graduação deste e de outros programas, pela amizade e companheirismo. Sempre presentes e dispostos a ajudar. Obrigado pelos agradáveis momentos de convívio.

A todos os meus **familiares** e **amigos**, pelo apoio e incentivo dispensados durante toda a minha vida.

A **todos** que indiretamente contribuíram ou torceram para a realização deste trabalho.

Meus sinceros agradecimentos.

RESUMO

Esta revisão sistemática e meta-análise em rede avaliou a influência de diferentes tratamentos de superfície do polieteretercetona (PEEK) na resistência de união entre PEEK e resinas compostas. A revisão sistemática foi conduzida de acordo com as diretrizes PRISMA. A pergunta da pesquisa - “Os tratamentos de superfície influenciam a resistência de união entre resina composta e PEEK?” - foi estruturada de acordo com o PICOS. População (P): espécimes de PEEK; Intervenção (I): tratamentos de superfície aplicados em PEEK; Comparação (C): PEEK não tratado (sem tratamento superficial experimental); Desfecho (O): valores de resistência de união (MPa); Delineamento do estudo (S): estudos *in vitro*. O tratamento superficial experimental consistiu na aplicação de qualquer método de modificação da superfície do PEEK, com exceção da aplicação de adesivos específicos para uso sobre o PEEK (controle positivo) e a ausência de tratamento (controle negativo). Estudos publicados em inglês, português ou espanhol foram considerados sem restrição de data. Sete critérios de exclusão foram usados: PEEK não foi usado para fins odontológicos; nenhum tratamento de superfície foi aplicado ao PEEK; ausência de um grupo controle (positivo ou negativo); limpeza superficial influenciando na resistência de união; resistência da união não avaliada de forma imediata (sem termociclagem); resistência da união não avaliada entre PEEK e resina composta; ou resultados não reportados em MPa. Nove bases de dados foram pesquisadas até fevereiro de 2025. Dois revisores independentes identificaram estudos potencialmente elegíveis, selecionaram os estudos e extraíram os dados relevantes. As discordâncias foram resolvidas com um terceiro revisor. Os valores médios do mesmo tratamento de superfície com diferentes parâmetros e marcas de resina composta foram combinados. O risco de viés foi avaliado usando a ferramenta RoBDEMAT. A função *netgraph* foi usada para construir e visualizar a geometria da rede com as comparações entre as intervenções. As classificações das intervenções quantificaram a probabilidade média de cada tratamento ser superior aos outros. Um total de 1.809 títulos e resumos relevantes foram encontrados, resultando em 14 estudos publicados entre 2013 e 2024, avaliando 18 protocolos distintos de tratamento de superfície. Treze estudos demonstraram que os tratamentos de superfície associados ao adesivo melhoraram a resistência da união em comparação ao grupo controle. O ácido sulfúrico combinado com o adesivo mostrou os maiores valores de resistência da união, seguido pela irradiação a laser combinada com adesivo. Com relação ao risco de viés, oito estudos foram classificados como moderado, três como baixo e três como alto. O tratamento de superfície com ácido sulfúrico combinado com o adesivo fornecido pelo fabricante apresentou a maior resistência da união entre o PEEK e a resina composta.

Palavras-chave: Adesivos Dentinários. Resinas Compostas. Revisão Sistemática.

ABSTRACT

This systematic review and network meta-analysis evaluated the influence of surface treatments on the bond strength between polyetheretherketone (PEEK) and resin composites. The review was conducted following the PRISMA guidelines. The research question - "Do surface treatments influence the bond strength between resin composite and PEEK?" - was structured according to the PICOS framework: Population (P) PEEK specimens; Intervention (I) surface treatments applied on PEEK; Comparison (C) untreated PEEK (without any experimental surface treatment); Outcome (O) bond strength values measured (MPa); and Study design (S) *in vitro* studies. The experimental surface treatment was defined as any surface modification method applied to PEEK, excluding the application of adhesives specifically indicated for use on PEEK (positive control) and the absence of any treatment (negative control). Studies published in English, Portuguese, or Spanish were considered, without date restrictions. Seven exclusion criteria were applied: PEEK not used for dental purposes; no surface treatment applied to PEEK; absence of a control group (positive or negative); use of surface cleaning methods influencing bond strength; bond strength not assessed immediately (e.g., only after thermocycling); bond strength was not measured of PEEK to resin composite; data not reported in MPa. Nine databases were systematically searched through February 2025. Two independent reviewers identified potentially eligible studies, selected appropriate studies, and extracted relevant data, with discrepancies resolved by a third reviewer. Mean values from identical surface treatments using varying parameters and resin composite brands were pooled. Risk of bias was assessed using the RoBDEMAT tool. The network geometry for intervention comparisons was constructed and visualized using the netgraph function, with intervention rankings quantifying the average probability of superiority among treatments. The search strategy yielded 1,809 relevant titles and abstracts, identifying 14 studies published between 2013 and 2024, which evaluated 18 different surface treatment protocols. Thirteen studies demonstrated that surface treatments in combination with the adhesive significantly improved bond strength compared to control groups. Among all treatments evaluated, sulfuric acid combined with adhesive application achieved the highest bond strength mean values, followed by laser irradiation combined with adhesive. Regarding risk of bias, eight studies were classified as moderate, three as low, and three as high. The surface treatment protocols involving sulfuric acid combined with adhesive application resulted in the highest bond strength between PEEK and resin composite.

Key Words: Dentin-Bonding Agents. Composite Resins. Systematic Review

SUMÁRIO

1 INTRODUÇÃO

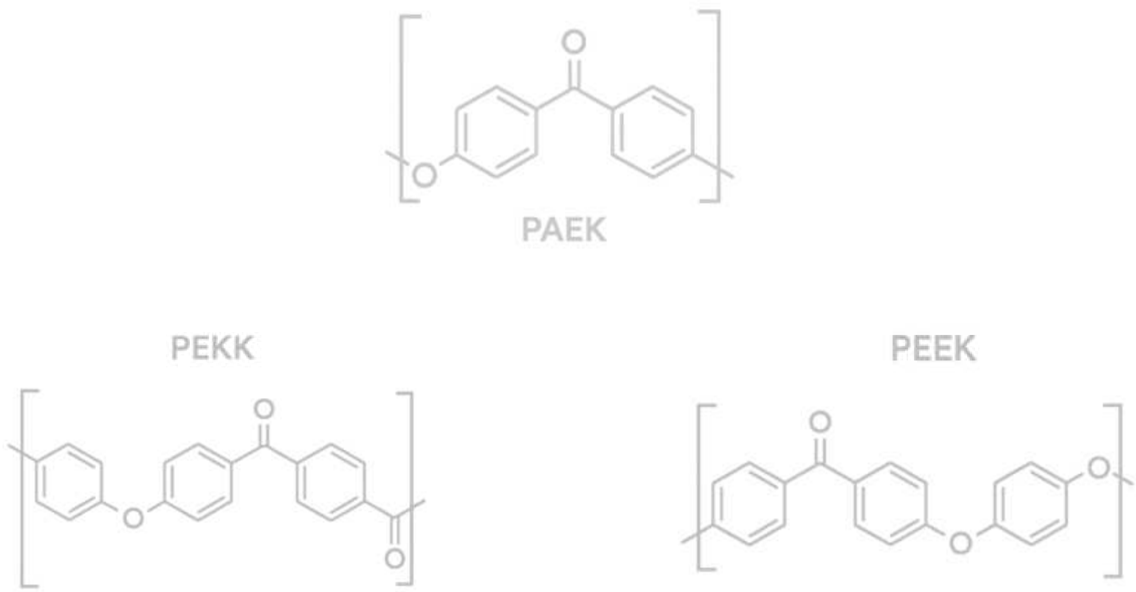
Na Odontologia, é constante a busca por materiais restauradores que aliem funcionalidade, resistência mecânica, biocompatibilidade e estética. Dentre as inovações, os polímeros semicristalinos de alto desempenho destacam-se como materiais utilizados em restaurações indiretas. Os estudos e o uso desses polímeros têm crescido exponencialmente na Odontologia nos últimos anos em função de suas boas propriedades físicas, químicas e biológicas, e do avanço das tecnologias de fabricação subtrativas (CAD/CAM) e aditivas (impressão 3D) (Çakar et al., 2022; Gouveia et al., 2022; Maloo et al., 2022; Taha et al., 2022; Zol et al., 2023; Taymour et al., 2024).

Os polímeros semicristalinos de alto desempenho pertencem à família do poliariletercetona (PAEK), sendo considerados materiais termoplásticos semicristalinos isentos de metacrilato, com alta resistência mecânica e elevada estabilidade química (Çakar et al., 2022; Gouveia et al., 2022; Zol et al., 2023). O PAEK é sintetizado por meio da acilação de Friedel-Crafts e quimicamente é formado por anéis de fenileno que são ligados por meio de pontes de oxigênio a grupos éter e cetona (Smith et al., 2017). A estrutura molecular contém alternadamente grupos cetona e éter (Figura 1), sendo que a proporção e a sequência de éter para cetonas afetam a temperatura de transição vítrea e o ponto de fusão do polímero. Quanto menor a quantidade de grupos éter, maior a temperatura de transição vítrea e ponto de fusão do polímero, além de deixar mais rígida a cadeia do polímero, uma vez que os grupos éter proporcionam flexibilidade à cadeia polimérica (Shibata et al., 1997; Maloo et al., 2022; Villefort et al., 2022).

Diferentes polímeros podem ser criados da família PAEK que se caracterizam por apresentarem diferentes propriedades, como resistência mecânica, estabilidade térmica, densidade e biocompatibilidade (Gouveia et al., 2022; Maloo et al., 2022; Villefort et al., 2022; Zol et al., 2023; Asik & Ozyilmaz, 2024). O polietercetonacetona (PEKK) e o polieteretercetona (PEEK) são materiais termoplástico semicristalinos da família PAEK que são muito utilizados como retentores intrarradiculares (Zhao et al., 2023) e componentes de reabilitações em implantes, próteses fixa e removível (Al-Rabab'ah et al., 2019; Gouveia et al., 2022; Villefort et al., 2022; Cevik et al., 2023; Asik & Ozyilmaz, 2024; Taymour et al., 2024).

O PEKK é um material utilizado principalmente na confecção de implantes, sendo formado por polímero orgânico que possui uma alta quantidade de grupos cetona (Zol et al., 2023) (Figura 1). Dessa forma, o PEKK possui elevada resistência mecânica, alta biocompatibilidade e módulo de elasticidade próximo ao do tecido ósseo (Taha et al., 2022; Zol et al., 2023). Já o PEEK tem se consolidado como o PAEK mais utilizado na Odontologia devido à sua versatilidade e propriedades mecânicas. O seu módulo de elasticidade é semelhante ao da dentina, o que possibilita uma melhor distribuição das forças mastigatórias e reduz o risco de fraturas em comparação a materiais mais rígidos (maior módulo de elasticidade e friáveis, como as cerâmicas (Maloo et al., 2022; Zol et al., 2023; Asik & Ozyilmaz, 2024). O PEEK apresenta uma cadeia linear e semicristalina composta por cadeias aromáticas interligadas por grupos éter e cetona (Zol et al., 2023) (Figura 1), o que lhe confere adequada flexibilidade e elevada resistência mecânica. Além disso, sua resistência química e estabilidade térmica garantem durabilidade mesmo em ambientes bucais adversos (Al-Rabab'ah et al., 2019; Maloo et al., 2022; Zol et al., 2023; Asik & Ozyilmaz, 2024).

Figura 1. Fórmula estrutural dos polímeros semicristalinos de alto desempenho.



Poliariletercetona (PAEK); polietercetonacetona (PEKK); e polieteretercetona (PEEK).

Além das suas propriedades físico-químicas e biológicas, a popularidade do PEEK é também atribuída à sua aplicabilidade na Odontologia. Na implantodontia, o material tem sido utilizado como pilar e estrutura de próteses devido ao seu módulo de elasticidade semelhante ao tecido ósseo. Nas reabilitações protéticas, o PEEK se destaca como uma alternativa as ligas metálicas para a confecção de próteses removíveis. Já na prótese fixa, estudos têm avaliado o PEEK como material para *copings*, núcleos de preenchimento e retentores intrarradiculares (Al-Rabab'ah et al., 2019; Gouveia et al., 2022; Villefort et al., 2022; Cevik et al., 2023; Zhao et al., 2023; Asik & Ozyilmaz, 2024; Taymour et al., 2024).

Contudo, o PEEK apresenta limitações devido à sua cor opaca e baixa translucidez. Especialmente em reabilitações estéticas, o PEEK exige o seu recobrimento com resinas compostas ou cerâmicas para alcançar resultados estéticos satisfatórios (El-Tahwi et al, 2020; Robaian et al., 2025). A baixa energia de superfície e inércia química do PEEK dificultam a sua adesão a substratos dentários e a materiais restauradores (Escobar et al., 2020). Esse desafio tem sido amplamente estudado, e diversas abordagens têm sido desenvolvidas para melhorar a adesão do PEEK. Essas abordagens podem ser físicas (aplicação de laser e plasma) (Stawarczyk et al., 2014b; Zhou et al., 2014; Caglar et al., 2019; Tsuka et al., 2019; Çulhaoğlu et al., 2020; Jahandideh et al., 2020; Attia et al., 2021; Dede et al., 2021; Akay et al., 2022; Taha et al., 2022; Kiliç et al., 2023; Turkkal et al., 2023; Zhao et al., 2023; Babu et al., 2024; Peng et al., 2024), mecânicas (jateamento com óxido de alumínio e desgaste com brocas) (Schmidlin et al., 2010; Stawarczyk et al., 2013; Keul et al., 2014; Zhou et al., 2014; Caglar et al., 2019; Tsuka et al., 2019; Vakkala et al., 2019; Kurahashi et al., 2019; Çulhaoğlu et al., 2020; Ata et al., 2021; Attia et al., 2021; Dede et al., 2021; Mayinger et al., 2021; Adem et al., 2022; Gouveia et al., 2022; Taha et al., 2022; Kiliç et al., 2023; Soliman et al., 2023a; Soliman et al., 2023b; Zhao et al., 2023; Ozdogan & Tosun, 2024; Peng et al., 2024; Sahin et al., 2024; Liu et al., 2025) e químicas (ácidos fortes, como o ácido sulfúrico e a solução de Piranha [mistura de 3:1 de ácido sulfúrico:peróxido de hidrogênio], adesivos e *primers*) (Schmidlin et al., 2010; Stawarczyk et al., 2013; Keul et al., 2014; Sproesser et al., 2014; Stawarczyk et al., 2014a; Zhou et al., 2014; Kurahashi et al., 2019; Çulhaoğlu et al., 2020; Ata et al., 2021; Attia et al., 2021; Dede et al., 2021; Zhang et al., 2021; Adem et al., 2022; Kiliç et al., 2023; Soliman et al., 2023a; Turkkal et al., 2023; Babu et al., 2024; Ozdogan & Tosun, 2024; Peng et al., 2024; Liu et al., 2025). Esses protocolos modificam o PEEK quimicamente, alterando a sua morfologia com objetivo de aumentar a energia de superfície, e/ou fisicamente, criar microrretenções na superfície do PEEK que favoreçam o embricamento mecânico dos materiais resinosos e, consequentemente, a adesão (Çulhaoğlu et al., 2020).

Apesar dos avanços, ainda não há consenso sobre o protocolo de tratamento de superfície mais eficaz para o PEEK. A falta de padronização desses protocolos dificulta a comparação entre estudos e a determinação do melhor protocolo para aplicação clínica. Além disso, o conhecimento sobre o potencial adesivo de cada protocolo e as limitações de cada tratamento é limitado (Escobar et al., 2020; Gouveia et al., 2022; Taymour et al., 2024). Por exemplo, o uso de ácidos fortes, embora eficaz e restrito em laboratório, apresenta riscos associados ao manuseio em ambiente clínico, limitando sua adoção rotineira (Sproesser et al., 2014; Gouveia et al., 2022; Asik & Ozyilmaz, 2024). Além disso, tratamentos químicos e mecânicos promovem a formação de resíduos (Escobar et al., 2020; Adem et al., 2022; Taha et al., 2022).

Uma revisão sistemática com metanálise sobre a adesão de PAEKs foi publicada em 2020, sendo que o artigo mais recente dessa revisão é de março de 2019 (Gama et al., 2020). Passados quase 6 anos, novos estudos com diversos protocolos de tratamento de superfície de PAEKs foram publicados avaliando a adesão. O trabalho de Gama et al. (2020) identificou 235 *reports*, sendo 33 no banco de dados PubMed. Utilizando a mesma estratégia de busca, na presente data (07/05/2025) podemos encontrar 139 *reports* no PubMed, um aumento de 321,2% em apenas um banco de dados. Além disso, essa revisão avaliou a adesão de PAEKs, incluindo PEEK e PEKK. Dessa forma, é importante realizar uma atualização na revisão sistemática dos estudos que avaliam protocolos de tratamento de superfície especificadamente do PEEK na Odontologia. Dessa forma, o objetivo do presente estudo foi avaliar a influência dos tratamentos de superfície na resistência de união entre o PEEK e as resinas compostas, por meio de uma revisão sistemática com metanálise em rede.

2 ARTIGO

Dental PEEK surface treatments and bond strength to resin composites: network meta-analysis of in vitro studies

Abstract

This systematic review and network meta-analysis assessed the effect of surface treatments on the bond strength of polyetheretherketone (PEEK) to resin composites. Following PRISMA guidelines, the research question was structured using the PICOS framework and focused on *in vitro* studies. Eligible studies were *in vitro*, with no date restriction, and published in English, Portuguese, or Spanish. Nine databases were searched up to February 2025. Exclusion criteria included non-dental use of PEEK; no surface treatment performed; absence control group (positive or negative); use of cleaning methods affecting adhesion; lack of immediate bond strength assessment; bond strength not tested between PEEK and resin composite; results not expressed in MPa. A total of 1,809 records were screened, leading to 14 included studies published between 2013 and 2024, covering 18 surface treatment protocols. Data were extracted and pooled from studies using comparable surface treatments with different parameters. Risk of bias was assessed with the RoBDEMAT tool. Thirteen studies showed improved bond strength after surface treatment and adhesive application. Sulfuric acid combined with adhesive promoted the highest bond strength, followed by laser treatment with adhesive. Most studies were rated as having moderate risk of bias. Sulfuric acid combined with adhesive was the most effective protocol for enhancing the bond strength between PEEK and resin composites.

Keywords: acid etching, adhesion, PEEK, resin-based materials.

1. Introduction

Restorative dentistry has increasingly embraced materials that combine functionality, mechanical strength, biocompatibility, and esthetics. Among these, high-performance thermoplastic polymers from the polyaryletherketone (PAEK) family have gained prominence due to their favorable physical, chemical, and biological properties, as well as their compatibility with digital manufacturing techniques such as CAD/CAM milling and 3D printing (1-6).

Structurally, PAEKs consist of aromatic rings linked by ether and ketone groups, with the ratio between these functional groups modulating properties such as flexibility and thermal stability (7,8). The two most relevant derivatives of the PAEK family used in dentistry, polyetherketoneketone (PEKK) and polyetheretherketone (PEEK), share fundamental similarities but differ in their ketone content, which affects their mechanical properties and clinical applications (2,5,9).

Among PAEK materials, PEEK has become the most widely used in dental applications. Its elastic modulus closely matches that of dentin, which contributes to favorable stress distribution and reduces the risk of catastrophic fractures. This represents a significant advantage compared to ceramics and metals (3,10). Additionally, PEEK exhibits high fatigue resistance, radiolucency, and dimensional stability under intraoral conditions (5,11). These characteristics have expanded its use across prosthetic and implant-supported rehabilitations, from frameworks for fixed and removable prostheses to posts, abutments, and endocrowns (12,13).

Despite these advantages, PEEK poses challenges when adhesive procedures are required. Its intrinsic chemical structure and low surface energy hinder bonding with resin-based materials and dental tissues, necessitating surface treatment to enhance adhesion (14). A broad range of surface treatments has been proposed, including physical (e.g., laser irradiation, plasma) (4,13,15-27), mechanical (e.g., airborne-particle abrasion, rotary instrumentation) (2,4,13,16-19,21,22,24,27-40), and chemical approaches (e.g., sulfuric acid etching, Piranha solution, primers) (16,19,21,22,24-30,32,33,35,36,38,40-43). These strategies aim to increase surface roughness and modify the surface chemistry of PEEK, thereby enhancing its surface area, surface energy, and wettability. In addition, they promote micromechanical interlocking and chemical interaction with resin-based materials, ultimately improving adhesion (2,19).

However, current evidence remains fragmented. Studies differ substantially in their experimental conditions, types of surface treatment, bonding agents, testing protocols, and performance metrics. The lack of standardization not only complicates comparisons across studies but also limits the potential for clinical application (2,6,14).

In 2020, a systematic review with meta-analysis by Gama et al. (44) evaluated adhesion to materials from the PAEK family, including both PEEK and PEKK. The review included studies published up to March 2019 and identified a total of 235 reports, of which only 33 were indexed in PubMed. Since then, research on this topic has grown substantially. A recent search using the same strategy retrieved 139 records in PubMed alone, representing a 321.2% increase in this single database. This substantial growth highlights the emergence of numerous studies investigating different surface treatment protocols for PAEK materials, underscoring the need for an updated systematic review to synthesize the current evidence.

Given the exponential growth of literature and the need to critically assess the adhesive behavior of PEEK as a distinct substrate, an updated systematic review is both timely and necessary. Unlike previous reviews that grouped all PAEK-based materials, it is important to specifically evaluate PEEK, including its surface treatment methods and adhesion protocols, within the dental context. This focused synthesis aims to bridge the gap between in vitro findings and clinical applicability, thereby guiding future research and supporting evidence-based decision-making in adhesive restorative dentistry. Therefore, the aim of this study was to evaluate the influence of surface treatments on the bond strength between PEEK and resin composites through a systematic review and network meta-analysis.

2. Material and methods

2.1. Protocol and registration

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (45). The study protocol was prospectively registered in the Open Science Framework (OSF) registry (https://doi.org/10.17605/OSF.IO/JGRDE).

2.2. Eligibility criteria

The following research question was formulated: “Do surface treatments influence the bond strength between resin composite and PEEK?”. This question was structured using the PICOS framework (Population, Intervention, Comparison, Outcome, and Study design), as follows:

Population (P): PEEK specimens;

Intervention (I): surface treatments applied on PEEK;

Comparison (C): untreated PEEK (without any experimental surface treatment);

Outcome (O): bond strength values (measured in MPa);

Study design (S): *in vitro* studies.

The experimental surface treatment was defined as any surface modification method applied to PEEK, excluding the application of adhesives specifically indicated for use on PEEK (positive control) and the absence of any treatment (negative control). This systematic review included *in vitro* studies that investigated the effect of surface treatments on the bond strength between resin composites and PEEK in dental applications. Only studies published in English, Portuguese, or Spanish were considered, with no date restriction. Studies were excluded if they met any of the following criteria: (i) PEEK was not used for dental purposes; (ii) no surface treatment was applied to PEEK; (iii) absence of a control group (positive or negative); (iv) surface cleaning methods that could influence bonding; (v) bond strength not assessed immediately (e.g., only after thermocycling); (vi) bond strength was not assessed of PEEK to resin composite; or (vii) results were not reported in megapascal (MPa). Manufacturer-recommended bonding agents used as positive controls included bond.lign (bredent GmbH & Co.KG, Senden, Bavaria, Germany), visio.link (bredent GmbH & Co.KG, Senden, Bavaria, Germany), Signum® Bond (Kulzer GmbH, Hanau, Hesse, Germany), and PEKKbond (Anaxdent, Stuttgart, Baden-Württemberg, Germany).

2.3. Information sources and search strategy

A systematic search was carried out in the following electronic databases: MEDLINE via PubMed, LILACS and BBO via BVS, and Embase via Elsevier. Additionally, grey literature was explored through Google Scholar, ProQuest, and the institutional repositories of the University of Campinas (UNICAMP), University of São Paulo (USP), and São Paulo State University (UNESP). To ensure completeness, the reference lists of all included studies were manually screened for additional relevant publications. The search was completed in February 2025. Both Medical Subject Headings (MeSH) and free-text terms were adapted to suit the indexing characteristics of each database (Table 1).

Table 1. Search strategy used in each electronic database.

MEDLINE via PubMed	**#1.** "Ethers, Cyclic"[Mesh] OR (Cyclic Ethers) OR (Cyclic Ether) OR (Ether, Cyclic) OR "Ketones"[Mesh] OR Ketone OR "polyetheretherketone" [Supplementary Concept] OR PEEK OR "polyether ether ketone" OR "poly ether ether ketone" OR "polyether ketoneether" OR "polyether ketone ether" **#2.** "Dentin-Bonding Agents"[Mesh] OR (Agent, Dentin-Bonding) OR (Agents, Dentin-Bonding) OR (Dentin Bonding Agents) OR (Dentin-Bonding Agent) OR (Bonding Agents, Dentin) OR (Agent, Dentin Bonding) OR (Agents, Dentin Bonding) OR (Bonding Agent, Dentin) OR (Dentin Bonding Agent) OR "Dental Bonding"[Mesh] OR (Bonding, Dental) OR (Cure of Orthodontic Adhesives) OR (Orthodontic Adhesives Cure) OR (Curing, Dental Cement) OR (Dental Cement Curing) OR "Surface Properties"[Mesh] OR (Properties, Surface) OR (Property, Surface) OR (Surface Property) OR "surface treatment" OR "surface treatments" OR "roughness" OR "Adhesives" OR "Adhesive" **#3.** "Tensile Strength"[Mesh] OR (Strengths, Tensile) OR (Strength, Tensile) OR (Tensile Strengths) OR "Shear Strength"[Mesh] OR (Strength, Shear) OR "push-out" OR "pull-out" OR "bond strength" OR "bond strengths" **#4.** #1 AND #2 AND #3
LILACS and BBO via BVS	**#1.** MH:”Éteres Cíclicos” OR (Éteres Cíclicos) OR (Ethers, Cyclic) OR (Éteres Cíclicos) OR (Éter Cíclico) OR MH:D02.355.291$ OR MH:D04.345.241$ OR Ketone OR “polyetheretherketone” OR PEEK OR “polyether ether ketone” OR “poly ether ether ketone” OR “polyether ketoneether” OR “polyether ketone ether” **#2.** MH:"Adesivos Dentinários" OR (Adesivos Dentinários) OR (Dentin-Bonding Agents) OR (Recubrimientos Dentinários) OR (Adesivo Dentinário) OR (Agente de Adesão Dentinária) OR (Camada Híbrida) OR (Hibridização Dentinária) OR (Impermeabilização Dentinária) OR MH:D25.339.291.300$ OR MH:J01.637.051.339.291.300 OR MH:"Colagem Dentária" OR (Dental Bonding) OR (Recubrimiento Dental Adhesivo) OR (Aderência Dental) OR (Aderência Dentária) OR (Cura de Adesivos Ortodônticos) OR MH:E06.095$ OR MH:"Propriedades de Superfície" OR (Surface Properties) OR (Propiedades de Superficie) OR (Rugosidade de Superfície) OR MH:G02.860$ OR "roughness" OR "Adhesives" OR "Adhesive" **#3.** MH:"Resistência à Tração" OR (Tensile Strength) OR (Resistencia a la Tracción) OR (Força de Tensão) OR MH:G01.374.850$ OR MH:"Resistência ao Cisalhamento" OR (Shear Strength) OR (Resistencia al Corte) OR (Resistência ao Corte) OR MH:G01.374.820$ OR "push-out" OR "pull-out" OR "bond strength" OR "bond strengths" **#4.**

	#1 AND #2 AND #3
Embase via Elsevier	**#1.** 'ether derivative'/exp OR 'cyclic ether' OR 'dicycloether' OR 'diethylether derivative' OR 'ether analog' OR 'ethers' OR 'ethers, cyclic' OR 'ethyl ethers' OR 'methyl ethers' OR 'ether derivative' OR 'ketone'/exp OR 'ketones' OR 'ketone' OR 'polyetheretherketone' OR PEEK OR 'polyether ether ketone' OR 'poly ether ether ketone' OR 'polyether ketoneether' OR 'polyether ketone ether' **#2.** 'dentin bonding agent'/exp OR 'dentin bonding agents' OR 'dentin-bonding agents' OR 'Gel Etchant' OR 'Optibond Solo Plus' OR 'Premise Flow' OR 'Vertise Flow' OR 'dentin bonding agent' OR 'dentin bonding agent'/exp OR 'chemically-cured dental bonding' OR 'dental bonding, chemically-cured' OR 'dental bonding' OR 'surface property'/exp OR 'capillarity' OR 'capillary action' OR 'surface' OR 'surface properties' OR 'surface property' OR 'roughness' OR 'Adhesives' OR 'Adhesive' **#3.** 'tensile strength'/exp OR 'tensile strength' OR 'shear strength'/exp OR 'shear strength' OR 'push-out' OR 'pull-out' OR 'bond strength' OR 'bond strengths' **#4.** #1 AND #2 AND #3 **#5.** #4 AND [embase]/lim NOT ([embase]/lim AND [medline]/lim)
Google Scholar, ProQuest, UNICAMP and UNESP libraries	**#1.** ("polyetheretherketone" OR PEEK) **#2.** ("surface treatment") **#3.** ("microtensile bond strength" OR "microshear bond strength" OR "push-out bond strength" OR "pull-out bond strength") **#4.** #1 AND #2 AND #3
USP library	**#1.** ("polyetheretherketone" OR PEEK)

2.4. Study selection and data extraction

All records were archived and managed using the Rayyan reference management platform (Rayyan Systems Inc., Cambridge, MA, USA). Duplicate references were manually identified and removed within Rayyan. Study selection was performed in two phases. In the first phase, titles and abstracts were independently screened by two independent reviewers (R.P.V. and S.G.O.) to identify potentially eligible studies. When there was any uncertainty, the study was retained for full-text evaluation. Clearly irrelevant or non-compliant reports were excluded at this stage. Any disagreements were resolved through discussion and consensus after disabling Rayyan's blinding feature.

In the second phase, studies that appeared to meet the inclusion criteria were subjected to full-text review. When multiple reports referred to the same study, they were grouped and analyzed as one. Full-text articles were critically assessed based on the predefined exclusion criteria. In this phase, the same two reviewers (R.P.V. and S.G.O.) independently screened the studies and extracted the relevant data. Any disagreements or uncertainties were resolved by discussion or by consulting a third reviewer (V.G.A.P.).

Mean values were combined from studies applying the same surface treatment but using different parameters, such as particle size and type of aluminum oxide, application time, airborne-particle abrasion pressure, laser type and frequency, as well as sulfuric acid concentration and exposure time. Additionally, data from different brands of resin composite were grouped. When results were originally reported as medians with ranges (minimum and maximum values), they were converted into means and standard deviations. These transformations were performed in accordance with the recommendations outlined in the Cochrane Handbook for Systematic Reviews of Interventions (49). For studies in which bond strength results (in MPa) were presented only in graphical form, numerical values were extracted using the WebPlotDigitizer tool (https://automeris.io/). All extracted data were recorded and organized using Microsoft® Excel® 365 (Microsoft Corporation, Redmond, WA, USA), following a structured template designed for systematic reviews. The collected information included Rayyan ID, author(s), year of publication, study title, characteristics of HPP specimens, restorative materials, control groups, experimental groups, number of specimens, type of bond strength test, and the main findings. When necessary, the corresponding authors were contacted by email to clarify uncertainties or to obtain missing data.

2.5. Quality assessment (risk of bias)

The risk of bias assessment for the included studies was independently performed by two reviewers (R.P.V. and S.G.O.) using the RoBDEMAT tool (46), a validated instrument specifically designed to guide the evaluation and reporting of preclinical studies in dental materials research. This tool evaluates nine items distributed across four domains: planning and allocation (D1), specimen preparation

(D2), outcome assessment (D3), and data analysis and reporting (D4). For each signaling question within the domains, responses were categorized as “sufficiently reported” (green), “insufficiently reported” (yellow), “not reported” (red) or “not applicable” (grey). A summary table was constructed to present the overall risk of bias findings for each study. Any disagreements between reviewers were resolved through discussion, and when consensus could not be reached, a third reviewer (V.G.A.P.) was consulted.

2.6. Statistical analysis

The netgraph function was used to construct and visualize the geometry of the network of comparisons among interventions. In the resulting plot, nodes represent the evaluated interventions, and edges indicate the direct comparisons made between them in the included studies. Node size is proportional to the number of participants who received each intervention, while edge thickness reflects the number of studies contributing to each direct comparison.

To synthesize the results, a frequentist network meta-analysis was performed. Since the network consisted of two disconnected sub-networks, an additive model was applied. This approach enables the estimation of treatment effects by incorporating a specific intercept for each sub-network, thereby allowing for a valid analysis without violating the assumption of network connectivity.

Intervention rankings were determined using P-scores, which quantify the average probability of each treatment being superior to the others. A league table was generated to display all pairwise comparisons, presenting the point estimates along with their respective 95% confidence intervals. All analyses were conducted using the netmeta package (version 3.2-0) in the R statistical computing environment.

3. Results

3.1. Search strategy

A total of 1,809 potentially relevant records were identified through the search strategy. After removing duplicates, 1,405 records remained and were screened by title and abstract. Of these, 1,303 were excluded based on the predefined inclusion and exclusion criteria. Among the 22 reports selected for full-text reading, two could not be retrieved (47,48). In total, 14 studies met the eligibility criteria and were included in the quantitative analysis (2,19,20,22,23,27,29,31,33,35-37,42,43) (Table 2). The search strategy details are illustrated in a PRISMA flowchart (Figure 1).

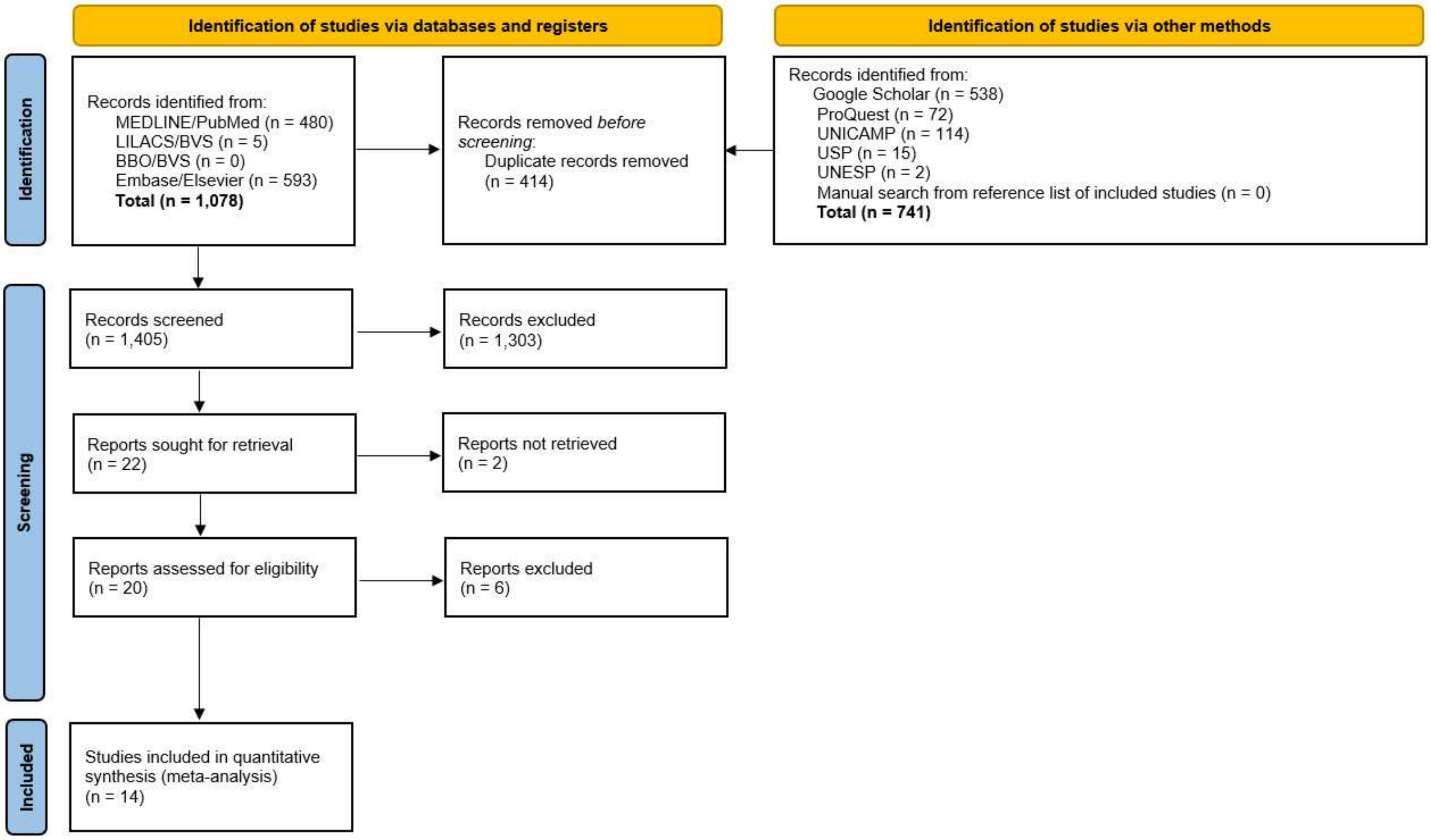
Table 2. Search strategy details analyzed in each selected study.

(reference) Study	n	Groups			Main conclusion
		Control -	Control +	Experimental	
(2) Gouveia et al. (2022)	15	No	Yes	1 - Airborne-particle abrasion with alumina particles (110 μm, 15 s, 20 bar).	Airborne-particle abrasion with 110 μm alumina improved bond strength.
(19) Çulhaoğlu et al. (2020)	11	No	Yes	1 - Airborne-particle abrasion (silica-coated - CoJet™ system; 15 s, pressão 3 bar); 2 - Acetone 99% (60 s); 3 - Sulfuric acid 98% (60 s); 4 - Airborne-particle abrasion with alumina particles (110 μm, 15 s, 2 bar); 5 - laser Yb:PL (5 W).	The highest bond strength values were observed with sulfuric acid.
(20) Jahandideh et al. (2020)	20	No	Yes	1 - CO_2 laser (4 W, 50 s); 2 - Er:YAG laser (1,5 W, 20 s).	The highest bond strength values were achieved with Er:YAG laser treatment.
(22) Dede et al. (2021)	16	No	Yes	1 - Plasma (13,5 W, 90 s); 2 - Plasma brush (30 W, 90 s); 3 - Airborne-particle abrasion with silica-coated alumina particles (110 μm, 10 s, 2.5 MPa); 4 - Airborne-particle abrasion with silica-coated alumina particles + plasma; 5 - Airborne-particle abrasion with silica-coated alumina particles + plasma brush; 6 - Sulfuric acid 98% (60 s); 7 - Sulfuric acid 98% (60 s) + plasma; 8 - Sulfuric acid 98% (60 s) + plasma brush.	Sulfuric acid resulted in the highest bond strength value.

(23) Akay et al. (2022)	10	Yes	Yes	1 - Argon 100% plasma (35 min.); 2 - Argon 50% + oxygen 50% plasma (35 min.); 3 - Argon 50% + nitrogen 50% plasma (35 min.); 4 - Argon 75% + oxygen 12,5% + nitrogen 12,5% plasma (35 min.).	Argon plasma and argon + oxygen + nitrogen plasma groups showed higher bond strength values.
(27) Peng et al. (2024)	10	No	Yes	1 - Airborne-particle abrasion with alumina particles (50 µm, 10 s, 2 MPa); 2 - Sulfuric acid 98% (60 s); 3 - Nd:YVO4 laser, 50 μm^2.	Laser surface treatment of PEEK has the potential to enhance bond strength.
(29) Stawarczyk et al. (2013)	15	Yes	No	1 - Sulfuric acid 98% (60 s); 2 - Airborne-particle abrasion with alumina particles (50 µm, 10 s, 2 bar); 3 - Airborne-particle abrasion with alumina particles (100 µm, 10 s, 2 bar); 4 - Airborne-particle abrasion with alumina particles - Rocatec™ Pre and Rocatec™ Plus 12 + silane (5 min.).	The highest bond strength values can be achieved following sulfuric acid treatment.
(31) Vakkala et al. (2018)	8	No	Yes	1 - Airborne-particle abrasion with alumina particles (100 µm, 60 s, 2 atm) + Piranha solution (30 s).	Combined airborne-particle abrasion and acid treatment yield superior results.
(33) Ata et al. (2021)	10	No	Yes	1 - Sulfuric acid 98% (60 s); 2 - Airborne-particle abrasion with alumina particles (110 µm, 60 s, 2 bar).	Surface treatment of PEEK plays a key role in bond strength.
(35) Adem et al. (2022)	12	No	Yes	1 - Airborne-particle abrasion with alumina particles (50 µm, 10 s, 2 MPa). 2 - Sulfuric acid 98% (60 s); 3 - Airborne-particle abrasion with alumina particles + sulfuric acid 98% (60 s).	Sulfuric acid resulted in the highest bond strength. Airborne-particle abrasion negatively affected bond strength.

(36) Soliman et al. (2023)	6	No	Yes	1 - Sulfuric acid 98% (60 s); 2 - Airborne-particle abrasion with alumina particles (50 µm, 10 s, 0.55 MPa).	Sulfuric acid and airborne-particle abrasion treatment led to an increase in bond strength.
(37) Soliman et al. (2023)	10	No	Yes	1 - Airborne-particle abrasion with alumina particles (50 µm, 10 s, 0.55 MPa); 2 - Airborne-particle abrasion with alumina particles (50 µm, 10 s, 0.55 MPa) + 5.000 thermocycling (5°C e 55°C, dwell time 30 s).	All tested CAD/CAM polymers can be repaired after airborne-particle abrasion.
(42) Stawarczyk et al. (2014)	20	Yes	Yes	1 - Sulfuric acid 98% (60 s); 2 - Piranha solution (30 s).	The adhesives Signum® PEEK Bond and visio.link should be applied to ensure durable bonding. Acid pretreatment is not required.
(43) Zhang et al. (2021)	13	No	Yes	1 - Sulfuric acid 98% (5 s); 2 - Sulfuric acid 98% (30 s); 3 - Sulfuric acid 98% (60 s); 4 - Sulfuric acid 98% (90 s); 5 - Sulfuric acid 98% (120 s); 6 - Sulfuric acid 98% (300 s).	Thirty seconds was considered the optimal acid etching time for PEEK.

Figure 1. Search flowchart of the study selection according to the PRISMA 2020 statement.



The included studies were published between 2013 and 2024, all in English. Twelve studies (2,19,20,22,23,27,29,31,33,35,37,43) assessed the effect of surface treatments on the bond strength between PEEK and resin composite using the shear bond strength test, one study used the micro push-out test (36), and another employed the tensile bond strength test (42). In all studies (2,19,20,22,23,27,29,31,33,35-37,42,43), PEEK specimens were polished using silicon carbide abrasive sandpaper(s) to standardize the surface. Two studies (31,36) did not report whether surface polishing was performed.

Two studies (23,42) included negative and positive control groups, while the remaining studies had only one control group, with 11 employing a positive control (2,19,20,22,27,31,33,35-37,43) and one using a negative control (29). In all studies, the manufacturer-recommended adhesive was applied after surface treatment, except in Akay et al., 2022 (23), Stawarczyk et al., 2013 (29), Adem et al., 2022 (35), and Stawarczyk et al., 2014 (42), where in some groups, the resin composite was applied directly after the surface treatment. Visio.link was the most frequently used adhesive

(85.7%). Dede et al., 2022 (22) used PEKKbond both as a positive control and after experimental surface treatment.

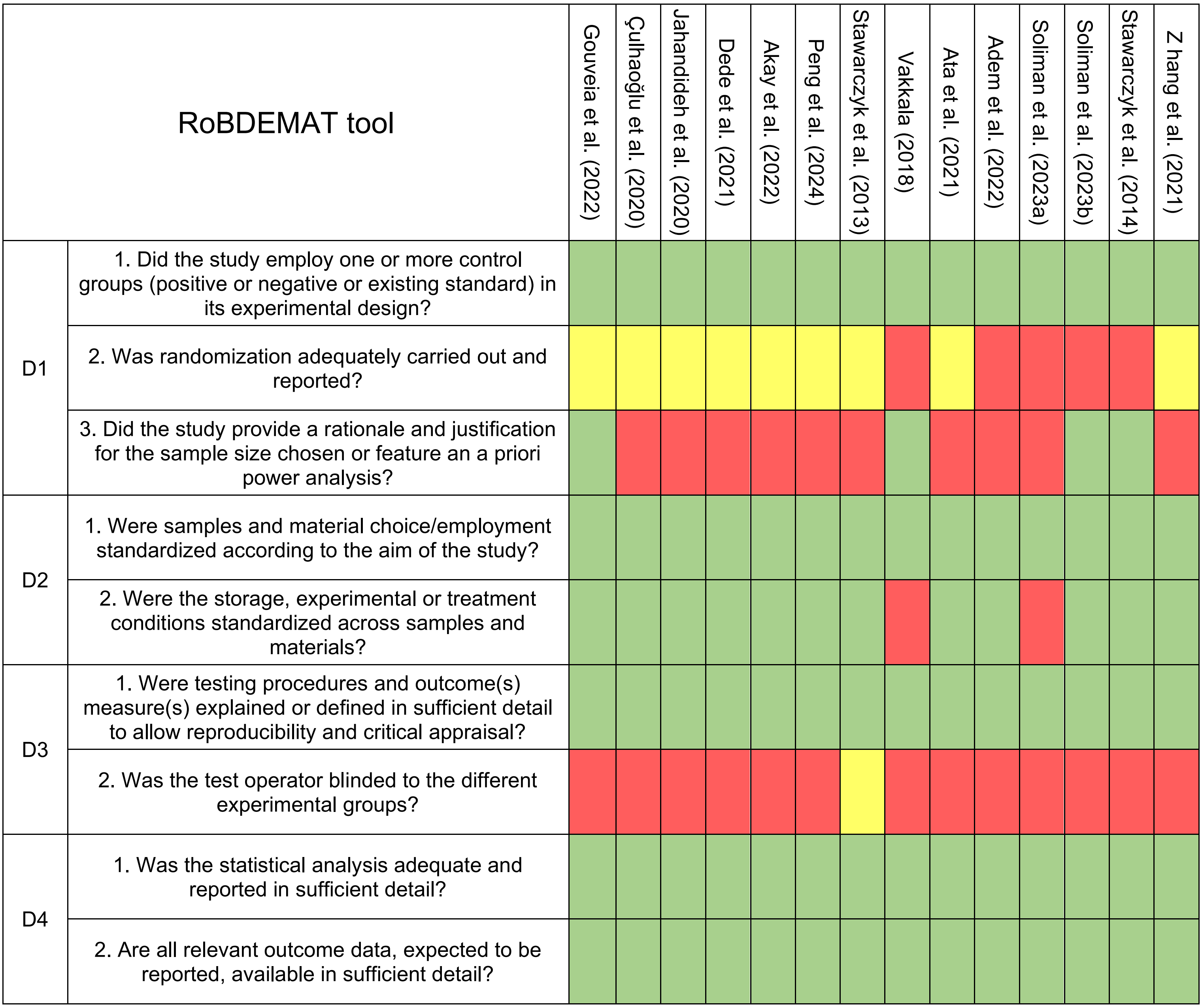
All included studies (2,19,20,22,23,27,29,31,33,35-37,43) demonstrated that surface treatments improved bond strength compared to the control group, except or Stawarczyk et al., 2014 (42). Only seven studies (19,22,27,29,33,35,36) compared different types of surface treatment, among which five (19,22,29,35,36) reported that sulfuric acid etching achieved the highest bond strength values between PEEK and resin composite.

3.3. Risk of bias

Eight studies included in this systematic review were classified as moderate risk of bias (19,20,22,23,27,29,33,43), as they reported at least six out of nine items as "sufficiently reported". Three studies (2,37,42) were classified as low risk of bias, with seven items classified as "sufficiently reported". Three studies were considered to have a high risk of bias: one presented only five items as "sufficiently reported" (36), and two had at least three items rated as "not reported" (31,35).

None of the studies adequately described the random allocation of samples (D1), and only 28% of the studies (2,31,37,42) sufficiently reported a sample size calculation. Two studies (31,36) were classified as "not reported" regarding the standardization of storage, experimental conditions, or treatment protocols (D2). Regarding operator blinding (D3), no study reported this procedure, except for one study (29), which was rated as "insufficiently reported". All studies were classified as "sufficiently reported" for bias in data treatment and outcome reporting (D4). A summary of the risk of bias across the 14 studies is illustrated in Figure 2.

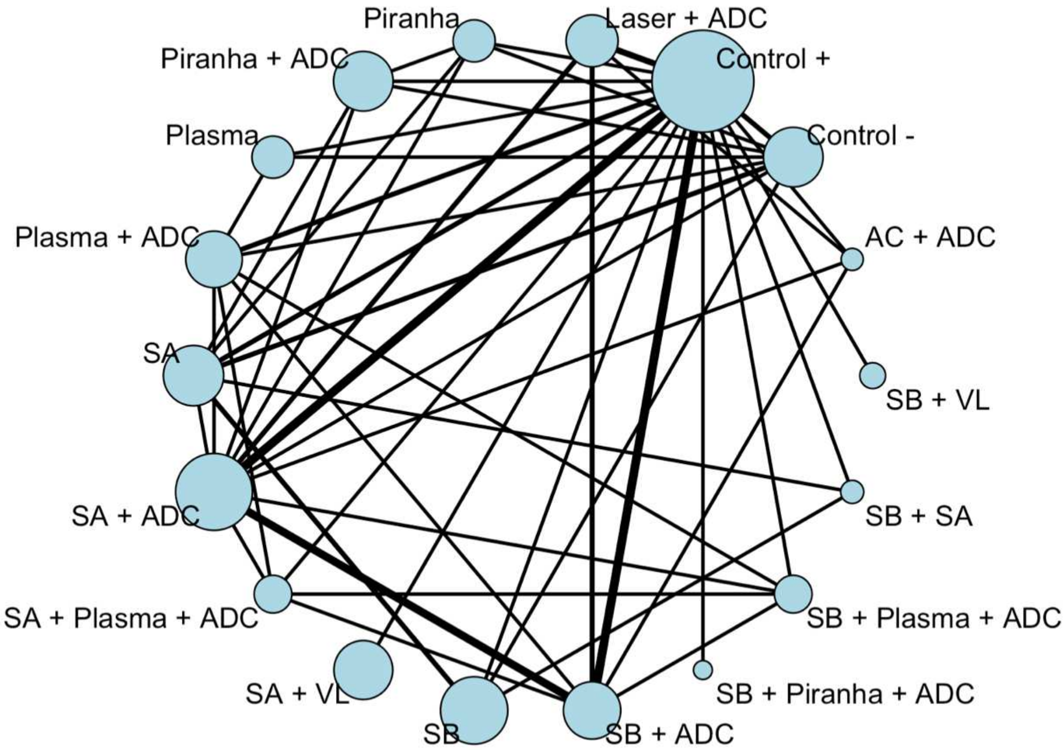
Figure 2. Risk of bias for each included study according to the RoBDEMAT tool.



3.4. Meta-analysis

A total of 14 studies were included, comprising 1,186 observations and evaluating 18 different surface treatments (Figure 3). Following the quantitative analysis (Table 2), given the number of studies (2,19,20,23,27,31,33,35-37,42,43) that used visio.link as the bonding agent for PEEK, the positive control was subdivided into two subgroups to allow a more accurate comparison: visio.link (VL), and a second group comprising bond.lign, Signum® Bond, and PEKKbond, referred to as the adhesive control (ADC).

Figura 3. Network of comparisons. Each node represents an intervention, and the edges indicate direct comparisons between the interventions.

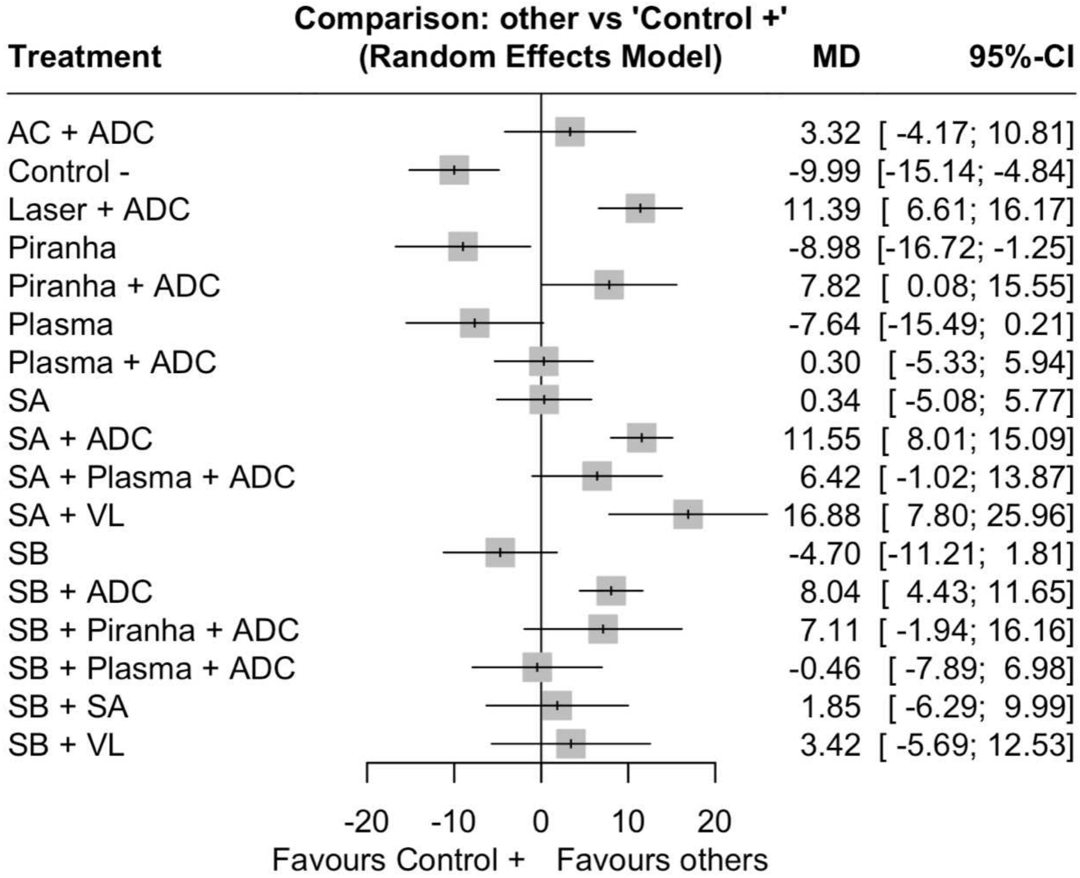


Legend: AC = acetone; ADC = adhesive control; VL = visio.link; SB = airborne-particle abrasion; SA: sulfuric acid.

The estimated effects of the treatments were expressed as mean differences (MD) with corresponding 95% confidence intervals (CI) (Figure 4). The following treatments showed statistically significant superiority compared to the Control+ group: SA + VL (MD = 16.88; 95% CI [7.80; 25.96]; $\rho = 0.0003$); SA + ADC (MD = 11.55; 95% CI [8.01; 15.09]; $\rho < 0.0001$); Laser + ADC (MD = 11.39; 95% CI [6.61; 16.17]; $\rho < 0.0001$); SB + ADC (MD = 8.04; 95% CI [4.43; 11.65]; $\rho < 0.0001$); Piranha + ADC (MD = 7.82; 95% CI [0.08; 15.55]; $\rho = 0.0478$).

In addition, the Control- group showed a significantly lower outcome compared to the Control+ group (MD = -9.99; 95% CI [-15.14; -4.84]; $\rho = 0.0001$), supporting the appropriateness of the positive control as a reference in the network. Other treatment comparisons did not demonstrate statistically significant differences relative to the reference group ($\rho > 0.05$). For example, Plasma (MD = -7.64; 95% CI [-15.49; 0.21]; $\rho = 0.0565$) showed a borderline ρ-value, suggesting a possible trend toward inferiority, and SA + Plasma + ADC (MD = 6.42; 95% CI [-1.02; 13.87]; $\rho = 0.0907$) also showed no significant difference.

Figure 4. Forest plot with the comparison of all interventions with the Control+ group.



Overall heterogeneity was substantial, with $\tau^2 = 20.80$, $\tau = 4.56$, and $I^2 = 97.5\%$ (95% CI [96.8%; 98.0%]), indicating high variability among the included studies. Inconsistency tests revealed significant differences both within designs ($Q_{within} = 18.15$; df = 2; p = 0.0001) and between designs ($Q_{between} = 652.23$; df = 15; $\rho < 0.0001$), confirming the presence of inconsistency across the comparison network.

Based on the P-score ranking, the most effective surface treatments were: SA + VL (P-score = 0.97), SA + ADC (0.89), Laser + ADC (0.87), SB + ADC (0.74), and Piranha + ADC (0.73). In contrast, the lowest-performing interventions were Control- (P-score = 0.05), Piranha alone (0.08), and Plasma (0.11), suggesting limited effectiveness compared to the reference group (Figure 5).

Figure 5. League table of the comparisons.

SA + VL																	
5.33 [-4.41; 15.07]	SA + ADC																
5.49 [-4.77; 15.75]	0.16 [-5.01; 5.33]	Laser + ADC															
8.84 [-0.93; 18.61]	3.51 [-0.44; 7.46]	3.35 [-1.85; 8.55]	SB + ADC														
9.06 [-2.86; 20.99]	3.73 [-4.19; 11.66]	3.58 [-5.33; 12.49]	0.22 [-8.07; 8.52]	Piranha + ADC													
9.77 [-3.04; 22.58]	4.44 [-5.27; 14.15]	4.28 [-5.95; 14.51]	0.93 [-8.81; 10.67]	0.71 [-11.20; 12.61]	SB + Piranha + ADC												
10.46 [-1.28; 22.19]	5.13 [-2.44; 12.69]	4.97 [-3.58; 13.51]	1.62 [-5.98; 9.21]	1.39 [-9.10; 11.88]	0.69 [-11.03; 12.40]	SA + Plasma + ADC											
13.46 [0.60; 26.32]	8.13 [-1.64; 17.90]	7.97 [-2.31; 18.26]	4.62 [-5.18; 14.42]	4.40 [-7.55; 16.35]	3.69 [-9.14; 16.52]	3.00 [-8.76; 14.76]	SB + VL										
13.56 [1.79; 25.33]	**8.23 [0.61; 15.85]**	**8.07 [0.14; 16.01]**	4.72 [-2.89; 12.33]	4.50 [-6.08; 15.07]	3.79 [-7.95; 15.54]	3.11 [-7.14; 13.35]	0.10 [-11.69; 11.89]	AC + ADC									
15.03 [2.84; 27.22]	**9.70 [1.04; 18.36]**	**9.54 [0.17; 18.91]**	6.19 [-2.62; 15.00]	5.97 [-4.69; 16.62]	5.26 [-6.91; 17.43]	4.57 [-6.34; 15.49]	1.57 [-10.64; 13.78]	1.47 [-9.52; 12.46]	SB + SA								
16.54 [5.96; 27.11]	**11.21 [5.24; 17.17]**	**11.05 [3.97; 18.12]**	**7.70 [1.40; 13.99]**	7.47 [-0.74; 15.68]	6.77 [-3.78; 17.31]	6.08 [-2.91; 15.06]	3.08 [-7.53; 13.68]	2.97 [-6.13; 12.07]	1.50 [-6.52; 9.53]	SA							
16.58 [5.89; 27.26]	**11.25 [5.21; 17.28]**	**11.09 [3.95; 18.22]**	**7.74 [1.60; 13.87]**	7.51 [-1.67; 16.69]	6.81 [-3.85; 17.46]	6.12 [-2.09; 14.33]	3.12 [-7.59; 13.82]	3.02 [-6.11; 12.14]	1.55 [-8.11; 11.20]	0.04 [-7.30; 7.39]	Plasma + ADC						
16.88 [7.80; 25.96]	**11.55 [8.01; 15.09]**	**11.39 [6.61; 16.17]**	**8.04 [4.43; 11.65]**	**7.82 [0.08; 15.55]**	7.11 [-1.94; 16.16]	6.42 [-1.02; 13.87]	3.42 [-5.69; 12.53]	3.32 [-4.17; 10.81]	1.85 [-6.29; 9.99]	0.34 [-5.08; 5.77]	0.30 [-5.33; 5.94]	Control +					
17.34 [5.60; 29.07]	**12.01 [4.45; 19.57]**	**11.85 [3.31; 20.39]**	**8.50 [0.90; 16.09]**	8.27 [-2.21; 18.76]	7.57 [-4.15; 19.28]	6.88 [-2.08; 15.84]	3.88 [-7.88; 15.63]	3.77 [-6.47; 14.02]	2.31 [-8.60; 13.21]	0.80 [-8.18; 9.78]	0.76 [-7.45; 8.97]	0.46 [-6.98; 7.89]	SB + Plasma + ADC				
21.58 [10.41; 32.75]	**16.25 [9.18; 23.32]**	**16.09 [8.13; 24.06]**	**12.74 [5.46; 20.03]**	**12.52 [3.24; 21.80]**	**11.81 [0.67; 22.96]**	**11.13 [1.42; 20.83]**	8.12 [-3.07; 19.32]	8.02 [-1.79; 17.84]	6.55 [-1.73; 14.83]	5.05 [-1.00; 11.09]	5.01 [-3.17; 13.18]	4.70 [-1.81; 11.21]	4.25 [-5.45; 13.95]	SB			
24.52 [12.52; 36.52]	**19.19 [10.87; 27.51]**	**19.03 [9.95; 28.11]**	**15.68 [7.24; 24.11]**	**15.45 [4.87; 26.03]**	**14.75 [2.77; 26.72]**	**14.06 [3.65; 24.48]**	11.06 [-0.96; 23.08]	**10.96 [0.22; 21.69]**	9.49 [-1.50; 20.48]	7.98 [-0.99; 16.96]	7.94 [-0.29; 16.17]	7.64 [-0.21; 15.49]	7.18 [-3.23; 17.59]	2.93 [-6.71; 12.58]	Plasma		
25.86 [13.94; 37.79]	**20.53 [12.62; 28.45]**	**20.38 [11.47; 29.28]**	**17.02 [8.74; 25.31]**	**16.80 [7.56; 26.04]**	**16.09 [4.19; 27.99]**	**15.41 [4.93; 25.89]**	**12.40 [0.46; 24.35]**	**12.30 [1.73; 22.88]**	**10.83 [0.19; 21.48]**	**9.33 [1.12; 17.54]**	**9.29 [0.11; 18.46]**	**8.98 [1.25; 16.72]**	8.53 [-1.95; 19.01]	4.28 [-4.99; 13.55]	1.35 [-9.23; 11.92]	Piranha	
26.87 [16.44; 37.30]	**21.54 [15.87; 27.21]**	**21.38 [14.54; 28.22]**	**18.03 [12.03; 24.03]**	**17.80 [9.72; 25.89]**	**17.10 [6.69; 27.51]**	**16.41 [7.71; 25.11]**	**13.41 [2.95; 23.87]**	**13.31 [4.39; 22.22]**	**11.84 [3.10; 20.58]**	**10.33 [4.67; 16.00]**	**10.29 [3.67; 16.92]**	**9.99 [4.84; 15.14]**	**9.53 [0.84; 18.23]**	5.29 [-1.32; 11.89]	2.35 [-5.74; 10.44]	1.00 [-7.07; 9.08]	Control -

4. Discussion

In the present study, a network meta-analysis was conducted, which not only allows for the comparison of multiple surface treatment strategies simultaneously but also enables indirect comparisons between treatments that have not been directly evaluated against each other in primary studies, providing a more comprehensive and hierarchized understanding of the available evidence. Interestingly, interest in this subject has surged in recent years, as reflected by the fact that 11 out of the 14 studies included in this study (~78%) were published after 2020 (Table 2).

The included studies comprised a diverse range of surface conditioning protocols, adhesive systems, and mechanical testing methodologies. However, the literature remains inconclusive as to which surface treatment protocol offers the most reliable enhancement in bonding performance (2,6,14). In light of this uncertainty, the present study offers timely and valuable insights into this clinically relevant issue. To the best of our knowledge, this is only the second meta-analysis addressing the bond strength of PEEK to resin composites, and the first to employ a network meta-analysis approach. This methodology represents a significant advancement over traditional pairwise meta-analyses by enabling the simultaneous comparison of multiple interventions within a single analytical framework. Through the integration of both direct and indirect evidence, network meta-analysis facilitates a more nuanced and hierarchical evaluation of treatment efficacy (50). Consequently, the present analysis provides a comprehensive evidence base to support clinical and research decisions, offering a comparative ranking of surface treatments that may inform future protocols and materials development.

The overall findings of this systematic review suggest that the majority of surface treatment protocols, when used in conjunction with bonding agent, significantly improve the bond strength between PEEK and resin composites compared to both negative and positive control groups. The use of network meta-analysis enabled a robust and integrated comparison across 18 distinct surface treatment strategies (Figure 3). The combination of sulfuric acid and visio.link (SA + VL) achieved the highest rank in bond strength, followed by sulfuric acid + adhesive control (SA + ADC) and laser + ADC (Figure 4). These protocols demonstrated significant superiority over the positive control group, underscoring their potential clinical relevance and efficacy of the experimental surface treatment. Notably, the SA + VL protocol yielded one of the highest P-scores (0.97), reinforcing its potential as a reference approach for future research and clinical applications. These findings also emphasize the critical role of bonding agents in promoting effective bonding by combining micromechanical interlocking with chemical interaction (14,44).

Sulfuric acid is a strong acid known to act on the carbonyl and ether functional groups within the PEEK polymer matrix, enabling chemical modification of its surface. This treatment increases surface energy and wettability, while also generating a microporous structure that enhances micromechanical retention (19,22,28,42). This microroughened surface allows for better penetration of the bonding agents into the material, thereby enhancing mechanical interlocking and potentially increasing the surface bonding capacity of resin composites (16,28,42). Thus, the use of sulfuric acid, particularly when combined with an appropriate adhesive, such as visio.link, represents a promising strategy for optimizing the adhesion of PEEK to resin composites in clinical settings.

Interestingly, groups employing physical treatments such as airborne-particle abrasion or laser irradiation, when combined with adhesives, demonstrated substantial improvements on bond strength (Figures 3 and 4). These findings reinforce the that micromechanical retention via surface roughening significantly contributes to adhesion, although it may not always be sufficient on its own (2,19,20,22,27,31,33,35-37,43). Although laser irradiation has been suggested as a surface treatment method for PEEK, its effectiveness in isolation for improving bond strength remains uncertain. Laser creates deep yet excessively narrow pits on the PEEK surface, potentially increasing the surface area. However, these narrow structures may impede proper infiltration of resin-based materials, limiting the anticipated micromechanical interlocking effect (17).

Airborne-particle abrasion effectively increases surface roughness while concurrently eliminating organic contaminants, creating an active surface layer (22,27). This procedure facilitates micromechanical interlocking by resin-based dental materials and enhances the penetration of bonding agents. The low viscosity of adhesives further improves their infiltration into the treated surface, thereby optimizing adhesion. Consequently, the best outcomes were observed when airborne-particle abrasion was followed by adhesive application (16,29). Airborne-particle abrasion alone exhibited lower bond strength values compared to the positive control group (Figure 4).

Most studies (2,19,20,23,27,31,33,35-37,42,43) have used visio.link as an adhesive for PEEK. Unlike other adhesives commonly applied to PEEK, such as Signum® Bond and PEKKbond, visio.link contains methyl methacrylate combined with pentaerythritol triacrylate (PETIA). The presence of PETIA significantly enhances its capacity to modify PEEK surfaces, efficiently improving bond strength (17,22,33). The PETIA is a highly reactive multifunctional acrylate monomer that contains three acrylate groups per molecule, enabling extensive crosslinking during photopolymerization. This results in the formation of a densely reticulated three-dimensional network that establishes interactions with the PEEK surface and the resin composite. Moreover, the acrylate groups in PETIA readily undergo free-radical polymerization, promoting effective copolymerization with the resin monomers and thereby enhancing bond strength.

Laser treatments function mainly via ablation, fusion, or localized vaporization of the surface, creating micro-irregularities, increasing surface roughness, and promoting mechanical interlocking. However, the extent of roughness and surface energy increase depends significantly on the laser type (e.g., Er:YAG, Nd:YAG, Yb:PL, Nd:YVO4, and CO_2) and specific operational parameters, including power, pulse duration, and frequency (19,20,27). Furthermore, improperly calibrated lasers can induce localized thermal degradation, negatively affecting the mechanical properties of PEEK. Consequently, laser techniques often face reproducibility challenges due to their sensitivity to these parameters, and the risk of thermal damage is particularly elevated when the laser settings are inadequately controlled (25-27).

Plasma treatment is considerably less aggressive and clinically safer than laser irradiation as well as sulfuric acid (22,23). However, plasma did not demonstrate statistically significant improvements compared to the positive controls (Figure 4). Although plasma is categorized as physical treatment, unlike laser, it interacts primarily through chemical mechanisms on the PEEK surface (15,22,47). Plasma interacts with PEEK primarily by chemically introducing polar functional groups, such as hydroxyl (-OH), carboxyl (-COOH), carbonyl (C=O), and nitrogen-based groups, via surface oxidation or activation. This chemical modification enhances surface energy and polarity (47). Depending on the type of plasma used and the exposure conditions (duration and power), it may also generate subtle mechanical changes by creating superficial micro-irregularities that contribute to micromechanical interlocking. However, despite being less aggressive and sensitive compared to laser, plasma processes alone have not been sufficient to substantially improve the adhesion between PEEK and resin composite (15,22,47). Figure 4 demonstrates that plasma treatment produced acceptable bond strength only when combined with the bonding agent provided by the manufacturer, yielding results comparable to the positive control group.

A notable finding of this systematic review was the high heterogeneity among the included studies (I^2 = 97.5%). Such heterogeneity likely arises from variations in experimental conditions, including differences in surface treatment methods and parameters, bonding agents employed, storage procedures, specimen preparation protocols, and testing methodologies (e.g., shear, tensile, or micro push-out tests) (2,19,20,22,23,27,29,31,33,35-37,42,43). While this variability limits the direct comparability of absolute values across individual studies, it realistically represents the complexity and diversity encountered in clinical and laboratory practice. Therefore, employing a network meta-analysis, which integrates both direct and indirect comparisons, was essential for a comprehensive synthesis of the evidence.

Another important aspect addressed in this review was the risk of bias. The RoBDEMAT tool (46) revealed that the experimental studies included were generally well-designed and adequately controlled, although they presented a moderate overall risk of bias (Figure 2). Methodological variations among the included studies further contributed to the heterogeneity observed in the meta-analysis, thereby warranting a cautious interpretation of the findings. Critical methodological weaknesses identified included the lack of appropriate randomization procedures, inadequate operator blinding, and insufficient sample size justification (Figure 2). Notably, none of the studies described proper randomization processes, and only one study (29) reported operator blinding, although inadequately. Moreover, only four studies performed sample size calculations or provided detailed justifications for their selected parameters (2,31,37,42), a shortcoming that potentially undermines internal validity and statistical power. These limitations underscore the necessity of enhancing methodological rigor in future *in vitro* studies to improve the reliability and reproducibility of their outcomes.

A positive aspect consistently observed across all studies (2,19,20,22,23,27,29,31,33,35-37,42,43) was the standardized polishing procedure using silicon carbide sandpapers, ensuring uniformity of initial surface roughness. After polishing, specimens were cleaned through various methods. However, it is crucial to note that studies examining cleaning methods that might influence bonding without subsequent surface treatment were not included in the current study. Additionally, none of the studies assessed long-term bond strength using standardized thermal or mechanical aging protocols. The absence of a unified methodology complicates the prediction of adhesive durability over extended periods. Therefore, incorporating standardized artificial aging protocols in future studies would significantly enhance the understanding of long-term adhesion between PEEK and resin composites.

The findings of the current systematic review align with conclusions from previous meta-analyses (44), confirming that the bond strength between PEEK and resin composites increases when surface treatments are combined with bonding agent. However, this study significantly expands upon earlier work by incorporating a greater number of recent studies specifically focused on PEEK (Table 2), indicating sulfuric acid as the most effective treatment in enhancing bond strength with resin composites. Furthermore, the employment of the RoBDEMAT tool to assess the risk of bias has provided greater transparency and reproducibility, thereby strengthening the reliability and validity of our synthesis.

The findings reveal a trade-off between clinical feasibility and adhesive performance. While sulfuric acid combined with adhesive (VL and ADC) yielded the highest bond strength values, alternative protocols such as laser and airborne-particle abrasion, when used with appropriate bonding agents, also demonstrated clinically acceptable results (51). These methods offer safer and more practical options for routine use. Despite its superior *in vitro* performance, sulfuric acid is highly toxic, strictly regulated, and unsuitable for use in dental offices. As such, PEEK surface treatment with sulfuric acid must be conducted in controlled laboratory settings. However, delays between laboratory treatment and clinical application may lead to surface contamination and reduced adhesion, necessitating additional chairside procedures. Therefore, future research should focus not only on the efficacy of surface treatments, but also on their clinical safety, ease of use, and long-term stability. Notably, in the present systematic review, none of the included studies evaluated bond durability under aging conditions, highlighting the need for further investigations into the long-term performance of these protocols.

5. Conclusion

This systematic review and network meta-analysis demonstrated that surface treatment with sulfuric acid combined and manufacturer-recommended bonding agents promote the highest bond strength between PEEK and resin composite.

References

1. Çakar VG, Tacir İH, Seyfioğlu Polat Z. High performance poly-aryl-ether-ketone (PAEK) polymers used in dentistry. Aydin Dent J. 2022;8(1):59-71. doi: 10.17932/IAU.DENTAL.2015.009/dental_v08i1005.
2. Gouveia DDNM, Razzoog ME, Sierraalta M, Alfaro MF. Effect of surface treatment and manufacturing process on the shear bond strength of veneering composite resin to polyetherketoneketone (PEKK) and polyetheretherketone (PEEK). J Prosthet Dent. 2022 Nov;128(5):1061-6. doi: 10.1016/j.prosdent.2021.02.003.
3. Maloo LM, Toshniwal SH, Reche A, Paul P, Wanjari MB. A Sneak peek toward polyaryletherketone (PAEK) polymer: a review. Cureus. 2022 Nov 3;14(11):e31042. doi: 10.7759/cureus.31042.
4. Taha D, Safwat F, Wahsh M. Effect of combining different surface treatments on the surface characteristics of polyetheretherketone-based core materials and shear bond strength to a veneering composite resin. J Prosthet Dent. 2022 Apr;127(4):599.e1-599.e7. doi: 10.1016/j.prosdent.2022.01.004.

5. Zol SM, Alauddin MS, Said Z, Mohd Ghazali MI, Hao-Ern L, Mohd Farid DA, et al. Description of poly(aryl-ether-ketone) materials (PAEKs), polyetheretherketone (PEEK) and polyetherketoneketone (PEKK) for application as a dental material: a materials science review. Polymers (Basel). 2023 May 2;15(9):2170. doi: 10.3390/polym15092170.
6. Taymour N, Abd El-Fattah A, Kandil S, Fahmy AE, Al-Qahtani NH, Khaled A, et al. Revolutionizing dental polymers: the versatility and future potential of polyetheretherketone in restorative dentistry. Polymers (Basel). 2024 Dec 31;17(1):80. doi: 10.3390/polym17010080.
7. Smith KJ, Towle IDH, Moloney MG. Polyaryletherketone polymers and copolymers by a Friedel-Crafts dispersion polymerisation. Eur Polym J. 2017;96:159-75. doi:10.1016/j.eurpolymj.2017.09.007.
8. Shibata M, Yosomiya R, Wang J, Zheng Y, Zhang W, Wu Z. Relationship between molecular structure and thermal properties of poly(aryl ether ketone)s. Macromol Rapid Commun. 1997;18: 99-105. doi:10.1002/marc.1997.030180205.
9. Villefort RF, Diamantino PJS, Zeidler SLVV, Borges ALS, Silva-Concílio LR, Saavedra GDFA, et al. Mechanical response of PEKK and PEEK as frameworks for implant-supported full-arch fixed dental prosthesis: 3D finite element analysis. Eur J Dent. 2022 Feb;16(1):115-21. doi: 10.1055/s-0041-1731833.
10. Asik B, Ozyilmaz OY. Effects of various laser applications on surface roughness and bond strength to veneering composites of polyether ether ketone (PEEK) and polyether ketone ketone (PEKK) materials. Lasers Med Sci. 2024 Nov 6;39(1):269. doi: 10.1007/s10103-024-04213-w.
11. Al-Rabab'ah M, Hamadneh W, Alsalem I, Khraisat A, Abu Karaky A. Use of high performance polymers as de
ntal implant abutments and frameworks: a case series report. J Prosthodont. 2019 Apr;28(4):365-72. doi: 10.1111/jopr.12639.
12. Cevik P, Yildirim AZ, Demir Sevinc EH, Gonder A, Kiat-Amnuay S. Using PEEK as a framework material for maxillofacial silicone prosthesis: an in vitro study. Polymers (Basel). 2023 Jun 15;15(12):2694. doi: 10.3390/polym15122694.
13. Zhao T, Jiang Z, Ge Y, Yin H, Yang Q, Li R, et al. Mechanical properties, biosafety, and shearing bonding strength of glass fiber-reinforced PEEK composites used as post-core materials. J Mech Behav Biomed Mater. 2023 Sep;145:106047. doi: 10.1016/j.jmbbm.2023.106047.

14. Escobar M, Henriques B, Fredel MC, Silva FS, Özcan M, Souza JCM. Adhesion of PEEK to resin-matrix composites used in dentistry: a short review on surface modification and bond strength. J Adhes Sci Technol. 2020;34(11):1241-52. doi:10.1080/01694243.2019.1706797.
15. Stawarczyk B, Bähr N, Beuer F, Wimmer T, Eichberger M, Gernet W, et al. Influence of plasma pretreatment on shear bond strength of self-adhesive resin cements to polyetheretherketone. Clin Oral Investig. 2014 Jan;18(1):163-70. doi: 10.1007/s00784-013-0966-7.
16. Zhou L, Qian Y, Zhu Y, Liu H, Gan K, Guo J. The effect of different surface treatments on the bond strength of PEEK composite materials. Dent Mater. 2014 Aug;30(8):e209-15. doi: 10.1016/j.dental.2014.03.011.
17. Caglar I, Ates SM, Yesil Duymus Z. An in vitro evaluation of the effect of various adhesives and surface treatments on bond strength of resin cement to polyetheretherketone. J Prosthodont. 2019 Jan;28(1):e342-9. doi: 10.1111/jopr.12791.
18. Tsuka H, Morita K, Kato K, Kimura H, Abekura H, Hirata I, et al. Effect of laser groove treatment on shear bond strength of resin-based luting agent to polyetheretherketone (PEEK). J Prosthodont Res. 2019 Jan;63(1):52-7. doi: 10.1016/j.jpor.2018.08.001.
19. Çulhaoğlu AK, Özkır SE, Şahin V, Yılmaz B, Kılıçarslan MA. Effect of various treatment modalities on surface characteristics and shear bond strengths of polyetheretherketone-based core materials. J Prosthodont. 2020 Feb;29(2):136-41. doi: 10.1111/jopr.12702.
20. Jahandideh Y, Falahchai M, Pourkhalili H. Effect of surface treatment with Er:YAG and CO2 lasers on shear bond strength of polyether ether ketone to composite resin veneers. J Lasers Med Sci. 2020 Spring;11(2):153-9. doi: 10.34172/jlms.2020.26.
21. Attia MA, Shokry TE, Abdel-Aziz M. Effect of different surface treatments on the bond strength of milled polyetheretherketone posts. J Prosthet Dent. 2022 Jun;127(6):866-74. doi: 10.1016/j.prosdent.2020.08.033.
22. Dede DÖ, Ercan UK, Küçükekenci AS, Kahveci Ç, Özdemir GD, Bağış B. Influence of non-thermal plasma systems and two favorable surface treatments on the shear bond strength of PAEKs to composite resin. J Adhes Sci Technol. 2021;36(7):748-61. doi:10.1080/01694243.2021.1936784.

23. Akay C, İsrafil N, Pat S. Enhancement of adhesive bonding properties of polyetheretherketone-based materials using plasma surface modifications. J Adhes Dent. 2022 Mar 24;24:117-24. doi: 10.3290/j.jad.b2838149.
24. Kiliç M, Dede DÖ, Küçükekenci AS. Comparing the shear bond strength of veneering materials to the PAEKs after surface treatments. BMC Oral Health. 2023 Mar 30;23(1):185. doi: 10.1186/s12903-023-02879-2.
25. Turkkal F, Culhaoglu AK, Sahin V. Composite-veneering of polyether-ether-ketone (PEEK): evaluating the effects of different surface modification methods on surface roughness, wettability, and bond strength. Lasers Med Sci. 2023 Mar 30;38(1):95. doi: 10.1007/s10103-023-03749-7.
26. Babu ADKBS, Nathan ASC, Balasubramanium MK. Effect of laser surface treatment on shear bond strength between polyetheretherketone and heat-activated polymethylmethacrylate resin. J Prosthodont. 2024 Jun;33(5):490-496. doi: 10.1111/jopr.13744.
27. Peng TY, Shimoe S, Higo M, Kato M, Hirata I, Iwaguro S, Kaku M. Effect of laser engraving on shear bond strength of polyetheretherketone to indirect composite and denture-base resins. J Dent Sci. 2024 Jan;19(1):32-38. doi: 10.1016/j.jds.2023.06.005.
28. Schmidlin PR, Stawarczyk B, Wieland M, Attin T, Hämmerle CH, Fischer J. Effect of different surface pre-treatments and luting materials on shear bond strength to PEEK. Dent Mater. 2010 Jun;26(6):553-9. doi: 10.1016/j.dental.2010.02.003.
29. Stawarczyk B, Beuer F, Wimmer T, Jahn D, Sener B, Roos M, et al. Polyetheretherketone-a suitable material for fixed dental prostheses? J Biomed Mater Res B Appl Biomater. 2013 Oct;101(7):1209-16. doi: 10.1002/jbm.b.32932.
30. Keul C, Liebermann A, Schmidlin PR, Roos M, Sener B, Stawarczyk B. Influence of PEEK surface modification on surface properties and bond strength to veneering resin composites. J Adhes Dent. 2014 Aug;16(4):383-92. doi: 10.3290/j.jad.a32570.
31. Vakkala SB. Comparison of surface roughness of PEKK and PEEK material after surface modification and its effect on the shear bond strength to indirect composite veneering material: an in vitro study [dissertação]. Bangalore: Rajiv Gandhi University of Health Sciences; 2019.
32. Kurahashi K, Matsuda T, Ishida Y, Ichikawa T. Effect of surface treatments on shear bond strength of polyetheretherketone to autopolymerizing resin. Dent J (Basel). 2019 Aug 1;7(3):82. doi: 10.3390/dj7030082.

33. Ata SO, Akay C, Ata N. Evaluation of bond strength of polyether ether ketone (PEEK) to composite resin on hypobaric and hyperbaric conditions. Int J Polym Mater Polym Biomater. 2021;71(7):540-7. doi:10.1080/00914037.2021.1960343.

34. Mayinger F, Fiebig M, Roos M, Eichberger M, Lümkemann N, Stawarczyk B. Bonding behavior between polyetheretherketone and polymethylmethacrylate acrylic denture polymer. J Adhes Dent. 2021 Apr 7;23(2):145-58. doi: 10.3290/j.jad.b1079579.

35. Adem N, Bal B, Kazazoğlu E. Comparative study of chemical and mechanical surface treatment effects on the shear bond strength of polyether-ether-ketone to veneering resin. Int J Prosthodont. 2022 March/April;35(2):201-7. doi: 10.11607/ijp.6938.

36. Soliman TA, Raffat-Hussein EM, Ellayeh M, Farahat DS. Effect of surface treatments on adhesion of milled polyetheretherketone post to different composite resin core build-up materials. J Clin Exp Dent. 2023a Sep 1;15(9):e742-8. doi: 10.4317/jced.60740.

37. Soliman TA, Robaian A, Al-Gerny Y, Hussein EMR. Influence of surface treatment on repair bond strength of CAD/CAM long-term provisional restorative materials: an in vitro study. BMC Oral Health. 2023b May 30;23(1):342. doi: 10.1186/s12903-023-03021-y.

38. Ozdogan A, Tosun B. Effect of different surface roughening treatment on polyether ether ketone and acrylic resin bonding: a pilot study. Dent Med Probl. 2024 Mar-Apr;61(2):249-55. doi: 10.17219/dmp/133071.

39. Sahin SC, Mutlu-Sagesen L, Karaokutan I, Özcan M. Effect of particle size and application pressure in air-borne particle abrasion on the adhesion of polyetheretherketone. Eur J Prosthodont Restor Dent. 2024 May 31;32(2):219-26. doi: 10.1922/EJPRD_2610Sahin08.

40. Liu Y, Bai S, Liu H, Li K, Zhong S, Li M, et al. Effect of different surface treatments on PEEK-enamel bonds: bonding durability and mechanism. J Prosthet Dent. 2025 Mar;133(3):892.e1-892.e10. doi: 10.1016/j.prosdent.2024.11.012.

41. Sproesser O, Schmidlin PR, Uhrenbacher J, Roos M, Gernet W, Stawarczyk B. Effect of sulfuric acid etching of polyetheretherketone on the shear bond strength to resin cements. J Adhes Dent. 2014 Oct;16(5):465-72. doi: 10.3290/j.jad.a32806.

42. Stawarczyk B, Jordan P, Schmidlin PR, Roos M, Eichberger M, Gernet W, et al. PEEK surface treatment effects on tensile bond strength to veneering resins. J Prosthet Dent. 2014 Nov;112(5):1278-88. doi: 10.1016/j.prosdent.2014.05.014.

43. Zhang J, Yi Y, Wang C, Ding L, Wang R, Wu G. Effect of acid-etching duration on the adhesive performance of printed polyetheretherketone to veneering resin. Polymers (Basel). 2021 Oct 13;13(20):3509. doi: 10.3390/polym13203509.
44. Gama LT, Duque TM, Özcan M, Philippi AG, Mezzomo LAM, Gonçalves TMSV. Adhesion to high-performance polymers applied in dentistry: A systematic review. Dent Mater. 2020 Apr;36(4):e93-e108. doi: 10.1016/j.dental.2020.01.002.
45. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021 Mar 29;372:n71. doi: 10.1136/bmj.n71.
46. Delgado AH, Sauro S, Lima AF, Loguercio AD, Della Bona A, Mazzoni A, et al. RoBDEMAT: A risk of bias tool and guideline to support reporting of pre-clinical dental materials research and assessment of systematic reviews. J Dent. 2022 Dec;127:104350. doi: 10.1016/j.jdent.2022.104350.
47. Zhou L, Qian YT, Zhu Y, Gan K, Guo J, Liu H. Influence of low temperature plasma treatment on bonding property of PEEK composite material for prosthodontics. J Jilin Univ Med Ed. 2014;40:311-5. doi:10.13481/j.1671-587x.20140220.
48. Alanazi AM, Khan AA, Mahmood A, Bajwa WN, Kamal MA, Kamal I. PEEK surface treatment using Nd:YAG, riboflavin activated by PDT, and alumina particles on surface roughness, bond failure, and bond integrity to composite resin. J Biomater Tissue Eng. 2023 Sep;13(9):940-5. doi:10.1166/jbt.2023.333.
49. Higgins JPT, Li T, Deeks JJ. Chapter 6: Choosing effect measures and computing estimates of effect. In: Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA, editors. Cochrane Handbook for Systematic Reviews of Interventions [Internet]. Version 6.4 (updated August 2023). Cochrane; 2023. Available from: https://training.cochrane.org/handbook/current/chapter-06
50. Catalá-López F, Tobías A, Cameron C, Moher D, Hutton B. Network meta-analysis for comparing treatment effects of multiple interventions: an introduction. Rheumatol Int. 2014 Nov;34(11):1489-96. doi: 10.1007/s00296-014-2994-2.
51. Kern M, Lehmann F. Influence of surface conditioning on bonding to polyetheretherketon (PEEK). Dent Mater. 2012 Dec;28(12):1280-3. doi: 10.1016/j.dental.2012.09.010.

3 CONCLUSÃO

Esta revisão sistemática com meta-análise em rede demonstrou que o tratamento de superfície com ácido sulfúrico, combinado com agentes adesivos recomendados pelos fabricantes, promove a maior resistência de união entre o PEEK e a resina composta.

REFERÊNCIAS*

Adem N, Bal B, Kazazoğlu E. Comparative study of chemical and mechanical surface treatment effects on the shear bond strength of polyether-ether-ketone to veneering resin. Int J Prosthodont. 2022 March/April;35(2):201-7. doi: 10.11607/ijp.6938.

Akay C, İsrafil N, Pat S. Enhancement of adhesive bonding properties of polyetheretherketone-based materials using plasma surface modifications. J Adhes Dent. 2022 Mar 24;24:117-24. doi: 10.3290/j.jad.b2838149.

Al-Rabab'ah M, Hamadneh W, Alsalem I, Khraisat A, Abu Karaky A. Use of high performance polymers as dental implant abutments and frameworks: a case series report. J Prosthodont. 2019 Apr;28(4):365-72. doi: 10.1111/jopr.12639.

Ata SO, Akay C, Ata N. Evaluation of bond strength of polyether ether ketone (PEEK) to composite resin on hypobaric and hyperbaric conditions. Int J Polym Mater Polym Biomater. 2021;71(7):540-7. doi:10.1080/00914037.2021.1960343.

Attia MA, Shokry TE, Abdel-Aziz M. Effect of different surface treatments on the bond strength of milled polyetheretherketone posts. J Prosthet Dent. 2022 Jun;127(6):866-74. doi: 10.1016/j.prosdent.2020.08.033.

Asik B, Ozyilmaz OY. Effects of various laser applications on surface roughness and bond strength to veneering composites of polyether ether ketone (PEEK) and polyether ketone ketone (PEKK) materials. Lasers Med Sci. 2024 Nov 6;39(1):269. doi: 10.1007/s10103-024-04213-w.

Babu ADKBS, Nathan ASC, Balasubramanium MK. Effect of laser surface treatment on shear bond strength between polyetheretherketone and heat-activated polymethylmethacrylate resin. J Prosthodont. 2024 Jun;33(5):490-496. doi: 10.1111/jopr.13744.

Caglar I, Ates SM, Yesil Duymus Z. An in vitro evaluation of the effect of various adhesives and surface treatments on bond strength of resin cement to polyetheretherketone. J Prosthodont. 2019 Jan;28(1):e342-9. doi: 10.1111/jopr.12791.

* 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.

Çakar VG, Tacir İH, Seyfioğlu Polat Z. High performance poly-aryl-ether-ketone (PAEK) polymers used in dentistry. Aydin Dent J. 2022;8(1):59-71. doi: 10.17932/IAU.DENTAL.2015.009/dental_v08i1005.

Cevik P, Yildirim AZ, Demir Sevinc EH, Gonder A, Kiat-Amnuay S. Using PEEK as a framework material for maxillofacial silicone prosthesis: an in vitro study. Polymers (Basel). 2023 Jun 15;15(12):2694. doi: 10.3390/polym15122694.

Çulhaoğlu AK, Özkır SE, Şahin V, Yılmaz B, Kılıçarslan MA. Effect of various treatment modalities on surface characteristics and shear bond strengths of polyetheretherketone-based core materials. J Prosthodont. 2020 Feb;29(2):136-41. doi: 10.1111/jopr.12702.

Dede DÖ, Ercan UK, Küçükekenci AS, Kahveci Ç, Özdemir GD, Bağış B. Influence of non-thermal plasma systems and two favorable surface treatments on the shear bond strength of PAEKs to composite resin. J Adhes Sci Technol. 2021;36(7):748-61. doi:10.1080/01694243.2021.1936784.

El-Tahwi RI, Abdelhalim EF, Amgad SW. The effect of different surface treatments on retention strength of resin nano ceramic and PEEK esthetic restorations. Egypt Dent J. 2020 Feb;66(2):891-902.

Escobar M, Henriques B, Fredel MC, Silva FS, Özcan M, Souza JCM. Adhesion of PEEK to resin-matrix composites used in dentistry: a short review on surface modification and bond strength. J Adhes Sci Technol. 2020;34(11):1241-52. doi:10.1080/01694243.2019.1706797.

Gama LT, Duque TM, Özcan M, Philippi AG, Mezzomo LAM, Gonçalves TMSV. Adhesion to high-performance polymers applied in dentistry: A systematic review. Dent Mater. 2020 Apr;36(4):e93-e108. doi: 10.1016/j.dental.2020.01.002.

Gouveia DDNM, Razzoog ME, Sierraalta M, Alfaro MF. Effect of surface treatment and manufacturing process on the shear bond strength of veneering composite resin to polyetherketoneketone (PEKK) and polyetheretherketone (PEEK). J Prosthet Dent. 2022 Nov;128(5):1061-6. doi: 10.1016/j.prosdent.2021.02.003.

Jahandideh Y, Falahchai M, Pourkhalili H. Effect of surface treatment with Er:YAG and CO2 lasers on shear bond strength of polyether ether ketone to composite resin veneers. J Lasers Med Sci. 2020 Spring;11(2):153-9. doi: 10.34172/jlms.2020.26.

Keul C, Liebermann A, Schmidlin PR, Roos M, Sener B, Stawarczyk B. Influence of PEEK surface modification on surface properties and bond strength to veneering resin composites. J Adhes Dent. 2014 Aug;16(4):383-92. doi: 10.3290/j.jad.a32570.

Kiliç M, Dede DÖ, Küçükekenci AS. Comparing the shear bond strength of veneering materials to the PAEKs after surface treatments. BMC Oral Health. 2023 Mar 30;23(1):185. doi: 10.1186/s12903-023-02879-2.

Kurahashi K, Matsuda T, Ishida Y, Ichikawa T. Effect of surface treatments on shear bond strength of polyetheretherketone to autopolymerizing resin. Dent J (Basel). 2019 Aug 1;7(3):82. doi: 10.3390/dj7030082.

Liu Y, Bai S, Liu H, Li K, Zhong S, Li M, et al. Effect of different surface treatments on PEEK-enamel bonds: bonding durability and mechanism. J Prosthet Dent. 2025 Mar;133(3):892.e1-892.e10. doi: 10.1016/j.prosdent.2024.11.012.

Maloo LM, Toshniwal SH, Reche A, Paul P, Wanjari MB. A Sneak peek toward polyaryletherketone (PAEK) polymer: a review. Cureus. 2022 Nov 3;14(11):e31042. doi: 10.7759/cureus.31042.

Mayinger F, Fiebig M, Roos M, Eichberger M, Lümkemann N, Stawarczyk B. Bonding behavior between polyetheretherketone and polymethylmethacrylate acrylic denture polymer. J Adhes Dent. 2021 Apr 7;23(2):145-58. doi: 10.3290/j.jad.b1079579.

Ozdogan A, Tosun B. Effect of different surface roughening treatment on polyether ether ketone and acrylic resin bonding: a pilot study. Dent Med Probl. 2024 Mar-Apr;61(2):249-55. doi: 10.17219/dmp/133071.

Peng TY, Shimoe S, Higo M, Kato M, Hirata I, Iwaguro S, Kaku M. Effect of laser engraving on shear bond strength of polyetheretherketone to indirect composite and denture-base resins. J Dent Sci. 2024 Jan;19(1):32-38. doi: 10.1016/j.jds.2023.06.005.

Robaian A, Alshehri AM, Alqhtani NR, Almudahi A, Alanazi KK, Abuelqomsan MAS, et al. Effect of surface treatments and thermal aging on bond strength between veneering resin and CAD/CAM provisional materials. Polymers. 2025;17(5):563. doi: 10.3390/polym17050563.

Sahin SC, Mutlu-Sagesen L, Karaokutan I, Özcan M. Effect of particle size and application pressure in air-borne particle abrasion on the adhesion of polyetheretherketone. Eur J Prosthodont Restor Dent. 2024 May 31;32(2):219-26. doi: 10.1922/EJPRD_2610Sahin08.

Schmidlin PR, Stawarczyk B, Wieland M, Attin T, Hämmerle CH, Fischer J. Effect of different surface pre-treatments and luting materials on shear bond strength to PEEK. Dent Mater. 2010 Jun;26(6):553-9. doi: 10.1016/j.dental.2010.02.003.

Shibata M, Yosomiya R, Wang J, Zheng Y, Zhang W, Wu Z. Relationship between molecular structure and thermal properties of poly(aryl ether ketone)s. Macromol Rapid Commun. 1997;18: 99-105. doi:10.1002/marc.1997.030180205.

Smith KJ, Towle IDH, Moloney MG. Polyaryletherketone polymers and copolymers by a Friedel-Crafts dispersion polymerisation. Eur Polym J. 2017;96:159-75. doi:10.1016/j.eurpolymj.2017.09.007.

Soliman TA, Raffat-Hussein EM, Ellayeh M, Farahat DS. Effect of surface treatments on adhesion of milled polyetheretherketone post to different composite resin core build-up materials. J Clin Exp Dent. 2023a Sep 1;15(9):e742-8. doi: 10.4317/jced.60740.

Soliman TA, Robaian A, Al-Gerny Y, Hussein EMR. Influence of surface treatment on repair bond strength of CAD/CAM long-term provisional restorative materials: an in vitro study. BMC Oral Health. 2023b May 30;23(1):342. doi: 10.1186/s12903-023-03021-y.

Stawarczyk B, Beuer F, Wimmer T, Jahn D, Sener B, Roos M, et al. Polyetheretherketone-a suitable material for fixed dental prostheses? J Biomed Mater Res B Appl Biomater. 2013 Oct;101(7):1209-16. doi: 10.1002/jbm.b.32932.

Stawarczyk B, Jordan P, Schmidlin PR, Roos M, Eichberger M, Gernet W, et al. PEEK surface treatment effects on tensile bond strength to veneering resins. J Prosthet Dent. 2014a Nov;112(5):1278-88. doi: 10.1016/j.prosdent.2014.05.014.

Stawarczyk B, Bähr N, Beuer F, Wimmer T, Eichberger M, Gernet W, et al. Influence of plasma pretreatment on shear bond strength of self-adhesive resin cements to polyetheretherketone. Clin Oral Investig. 2014b Jan;18(1):163-70. doi: 10.1007/s00784-013-0966-7.

Sproesser O, Schmidlin PR, Uhrenbacher J, Roos M, Gernet W, Stawarczyk B. Effect of sulfuric acid etching of polyetheretherketone on the shear bond strength to resin cements. J Adhes Dent. 2014 Oct;16(5):465-72. doi: 10.3290/j.jad.a32806.

Taha D, Safwat F, Wahsh M. Effect of combining different surface treatments on the surface characteristics of polyetheretherketone-based core materials and shear bond strength to a veneering composite resin. J Prosthet Dent. 2022 Apr;127(4):599.e1-599.e7. doi: 10.1016/j.prosdent.2022.01.004.

Taymour N, Abd El-Fattah A, Kandil S, Fahmy AE, Al-Qahtani NH, Khaled A, et al. Revolutionizing dental polymers: the versatility and future potential of polyetheretherketone in restorative dentistry. Polymers (Basel). 2024 Dec 31;17(1):80. doi: 10.3390/polym17010080.

Tsuka H, Morita K, Kato K, Kimura H, Abekura H, Hirata I, et al. Effect of laser groove treatment on shear bond strength of resin-based luting agent to polyetheretherketone (PEEK). J Prosthodont Res. 2019 Jan;63(1):52-7. doi: 10.1016/j.jpor.2018.08.001.

Turkkal F, Culhaoglu AK, Sahin V. Composite-veneering of polyether-ether-ketone (PEEK): evaluating the effects of different surface modification methods on surface roughness, wettability, and bond strength. Lasers Med Sci. 2023 Mar 30;38(1):95. doi: 10.1007/s10103-023-03749-7.

Vakkala SB. Comparison of surface roughness of PEKK and PEEK material after surface modification and its effect on the shear bond strength to indirect composite veneering material: an in vitro study [dissertação]. Bangalore: Rajiv Gandhi University of Health Sciences; 2019.

Villefort RF, Diamantino PJS, Zeidler SLVV, Borges ALS, Silva-Concílio LR, Saavedra GDFA, et al. Mechanical response of PEKK and PEEK as frameworks for implant-supported full-arch fixed dental prosthesis: 3D finite element analysis. Eur J Dent. 2022 Feb;16(1):115-21. doi: 10.1055/s-0041-1731833.

Zhang J, Yi Y, Wang C, Ding L, Wang R, Wu G. Effect of acid-etching duration on the adhesive performance of printed polyetheretherketone to veneering resin. Polymers (Basel). 2021 Oct 13;13(20):3509. doi: 10.3390/polym13203509.

Zhao T, Jiang Z, Ge Y, Yin H, Yang Q, Li R, et al. Mechanical properties, biosafety, and shearing bonding strength of glass fiber-reinforced PEEK composites used as post-core materials. J Mech Behav Biomed Mater. 2023 Sep;145:106047. doi: 10.1016/j.jmbbm.2023.106047.

Zhou L, Qian Y, Zhu Y, Liu H, Gan K, Guo J. The effect of different surface treatments on the bond strength of PEEK composite materials. Dent Mater. 2014 Aug;30(8):e209-15. doi: 10.1016/j.dental.2014.03.011.

Zol SM, Alauddin MS, Said Z, Mohd Ghazali MI, Hao-Ern L, Mohd Farid DA, et al. Description of poly(aryl-ether-ketone) materials (PAEKs), polyetheretherketone (PEEK) and polyetherketoneketone (PEKK) for application as a dental material: a materials science review. Polymers (Basel). 2023 May 2;15(9):2170. doi: 10.3390/polym15092170.

ANEXO

Anexo 1 - Relatório de similaridade

Tese

ORIGINALITY REPORT

26%	20%	20%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.repositorio.unicamp.br Internet Source	3%
2	Bruna Tavares Carneiro, Marina Minici Dumont Prado, Iara de Oliveira Nogueira, Allyson Nogueira Moreira, Carolina Bosso André. "Exploring the effectiveness of doxycycline in restorative dentistry: a systematic review of in vitro studies", Odontology, 2024 Publication	1%
3	www.researchgate.net Internet Source	1%
4	www.zora.uzh.ch Internet Source	1%
5	lutpub.lut.fi Internet Source	1%
6	www.ncbi.nlm.nih.gov Internet Source	1%
7	www.mdpi.com Internet Source	1%
8	bmcoralhealth.biomedcentral.com Internet Source	1%
9	Akula Siva Bhaskar, Akhtar Khan. "Comparative Analysis of Hybrid MCDM Methods in Material Selection for Dental Applications", Expert Systems with Applications, 2022 Publication	1%

Anexo 2 - Comprovante de submissão do artigo

Brazilian Dental Journal - Manuscript ID BDJ-2025-6719

Carlos Feitosa <onbehalfof@manuscriptcentral.com>

23-Jul-2025

Dear Prof. Vitti:

Thank you for submitting your manuscript entitled Dental PEEK surface treatments and bond strength to resin composite: network meta-analysis of in vitro studies" to the Brazilian Dental Journal. Your manuscript ID is BDJ-2025-6719.

Please mention the above manuscript ID in all future correspondence or when calling the office for questions. If there are any changes in your street address or e-mail address, please log in to ScholarOne Manuscripts at http://mc04.manuscriptcentral.com/bdj-scielo and edit your user information as appropriate.

You can also view the status of your manuscript at any time by checking your Author Center after logging in to http://mc04.manuscriptcentral.com/bdj-scielo.

In accordance with the Brazilian Dental Journal's policies referring to the review process that precedes publication, all manuscripts accepted for publication undergo a Technical Review, which includes revision of language and scientific writing style, formatting corrections and technical editing to fit the manuscript into Journal's standards, and preparation of galley proofs.

The Technical Review Fee ranges from R$ 550,00 Reais Brasileiros (for Brazilian authors) or U$ 300 American dollars (for foreign authors) and will be charged to the corresponding author, even if only minor corrections to the manuscript are needed.

For foreign authors, the Technical Review Fee should be paid upon acceptance of the manuscript for publication, using the PAYPAL ONLINE MONEY TRANSFER SYSTEM (www.paypal.com).

For both Brazilian and foreign authors, more detailed explanation will be provided if the manuscript is accepted.

If you DO NOT agree with these conditions, please inform your decision to withdraw the manuscript from the review process immediately.

Sincerely,
Brazilian Dental Journal Editorial Office