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Avaliação das propriedades de resinas utilizadas em impressão 3D na Odontologia: Uma revisão sistemática e um estudo laboratorial

Marcelo Pereira Brod

2025

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Dissertação apresentada ao Programa de Pós-Graduação em Odontologia da Faculdade de Odontologia da Universidade Federal de Pelotas, como requisito parcial à obtenção do título de Mestre em Clínica Odontológica, com ênfase em Dentística e Cariologia.

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Dedico este trabalho a minha família,

que sempre acreditou em mim e me apoiaram.

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Se eu vi mais longe, foi porque estava sobre os ombros de gigantes".

Sir Isaac Newton – 1675

Notas Preliminares

A presente dissertação foi redigida segundo o Manual de Normas para Dissertações, Teses e Trabalhos Científicos da Universidade Federal de Pelotas de 2019, adotando o Nível de Descrição de Artigos do referido manual. <http://sisbi.ufpel.edu.br/?p=documentos&i=7> Acesso em: 15 de fevereiro de 2025.

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Resumo

PEREIRA BROD, Marcelo. **Avaliação das propriedades de resinas utilizadas em impressão 3D na Odontologia: Uma revisão sistemática e um estudo laboratorial**. 2025. 118f. Dissertação (Mestrado em Clínica Odontológica) – Programa de Pós-Graduação em Odontologia. Universidade Federal de Pelotas, Pelotas, 2025.

Métodos tradicionais de manufatura de placas oclusais com o uso de resinas de polimetilmetacrilato (PMMA), estão sendo gradualmente substituídos por resinas fotossensíveis adaptadas para impressão 3D, proporcionando uma alternativa mais eficiente e personalizada. Entre as tecnologias de impressão 3D, destacam-se a estereolitografia (SLA) e o processamento digital de luz (DLP), com a propagação de impressoras de baixo custo baseadas em SLA/LCD, está se ampliando o acesso à manufatura aditiva. Este estudo foi conduzido em duas fases. Na primeira, uma revisão sistemática foi realizada para avaliar as propriedades físicas, mecânicas e biológicas das resinas fotossensíveis para a fabricação de placas oclusais, comparando-as com as resinas PMMA. A revisão de estudos laboratoriais revelou que, em geral, o PMMA apresentou melhor desempenho, especialmente em propriedades como resistência à fratura e durabilidade na meta-análise. Este estudo demonstrou que resinas fotossensíveis usadas na impressão 3D para placas oclusais geralmente exibiram propriedades físicas, mecânicas e biológicas inferiores em comparação aos materiais PMMA convencionais. Na segunda fase, foi realizado um estudo experimental com três resinas fotossensíveis (Cosmos Splint, NextDent OrthoRigid e Prizma BioSplint) impressas com uma impressora LCD acessível, comparando-as com PMMA termo e auto polimerizável. os resultados indicaram que as resinas fotossensíveis mostraram boa resistência à flexão e menor absorção de água, mas algumas apresentaram resistência e dureza inferiores ao PMMA. a viabilidade celular variou, com algumas resinas mostrando desempenho citotóxico após 14 dias. as resinas fotossensíveis, embora não superem totalmente o PMMA e possam não ter resistência tão duradoura, podem ser uma alternativa promissora e mais rápida para a fabricação de placas oclusais.

Palavras-chave: Placa Oclusal; Manufatura Aditiva, Impressão Tridimensional, Resinas Fotossensíveis.

Abstract

PEREIRA BROD, Marcelo. **Evaluation of the properties of resins used in 3D printing in Dentistry: A systematic review and a laboratory study.** 2025. 110. Dissertation (Master's in Clinical Dentistry) – Graduate Program in Dentistry. Federal University of Pelotas, Pelotas, 2025.

Traditional methods of manufacturing occlusal splints using polymethyl methacrylate (PMMA) resins are gradually being replaced by photosensitive resins adapted for 3D printing, providing a more efficient and customized alternative. Among the 3D printing technologies, stereolithography (SLA) and digital light processing (DLP) stand out, with the spread of low-cost SLA/LCD-based printers, access to additive manufacturing is expanding. This study was conducted in two phases. In the first, a systematic review was performed to evaluate the physical, mechanical and biological properties of photosensitive resins for the manufacture of occlusal splints, comparing them with PMMA resins. The review of laboratory studies revealed that, in general, PMMA presented better performance, especially in properties such as fracture resistance and durability in the meta-analysis. This study demonstrated that photosensitive resins used in 3D printing for occlusal splints generally exhibited inferior physical, mechanical and biological properties compared to conventional PMMA materials. In the second phase, an experimental study was conducted with three photosensitive resins (Cosmos Splint, NextDent OrthoRigid, and Prizma BioSplint) printed with an affordable LCD printer, comparing them with thermosetting and self-curing PMMA. The results indicated that the photosensitive resins showed good flexural strength and lower water absorption, but some showed lower strength and hardness than PMMA. Cell viability varied, with some resins showing cytotoxic performance after 14 days. Photosensitive resins, although they do not completely outperform PMMA and may not have as long-lasting strength, may be a promising and faster alternative for the fabrication of occlusal splints.

Keywords: Occlusal Splint; Additive Manufacturing; Three-Dimensional Printing; Photosensitive Resins.

Sumário

1. Introdução

A crescente aplicação das tecnologias de impressão 3D na odontologia tem impulsionado mudanças significativas na fabricação de dispositivos, especialmente os dispositivos oclusais, como as placas. A utilização de resinas fotossensíveis e a comparação com métodos tradicionais de fabricação, como o fresamento e a termopolimerizável, têm mostrado avanços no desempenho desses materiais (MARCEL; REINHARD; ANDREAS, 2020; PRPIC et al., 2018) A impressão 3D permite maior personalização e precisão na produção de placas oclusais, adequando-se melhor às necessidades individuais dos pacientes, ao mesmo tempo em que reduz o desperdício de material e o tempo de produção (WEŻGOWIEC; MAŁYSA; WIĘCKIEWICZ, 2024) No entanto, a exatidão e a durabilidade dos objetos impressos em 3D ainda são pontos críticos que necessitam de mais investigações.

Estudos recentes têm explorado diferentes aspectos da fabricação digital de placas, desde a precisão dimensional até as propriedades mecânicas e biocompatibilidade dos materiais utilizados. A posição de impressão (horizontal ou vertical) e os tipos de resina utilizados influenciam diretamente a precisão e a durabilidade do produto final (CRUZ-ARAÚJO et al., 2025; REYMUS; STAWARCZYK, 2019). Além disso, a biocompatibilidade desses materiais, que é essencial para o uso prolongado intraoral, foi avaliada em vários estudos, que indicam que, embora os materiais impressos em 3D apresentem boa biocompatibilidade, eles podem exibir variações nas propriedades mecânicas ao longo do tempo devido à desidratação e envelhecimento (WEŻGOWIEC; MAŁYSA; WIĘCKIEWICZ, 2024).

A integração das tecnologias CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) e impressão 3D também traz desafios relacionados à escolha de materiais que combinem boas propriedades mecânicas com segurança biológica. De acordo com estudos (TOPSAKAL; AKSOY; DURAN, 2023; WEŻGOWIEC et al., 2024), embora as resinas fotossensíveis usadas na impressão 3D ofereçam vantagens em termos de custo e personalização, a resistência mecânica e a longevidade desses materiais ainda estão sendo aprimoradas. Em comparação, os métodos de fabricação convencionais, como a auto polimerização, termo polimerização e o fresamento, continuam a ser amplamente utilizados devido às suas propriedades mecânicas superiores, especialmente no que diz respeito à resistência à fratura e a durabilidade (PRPIC et al., 2019).

Portanto, este estudo visa analisar as implicações dessas novas abordagens digitais, destacando a importância de uma escolha cuidadosa do material e do processo de fabricação para garantir que as placas oclusais impressas em 3D atendam aos requisitos clínicos e de durabilidade. A busca por alternativas mais eficientes e seguras continua a ser um desafio para a odontologia moderna, embora as inovações tecnológicas estejam oferecendo soluções promissoras (CRUZ-ARAÚJO et al., 2025; JANJIĆ et al., 2024).

2. Objetivos

Realizar uma revisão sistemática para sintetizar os dados da literatura sobre as principais propriedades e comportamento das resinas para manufatura aditiva de placa oclusal em comparação com os controles estabelecidos na literatura presente, além de analisar as propriedades mecânicas e biológicas desses materiais por meio de um estudo laboratorial utilizando uma impressora do tipo SLA-LCD com os parâmetros do fabricante.

2.1 Objetivos específicos

Realizar uma revisão comparando as propriedades físicas, mecânicas e biológicas de resinas fotossensíveis usadas na fabricação aditiva de placas oclusais com PMMA convencional, incluindo tipos fresados, auto polimerizados e termo polimerizados.

Avaliar as propriedades físicas e biológicas de resinas fotossensíveis para AM usadas na produção de placas oclusais com uma impressora LCD acessível e compará-las com materiais tradicionais, como resina termopolimerizável e PMMA autopolimerizável.

2.2. Hipóteses

As hipóteses testadas são de que o desempenho de resinas impressas em 3D em termos de propriedades físicas, mecânicas e biológicas se compara ao de materiais PMMA tradicionais usados em placas oclusais e que as resinas fotossensíveis impressas com uma impressora LCD acessível terão resistência à flexão, módulo de elasticidade, microdureza Knoop, rugosidade da superfície, sorção de água, solubilidade em água e viabilidade celular semelhantes aos materiais convencionais usados para placas oclusais.

3. Projeto de Qualificação

3.1. Introdução

Com o surgimento de novas tecnologias na área da odontologia, foi inserida na prática odontológica uma abordagem conhecida como workflow digital (SON et al., 2021) que diminui trabalhos manuais dando espaço para o digital na confecção de placas oclusais, modelos de estudo, coroas provisórias, entre outros. Somado a isso, a integração com essa abordagem também ofertou uma valiosa ferramenta nas etapas de diagnóstico e planejamento odontológico (KESSLER et al., 2020). Basicamente, o primeiro passo do workflow digital odontológico é baseado na aquisição dos dados através da tecnologia de escaneamento de uma determinada estrutura, por meio de um dispositivo de escaneamento intra ou extraoral. Num segundo momento, os dados obtidos em formato através do escaneamento são convertidos em um arquivo STL (formato de arquivo), o qual é processado e manipulado utilizando um software para desenho assistido por computador ou CAD (computer-aided design). Finalmente, os dados processados são então empregados na fabricação de estruturas usando a manufatura assistida por computador ou CAM (computer-aided manufacturing) através de abordagens subtrativas e aditivas (ELLAKANY et al., 2022) (Figura 1).

A manufatura aditiva (MA), prototipagem rápida (PR), ou impressão 3D como é coloquialmente referida, tem obtido destaque na Odontologia digital como um dos setores que mais se desenvolveu nos últimos anos (HATA et al., 2021). Esse método de fabricação foi definido pela Sociedade Americana de Testes e Materiais (ASTM) em 2015, como uma tecnologia CAM a qual é baseada na construção aditiva de uma camada de cada vez (ISO/ASTM 52900.,2015). Seu princípio é fundamentado na ideia de que qualquer objeto pode ser decomposto em camadas e reconstruído a partir das mesmas, independente da forma geométrica (GEBHARDT et al., 2016). Mais especificamente, o objeto a ser fabricado é fatiado em várias camadas bidimensionais, as quais possuem o caminho traçado pela máquina de MA ao longo dos eixos X e Y. Esse processo se repete, sendo cada camada de material depositada uma sobre a outra (eixo Z), formando uma peça tridimensional (ESPERA et al., 2019).

Atualmente, existem diversas tecnologias de MA que podem ser categorizadas de acordo com diferentes critérios, desde a aplicação (prototipagem visual, prototipagem funcional, ferramental rápido e manufatura rápida) até a condição inicial dos materiais processados ou o princípio físico subjacente ao processo de solidificação em camadas (LIGON et al., 2017). Para padronizar a terminologia e classificar cada uma das diferentes tecnologias de MA, a norma emitida pela ISO/ASTM 52900:2015) estabeleceu sete categorias de processos: polimerização de cuba (estereolitografia, SLA) e processamento por luz digital (DLP), jateamento de material (MJ), extrusão de material (ME) ou modelagem por depósito fundido (FDM), jateamento aglutinante, fusão de cama em pó (PBF), laminação de folhas e deposição de energia direta. A Figura 2 apresenta a classificação de cada tecnologia de acordo isso a ISO/ASTM 52900:2015.

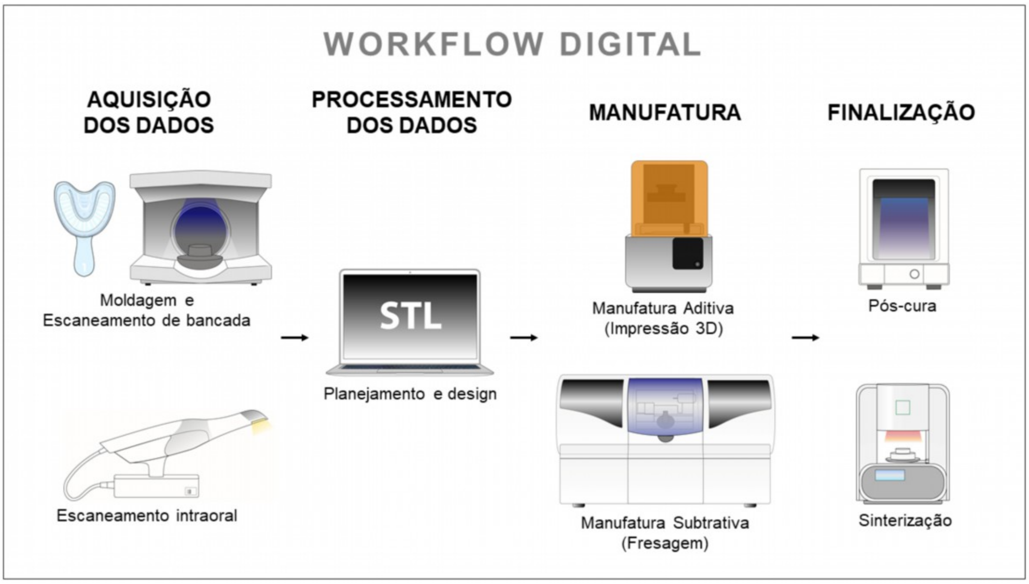

Figura 1. Passo-a-passo do workflow digital empregado na Odontologia.

3.2. Placas oclusais

A utilização de placas oclusais como opção de tratamento para disfunções temporomandibulares é comumente realizada por se tratar de uma terapia conservadora, não invasiva, de baixo custo, (NISHIMORI et al., 2014). Rotineiramente, as placas oclusais são confeccionadas a partir da resina acrílica, a base de polimetilmetacrilato (PMMA), um polímero sintético preparado através de uma reação pó (polímero) e líquido (monômero). O PMMA é amplamente utilizado na odontologia, visto que apresenta características como: biocompatibilidade, ausência de sabor e odor, propriedades térmicas satisfatórias, estabilidade dimensional, boa capacidade de polimento, aparência agradável e simplicidade técnica (WEDEKIND et al., 2020). A qualidade e desempenho clínico das placas são afetados por falhas que podem ocorrer durante o processo de produção, como a formação de poros, teor elevado de monômero residual ou contração de polimerização da resina (PEREA-LOWERY et al., 2020). Visando minimizar ou eliminar essas desvantagens, placas oclusais produzidas por sistemas digitais têm sido desenvolvidas, uma vez que a odontologia está em constante busca por novas ferramentas tecnológicas e formas de tratamento que visem otimizar o atendimento odontológico (CARDOSO et al., 2019).

Em modelos impressos por DLP (estereolitografia por processamento digital de luz) as camadas de impressão não são totalmente polimerizadas durante a impressão, por isso, os modelos precisam passar por um processo de pós cura com luz ultravioleta (KIM et al., 2020). Foi comprovado que o processo de pós-cura produz um aumento significativo nas propriedades mecânicas de resistência flexural e microdureza das resinas para impressão 3D (HANON et al., 2020). Estudo demonstram que o tempo de pós-cura pode afetar a cor e as propriedades mecânicas das resinas para restaurações provisórias manufaturadas em impressoras 3D (REYMUS et al., 2019). O conhecimento de como as características dos objetos impressos em 3D variam com o tempo de pós-cura pode fornecer orientações muito significativas para melhorar os materiais impressos.

Assim, o objetivo geral deste estudo será avaliar as propriedades físicas e biológicas de resinas para MA utilizadas para placas oclusais e restaurações provisórias, bem como revisar sistematicamente a literatura existente sobre as propriedades desses materiais.

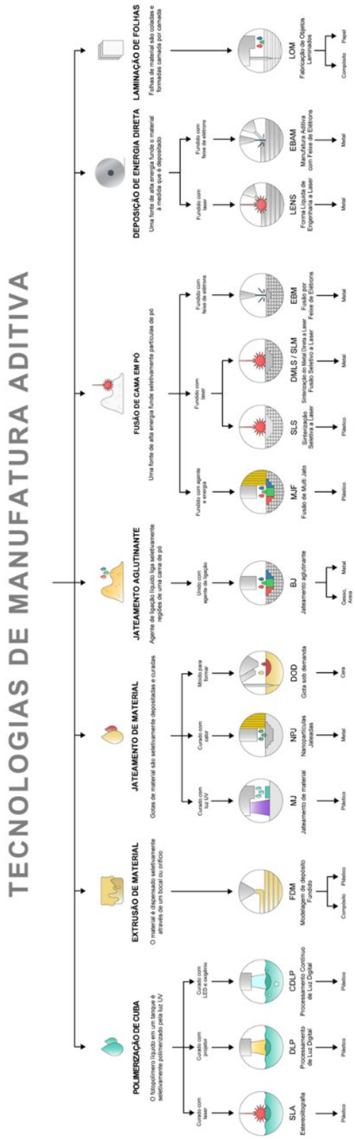

Figura 2. Esquema de classificação das tecnologias para Manufatura Aditiva (MA) de acordo com a ASTM (Fonte: Adaptado do site 3dhubs.com)

3. 3 Justificativa

Apesar do número relativamente grande de artigos de revisão recentes discutindo o uso da manufatura aditiva na odontologia (GALANTE et al., 2019; SCHWEIGER et al., 2021; SELVARAJ et al., 2022), pesquisas na área são necessárias a fim de estabelecer parâmetros e definir as características dos produtos dentários a serem impressos em 3D com objetivo de gerar mais evidências para a fabricação de futuros materiais que estão sendo desenvolvidos. O desenvolvimento de resinas estáveis e biocompatíveis para manufatura aditiva tornou possível a produção de dispositivos para utilização intraoral. Entretanto, diferentes configurações na impressão dos elementos da manufatura aditiva podem alterar as propriedades da peça como: angulação de impressão, comprimento de onda da impressora, espessura de camada, a potência da câmara ultravioleta, o tempo de pós-cura (ESPINAR et al., 2023). A maioria desses materiais foi aprovada para uso clínico por agências reguladoras pelo mundo, tal como nos Estados Unidos, Brasil e Europa. Contudo, existe pouca evidência científica com relação as propriedades físicas e mecânicas de resinas fotossensíveis biocompatíveis com aplicação na Odontologia, bem como qual a sua real biocompatibilidade.

3.4 Objetivo Geral

O objetivo geral deste estudo será avaliar as propriedades físicas e biológicas de resinas para MA utilizadas para placas oclusais e restaurações provisórias, bem como revisar sistematicamente a literatura existente sobre as propriedades desses materiais.

3.5 Metas

Meta 1. Realizar uma revisão sistemática de estudos que avaliaram as propriedades físicas e biológicas de resinas fotossensíveis de MA para confecção de placas oclusais.

Meta 2. Avaliar as propriedades físicas de resinas fotossensíveis utilizadas em MA para confecção de placas oclusais.

Meta 3. Avaliação da influência do tempo de pós-cura nas propriedades mecânicas e biológicas de resinas fotossensíveis utilizadas em MA para confecção de coroas provisórias.

A hipótese testada é que as resinas fotossensíveis para MA apresentarão desempenho semelhante em relação as propriedades físicas quando comparada com as resinas a base polimetilmetacrilatos (PMMA) convencionais.

3.6 Metodologia

As metodologias serão divididas em 2 segmentos. Um deles será a busca na literatura e uma sintetização teórica dos achados sobre placas oclusais (Meta 1). No outro segmento, as resinas fotossensíveis para manufatura aditiva empregadas na fabricação de placas oclusais das marcas comerciais Yller®, Prizma® e Next Dent®, terão suas propriedades mecânicas e biológicas avaliadas através de ensaios in vitro.

3.7 Meta 1: Revisão sistemática de Placas Oclusais

Inicialmente será realizada uma revisão sistemática da literatura a fim de levantar os conhecimentos atuais a respeito da utilização da manufatura aditiva na odontologia, mais especificamente sobre estudos avaliando materiais de impressão para placas oclusais.

3.7.1 Revisão sistemática

A seguinte questão de pesquisa foi estabelecida: “As resinas utilizadas na manufatura aditiva para fabricação de placas oclusais apresentam resultados semelhantes com relação as propriedades físicas, mecânicas e biológicas quando comparadas com resinas convencionais a base de PMMA?”. Os protocolos serão registrados no OSF (Open Science Framework) seguindo o guia de registro.

3.7.2 Estratégia de busca

A pesquisa bibliográfica será realizada por dois revisores independentes até dezembro de 2023. Serão selecionadas seis bases de dados: PubMed (Medline), EMBASE, Web of Science, Scopus, SciELO, Ibecs e BBO. A estratégia de pesquisa desenvolvida para PubMed (Medline) (Tabela 1) foi adaptada para outras bases de dados. Ademais será realizada uma busca na literatura cinza (Teses da CAPES, Opengrey e ProQuest) e as referências citadas nos artigos incluídos também serão verificadas para identificar outros artigos potencialmente relevantes. Após a identificação de artigos nas bases de dados, os artigos serão importados para o software RAYYAN (Qatar Computing Research Institute) para remoção de duplicatas e seleção dos estudos independentemente por dois revisores.

3.7.3 Seleção dos estudos

Inicialmente, dois autores independentemente avaliarão os títulos e resumos de todos os documentos. Os estudos irão ser analisados de acordo com os seguintes critérios de inclusão:

- Ensaios in vitro que avaliaram as propriedades das resinas fotossensíveis para MA utilizadas para confecção de placas oclusais;

- Estudos que avaliaram como controle uma resina acrílica convencional a base de PMMA.

Enquanto isso serão excluídos:

- Artigos de revisão, estudos clínicos, séries de casos ou relatos de casos;

- Estudos sem as resinas a base de PMMA como controle.

- Estudos com o idioma diferente do Inglês, espanhol e português

Tabela 1 – Estratégia de busca utilizada no *PubMed (Medline), EMBASE, Web of Science, Scopus*, SciELO, Ibecs e BBO.

	Termos de Pesquisa
#3	#1 AND #2
#2	(Printing, Three-Dimensional) OR (Printing, Three-Dimensional) OR (Printing, Three Dimensional) OR (Printings, Three-Dimensional) OR (Three-Dimensional Printings) OR (3-Dimensional Printing) OR (3 Dimensional Printing) OR (3-Dimensional Printings) OR (Printing, 3-Dimensional) OR (Printings, 3-Dimensional) OR (3-D Printing) OR (3 D Printing) OR (3-D Printings) OR (Printing, 3-D) OR (Printings, 3-D) OR (Three-Dimensional Printing) OR (Three Dimensional Printing) OR (3D Printing) OR (3D Printings) OR (Printing, 3D) OR (Printings, 3D) OR (Additive manufacturing technologies) OR (Additive manufacturing system) OR (Additive manufacturing) OR (Stereolithography) OR (SLA) OR (material jetting) OR (material extrusion) OR (fused deposition modelling) OR (binder jetting, powder bed fusion) OR (sheet lamination) OR (direct energy deposition) OR (polymer printing)
#1	(Occlusal Splints) OR (Occlusal Splints) OR (Splints, Occlusal) OR (Occlusal Splint) OR (Splint, Occlusal) OR (Occlusal devices) OR (Occlusal device) OR (Occlusal Appliances) OR (Cosmos Split) OR (NextDent) OR (FreePrint Splint) OR (E-Guard) OR (GP-400 Clear) OR (Guide Plate) OR (Dental LT Clean) OR (DentaCLEAR) OR (Optiprint Splint) OR (Fotodent Splint) OR (VarseoWax Splint)

Após a triagem inicial, os estudos que parecerem preencher os critérios de inclusão ou para os quais houver dados insuficientes no título e resumo para tomar uma decisão clara quanto a sua inclusão será selecionado para análise completa. Qualquer desacordo será resolvido através de discussão e consenso, ou por um terceiro revisor. Serão incluídos apenas os trabalhos que preencherem todos os critérios de seleção.

3.7.4 Tabulação dos dados

Os dados serão extraídos independentemente por dois revisores utilizando uma planilha padronizada do Microsoft Office Excel (Microsoft Corporation, Redmond, WA, Estados Unidos). Caso haja alguma informação ausente, os autores dos artigos incluídos serão contactados via e-mail.

Os seguintes dados dos estudos incluídos serão tabulados: dados demográficos, dados das resinas para impressão 3D utilizadas, sua composição e características de confecção (impressora, configuração de impressão e pós-cura) e número de espécimes. Serão analisados ainda os resultados obtidos para cada teste, método de avaliação, características das amostras e principais resultados para as resinas para impressão 3D e resinas convencionais a base de PMMA.

3.7.5 Avaliação do risco de viés

A avaliação dos estudos laboratoriais será realizada por dois revisores de acordo com os parâmetros do RoBDEMAT (Cochrane, UK) (DELGADO et al., 2022) sendo estes: viés no planejamento e alocação, viés na preparação da amostra/amostra, viés na avaliação de resultados e viés no tratamento de dados e relatórios de resultados. Quando o artigo atendia ao critério era considerado de baixo risco, quando não era conclusivo era classificado com alguma preocupação e quando não atendia era considerado de alto risco.

3.8 Meta 2: Avaliação das propriedades físicas e biológicas de resinas fotossensíveis utilizadas em MA de dispositivos oclusal.

As metodologias serão descritas de acordo com a utilização das resinas, assim, serão descritas as metodologias a serem realizadas para as resinas utilizadas para placas oclusais. Como não existem normas ISO específicas para avaliação das propriedades de resinas utilizadas para MA, as normas utilizadas pelos fabricantes e/ou estudos prévios serão seguidas.

Para avaliar as propriedades físicas de resinas utilizadas para confecção de placas oclusais, serão realizados os seguintes ensaios: rugosidade superficial, resistência a flexão e módulo de elasticidade e sorção e solubilidade. Adicionalmente, serão realizados os ensaios de viabilidade celular para avaliar as propriedades biológicas desses materiais. A seguir, cada metodologia será descrita detalhadamente.

3.8.1 Materiais utilizados

As resinas que serão utilizadas estão relacionadas na Tabela 2. Ao total, 3 marcas comerciais de resinas para MA de placas oclusais (2 nacionais e 1 importada) serão utilizadas para cada uma das categorias de materiais testados. Para cada grupo, serão utilizadas resinas acrílicas convencionais termopolimerizável e autopolimerizavel como controle para placas oclusais. Os ensaios a serem realizados estão descritos a seguir.

Tabela 2. Resinas avaliadas, parâmetros de impressão das resinas para MA e os ensaios a serem realizados para cada grupo

Categoria	**Empresa**	**Marca comercial**	**Tecnologia e parâmetros de impressão**	**Ensaios**
Placas oclusais	Yller Biomateriais (Brasil)	Cosmos Splint	Impressora Anycubic Photon Mono 2 (Anycubic, Shenzhen, Guangdong, CHINA), usando a tecnologia DLP na angulação de 45° e um comprimento de onda de 405 nm. Será utilizada uma espessura de	Rugosidade superficial; Resistência a flexão e módulo de elasticidade; Sorção e solubilidade (ISO 10477:2004) Viabilidade celular (ISO 10993-2009);
	MakertechLabs (Brasil)	Prizma BioSplint		
	3D Systems (Estados Unidos)	NextDent Ortho Rigid		

			camada de 35µm.Pós-cura em câmara Ultravioleta de 25W de potência.	
	Controle Autopolimerizável	Jet Clássico, São Paulo, Brasil	Conforme instruções do fabricante	
	Controle termopolimerizável	Triunfo Dents, Reaw Ltda Materiais, São Paulo, Brasil	Conforme instruções do fabricante	

3.8.2 Rugosidade superficial

A avaliação da rugosidade superficial será realizada com base na metodologia descrita no estudo de Huetting et al. (HUETTING et al., 2017) avaliando resinas utilizadas na MA e resinas convencionais para placas oclusais e a norma ISO 4287 (ISO 4287-2009). A rugosidade da superfície das amostras polidas será medida com um método tátil (Perthometer S6P, Mahr GmbH, Alemanha) avaliando 121 perfis únicos em um quadrado de 9 mm2 localizado no centro da amostra. O filtro gaussiano será ajustado para 0,6 mm (1/5 do comprimento de amostragem) e a rugosidade da superfície (valores de Ra) será calculada como uma média dos 121 valores de Ra derivados, usando o MountainsMap Software (Versão 7.2, DigitalSurf, Besancon, França) de acordo com para ISO 4287 (ISO 4287-2009).

3.8.3 Resistência a flexão e módulo de elasticidade

A resina do grupo controle será processada de acordo com as instruções do fabricante para confecção de placas medindo 65X40X5 mm. Para as resinas para manufatura aditiva os mesmos espécimes serão desenhados em software específico de livre acesso e código aberto (FreeCAD, www.freecadweb.org) com as mesmas medidas (65X40X5 mm) e confeccionados conforme descrito na tabela 2. As superfícies das placas devem receber acabamento e polimento por até 1 min com pedra-pomes e disco de feltro (velocidade de 650±350 m/min).

Um grupo será de avaliação imediata onde os espécimes serão armazenados em água a uma temperatura de 37 ± 1°C durante ± 2h antes do teste de flexão. Demais espécimes serão separados em grupos (n= 10) para avaliação longo prazo, serão armazenados em água a uma temperatura de 37 ± 1°C pelos períodos de 01 mês, 03 meses, 06 meses e 12 meses anteriormente ao teste de flexão. Os espécimes serão retirados do armazenamento em água e colocados imediatamente na superfície plana simetricamente sobre os suportes do dispositivo de ensaio de flexão, imersos no banho de água. Os espécimes devem chegar em equilíbrio com a temperatura do banho de água. A força do pistão de carga irá aumentar de zero, uniformemente, usando uma taxa de deslocamento constante de (5 ± 1) mm/min até a amostra se romper.

A resistência a flexão (σ), será calculada em megapascais (Mpa) usando a seguinte equação:

$\sigma B=3Fl/2bh^2$

Onde:

F é a carga máxima aplicada, em newtons;

l é a distância, em milímetros;

b é a largura do espécime testado, em milímetros;

h é a altura do corpo de prova, em milímetros.

O módulo de elasticidade dos espécimes (E), será calculado usando a seguinte equação:

E=(F_(1) l^3)/(4bh^3 d)

Onde:

F1 é a carga, em newtons, em um ponto da parte reta (com máximo de declive) de curva carga/deflexão;

d é a deflexão, em milímetros, na carga F1;

l, b e h foram definidos acima.

Os resultados preliminares estão descritos na Figura 3.

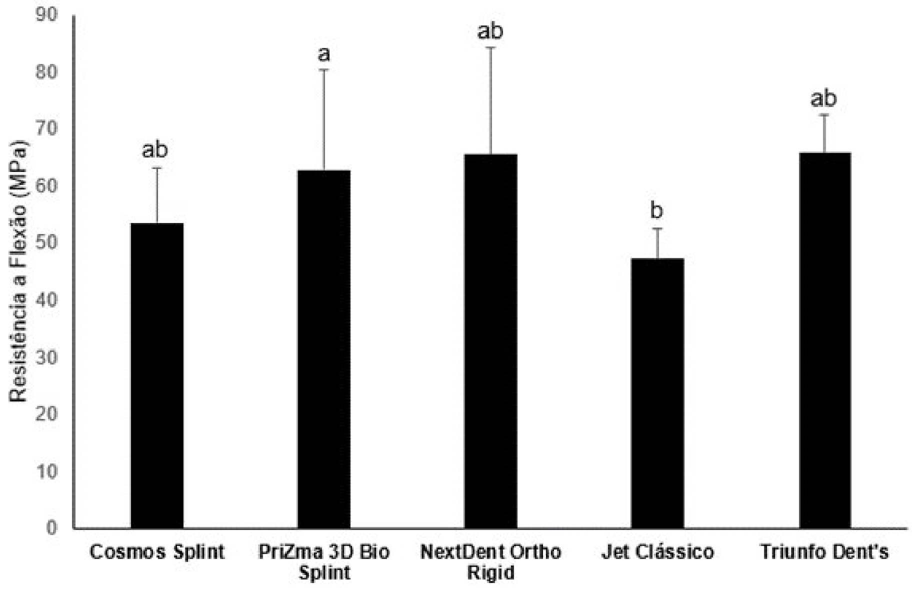

Figura 3. Médias e desvio padrão de resistência à flexão (MPa) nos diferentes grupos estudados. Letras diferentes indicam diferenças estatisticamente significativas entre os grupos (p<0.05).

3.8.4 Sorção e solubilidade

Os espécimes serão preparados de acordo com a norma ISO 20795-1 (ISO 20795-1-2013). Assim, serão fabricados 2 espécimes para cada grupo com diâmetro de 50 mm e espessura de 0,5 mm e superfícies planas seguindo as instruções do fabricante. Para as resinas para manufatura aditiva os espécimes serão desenhados em software específico de livre acesso e código aberto (FreeCAD, www.freecadweb.org) com as mesmas medidas (50X0,5 mm) e confeccionados conforme descrito na Tabela 2.

Os espécimes serão colocados dentro de um dos dessecadores contendo sílica gel que será colocado numa estufa a 37 ± 1°C por 23 ± 1 h e depois será removido o dessecador da estufa. Após os espécimes serão colocados em um segundo dessecador, com uma temperatura mantida a 23±2°C. Após 60 min as amostras serão pesadas em uma balança analítica (Shimadzu Atx224, Brasil) com precisão de 0,2 mg. O dessecador permanecerá selado, exceto no período para substituir um espécime. Após a pesagem de todas as amostras, o dessecador será recolocado na estufa. Este processo será repetido até que uma massa constante (m1 – massa condicionada) seja atingida, ou seja, a perda de massa de cada amostra não seja superior a 0,2 mg entre as pesagens sucessivas. Neste momento, será calculado o volume (V) de cada amostra utilizando a média de cinco pontos da medida de espessura. Os espécimes serão mergulhados em água a 37 ± 1°C por 7 dias. Após esse período, os espécimes serão removidos da água com uma pinça revestida de polímero, limpas com uma toalha limpa e seca até que não fique com umidade visível, e agitados no ar por 15 s, e pesados 60 s após remoção da água (m2). Após essa pesagem, as amostras serão recondicionadas no dissecador até obter massa constante (m3 – massa recondicionada).

O valor de sorção em água (ρws) será calculado em microgramas por milímetro cúbico (µg/mm3) de acordo com a seguinte equação:

ρws=(m2-m3)/V,

Onde:

m2 é a massa do espécime em microgramas, após a imersão em água por 7 dias;

m3 é a massa do espécime recondicionado, em microgramas;

V é o volume da amostra, em milímetros cúbicos.

Além disso, será calculado também o valor de solubilidade (ρsl) em microgramas por mi cúbico (µg/mm3) de acordo com a seguinte equação:

ρsl=(m1-m3)/V,

Onde:

m1 é a massa do espécime condicionado em microgramas;

m3 é a massa do espécime recondicionado, em microgramas;

V é o volume da amostra, em milímetros cúbicos.

Os resultados preliminares estão descritos na Figura 4.

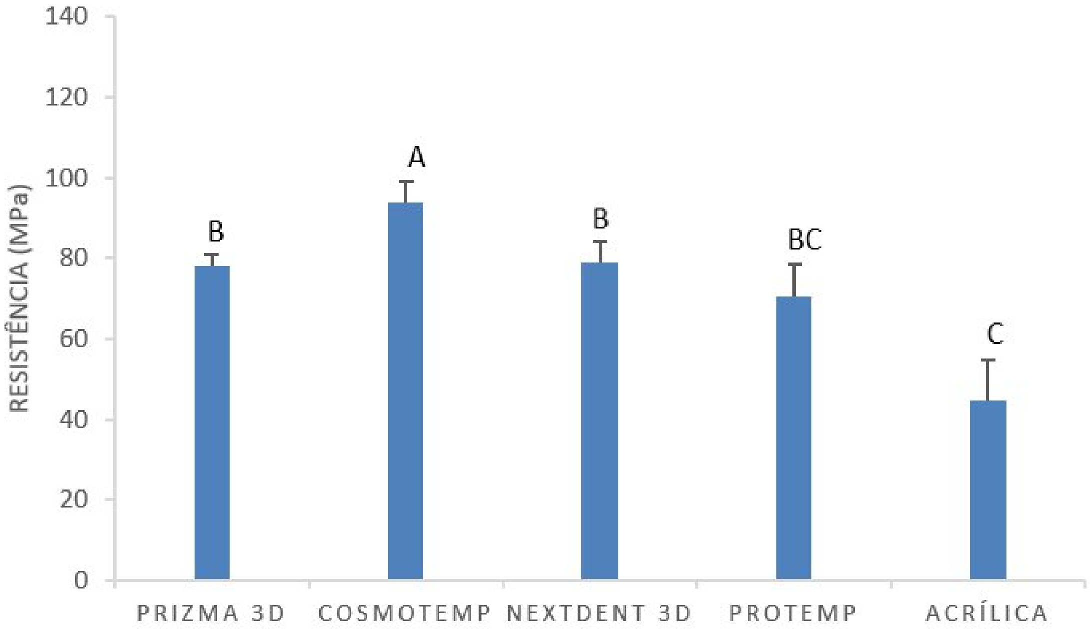

Figura 4. Resultados da resistência a flexão. Grupos com letras diferentes indicam diferenças estatisticamente significativas ($p<0.05$). Estatística Kruskall-Wallis seguido de Teste de Tukey.

3.8.5 Viabilidade celular

O ensaio de viabilidade celular será realizado conforme adaptação da ISO 10993 (ISO 10993-2009). O meio de cultura celular de Eagle modificado por Dulbecco (DMEM) será utilizado suplementado com 10% de soro fetal bovino (SFB), 2% de L-glutamina, penicilina (100 U/mL) e estreptomicina (100 mg/mL); ou meios específicos para cada linhagem celular utilizada. As células serão mantidas como DMEM e incubadas a 37°C em uma atmosfera umidificada de 5% de CO2 em ar até que a subconfluência celular seja atingida. Posteriormente, as células serão cultivadas (2x104 células/cm2) em placa de 96 poços e incubadas a 37°C em 100% de umidade, 5% de CO2. Para cada um dos grupos, os espécimes de resina medindo 6X1 mm ficarão armazenados por 24 horas num meio de cultivo celular com quantidade padronizada. Após esse período de 24 horas, o meio contendo os espécimes será utilizado como eludato, sendo colocado em contato com as células por 24 e 48 h. Transcorrido esse tempo, será feita a avaliação da viabilidade celular com WST-1 (Roche, EUA). Após 4h de incubação a 37°C no escuro, o precipitado de azul de formazan será extraído das mitocôndrias utilizando 200µl/poço de DMSO. A absorção a 450nm será determinada por espectrofotômetro (Thermo Fisher Scientific, EUA).

Os resultados preliminares estão descritos na Figura 5.

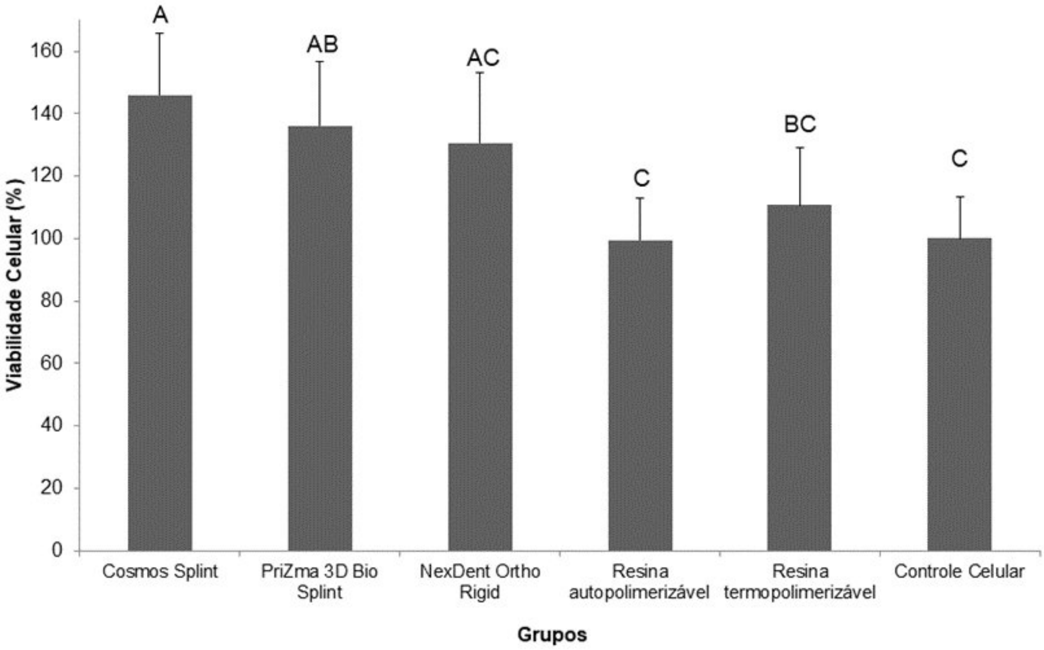

Figura 5. Resultados da Viabilidade Celular (%). Letras diferentes indicam diferenças estatisticamente significativas (p<0.05). Estatística One-Way Anova seguido de Teste de Tukey.

3.9. Meta 3. Avaliação da influência da pós-cura nas propriedades mecânicas e biológicas de resinas fotossensíveis utilizadas em MA para confecção de coroas provisórias

3.9.1 Resistência a flexão e módulo de elasticidade com diferentes tempos de cura

A metodologia foi de acordo com o item 3.4.4, tendo modificação de diferentes tempos de pós-cura na fotopolimerização por luz UV (405 nm) foram usados: 15min, 30min, 45min, 60min, 90min e 120min de tempo de pós polimerização (Anycubic Wash and Cure 2.0, Anycubic, Shenzhen, Guangdong, CHINA) as amostras após retiradas da câmara de pós cura foram colocas em embalagens recobertas com papel alumínio para não permitir que nenhuma luz chegasse até as amostras com o objetivo de não sofrem nenhuma interferência. O ensaio de resistência à flexão foi realizado conforme a ISO 20795-1, em máquina universal (EMIC DL 2000, Instron, Brasil). Os resultados preliminares com diferentes tempos de pós-cura estão descritos na Figura 7.

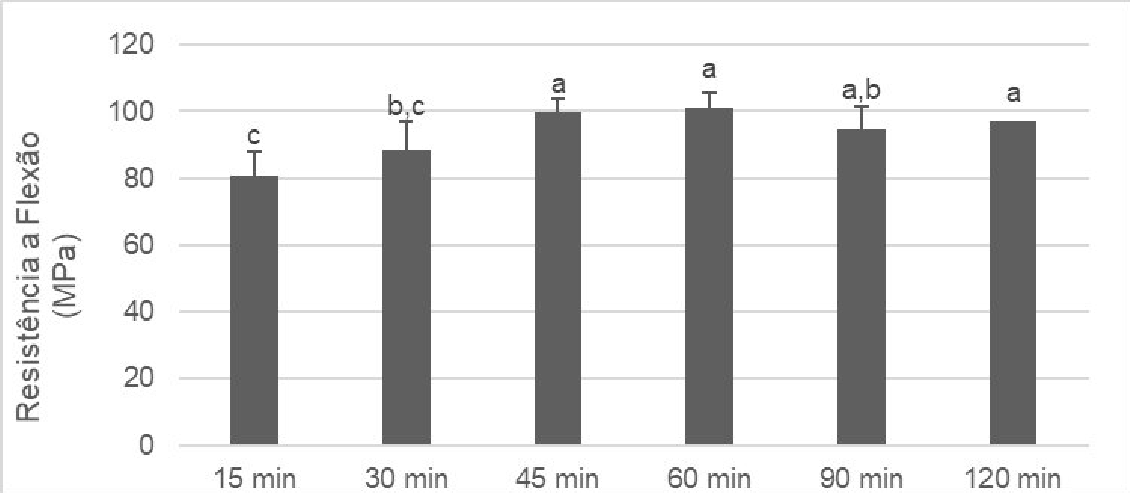

Figura 7. Médias e desvio padrão dos valores de resistência à flexão (MPa) nos grupos com diferentes tempos de pós-cura. Letras diferentes indicam diferenças estatisticamente significativas entre os grupos (p<0.05).

3.9.2 Viabilidade celular com diferentes tempos de cura

A metodologia foi de acordo com o item 3.4.5, tendo modificação de diferentes tempos de pós-cura na fotopolimerização por luz UV (405 nm) foram usados: 15min, 30min, 45min, 60min, 90min e 120min de tempo de pós polimerização (Anycubic Wash and Cure 2.0, Anycubic, Shenzhen, Guangdong, CHINA). As amostras para o ensaio de sorção e solubilidade serão confeccionadas de acordo com a ISO 10477 (ISO 10477-2004).

3.10 Resultados e impactos esperados

3.10.1 Indicadores de resultados ao final do projeto

Realizar todas as etapas das metodologias propostas;

Apresentação de um trabalho em congressos científico nacional (SBPqO/GBMD) e/ou internacional (IADR);

Publicar pelo menos 3 artigos em periódico internacional;

3.10.2 Repercussão e/ou impactos dos resultados

Apresentar evidências científicas com relação as propriedades físicas e biológicas das resinas fotossensíveis empregadas na Manufatura Aditiva com aplicação na Odontologia;

Obter informações e dados técnicos para o desenvolvimento de novos processos e produtos que contenham valor agregado.

3.10.3 Riscos e dificuldades

Controle das diversas variáveis contidas no processo de Manufatura aditiva; dificuldade de manipular nova tecnologia, custo financeiro dos materiais.

3.11 Cronograma

Na Tabela 6 está demonstrado o cronograma previsto para o presente projeto

Tabela 6. Cronograma referente a março de 2023 até Dezembro de 2024

		2023									**2024**											
Atividades / mês	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez	Jan	Fev	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez
Início das conversas sobre o trabalho	X																					
Revisão da Literatura		X	X	X	X	X	X	X	X	X												
Treinamento das metodologias propostas					X	X	X	X	X	x												
Estabilidade de cor								X	X	X	X	X	X									
Rugosidade superficial										X	x	x	X									
Resistência a flexão								x	x	X	X	x	X	X	X	x	x	x				

e módulo de elasticidade																						
Sorção e solubilidade												X	X	x	X	X						
Viabilidade celular													X	X	X	X	X	X	X			
Redação dos artigos das revisões										X	X	X	X				X	X	X			
Envio para congressos							X												X			
Redação do artigo referente a avaliação das propriedades dos materiais																		X	X	X	X	
Envio para publicação do artigo científico																						X
Defesa da dissertação de																				x		

mestrado																						

3.12 Orçamento

Na Tabela 7 está demonstrado os gastos gerais estimados com o presente projeto. Este projeto não possui financiamento de órgãos de fomento à pesquisa.

Tabela 7 – Orçamento de despesas gerais do projeto

Item	**Discriminação**	**Valor**
1	Serviço de Terceiros	R$ 4.000,00
3	Resinas importadas e nacionais, demais materiais empregados nos ensaios físico-mecânicos	R$ 12.500,00
5	Utensílios gerais de laboratório: gases, luvas, algodão	R$ 1.000,00
6	Gastos com correção de inglês	R$ 5.000,00
7	Despesas com material e consumíveis de escritório	R$ 500,00
	Total	R$ 23.000,00

4. Relatório de Campo

Durante a execução das metodologias descritas e planejadas na qualificação desta dissertação haviam outras metas para a execução de uma revisão sistemática e testes laboratoriais para resinas de manufatura aditiva de coroa provisórias. Entretanto, houve a decisão de prosseguir com a parte de resinas para dispositivos oclusais nessa dissertação e as metas relacionadas a esse outro material foram realizadas por demais orientados do grupo de pesquisa do nosso orientador. Os laboratórios CDC-Bio e NTC-Bio foram fundamentais para o desenvolvimento desse trabalho. A meta 3 descrita nesse projeto foi realizada como piloto para desenvolver habilidades na prática de impressão e na área laboratorial dos ensaios de resistência a flexão e viabilidade celular, resultando num trabalho apresentado na Semana Integrada de Inovação Ensino e Pesquisa da UFPel (Apêndice 2). As metas executas que originaram essa dissertação ocorreram conforme planejadas e sem demais alterações.

4. Artigo 1

Photosensitive Resins for Additive Manufacturing of Occlusal Splints: A Systematic Review and Meta-Analysis

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ABSTRACT

Objective: This systematic review aims to compare the physical, mechanical, and biological properties of photosensitive resins used in the additive manufacture of occlusal splints with conventional PMMA, including milled, auto-polimerized and thermo-polimerized types.

Methods: This systematic review was reported according to the PRISMA guidelines. A comprehensive search was conducted across PubMed (Medline), EMBASE, Web of Science, Scopus, SciELO, and BVS databases. Key outcomes analyzed included the following physical, mechanical, and biological properties: hardness, flexural strength, wear resistance, tensile strength, fracture resistance, volumetric loss and wear, surface evaluation, tensile strength, fracture resistance, cell viability, and antimicrobial evaluation. Meta-analyses were conducted using random-effects models in Review Manager Software version 5.3.5, and the risk of bias was assessed using the RoBDEMAT tool.

Results: The search revealed 5,144 records, of which 43 studies were included in the systematic review and 16 in the meta-analysis. The most evaluated properties in the studies included hardness, flexural strength, fracture resistance, and biological properties such as cell viability and biofilm formation. The meta-analysis found that photosensitive resins exhibited lower hardness and flexural strength compared to conventional PMMA ($p < 0.05$). Additionally, conventional materials demonstrated lower volume loss and wear, higher tensile strength, fracture resistance, and cell viability than photosensitive resins in the qualitative analysis.

Significance: Overall, photosensitive resins showed inferior physical, mechanical, and biological properties compared to conventional PMMA materials for occlusal splints.

Keywords: Occlusal Splint; Additive Manufacturing, Three-Dimensional Printing, Photosensitive Resins, Review.

1. INTRODUCTION

Occlusal devices are crucial in the treatment of temporomandibular disorders (TMDs) and bruxism, as well as in protecting dental structures from excessive wear and occlusal forces (1). Traditionally, polymethyl methacrylate (PMMA) has been the material of choice for occlusal devices, available in auto-polimerized, thermo-polimerized, and milled forms (2,3). Thermo-polimerized is often preferred for its higher durability and mechanical properties, but milled PMMA provides an excellent balance of strength and clinical adaptability, particularly for occlusal devices (3)

The introduction of digital technologies, such as computer-aided design and manufacturing (CAD-CAM) and 3D printing with photosensitive resins, has revolutionized occlusal device production by offering increased precision, reproducibility, and the potential for mass production (4). While traditional PMMA (including both milled, auto-polimerized and thermo-polimerized) has established itself as a reliable material due to its ease of handling and clinical performance, 3D printed materials are quickly gaining ground due to their customizable nature and improved manufacturing efficiencies (5). However, the mechanical properties of these materials, including their flexural strength, surface hardness, and wear resistance, can vary significantly depending on the manufacturing method used (6). For instance, thermo-polimerized PMMA typically exhibits higher hardness than 3D printed resins, especially when not post-cured properly (7). Milled PMMA, though not as hard as thermo-polimerized versions, provides excellent flexibility in customization and strength in clinical settings (8).

The digital manufacturing of occlusal devices has evolved with the use of 3D printing technologies, such as DLP and SLA/LCD, which offer advantages in precision, cost, and time efficiency (9). These technologies use photosensitive resins that should have suitable mechanical properties and biocompatibility, which are essential for the durability of the devices (10,11). The digital workflow, involving scanning and manufacturing, enables fast and precise modifications, which surpass traditional techniques like molding (5,12). Factors such as print orientation, post-processing, and surface polishing may directly influence the accuracy, wear resistance, and biocompatibility of the devices (5,9). In addition, 3D printed materials must undergo proper post-processing to enhance their mechanical properties and ensure they meet the required standards for use in clinical applications (7).

Given these factors, the selection of materials and manufacturing methods for occlusal devices should not be based solely on production efficiency or cost-effectiveness. It is essential to consider both the mechanical properties and the biological interactions of the materials. Thus, this review aims to compare the physical, mechanical, and biological properties of photosensitive resins used in the additive manufacture of occlusal splints with conventional PMMA, including milled, auto-polimerized and thermo-polimerized types. The hypothesis tested is that the performance of 3D printed resins in terms of physical, mechanical, and biological properties compares to that of traditional PMMA materials used in occlusal splints.

2. METHODOLOGY

This systematic review was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (13). Figure 1 is a flowchart according to PRISMA 2020. The study protocol was registered in the Open Science Framework (OSF) Registry under the identifier https://doi.org/10.17605/OSF.IO/GU5ZP.

2.1 Eligibility Criteria

The review employed the PICO (population-intervention-comparison-outcome) framework to address the following research question: “Do the resins used in additive manufacturing for the manufacture of occlusal splints present similar performance in terms of physical, mechanical and biological properties when compared with conventional PMMA-based resins?” In this framework, the population (P) consisted of occlusal splints; the intervention (I) involved photosensitive resins AM; the comparison (C) was milled, auto-polimerized and thermo-polimerized PMMA-based resins; and the primary outcomes (O) evaluated were physical, mechanical and biological properties. Additionally, secondary outcomes included other factors affecting material performance, such as the impact of compound additions, the post-curing method used, and the printer (SLA or DLP). This review included in vitro studies for occlusal splints fabricated using AM techniques.

Exclusion criteria were applied to review articles, case series, case reports, and studies that did not include milled or auto-polymerized and thermo-polymerized PMMA base resins as a control, such as clinical trials, and studies in other languages, and those that did not use PMMA as a control

2.2. Search strategy and information sources

The search was independently conducted by two reviewers (MB and WR) across PubMed (Medline), EMBASE, Web of Science, Scopus, SciELO, and BVS databases. Detailed search strategies for each database are provided in Table 1. The final search was completed on January 29, 2025.

2.3. Study Selection

All records were imported into Rayyan (Rayyan Systems Inc., Qatar) for duplicate removal. Titles and abstracts of all eligible studies were independently screened using Rayyan by two reviewers. Articles without abstracts but with titles indicating potential relevance to the review objectives were also pre-screened and subjected to full-text analysis for eligibility. Full-text articles meeting all inclusion criteria were included in the data extraction process. Additionally, a manual search of the reference lists of included studies was conducted. Any disagreements between reviewers were resolved through discussion and consensus or, when necessary, by consulting an experienced reviewer (NB).

2.4. Data collection and analysis

The information from the included studies was extracted and compiled into a standardized table by two reviewers independently. The extracted information included: author, year, country, journal, resin used, sample size and dimensions per group, control resin, 3D printer, printing parameters, post-curing methods, and title (Table 2).

Physical and mechanical properties were grouped as hardness, flexural strength, volumetric loss and wear, surface evaluation, tensile strength and fracture resistance. Biological properties were also catalogued as cell viability and antimicrobial. Furthermore, a qualitative evaluation of the results was performed, focusing on the main findings of each study. The data were tabulated based on the following parameters: author (year), 3D resins, mean ± SD, control resins, mean ± SD, number of samples (per group) and dimensions, main characteristics, main findings and material that performed best (Table 3). The numerical results of the tests described in the studies were tabulated to perform a meta-analysis between the studies.

2.5. Study risk of bias assessment

The risk of bias was evaluated using the RoBDEMAT tool, which supports research reporting on preclinical dental materials (14). Two independent reviewers assessed each study based on parameters such as sample randomization, sample size calculation, consistent sample preparation by a single operator, adherence to manufacturer's specifications for materials, inclusion of control groups, robust statistical analysis, and accurate measurement and reporting of outcomes. Each parameter was rated as "sufficiently reported," "insufficiently reported," "not reported," or "not applicable."

2.6. Meta-analysis

A meta-analysis was conducted focusing exclusively on hardness and flexural strength outcomes, as these were the most frequently evaluated in the included studies and provided consistent data with mean, standard deviation, and standardized test methods. These properties are clinically relevant, directly impacting the durability, rigidity, and performance of oral devices (15). The methodological homogeneity across the studies also facilitated group comparisons. However, other outcomes like volumetric loss and wear, surface evaluation, tensile strength, fracture resistance, cell viability and antimicrobial were measured using various methodologies, preventing standardization for reliable statistical synthesis. These outcomes were thus analyzed and discussed qualitatively.

Meta-analyses were performed using Review Manager Software version 5.3.5 (The Nordic Cochrane Centre, The Cochrane Collaboration; Copenhagen, Denmark). Analyses were performed using a random-effects model, and pooled effect estimates were obtained by comparing the standardized mean difference between studies. Comparisons were made in hardness and flexural strength tests, comparing 3D resin with milled resins, auto-polymerized PMMA, and thermo-polymerized PMMA. Statistical heterogeneity of treatment effect between studies was assessed using Cochran's Q test and the I^2 inconsistency test, in which values above 50% were considered to indicate substantial heterogeneity, once the level of significance was established for $p \leq 0.05$.

3. RESULTS

The search in the databases revealed 5.144 records initially. After removing duplicates, 2.017 remained, of which 1.975 were excluded because they did not meet the eligibility criteria, such as clinical trials, and studies in other languages, and those that did not use PMMA as a control. Thus, 43 studies were included in the systematic review, and 16 in meta-analysis, as shown in Figure 1.

3.1 General Analysis

Data from the 43 scientific studies published between 2016 and 2025, materials, and manufacturing methods for occlusal devices are compiled in Tables 2 and 3. These studies were conducted in 19 different countries. A total of 93 distinct material groups were investigated, including 43 types of photosensitive resins used in 3D printing, 23 milled PMMA resins, 12 auto-polymerized and thermo-polymerized acrylic resins, and 5 experimental materials containing additives such as graphene and chitosan. In terms of technology, at least 35 different 3D printer models were employed. Curing methods varied and included exposure to UV light with up to 2000 flashes, thermal ovens, and controlled environments using inert gases such as nitrogen or argon, in addition to manufacturer-specific protocols. Figure 2 illustrates the distribution of studies on photosensitive resins used (a), properties evaluated (b), and 3D printers used (c) in the included studies.

3.2 Data Analyses

3.2.1 Hardness

Ten different scientific studies were analyzed, totaling the evaluation of 27 different dental resins, including 3D printed, milled (CAD-CAM) and conventional (auto-polymerized and thermo-polymerized). Hardness properties were measured using seven different methods, with emphasis on: Nano-hardness (MPa), Martens Hardness (N/mm²), Knoop Hardness (HK), Shore D, Vickers Hardness (VH), and Surface Microhardness (kgf/mm²). The diversity of methods reflects the variety of approaches of the studies, ranging from the initial behavior of the resins to the effects of artificial aging and post-curing protocols.

The meta-analysis of hardness (Figure 3) between photosensitive resins and different types of conventional resins revealed statistically significant differences in favor of traditional materials. In the subgroup analysis between 3D resins and milled resins, a standardized mean difference of -5.05 (95% CI: -8.49 to -1.61; p = 0.004) was found, indicating greater hardness for milled resins. Additionally, auto-polymerized resins exhibited higher hardness compared to 3D printed resins (standardized mean difference = --5.60; 95% CI: -9.76 to -1.45; p = 0.008). Similarly, thermo-polymerized resins demonstrated superior performance with a standardized mean difference of -3.99 (95% CI: -8.03 to 0.05; p = 0.05). The overall analysis of all studies revealed a standardized mean difference of -4.77 (95% CI: -6.79 to -2.75; p < 0.0001), indicating that, in general, 3D resins had lower hardness when compared to conventional resins. The inconsistency between the studies was high (I^2 = 97%) and a significant heterogeneity (p<0.001) was found, suggesting significant methodological variations, such as differences in resin types, post-curing methods, printing orientations, and testing protocols for hardness.

The qualitative analysis of all studies that evaluated hardness indicated that photosensitive resins present significant variation in hardness values, being generally lower than auto-polymerized, thermo-polymerized, and milled (CAD-CAM) materials. In several studies, PMMA-milled materials demonstrated greater stability and higher hardness values, while 3D resins presented intermediate performance and showed lower hardness and greater wear (Table 3). Despite this, it was found that post-curing protocols (such as polishing or curing according to the manufacturer) could significantly improve the hardness of 3D resins (16).

3.2.2 Flexural Strength

Twelve studies were analyzed, totaling the evaluation of 26 different resins, 15 of which were 3D printed, 7 milled, 3 thermo-polymerized, and 1 injected. Most of the studies used the three-point flexural strength test, with standardized specimens, generally with dimensions of 64 × 10 × 3.3 mm. The flexural strength values of the 3D resins varied widely, with emphasis on Smart

Dent Bio Bite Splint (94.80 ± 20.05 MPa) and Dental LT Clear (up to 100 ± 5 MPa). Among the milled resins, the best results were obtained with Temp Premium Flexible (122 ± 3.1 MPa), Ceramill A-Splint (252 ± 18 MPa in biaxial test) and Zirlux Splint Transparent (112.13 ± 1.73 MPa). The best overall performance was found in the milled and thermo-polymerized resins, which presented consistently higher flexural strength than the photosensitive resins.

The meta-analysis of flexural strength (Figure 4) comparing photosensitive resins and conventional materials revealed that, in general, conventional materials presented superior performance. In the comparison between photosensitive resins and milled resins, a standardized mean difference of -6.17 (95% CI: -8.62 to -3.71; $p < 0.0001$) was found, indicating significantly higher flexural strength in milled materials. For auto-polymerized resins, the standardized mean difference was -0.96 (95% CI: -2.51 to 0.59; $p = 0.22$) and no differences was found between groups. In contrast, the thermo-polymerized resins showed a statistically higher flexural strength than 3D resins with an standardized mean difference of -6.73 (95% CI: -9.94 to -3.51; $p < 0.0001$). The combined analysis of all groups revealed an overall standardized mean difference of -4.86 (95% CI: -6.25 to -3.46; $p < 0.0001$), favoring conventional materials. As with the hardness analysis, high inconsistency ($I^2 = 96\%$) and significant heterogeneity ($p<0.001$) was found, indicating substantial methodological variations, such as differences in resin formulations, testing conditions, and other factors, which should be considered when interpreting the results.

The studies analyzed demonstrate that the milled and thermo-polymerized resins generally present greater flexural resistance compared to the photosensitive resins. The average values of the milled resins varied between 105 MPa and 122 MPa, while the 3D printed resins, even with variations in orientation and post-curing time, generally presented lower values, with an average between 36 MPa and 95 MPa. While some printed resins have achieved good results with adjustments to the printing process, such as curing time and orientation, traditional techniques still stand out for their stability and superior mechanical performance.

3.2.3 Tensile Strength and Fracture Resistance

Five studies were analyzed, of which three (17–19) evaluated the fracture resistance and two (20,21) the tensile strength of different materials used in the manufacture of occlusal splints, totaling nine different types of resins, including 3D printed, auto-polymerized, thermo-polymerized and milled (CAM). Fracture resistance tests were performed with the application of force in Newtons (N), allowing a direct comparison between the materials. Significant variation was found between the different manufacturing methods. In general, milled resins showed the best performance, with fracture resistance values between 3051.2 ± 179.07 N and 3398 ± 435 N, surpassing both 3D printed and conventional acrylic resins (18). The 3D resins demonstrated intermediate performance, with values between 1489.9 ± 99.8 N and 2286 ± 499 N, while the conventional acrylic resins presented the lowest values, with an average resistance of 1303.9 ± 90.7 N (18). These results indicate the superiority of the milled resins in relation to the other materials tested in terms of flexural resistance.

3.2.4 Volumetric Loss and Wear

Three studies evaluated 13 resins: 8 photosensitive, 3 thermo-polymerized, and 2 CAD-milled materials. Volumetric wear tests simulated clinical use with artificial antagonists. The highest wear was found in the 3D printed Freeprint Splint 2.0 (204.59 ± 25.67 mm³) (22), while the lowest values were recorded for Eclipse Prosthetic Resin (0.013 ± 0.003 mm³), KeySplint Hard (0.028 ± 0.011 mm³) [Lawson et al., 2024], and Ceramill A-Splint (0.041 ± 0.017 mm³). KeySplint Soft had moderate wear (0.289 mm³). The best overall performance was by SMB (ceramic reinforced PEEK), with the lowest wear and depth (23). CAD-milled materials generally showed inferior volumetric loss followed by thermo-polymerized resins. In general, photosensitive resins showed the highest wear, with significant variability among brands evaluated.

3.2.5 Surface evaluation

The qualitative analysis examined over 15 studies (2017-2025) comparing 3D printing, milling, and conventional methods (auto-polymerized and thermo-polymerized) on surface roughness, wear resistance, color stability, gloss, accuracy, and bacterial adhesion. A consistent trend was observed in the data favoring milled PMMA materials in terms of surface roughness, wear resistance, and dimensional accuracy. For example, in terms of trueness, the ProArt CAD Splint material had a deviation of only 67.69 ± 2.16 μm, while the Freeprint Splint (3D) achieved 135.49 ± 7.10 μm. In terms of wear, the milled PMMA (Zirlux Splint) presented a wear depth of 0.61 ± 0.11 mm, considerably lower than the average for SLA-printed splints (2.53 ± 0.49 mm). Roughness values also corroborate the superiority of the subtractive method: the Promolux HC (conventional) had 0.083 ± 0.006 μm, while the Freeprint Splint 2.0 (3D) achieved 0.168 ± 0.006 μm.

The qualitative analysis also indicated that, despite having lower resistance and greater roughness overall, photosensitive resins are preferred for their adaptability, lightness, and faster production process (24). Some printing variations (DLP and SLA) showed acceptable performance when properly oriented on the printing platform (25). Furthermore, materials such as LuxaPrint Ortho Plus demonstrated good color and brightness stability over time. It is also worth noting that in clinical contexts, such as bacterial adhesion, milled devices were more effective in minimizing biofilm formation (26).

Comparatively, subtractive materials lead in performance in most of the parameters evaluated, being considered the most reliable for the longevity and precision of occlusal devices. Photosensitive resins, on the other hand, stand out for their practical viability, with increasing quality as the technology is refined, which surpassed traditional DLPs in some studies (5). Auto-polymerized and thermo-polymerized, in turn, showed intermediate performance, with an emphasis on lower roughness after polishing (27). In short, studies converge in the conclusion that milling still offers the best results in terms of the physical and mechanical performance of occlusal devices. However, more modern 3D technologies have been reducing this gap, being a viable option when cost and agility are prioritized.

3.2.6 Biological Properties

Six studies evaluated the biological properties of occlusal resins, totaling the investigation of 16 different materials, including 3D printed and conventional resins (PMMA and thermo-polimerized). The tests applied included evaluation of cell viability (MTT, LDH, Presto Blue), elution of residual monomers, and bacterial biofilm formation. The best biological performances were found in the resins

Dental LT Clear (polished), Keysplint Soft, and in the conventional materials Tizian Blank PMMA (TR) and Tizian Flex Splint Comfort (TF), which presented high cell viability and low cytotoxicity. Regarding monomer elution, the SHERAprint-ortho plus 3D resin demonstrated elution of only 7.47 μmol/l, while conventional PMMA showed 8768 μmol/l, showing a significant difference. Monomer elution was considerably lower in photosensitive resins compared to conventional PMMA materials, which released a greater quantity of potentially toxic compounds.

Regarding antimicrobial activity, the surface treated with eugenol showed biofilm inhibition of 92.39%, being the most effective in this regard. In general, polished 3D resins showed better biological performance compared to unpolished ones, with increased cell viability. Materials such as Dental LT Clear Resin and Keysplint Soft demonstrated good biocompatibility, while others, such as Freeprint Splint and some NextDent resins, showed high levels of cytotoxicity.

Concerning biofilm, surfaces treated with eugenol showed a significant reduction in bacterial adhesion, standing out as a complementary alternative in microbiological control. Despite some variations between materials, studies indicate that 3D resins, when subjected to treatments such as polishing or surface modification, can present biological performance similar to or superior to conventional resins.

3.3 Risk of bias

All studies included in the review adequately reported control groups, standardization of samples and materials, identical experimental conditions across groups, statistical analysis, and reporting study outcomes (Table 4). Sample size rationale and reporting were insufficiently reported for only 4 studies (8,19,28). Adequate and standardized testing procedures and outcomes were insufficiently reported for 4 studies (10,28–30). Randomization of samples and blinding of the test operator was not applicable for all studies.

4. Discussion

The introduction of additive manufacturing raises new challenges related to the physical, mechanical and biological properties of photosensitive resins. In general, the results from the included studies found that photosensitive resins did demonstrate comparable or superior performance to conventional materials used for occlusal splints. Thus, our hypotheses was rejected. Besides, our review revealed a clear evolution in the complexity and sophistication of the studies over the analyzed period. In the early years (2016–2018), the studies primarily focused on basic mechanical evaluations, such as flexural strength, elastic modulus, and wear resistance, often comparing printed resins with conventional materials. From 2019 onward, a significant methodological advancement is observed, with the inclusion of more refined analyses such as artificial aging effects, printing orientation influence, water absorption and solubility, and topographic assessments using microscopy and nanomechanical property mapping. Biological aspects also gained importance starting in 2020, with studies addressing cytotoxicity, cell viability, bacterial adhesion, and biofilm formation, reflecting a growing interest in the biocompatibility of the materials used. Between 2022 and 2024, the studies began to incorporate comparisons between different manufacturing technologies and explored the impact of variables such as post-processing, curing temperature, and polymerization atmosphere on the dimensional stability and mechanical performance of the devices. Overall, the progressive diversification of methodologies and expansion of evaluated parameters demonstrates the maturation of the field, with a strong interdisciplinary character and a clear clinical application focus, in line with the evolution of digital dentistry and personalized manufacturing technologies.

The property of hardness is crucial to ensure the wear resistance of occlusal devices, especially in cases involving parafunctional habits (31). The reviewed studies show significant variation in the hardness values between materials used, strongly influenced by the manufacturing technology, resin type, and post-processing protocols. In general, milled materials (CAD-CAM), such as industrially polymerized PMMA blocks, tend to show higher surface hardness. A study (3) found that the CAD-CAM group exhibited the highest Knoop microhardness values among the evaluated groups, surpassing even auto-polymerized and thermo-polymerized materials (15). Similar results were reported by other authors (32), where milled CopraDur® material reached 116.2 MPa, while printed materials such as VarseoWax Splint® and Ortho Rigid® exhibited significantly lower values. Three-dimensional printed materials, while promising for customization and time efficiency, exhibit greater variability in hardness, primarily due to post-curing protocols. Inadequate post-polymerization can significantly reduce hardness, as seen with SLA resins like Dental LT®, whereas optimal curing improves their properties.

Furthermore, studies have shown that printing direction and moisture exposure may also impact hardness and elasticity, with better results when layers are printed perpendicular to the load axis (16). Water absorption leads to a decline in flexural strength and hardness, particularly in horizontally printed samples (33). Proper polishing enhances microhardness and thermal aging resistance, while lack of polishing is linked to lower hardness and increased cytotoxicity (34). Additionally, lower hardness in resins for occlusal splints correlates with higher wear volume, indicating that while some 3D resins initially show acceptable hardness, their resistance to abrasion may decrease over time (6). Thus, although printed resins offer operational advantages and are constantly improving, their performance in terms of hardness still generally falls short compared to milled or thermo-polymerized materials as shown in the meta-analysis. Standardizing post-polymerization and polishing protocols, as well as controlling variables such as printing orientation and aging, are crucial factors for enhancing their clinical performance.

The use of 3D printers in dentistry offers advantages in terms of customization and reduced manufacturing costs, but in terms of mechanical performance, conventional resins may still hold superiority (24). Based on our results, it was found that the flexural strength of photosensitive resins varies significantly compared to conventional resins, such as milled and thermo-polymerized ones. Besides, the meta-analysis on flexural strength revealed that milled and thermo-polymerized resins outperformed 3D-printed resins. In the meta-analysis, photosensitive resins were only comparable to the auto-polymerized PMMA control. Despite the heterogeneity observed, the risk of bias was generally low across the studies included in the meta-analysis, with the qualitative analysis revealing the same results. The studies found that milled and thermo-polymerized resins maintained more consistent flexural strength, especially after artificial aging (thermal cycling) (28). In contrast, photosensitive resins showed lower flexural strength, particularly when subjected to thermal cycles.

Furthermore, a study (3) showed that photosensitive resins, even with adjustments in orientation and post-print curing, were unable to reach the same levels of strength as conventional acrylic resins and were more vulnerable to aging. Moreover, another study (28) emphasized that while photosensitive resins exhibit good mechanical properties in controlled conditions, the impact of artificial aging revealed significant degradation in their hardness and flexural strength. This finding was supported by other studies (30), which demonstrated that after thermal cycling, photosensitive resins failed to maintain the necessary flexural strength for prolonged use in devices like occlusal splints. However, studies on the influence of print orientation on flexural strength (11,35) found that adjusting the printing orientation can significantly improve the performance of 3D resins. Specifically, vertical printing demonstrated superior flexural strength compared to other orientations like horizontal printing (36). The results should be interpreted with caution in this property because studies presented a risk of bias regarding sample size rationale and reporting (8,28), and adequate and standardized testing procedures and outcomes (28,30). Therefore, despite advancements in 3D printing for manufacturing occlusal splints, conventional resins still stand out for their higher long-term mechanical stability. However, 3D printing offers benefits in terms of customization and efficiency if it is used in contexts where mechanical strength is not a critical priority.

Other mechanical property evaluated was fracture resistance. A study compared the fracture resistance of splints produced by various methods, including 3D printing, milling (CAD/CAM), and conventional acrylic (18). The results showed that milled resins exhibited the highest fracture resistance, followed by photosensitive resins, with conventional acrylic resins showing the lowest values (18). A study indicated that milled devices provided the highest fracture resistance, with initial values significantly higher than those of photosensitive resins (17). They also found that after simulating chewing cycles (120,000 cycles), fracture resistance was reduced in milled and conventional materials, but photosensitive resins remained largely unaffected (17) These data suggest that while milled resins offer superior fracture resistance, photosensitive resins may still be viable for short-term clinical use, especially when long-term durability is not a critical factor (17). The results should be interpreted with caution in this property because studies presented a risk of bias regarding Sample size rationale and reporting (19).

Regarding wear, studies have shown significant variation in the volumetric wear of resins for occlusal devices, depending on the material type and manufacturing process used (23). CAD-milled materials, such as Ceramill A-Splint resin, exhibited the best wear resistance, with the lowest wear (6.44 ± 1.77 mm^3) (22). In contrast, 3D printed materials like FreePrint Splint 2.0 showed the highest wear (204.59 ± 25.67 mm^3), particularly in flexible versions (37) Rigid 3D printed materials, such as KeySplint Hard, demonstrated wear resistance like milled materials, while flexible resins like KeySplint Soft had significantly higher wear (6). Ceramic-reinforced PEEK, a rigid material, showed the least wear in both volume and depth (23). So, in terms of wear, 3D printed resins, especially flexible versions like Freeprint Splint 2.0, exhibited higher volumetric wear, which may limit their use in patients with severe bruxism where wear resistance is critical. These findings suggest that rigid, reinforced materials are more durable and suitable for patients with bruxism, while flexible 3D-printed materials should be used cautiously for those with severe bruxism (23).

In general, milling provides superior surface accuracy for occlusal devices compared to 3D printing, particularly in terms of surface roughness, wear resistance, and dimensional accuracy (26) Milled materials tend to have significantly lower roughness values, which can be crucial for reducing bacterial biofilm formation and increasing clinical durability. They also exhibit better wear resistance, while printed materials exhibited greater volume loss during wear tests (26). These materials also demonstrated better wear resistance compared to printed materials such as Freeprint Splint (37). The choice of manufacturing method should thus balance physical resistance properties with clinical factors such as ease of adaptation and cost. However, when cost and production speed are prioritized, 3D-printed materials may be a viable option. Recent advancements in printing technology have allowed for significant improvements in color stability and wear resistance in materials like LuxaPrint Ortho Plus, bringing printed materials closer to their milled counterparts in terms of performance (38). The results should be interpreted with caution in this property because studies presented a risk of bias regarding adequate and standardized testing procedures and outcomes (29). Therefore, the growing capabilities of 3D printing technologies may narrow the performance gap between these materials (38).

Regarding the biological properties of 3D printed resins, studies indicate that surface treatments significantly affect the biocompatibility of these materials. A study (34) found that unpolished resins like Dental LT Clear and Freeprint Splint showed low cellular viability, indicating significant cytotoxicity, whereas polished surfaces exhibited cell behavior like conventional materials. Additionally, studie on residual monomer release (39), found that photosensitive resins like Freeprint Splint release higher levels of monomers compared to conventional PMMA resins, contributing to increased cytotoxicity. This highlights the importance of post-processing, including polishing and ensuring minimal residual monomer release, to enhance the safety and efficacy of 3D printed dental materials.

Finally, this study acknowledges some limitations. First, the high methodological heterogeneity across the included studies introduces variability that may affect the interpretation of the results. Differences in resin types, 3D printing techniques, post-curing processes, and testing protocols for each material may influence the outcomes and were qualitatively analyzed to provide a comprehensive overview of this field. Besides, the risk of bias assessment showed that some studies did not report sample randomization, sample size justification, and standardized testing procedures adequately. These factors were considered when interpreting the results. Moreover, the studies primarily focused on *in vitro* data, and the findings may not fully reflect the real-world clinical performance of these materials. While the meta-analysis provided insights into the mechanical properties of 3D printed resins, other factors such as long-term durability and clinical adaptation were not consistently evaluated across studies. Finally, the limited scope of biological property assessments (such as monomer release and biofilm formation) may not fully capture the complex biological interactions of these materials *in vivo.* Future studies with more standardized methodologies, larger sample sizes, and clinical trials are needed to better understand the real-world performance of photosensitive resins for occlusal splints.

In summary, 3D printed resins present a promising alternative to conventional materials, offering significant advantages in customization and production efficiency, as well as reduced costs. However, their biological safety and mechanical performance depend on post-processing processes and strict control of manufacturing conditions. Although photosensitive resins still lag behind traditional PMMA-based materials in mechanical properties like hardness and flexural strength, advancements in 3D printing technologies and proper post-processing could enhance both their mechanical and biological performance, making them a viable option for specific clinical applications, such as occlusal splints. Moreover, the selection of materials and methods for manufacturing occlusal splints should balance physical, mechanical, and biological properties with clinical precision, durability, and technical and economic feasibility.

5. Conclusion

In conclusion, this study demonstrated that photosensitive resins used in 3D printing for occlusal splints generally exhibited inferior physical, mechanical, and biological properties compared to conventional PMMA materials. Therefore, the indication of printed splints should be carefully evaluated.

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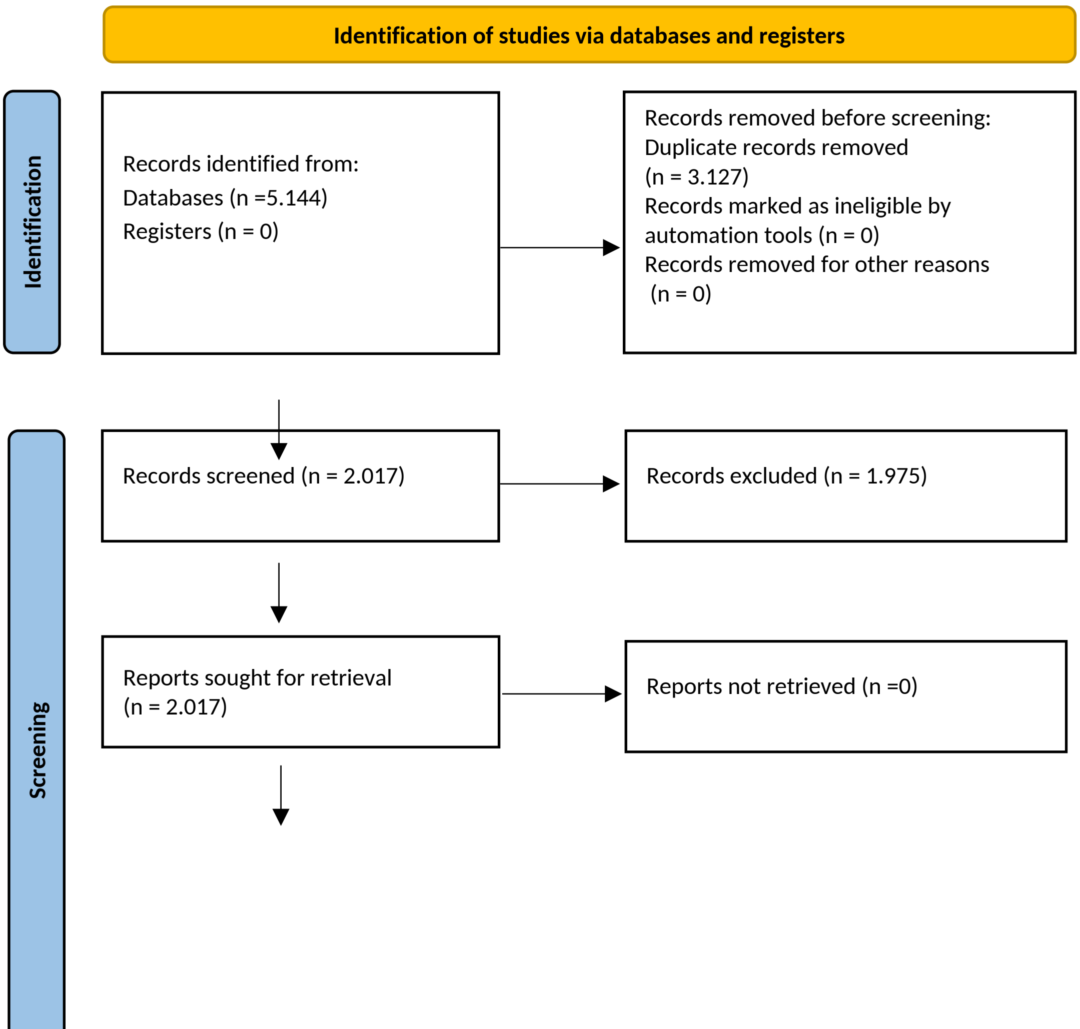
Identification of studies via databases and registers
Identification
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Registers (n = 0)
Records removed before screening:
Duplicate records removed
(n = 3.127)
Records marked as ineligible by
automation tools (n = 0)
Records removed for other reasons
(n = 0)
Screening
Records screened (n = 2.017)
Records excluded (n = 1.975)
Reports sought for retrieval
(n = 2.017)
Reports not retrieved (n =0)

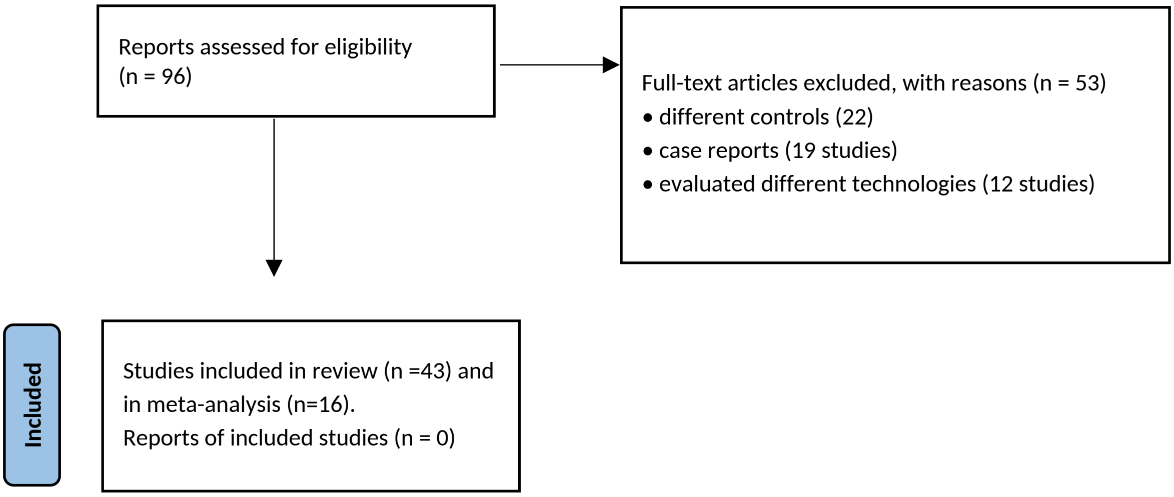

Figure 1. Research flowchart according to PRISMA 2020.

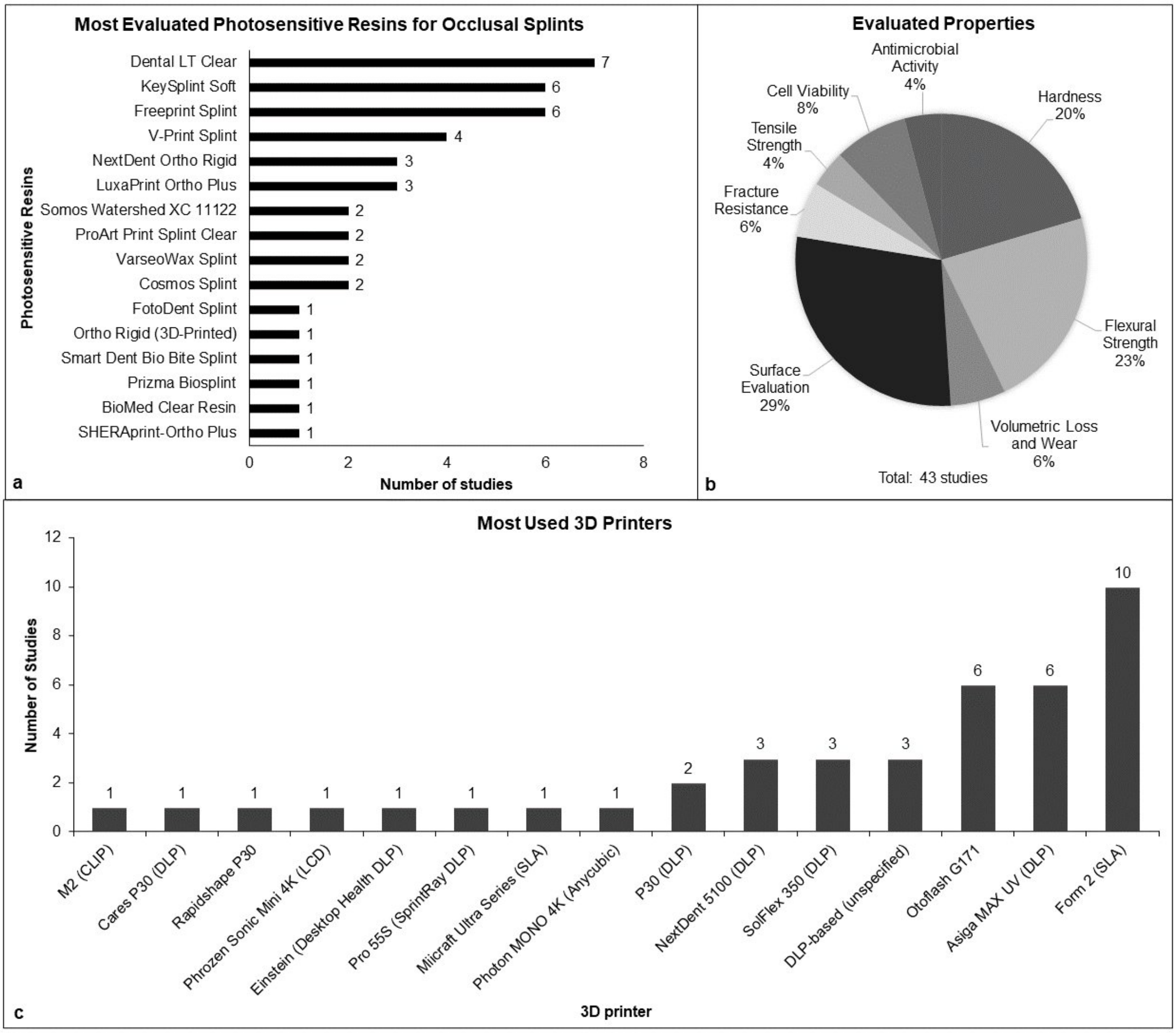

Figure 2. Distribution of (a) photosensitive resins used in the included studies, (b) evaluated properties, and (c) most commonly used 3D printers.

Study or Subgroup	3D Resin Mean	3D Resin SD	3D Resin Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.2.1 3D Resin vs Milled								
Christian Wesemann 2020	178.64	9.8	8	215.75	5.88	8	5.3%	−4.34 [−6.33, −2.35]
Christian Wesemann 2020	144.16	14.7	8	215.75	5.88	8	5.1%	−6.05 [−8.65, −3.44]
Danielly Guimaraes 2023	118.26	32.26	4	244.67	12.94	4	4.8%	−4.47 [−7.85, −1.10]
Marcel Reymus 2020	130	7.22	30	114	6.7	10	5.5%	2.21 [1.33, 3.09]
Marcel Reymus 2020	142	6.21	30	114	6.7	10	5.5%	4.34 [3.11, 5.57]
Marcel Reymus 2020	97	8.21	30	114	6.7	10	5.5%	−2.11 [−2.98, −1.25]
Prpic 2019	28.5	2.5	20	116.2	1.6	20	2.5%	−40.96 [−50.43, −31.48]
Prpic 2019	89.3	4.9	20	116.2	1.6	20	5.3%	−7.23 [−9.01, −5.45]
Subtotal (95% CI)			**150**			**90**	**39.5%**	**−5.05 [−8.49, −1.61]**
Heterogeneity: Tau² = 22.13; Chi² = 271.23, df = 7 (P < 0.00001); I² = 97%								
Test for overall effect: Z = 2.87 (P = 0.004)								
1.2.2 3D Resin vs Auto-polymerized PMMA								
Danielly Guimaraes 2023	118.26	32.26	4	199.56	11.17	4	5.2%	−2.93 [−5.37, −0.48]
Junichiro Wada 2023	228.6	4.2	20	279	9.5	20	5.4%	−6.73 [−8.40, −5.05]
Nathaniel C. Lawson 2024	72.38	9.905	8	117.39	2.158	8	5.1%	−5.94 [−8.50, −3.37]
Nathaniel C. Lawson 2024	203.1	16.38	8	117.39	2.158	8	5.0%	6.94 [4.00, 9.87]
Prpic 2019	89.3	4.9	20	111.7	0.1	20	5.4%	−6.34 [−7.92, −4.75]
Prpic 2019	28.5	2.5	20	106	2.1	20	3.1%	−32.90 [−40.52, −25.28]
Samer M. Alaqeel 2019	180	22	10	165	60	10	5.5%	0.32 [−0.57, 1.20]
Subtotal (95% CI)			**90**			**90**	**34.6%**	**−5.60 [−9.76, −1.45]**
Heterogeneity: Tau² = 28.91; Chi² = 193.43, df = 6 (P < 0.00001); I² = 97%								
Test for overall effect: Z = 2.64 (P = 0.008)								
1.2.3 3D Resin vs Thermo-polymerized PMMA								
Danielly Guimaraes 2023	118.26	32.26	4	208.97	10.58	4	5.1%	−3.29 [−5.94, −0.63]
Junichiro Wada 2023	228.6	4.2	20	332.8	13.7	20	5.2%	−10.08 [−12.49, −7.67]
Mayra Torres Vasques 2019	18.7	0.5	3	16.6	2.2	3	5.3%	1.05 [−0.84, 2.95]
Nathaniel C. Lawson 2024	72.38	9.905	8	204.1	18.93	8	4.8%	−8.24 [−11.68, −4.81]
Nathaniel C. Lawson 2024	203.1	16.38	8	204.1	18.93	8	5.5%	−0.05 [−1.03, 0.93]
Subtotal (95% CI)			**43**			**43**	**25.9%**	**−3.99 [−8.03, 0.05]**
Heterogeneity: Tau² = 19.76; Chi² = 80.67, df = 4 (P < 0.00001); I² = 95%								
Test for overall effect: Z = 1.94 (P = 0.05)								
Total (95% CI)			**283**			**223**	**100.0%**	**−4.77 [−6.79, −2.75]**
Heterogeneity: Tau² = 19.09; Chi² = 564.00, df = 19 (P < 0.00001); I² = 97%								
Test for overall effect: Z = 4.63 (P < 0.00001)								
Test for subgroup differences: Chi² = 0.31, df = 2 (P = 0.86), I² = 0%								

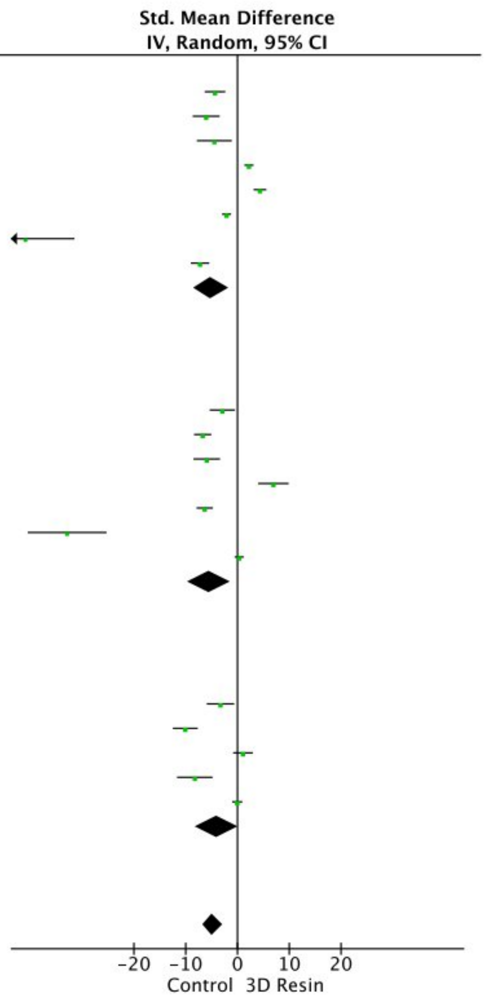

Figure 3. Meta-analysis of hardness outcomes between 3D printed resins and milled, auto-polymerized, and thermo-polymerized PMMA-based resins as controls. The controls showed statistically significant higher hardness than the photosensitive resins in all subgroup and global analyses ($p \leq 0.05$)

Study or Subgroup	3D Resin Mean	3D Resin SD	3D Resin Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.1.1 3D Resin vs Milled								
Christian Wesemann 2020	40	4	8	105	5	8	2.4%	−13.57 [−19.08, −8.07]
Christian Wesemann 2020	100	5	8	105	5	8	3.8%	−0.95 [−2.00, 0.10]
Constantin Berli 2020	39.3	2	3	117.2	7.1	3	1.0%	−11.95 [−23.60, −0.30]
Constantin Berli 2020	91.3	5.9	3	117.2	7.1	3	3.1%	−3.17 [−6.63, 0.28]
Constantin Berli 2020	19.5	2.5	3	117.2	7.1	3	0.8%	−14.68 [−28.95, −0.42]
Danielly Guimaraes 2023	94.8	20.05	4	111.13	17.59	4	3.7%	−0.75 [−2.23, 0.73]
Klara Janjic 2024	350	18	5	252	18	5	3.3%	4.92 [1.88, 7.95]
Philipp Simeon 2024	85.81	3.03	8	112.13	1.73	8	2.9%	−10.09 [−14.23, −5.94]
Philipp Simeon 2024	72.7	5.09	8	112.13	1.73	8	2.9%	−9.81 [−13.84, −5.77]
Philipp Simeon 2024	62.25	5.94	8	112.13	1.73	8	2.8%	−10.78 [−15.19, −6.37]
Prpic 2019	75	12	10	104	10.4	10	3.7%	−2.47 [−3.70, −1.25]
Prpic 2019	117.2	0.1	10	104	10.4	10	3.8%	1.72 [0.66, 2.78]
Tina Maleki 2024	63.4	3.5	45	106	5.5	45	3.7%	−9.16 [−10.59, −7.73]
Tina Maleki 2024	90.7	3.3	45	106	5.5	45	3.8%	−3.34 [−3.99, −2.70]
Tina Maleki 2024	12.4	1.1	45	106	5.5	45	3.1%	−23.40 [−26.92, −19.88]
Subtotal (95% CI)			**213**			**213**	**44.7%**	**−6.17 [−8.62, −3.71]**
Heterogeneity: $Tau^2 = 19.19$; $Chi^2 = 380.55$, df = 14 (P < 0.00001); $I^2 = 96\%$								
Test for overall effect: Z = 4.93 (P < 0.00001)								
1.1.2 3D Resin vs Auto-polymerized PMMA								
Constantin Berli 2020	39.3	2	3	93.8	3.8	3	0.8%	−14.36 [−28.32, −0.40]
Constantin Berli 2020	91.3	5.9	3	93.8	3.8	3	3.7%	−0.40 [−2.05, 1.24]
Constantin Berli 2020	19.5	2.5	3	93.8	3.8	3	0.5%	−18.48 [−36.40, −0.56]
Danielly Guimaraes 2023	94.8	20.05	4	37.96	4.97	4	3.4%	3.38 [0.68, 6.09]
Otavio M.Santos Neto 2023	80.67	14.87	10	120.2	14.9	10	3.7%	−2.54 [−3.79, −1.30]
Otavio M.Santos Neto 2023	70.49	9.85	10	110.9	14.62	10	3.7%	−3.10 [−4.49, −1.72]
Prpic 2019	117.2	1	10	102.6	7.3	10	3.7%	2.68 [1.41, 3.96]
Prpic 2019	75	12	10	102.6	7.3	10	3.7%	−2.66 [−3.93, −1.39]
Valttteri Väyrynen 2016	78.3	3.4	30	83.8	6.6	30	3.8%	−1.03 [−1.58, −0.49]
Subtotal (95% CI)			**83**			**83**	**27.1%**	**−0.96 [−2.51, 0.59]**
Heterogeneity: $Tau^2 = 3.88$; $Chi^2 = 71.05$, df = 8 (P < 0.00001); $I^2 = 89\%$								
Test for overall effect: Z = 1.22 (P = 0.22)								
1.1.3 3D Resin vs Thermo-polymerized PMMA								
Al-Dulaijan 2023	65.55	1.73	10	79.46	2.6	10	3.5%	−6.03 [−8.30, −3.77]
Al-Dulaijan 2023	75.52	3.42	10	79.46	2.6	10	3.8%	−1.24 [−2.22, −0.27]
Danielly Guimaraes 2023	94.8	20.05	4	43.6	8.25	4	3.4%	2.90 [0.47, 5.34]
Otavio M.Santos Neto 2023	80.67	14.87	10	140.5	17.87	10	3.7%	−3.49 [−4.98, −2.00]
Otavio M.Santos Neto 2023	70.49	9.85	10	129	16.16	10	3.6%	−4.19 [−5.88, −2.49]
Tina Maleki 2024	63.4	3.5	45	107	4.2	45	3.6%	−11.18 [−12.90, −9.46]
Tina Maleki 2024	90.7	3.3	45	107	4.2	45	3.8%	−4.28 [−5.04, −3.52]
Tina Maleki 2024	12.4	1.1	45	107	4.2	45	2.7%	−30.55 [−35.13, −25.97]
Subtotal (95% CI)			**179**			**179**	**28.2%**	**−6.73 [−9.94, −3.51]**
Heterogeneity: $Tau^2 = 20.30$; $Chi^2 = 261.51$, df = 7 (P < 0.00001); $I^2 = 97\%$								
Test for overall effect: Z = 4.10 (P < 0.0001)								
Total (95% CI)			**475**			**475**	**100.0%**	**−4.86 [−6.25, −3.46]**
Heterogeneity: $Tau^2 = 13.15$; $Chi^2 = 808.46$, df = 31 (P < 0.00001); $I^2 = 96\%$								
Test for overall effect: Z = 6.83 (P < 0.00001)								
Test for subgroup differences: $Chi^2 = 18.21$, df = 2 (P = 0.0001), $I^2 = 89.0\%$								

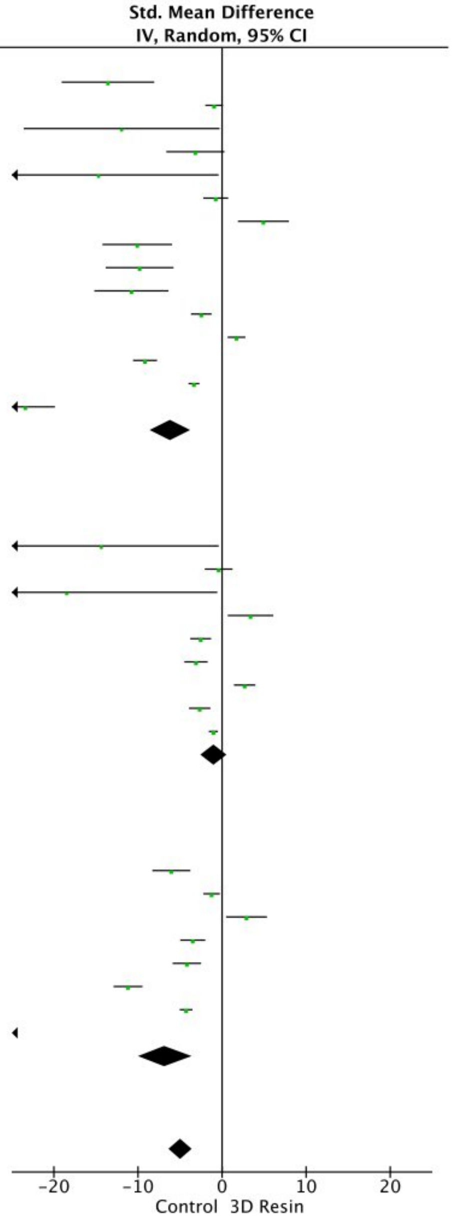

Figure 4. Meta-analysis of flexural strength outcomes between 3D printed resins and milled, auto-polymerized, and thermo-polymerized PMMA-based resins as controls. Milled and thermo-polymerized PMMA controls showed significantly higher flexural strength than photosensitive resins in the subgroup analysis (p ≤ 0.05), while the results were statistically similar when 3D printed resins were compared to auto-polymerized PMMA (p = 0.22).

Table 1. Search strategy used in all databases

Database	Search	Search strategy
PubMed/Medline Scopus Embase BVS	**#1**	(Printing, Three-Dimensional) OR (Printing, Three-Dimensional) OR (Printing, Three Dimensional) OR (Printings, Three-Dimensional) OR (Three-Dimensional Printings) OR (3-Dimensional Printing) OR (3 Dimensional Printing) OR (3-Dimensional Printings) OR (Printing, 3-Dimensional) OR (Printings, 3-Dimensional) OR (3-D Printing) OR (3 D Printing) OR (3-D Printings) OR (Printing, 3-D) OR (Printings, 3-D) OR (Three-Dimensional Printing) OR (Three Dimensional Printing) OR (3D Printing) OR (3D Printings) OR (Printing, 3D) OR (Printings, 3D) OR (Additive manufacturing technologies) OR (Additive manufacturing system) OR (Additive manufacturing) OR (Stereolithography) OR (SLA) OR (material jetting) OR (material extrusion) OR (fused deposition modelling) OR (binder jetting, powder bed fusion) OR (sheet lamination) OR (direct energy deposition) OR (polymer printing)
	#2	(Occlusal Splints) OR (Occlusal Splints) OR (Splints, Occlusal) OR (Occlusal Splint) OR (Splint, Occlusal) OR (Occlusal devices) OR (Occlusal device) OR (Occlusal Appliances) OR (Cosmos Split) OR (NextDent) OR (FreePrint Splint) OR (E-Guard) OR (GP-400 Clear) OR (Guide Plate) OR (Dental LT Clean) OR (DentaCLEAR) OR (Optiprint Splint) OR (Fotodent Splint) OR (VarseoWax Splint)
	#3	#1 AND #2
Web of Science	**#1**	TS= (Printing, Three-Dimensional) OR (Printing, Three-Dimensional) OR (Printing, Three Dimensional) OR (Printings, Three-Dimensional) OR (Three-Dimensional Printings) OR (3-Dimensional Printing) OR (3 Dimensional Printing) OR (3-Dimensional Printings) OR (Printing, 3-Dimensional) OR (Printings, 3-Dimensional) OR (3-D Printing) OR (3 D Printing) OR (3-D Printings) OR (Printing, 3-D) OR (Printings, 3-D) OR (Three-Dimensional Printing) OR (Three Dimensional Printing) OR (3D Printing) OR (3D Printings) OR (Printing, 3D) OR (Printings, 3D) OR (Additive manufacturing technologies) OR (Additive manufacturing system) OR (Additive manufacturing) OR (Stereolithography) OR (SLA) OR (material jetting) OR (material extrusion) OR (fused deposition modelling) OR (binder jetting, powder bed fusion) OR (sheet lamination) OR (direct energy deposition) OR (polymer printing)
	#2	TS= (Occlusal Splints) OR (Occlusal Splints) OR (Splints, Occlusal) OR (Occlusal Splint) OR (Splint, Occlusal) OR (Occlusal devices) OR (Occlusal device) OR (Occlusal Appliances) OR (Cosmos Split) OR (NextDent) OR (FreePrint Splint) OR (E-Guard) OR (GP-400 Clear) OR (Guide Plate) OR (Dental LT Clean) OR (DentaCLEAR) OR (Optiprint Splint) OR (Fotodent Splint) OR (VarseoWax Splint)
	#3	#1 AND #2
SciELO	**#1**	Printing, Three-Dimensional OR Printing, Three-Dimensional OR Printing, Three Dimensional OR Printings, Three-Dimensional OR Three-Dimensional Printings OR 3-Dimensional Printing OR 3 Dimensional Printing OR 3-Dimensional Printings OR Printing, 3-Dimensional OR Printings, 3-Dimensional OR 3-D Printing OR 3 D Printing OR 3-D Printings OR Printing, 3-D OR Printings, 3-D OR Three-Dimensional Printing OR Three Dimensional Printing OR 3D Printing OR 3D Printings OR Printing, 3D OR Printings, 3D OR Additive manufacturing technologies OR Additive manufacturing system OR Additive manufacturing OR Stereolithography OR SLA OR material jetting OR material extrusion OR fused deposition modelling OR binder jetting, powder bed fusion OR sheet lamination OR direct energy deposition OR polymer printing
	#2	Occlusal Splints OR Occlusal Splints OR Splints, Occlusal OR Occlusal Splint OR Splint, Occlusal OR Occlusal devices OR Occlusal device OR Occlusal Appliances OR Cosmos Split OR NextDent OR FreePrint Splint OR E-Guard OR GP-400 Clear OR Guide Plate OR Dental LT Clean OR DentaCLEAR OR Optiprint Splint OR Fotodent Splint OR VarseoWax Splint

	#3	#1 AND #2

Table 2. Demographic data of all included studies, resin groups and controls used, evaluated properties, 3D printer details, post-curing, and study title.

Author	Year	Country	Journal	Groups of resins used	Control resin	Properties evaluated	3d Printer	Post-cure	Title
Valtteri O. E. Väyrynen et al.	2016	Finland	Journal of Prosthetic Dentistry	Somos WaterShed XC 11122 (SLA Printed), Palapress (Autopolymerized Acrylic Resin)	Palapress (Autopolymerized Acrylic Resin)	Flexural Strength, Flexural Modulus, Water Sorption, Surface Topography	SLA350 (SLA)	UV oven polymerization, 15 min	The anisotropicity of the flexural properties of an occlusal device material processed by stereolithography
Fabian Huettig et al.	2017	Germany	Journal of the Mechanical Behavior of Biomedical Materials	Palapress (Heat-Cured PMMA), innoBlanc Splint Plus (Polycarbonate), VarseoWax Splint (DLP-Printed)	Conventional Palapress, Heraeus Kulzer Subtractive innoBlanc splint plus, innoBlanc GmbH, E	Polishability, Surface Roughness, Wear Resistance	Varseo 3D-Printer (DLP)	Otoflash G171, 4 cycles of 5 min	Polishability and wear resistance of splint material for oral appliances produced with conventional, subtractive, and additive manufacturing
Anna-Maria Lutz et al.	2018	Germany	Journal of Prosthetic Dentistry	FotoDent Splint (3D-Printed)	Temp Basic PMMA (Milled), Castdon PMMA (Conventional Casting)	Fracture Resistance, Wear Resistance	DLP 3D Printer at 405 nm	HiLite Power, 10 min UV cure	Fracture resistance and 2-body wear of 3-dimensional-printed occlusal devices
Marisol Reyes Sevilla et al.	2018	Netherlands	Journal of Oral Rehabilitation	Printed PMMA	ThermoSens, Conventional (Hand-Processed) PMMA, Milled PMMA,	Wear Rate, Two-Body Wear	Not Specified	Not Specified	Comparison of wear between occlusal splint materials and resin composite materials
Samer M. Alaqeel et al.	2019	Saudi Arabia	Materials Express	G1: horizontal printing direction G2: vertical printing direction Resin: Somos watershed XC 11122 DSM,	G3: PMMA based autopolymerizing resin Palapress Heraeus Kulzer	Nano-Mechanical Properties, Printing Layer Orientation, Water Storage Effects	SLA 350 (SLA)	UV Polymerization for 15 min	Effect of 3D printing direction and water storage on nano-mechanical properties of 3D printed and auto-polymerized polymer with special emphasis on printing layer interface
Leila Perea-Lowery et al.	2019	Finland	Journal of the Mechanical Behavior of Biomedical Materials	NextDent Ortho Rigid (3D Printed),	Thermoplastic Plates	Bond Strength, Aging Effects	Form 2 (SLA)	LC-3DPrint Box	Resin adjustment of three-dimensional printed thermoset occlusal splints: Bonding properties – Short communication
Vladimir Prpic et al.	2019	Croatia	Journal of Prosthetic Dentistry	VarseoWax Splint, Ortho Rigid, Ceramill Splintec, CopraDur, ProBase Cold, Resilit S, Orthocryl	CAD-cameproduced (Ceramill Splintec and copradur), 3 conventional autopolymerizing occlusal device materials (probase Cold, Resilit S, and Orthocryl)	Flexural Strength, Surface Hardness	Varseo 3D-Printer (DLP)	Bego Otoflash, 2000 flashes	A study of the flexural strength and surface hardness of different materials and technologies for occlusal device fabrication
Mayra Torres Vasques et al.	2019	Brazil	Clinical and Laboratorial Research in	Dental SG, Dental LT, Clear (SLA Printed), Thermopolymerized and	Thermopolymerized and Autopolymerized Acrylic Resins	Knoop Hardness	Form 2 (SLA)	LC-3DPrint Box	The influence of the post-processing method on knoop hardness of photosensitive resins for 3D SLA printer

			Dentistry	Autopolymerized Acrylic Resins					used in Dentistry
Constantin Berli et al.	2020	Switzerland	Journal of Prosthetic Dentistry	ProBase Cold, Palapress Clear, Aesthetic Blue Clear, Freeprint Splint, LuxaPrint Ortho Plus, Nextdent Ortho Clear	Milled PMMA (Temp Premium Flexible Transpa, Idodentine PMMA, Yamahachi PMMA)	Flexural Strength, Hardness, Water Sorption, Water Solubility	Form 2 (SLA)	UV Polymerization for 20 min	Comparing the mechanical properties of pressed, milled, and 3D-printed resins for occlusal devices
Marcel Reymus et al.	2020	Germany	Journal of Prosthetic Dentistry	NextDent Splint, Formlabs Dental LT Clear, Freeprint Splint (3D Printed), Temp Premium (Milled)	Temp Premium (Milled)	Martens Hardness, Indentation Modulus, Post-Polymerization Effects, Aging Effects	D20 II (DLP), Form 2 (SLA)	LC-3DPrint Box, Otoflash G171, Labolight DUO	In vitro study on the influence of postpolymerization and aging on the Martens parameters of 3D-printed occlusal devices
Marcel Reymus et al.	2020	Germany	Clinical Oral Investigations	Dental LT, Ortho Clear, Freeprint Splint, V-Splint, ProArt CAD Splint	ProArt CAD Splint (Milled PMMA)	Accuracy, Trueness, Precision	Form 2 (SLA), D20 II (DLP), SolFlex 350 (DLP)	Otoflash G171 (2000 flashes under nitrogen)	Accuracy of CAD/CAM-fabricated bite splints: milling vs 3D printing
Anastasiia Grymak et al.	2021	New Zealand	Journal of the Mechanical Behavior of Biomedical Materials	Vertex Rapid Simplified Clear, Ceramill A-Splint, Proform Splint, Freeprint Ortho, KeySplint Soft, DentaClear, FreePrint Splint 2.0	Heat cured (Vertex Rapid simplified Clear), CAD-milled (Ceramill a-splint), Vacuum-formed (Proform splint)	Hardness, Polishability, Surface Roughness, Gloss	Asiga 3D Printer	Standard manufacturer curing protocol	Comparison of hardness and polishability of various occlusal splint materials
Vivien Biege et al.	2021	Germany	Journal of Prosthetic Dentistry	Dental LT Clear Resin, Freeprint Splint (3D Printed)	PalaXpress Clear (Conventional), Yamahachi PMMA Clear (Milled),	Fibroblast Viability, Morphology, Surface Roughness	Form 2 (SLA), DLP Printer	UV-Light (2000 Flashes)	Fibroblast behavior on conventionally processed, milled, and printed occlusal device materials with different surface treatments
Lennart Wedekind et al.	2021	Germany	Dental Materials	SHERAprint-ortho plus (3D Printed),	SHERAeco-disc PM20 (Milled PMMA), SHERAORTHOMER (Conventional PMMA)	Elution Behavior, Residual Monomers, Cytotoxicity	SHERAeco-print 30 (DLP)	Xenon Flash (2000 Flashes), Nitrogen Environment	Elution behavior of a 3D-printed, milled and conventional resin-based occlusal splint material
Christian Wesemann et al.	2021	Germany	Dental Materials	Dental LT Clear (SLA), Dental LT Clear V2 (LFS), V-Print Splint (DLP)	ProArt CAD (Milled PMMA) PalaXpress (Injection molding),	Hardness, Flexural Properties, Wear Resistance	Form 2 (SLA), Form 3 (LFS), SolFlex 170 (DLP)	UV Oven Polymerization, Otoflash G171, Form Cure (80°C for 20 min)	Polymers for conventional, subtractive, and additive manufacturing of occlusal devices differ in hardness and flexural properties but not in wear resistance
Anastasiia Grymak et al.	2022	New Zealand	Journal of the Mechanical Behavior of Biomedical Materials	Vertex Rapid Simplified Clear, Ceramill A-Splint, Freeprint Ortho, KeySplint Soft, DentaClear, FreePrint Splint 2.0	Heat-Cured PMMA, CAD-Milled PMMA	Wear Resistance, Volumetric Loss, Surface Roughness, Build Orientation Effects	Asiga Max UV (DLP)	Otoflash G171 (2000 flashes under nitrogen)	Evaluation of wear behaviour of various occlusal splint materials and manufacturing processes
Julia Guerrero-	2022	Spain	Journal of	Keysplint Soft, NextDent	Orthocryl (Dentaurum)	Cytotoxicity,	Phrozen Sonic	LC-3D Print Box,	In vitro biocompatibility testing of 3D

Gironés et al.			Dentistry	Ortho Rigid, Freeprint Splint, Orthocryl		Biocompatibility, Cell Metabolism, ROS Generation	Mini 4K (LCD)	submerged in liquid glycerin	printing and conventional resins for occlusal devices
Verena Hickl et al.	2022	Germany	Clinical Oral Investigations	LuxaPrint Ortho Plus, KeySplint Soft, V-Print Splint, Splint Flex	Thermoforming foil Erkodur, Thermoforming foil Erkodur, CAD/CAM Optimill crystal clear	Color Stability, Gloss, Surface Roughness, Storage and Toothbrushing Effects	P30+ (Straumann, DLP), Solflex 650 (Voco, DLP)	Otoflash G171 (2000 flashes under nitrogen)	Effects of storage and toothbrush simulation on color, gloss, and roughness of CAD/CAM, hand-cast, thermoforming, and 3D-printed splint materials
Mona Gibreel et al.	2022	Finland	Dental Materials Journal	Paladon 65, Palapress, Cast, Aqua, Temp Premium Flexible Transpa, IMPRIMO LC Splint, KeySplint Soft, IMPRIMO LC Splint flex, V-Print Splint Comfort	PMMA-based Milled and Heat-Cured Resins	Two-Body Wear, Surface Hardness	Asiga MAX (DLP)	Form Cure, 60°C for 30 min	Two-body wear and surface hardness of occlusal splint materials
Sabina Noreen Wuersching et al.	2022	Germany	Clinical Oral Investigations	SHERAprint-ortho plus UV, NextDent Ortho Rigid, LuxaPrint Ortho Plus, V-Print Splint, KeySplint Soft),	Astron CLEARsplint Disc (Milled PMMA), FuturaGen, Astron CLEARsplint, Erkodur Thermoforming Foil	Surface Roughness, Bacterial Adhesion, Biofilm Formation	P30 (DLP), NextDent 5100 (DLP)	Otoflash G171, Xenon Flash Unit	Surface properties and initial bacterial biofilm growth on 3D-printed oral appliances: a comparative in vitro study
Merve Özarslan et al.	2023	Turkey	Journal of Prosthetic Dentistry	3D-Printed Freeprint Ortho	Vacuum-formed thermoplastic Dispodent Dental Plak (Dispodent) (Group V), head-press Vertex Rapid Simplified (Vertex) (Group H),	Candida Albicans Biofilm Formation, Antibiofilm Effects of Chitosan and Eugenol	Asiga 3D Printer (DLP)	Standard manufacturer curing protocol	Biofilm formation of C. albicans on occlusal device materials and antibiofilm effects of chitosan and eugenol
Cristian Abad-Coronel et al.	2023	Ecuador	Materials	Acrylic, Printed Resin, Flex Printed Resin, Milled PMMA	Conventional Acrylic	Fracture resistance	SprintRay Pro-95	ProCure 2 (Automated Light Curing)	Comparative Analysis between Conventional Acrylic, CAD/CAM Milled, and 3D CAD/CAM Printed Occlusal Splints
Jan Raffael Rosello Jimenez et al.	2023	Germany	Polymers	Dimethacrylate-based (FRE, LUX, VPR), Methacrylate-based (KEY, CLE)	CLEAR Splint (Milled PMMA)	Tensile strength, modulus of elasticity, Vickers hardness	Rapidshape P30	2×2000 light flashes (SHERAflash-light plus)	Aging Processes and Their Influence on the Mechanical Properties of Printable Occlusal Splint Materials
Junichiro Wada et al.	2023	Finland, Japan	Journal of the Mechanical Behavior of Biomedical Materials	KeySplint Hard, KeySplint Soft	KeySplint Hard	Micro-wear, nano-wear resistance, flexural strength, Vickers hardness	Creo C5 (LCD), Asiga MAX UV (DLP)	Otoflash G171 with nitrogen	Effect of 3D Printing System and Post-Curing Atmosphere on Micro- and Nano-Wear of Additive-Manufactured Occlusal Splint Materials
Halenur Bilir et al.	2023	Turkey, Switzerland	Brazilian Dental Science	M-PM Disc (Milled), Freeprint Splint 2.0 (3D-Printed), Promolux HC (Heat-Polymerized)	Promolux HC	Surface roughness after different polishing methods	D20+ (DLP)	10 min in SHERA Flash-Light Plus	Effect of laboratory and chairside polishing methods on the surface topography of occlusal splint materials manufactured using conventional, subtractive and additive digital technologies

Andrew B. Cameron et al.	2023	Australia	Journal of Oral Science	KeySplint Soft (Printed at 0°, 30°, 45°, 60°, 90° orientations)	Subtractive Manufactured PMMA	Trueness (accuracy in different build orientations)	Asiga Max UV (DLP), Rapid Shape D30II (DLP)	2000 flashes (Otoflash G171) under nitrogen	Effect of build orientation on the trueness of occlusal splints fabricated by three-dimensional printing
Yousif A. Al-Dulaijan et al.	2023	Saudi Arabia	Journal of Prosthodontics	NextDent Base, ASIGA DentaBASE	Heat-polymerized PMMA	Flexural strength based on printing orientation and post-curing time	ASIGA MAX (DLP), NextDent 5100 (DLP)	30, 60, 90, 120 min in Asiga Flash or LC-D Print Box	Effect of Printing Orientation and Postcuring Time on the Flexural Strength of 3D-Printed Resins
Danielly Mendonça Guimaraes et al.	2023	Brazil	Brazilian Oral Research	Self-Curing Acrylic Resin (SC), Heat-Cured Acrylic Resin (WB), Microwave-Polymerized Acrylic Resin (ME), 3D Printing Resin (P), Milled PMMA Block (M)	None	Surface Roughness, Knoop Microhardness, Flexural Strength, Modulus of Elasticity	Miicraft Ultra Series (SLA)	UV light for 10s	Evaluation of the mechanical properties of different materials for manufacturing occlusal splints
Otavio Marino dos Santos Neto et al.	2023	Brazil	Revista de Odontologia da UNESP	3D Printing Resin, Chemically Activated Acrylic Resin, Thermally Activated Acrylic Resin	Thermally Activated Acrylic Resin	Flexural Resistance, Effects of Thermocycling	Phrozen Tech Co. Ltd (SLA)	5 min in post-cure unit	Flexural resistance of 3D printing resin compared to conventional acrylic resins employed to build occlusal bite splints
Ahmet Orgev et al.	2023	USA	Journal of Prosthodontics	KeySplint Hard	Ceramill A-Splint (Milled PMMA), Heat-Polymerized Acrylic	Surface Accuracy, Trueness, Precision	Cares P30 (DLP), M2 (CLIP)	Otoflash G171 (2000 flashes per side under nitrogen)	The effects of manufacturing technologies on the surface accuracy of CAD-CAM occlusal splints
Gökçen Ateş et al.	2024	Turkey	Journal of Prosthetic Dentistry	Heat-Polymerized PMMA, 3D-Printed Dental LT Clear Resin, Milled PMMA, Milled Ceramic-Reinforced PEEK	None	Wear Resistance, Volume Loss, Depth of Wear	Form 3+ (SLA)	Form Cure (60°C for 60 min)	Effect of material and antagonist type on the wear of occlusal devices with different compositions fabricated by using conventional, additive, and subtractive manufacturing
Ahmet Orgev et al.	2024	USA, Turkey, Switzerland, Saudi Arabia	The Journal of Prosthetic Dentistry	Additive (AM-1, AM-2), Subtractive (SM-1, SM-2), Conventional (TM-HP)	TM-HP	Cameo and intaglio surface stability and variability	Cares P30 (DLP), M2 (CLIP)	Moist storage for 18 months	Cameo and intaglio surface stability and variability of additively, subtractively, and conventionally manufactured occlusal devices after long-term storage
Joanna Weżgowiec et al.	2024	Poland, Lithuania	Frontiers in Bioengineering and Biotechnology	3D-printed (Dental LT Clear), Thermoformed (Duran + Durasplint LC), Heat-cured (Villacryl H Plus)	Heat-cured Villacryl H Plus	Biocompatibility (Cytotoxicity, oxidative stress, cell viability)	Form 2 (Formlabs)	80°C for 20 min (Form Cure)	Biocompatibility of 3D-printed vs. thermoformed and heat-cured intraoral appliances
Ketil Hegerstrøm Haugli et al.	2024	Norway	Clinical Oral Investigations	Dental LT Clear V1, FREEPRINT Splint 2.0, Therapon Transpa, PalaXtreme	PalaXtreme (Auto-polymerized resin)	Biocompatibility (Cytotoxicity, oxidative stress, cell viability)	Form 2 (SLA), Asiga MAX UV (DLP)	Asiga Flash, Form Cure, Otoflash G171	Digital Manufacturing Techniques and the In Vitro Biocompatibility of Acrylic-Based Occlusal Device Materials
Thiago Carvalho de Sousa et al.	2024	Brazil	The Journal of Prosthetic Dentistry	Prizma Biosplint (3D Printed), Microwave-polymerized acrylic resin	Microwave-polymerized acrylic resin	Microhardness, Surface roughness	Photon MONO 4K (Anycubic)	405 nm UV light for 20 min	Comparative Analysis of Polishing Protocols on Microhardness and Surface Roughness of Occlusal Device Materials Fabricated Using Microwave-

									Polymerized Acrylic or 3D Printed Resins
Joanna Weżgowiec et al.	2024	Poland	Dental and Medical Problems	Villacryl H Plus (Heat-Cured PMMA), DURAN + Durasplint LC (Thermoformed + Light-Cured), Dental LT Clear (SLA-Printed)	Heat-Cured PMMA	Hardness, Flexural Strength, Artificial Aging Effects	Form 2 (SLA)	80°C for 20 min in Form Cure	How does artificial aging affect the mechanical properties of occlusal splint materials processed via various technologies?
Maximilian Kollmuss et al.	2024	Germany	Polymers	KeySplint Hard, KeySplint Soft, V-Print Splint, V-Print Splint Comfort, NextDent Ortho Rigid, NextDent Ortho Flex	Tizian Blank PMMA, Tizian Flex Splint Comfort	Cytotoxicity, Inflammatory Response, Apoptosis, Necrosis	NextDent 5100 (DLP), RapidShape P30+ (DLP)	Various post-processing conditions based on manufacturer recommendations	In Vitro Cytotoxic and Inflammatory Response of Gingival Fibroblasts and Oral Mucosal Keratinocytes to 3D Printed Oral Devices
Bardia Saadat Sarmadi et al.	2024	Germany	Polymers	Dental LT Clear (SLA), LuxaPrint Ortho Plus (DLP), V-Print Splint (DLP)	Subtractive Manufactured PMMA	Trueness, Precision, Dimensional Stability, Effect of Build Angle	Form 3B (SLA), 3Demax (DLP), Solflex 170 (DLP)	80°C for 20 min in Form Cure (SLA), 2000 flashes (Otoflash G171) under nitrogen	The Effect of Build Angle and Artificial Aging on the Accuracy of SLA- and DLP-Printed Occlusal Devices
Tina Maleki et al.	2024	Germany	Dental Materials	GR-22 flex, GR-10 guide, ProArt Print Splint Clear, V-Print Splint, V-Print Splint Comfort	Injection Molded PMMA, Milled PMMA	Flexural Strength, Elastic Modulus, Martens Hardness, Water Sorption, Water Solubility, Degree of Conversion	D20II (DLP), PrograPrint PR5 (DLP)	2000 flashes (Otoflash G171) under nitrogen	Mechanical and physical properties of splint materials for oral appliances produced by additive, subtractive and conventional manufacturing
Philipp Simeon et al.	2024	Germany	Journal of the Mechanical Behavior of Biomedical Materials	V-Print splint, LuxaPrint Ortho Plus, Dental LT Clear	Zirlux Splint Transparent (Milled PMMA)	Wear Resistance, Flexural Properties, Printing Orientation Effects	Form 3B (SLA), Solflex 170 (DLP)	Otoflash G171 (2000 flashes under nitrogen), Form Cure (80°C for 20 min)	Wear resistance and flexural properties of low force SLA- and DLP-printed splint materials in different printing orientations: An in vitro study
Nathaniel C. Lawson et al.	2024	USA	The Journal of Prosthetic Dentistry	KeySplint Soft, NightGuard Flex 2, SmileGuard, KeySplint Hard, NightGuard Firm 2	Ceramill A-Splint (Milled PMMA), Erkoloc-Pro (Thermoformed), Eclipse Prosthetic Resin (Light-Polymerized), Excel Formula Heat Cure (Heat-Polymerized), Great Lakes Splint Resin Acrylic (Autopolymerized)	Wear Resistance, Microhardness	Pro 55S (SprintRay DLP), Einstein (Desktop Health DLP)	ProCure 2 (SprintRay), Otoflash G171 (2000 flashes under argon gas)	Wear resistance of 3D printed occlusal device materials
Klara Janjić et al.	2024	Austria	Dental Materials	Experimental 3D-Printable Resin with Graphene Nanoplatelets	Polymethyl Methacrylate (PMMA)	Biaxial Flexural Strength, Cytotoxicity, Print Orientation Effects	Form 2 (SLA)	Form Cure (60°C for 60 min)	The impact of print orientation and graphene nanoplatelets on biaxial flexural strength and cytotoxicity of a 3D printable resin for occlusal splints
Sarah Ribeiro Cruz-Araújo et al.	2025	Brazil, Portugal, Denmark	Journal of Dentistry	3D Printed (LCD) in different orientations (0, 45, 70 degrees)	None	Accuracy (trueness, precision)	Phrozen Sonic 4k	UV polymerization (Phrozen Cure V2)	Accuracy of occlusal splints printed in different orientations by liquid crystal display technology: an in vitro study

Table 3. Main results of each study categorized by evaluated physical, mechanical, and biological properties

Author (year)	3D Resins	Mean ±SD	Control Resins	Mean ±SD	Number of samples (per group) and dimensions	Main characteristic	Main findings	Material that performed best
PHYSICAL AND MECHANICAL PROPERTIES								
HARDNESS								
Samer M. Alaqeel et al. (2019)	Somos watershed XC 11122 DSM	Nano-hardness: 180 ±22 mpa	Palapress Heraeus Kulzer	Nano-hardness: 165± 60 mpa	10 per group, 2×2×25 mm	Nano-mechanical properties	3D resin had better nano-mechanical properties than conventional resin, even after water storage.	3D printed resin (perpendicular layers)
Prpić et al. (2019)	Varseowax Splint, Ortho Rigid (3D-Printed) Ortho Rigid 3D-Printed)	28.5 +/-2.5 mpa 89.3 +/- 4.9 mpa	Probase Cold, Orthocryl (Conventional) Ceramill Splintec (milled)	106 +/- 2.1 mpa 111.7 +/- 0 mpa 116.2 +/- 1.6 mpa	140 specimens, 64×10×3.3 mm n=10	Surface Hardness	PMMA-based materials exhibited the most consistent hardness values, while 3D-printed polyamide materials showed lower hardness.	CAD-CAM PMMA-based materials
Marcel Reymus et al. (2020)	Formlabs Dental LT Clear Nextdent orto clear Freeprint Splint	Martens hardness: 130 ± 7.22 N/mm² 142 ± 6.21 N/mm² 97 ± 8.21 N/mm²	Temp Premium (milled)	114 ± 6.7 N/mm²	4 groups, 20×5 mm disks	Aging and hardness	Milled materials resisted aging better than 3D-printed resins; Otoflash post-curing yielded higher hardness.	Temp Premium
Mayra	Dental SG, Dental	Knoop Hardness:	Thermo-polymerized	16.6 ± 2.2 HK	5 groups, 30×2.5	Knoop hardness	3D-printed resins	Dental SG resin

Torres Vasques et al. (2019)	LT, Clear	Dental SG: 18.7 ± 0.5 HK	resin		mm discs	comparison	matched conventional resins when post-processing was applied; no curing reduced hardness.	
Christian Wesemann et al. (2021)	Dental LT Clear Resin, V-Print Splint	Dental LT Clear Resin 178.64 ± 9.8 mpa, V-Print 144.16 ± 14.7 mpa	Proart CAD (milled)	Hardness: 215.75 ± 5.88 mpa	8 samples, Ø32×5.5 mm	Mechanical properties, wear resistance	Milled and injection-molded resins outperformed 3D-printed in mechanical properties.	Palaxpress
Junichiro Wada et al.(2023)	Keysplint Hard & Soft	228. 6 ± 4.2 mpa	Autopolymerized PMMA Heat Cured	279.5 ± 9.5 mpa 332.8 ± 13.7 mpa	80 samples, 3.5×10.0×60.0 mm	Effect of 3D printing system and post-curing atmosphere	Post-curing with N_2 improved wear resistance, reducing degradation	DLP printed hard resin with N_2 post-curing
Danielly Mendonça Guimaraes et al. (2023)	Smart Dent Bio Bite Splint (Smart Dent)	Knoop hardness: 118.26 ± 32.26 mpa	Self-curing, Heat-cured, Microwave-polymerized acrylic resins ; Milled PMMA block	199.56 ± 11.17 mpa 208.97 ± 10.58 mpa 190.73 ± 14.02 mpa 244.67 ± 12.94 mpa	N=50; 64 × 10 × 3.3 mm	Compares mechanical properties of different materials for manufacturing occlusal splints, including 3D-printed resins and milled PMMA	Milled PMMA resin had superior flexural strength, hardness, and modulus of elasticity compared to 3D-printed resin. Printed resin had lower hardness but acceptable mechanical performance.	Milled PMMA block
Joanna Weżgowiec et al. (2024)*	Dental LT Clear (Vertex Dental, Soesterberg, Netherlands)	Shore D hardness (non-aged): 85.3D; After 90 days in water: 80.4D;	Heat-cured PMMA (Villacryl H Plus 0, Everall7, Warsaw, Poland)	Shore D hardness (non-aged): 83.4D; After 90 days in water: 81.0D	N=120 discs (Shore D hardness)	Investigates the effect of artificial aging on the mechanical properties of occlusal splint materials processed via different techniques	The 3D-printed resin had the highest initial Shore D hardness but was significantly affected by artificial aging. Heat-cured PMMA showed superior flexural properties and resistance to aging.	Heat-cured PMMA (Villacryl H Plus 0)
Thiago Carvalho de Sousa et al.(2024)	Prizma Biosplint	18.36 ± 1.23 kgf/mm² (Surface Microhardness)	Microwave-polymerized acrylic	15.42 ± 0.29 kgf/mm² (Surface Microhardness)	120 samples, 40×40×3 mm	Impact of polishing protocols on microhardness and roughness	Trihawk polishing significantly improved surface microhardness	3D printed resin with trihawk polishing
Nathaniel C. Lawson et al. (2024)	3D printed (flexible) keysplint Soft 3D printed (firm) keysplint Hard	Hardness (Vickers Hardness - VH): keysplint Soft (72.38 ± 9.905 mpa), Keysplint Hard	Heat-polymerized Excel Fromula Heat Cure Denture Base Material Autopolymerized Splint	Heat-polymerized: 204.1 ±18.93 mpa Autopolymerized: 117.39 ± 2.158 mpa	N=8 per material; block specimens: 8 × 4 × 4 mm	Investigates the wear resistance of flexible and rigid 3D-printed occlusal device materials compared to milled	Rigid 3D-printed occlusal device materials had similar wear resistance to milled and conventionally	Ceramill A-Splint (Amann Girrbach) and keysplint Hard (Keystone Industries)

		(203.10 ± 16.38 mpa)	Resin Acrylic			and conventionally processed occlusal device materials	processed materials, whereas flexible 3D-printed materials exhibited significantly more wear. There was a strong negative correlation between hardness and wear resistance (r=-0.93).	
FLEXURAL STRENGTH								
Constantin Berli et al. (2020)	Freeprint Luxaprint Next dent	Flexural strength: 19.5 ± 2.5 mpa 39.3 ± 2.0 mpa 91.3 ± 5.9 mpa	Milled Yamahachi Milled Temp premium Auto probase Auto Palapress	Flexural strength: 117.2 ± 7.1mpa 122± 3.1 mpa 93.8 ± 3.8 mpa 99.5 ± 5.3 mpa	Specimens: 65×10×3.3 mm N=3	Mechanical properties	Milled and pressed resins had superior mechanical properties compared to 3D-printed resins.	Milled resins (Temp Premium Flexible)
Joanna Weżgowiec et al. (2024)*	Dental LT Clear (Vertex Dental, Soesterberg, Netherlands)	Flexural strength: 36.70 mpa	Heat-cured PMMA (Villacryl H Plus 0, Everall7, Warsaw, Poland)	Flexural strength: 89.63 mpa	N=120 bars (flexural properties); 64 × 10 × 3.3 mm	Investigates the effect of artificial aging on the mechanical properties of occlusal splint materials processed via different techniques	The 3D-printed resin had the highest initial Shore D hardness but was significantly affected by artificial aging. Heat-cured PMMA showed superior flexural properties and resistance to aging.	Heat-cured PMMA (Villacryl H Plus 0)
Valtteri O. E. Väyrynen et al. (2016)	Somos watershed XC 11122	Flexural strength: 78.3 ± 3.4 mpa (45° angle dry)	Palapress (acrylic resin)	Flexural strength: 83.8 ± 6.6 mpa	30 bars, 2×2×25 mm	Anisotropic flexural properties	Vertical printing direction improved strength; water sorption reduced properties in 3D-printed resins.	Palapress
Christian Wesemann et al. (2021)	Dental LT Clear Resin, V-Print Splint	Flexural strength: 100± 5 mpa 40± 4 mpa	Proart CAD (milled)	Flexural: 105 ± 5 mpa	8 samples, Ø32×5.5 mm	Mechanical properties, wear resistance	Milled and injection-molded resins outperformed 3D-printed in mechanical properties.	Palaxpress
Al-Dulaijan et al. (2023)	Nextdent and ASIGA 3D-printed acrylic resins	ND 45°/30 min: 65.55 ± 1.73 mpa Asiga 90°/120 miin: 75.52 ± 3.42 mpa	Heat-polymerized acrylic resin (Major Base 20)	79.46 ± 2.6 mpa (all orientations)	N=480 (3 orientations × 4 post-curing times × 2 materials); 64mm × 10mm × 3.3mm N=10	Examines how printing orientation and post-curing time influence the flexural strength of 3D-printed resins compared to heat-polymerized resins	Flexural strength was highest in 0-degree orientation and increased with longer post-curing times. 120-minute post-curing resulted in the highest flexural	Heat-polymerized acrylic resin (Major Base 20) performed best overall, but nextdent and ASIGA at 0-degree with 120-minute post-curing showed

							strength in all orientations.	significant improvements
Danielly Mendonça Guimaraes et al. (2023)	Smart Dent Bio Bite Splint (Smart Dent)	Flexural strength: 94.80 ± 20.05 mpa	Self-curing, Heat-cured, Microwave-polymerized acrylic resins ; Milled PMMA block	Flexural strength 37.96 ± 4.97 mpa 43.6 ± 8.25 mpa 68.60 ± 14.74 mpa 111.13 ± 17.59 mpa	N=4 ; 64 × 10 × 3.3 mm	Compares mechanical properties of different materials for manufacturing occlusal splints, including 3D-printed resins and milled PMMA	Milled PMMA resin had superior flexural strength, hardness, and modulus of elasticity compared to 3D-printed resin. Printed resin had lower hardness but acceptable mechanical performance.	Milled PMMA block
Otavio Marino dos Santos Neto et al. (2023)	Yller Cosmos Splint Incolor (Yller Biomateriais, Brazil)	Control: 80.67 ± 14.87 mpa, Thermocycled: 70.49 ± 9.85 mpa	Chemically activated acrylic resin (vipiflash), Thermally activated acrylic resin (vipicril Plus)	Chemically activated: Control: 120.20 ± 14.90 mpa, Thermocycled: 110.90 ± 14.62 mpa; Thermally activated: Control: 140.50 ± 17.87 mpa, Thermocycled: 129.00 ± 16.16 mpa	N=60 (10 per group); 65 × 10 × 3.3 mm	Analyzes the flexural resistance of 3D printing resin compared to conventional acrylic resins for occlusal bite splints	3D printing resin exhibited the lowest flexural resistance compared to conventional acrylic resins, especially after thermocycling.	Thermally activated acrylic resin (vipicril Plus)
Philipp Simeon et al. (2024)	Dental LT Clear (Formlabs), luxaprint Ortho Plus (DMG), V-Print Splint (VOCO)	Flexural strength (mpa): SLA1 90° (85.81 ± 3.03), DLP2 90° (72.70 ± 5.09), DLP1 90° (62.25 ± 5.94)	Milled PMMA (Zirlux Splint rtransparent)	Flexural strength (mpa): 112.13 ± 1.73	Flexural test n=80 64 × 10 × 3.3 mm n=8	Examines the wear resistance and flexural properties of SLA- and DLP-printed occlusal splint materials, considering different printing orientations	Milled splints exhibited significantly higher wear resistance and flexural strength than all 3D-printed splints. Printing orientation had a minor effect, but SLA1 showed anisotropy in flexural strength, with 90° oriented specimens performing best.	Milled PMMA (Zirlux Splint Transparent)
Tina Maleki et al. (2024)	Proart Print Splint clear, V-Print Splint,**avs** V-Print Splint comfort	Flexural strength 63.4 ± 3.5 mpa 90.7 ± 3.3 mpa 12.4 ± 1.1 mpa	Milled proart CAD Splint clear, Thermeo	Flexural strength 106 ± 5.5 mpa 3.8 ± 1.1	N=1140 total; different sizes (64 × 10 × 3.5 mm, 5 × 10 × 25 mm, 50 × 0.5 mm) depending on test	Investigates mechanical and physical properties of 3D-printed, milled, and injection-molded splint materials, focusing on flexural strength, elasticity,	Injection-molded resins had the highest mechanical strength, while 3D-printed resins showed higher water sorption and solubility. Aging reduced mechanical properties, but some	Injection-molded resins (palaxpress clear, Pro Base Cold) exhibited the best mechanical performance, but some milled resins also performed well

						hardness, water sorption, and solubility	3D-printed resins performed comparably to milled ones.	
Klara Janjić et al. (2024)	Biomed Clear Resin (Formlabs) with added graphene nanoplatelets (GNP)	Biaxial flexural strength (mpa): 0.025% Horizontal prints 350 ± 18 mpa, 0.025% Vertical prints 210 ± 14 mpa;	Milled PMMA (Ceramill A-Splint, Amann Girrbach)	Biaxial flexural strength: PMMA 252 ± 18 mpa	N=5 per group; disc shape 14 mm × 1.2 mm	Investigates the effect of print orientation and graphene nanoplatelets on biaxial flexural strength and cytotoxicity of a 3D printable resin for occlusal splints	Print orientation significantly affected biaxial flexural strength, with horizontal printing yielding the highest strength. Adding graphene nanoplatelets did not improve strength and, in some cases, reduced it.	Horizontally printed biomed Clear Resin without graphene nanoplatelets
Prpić et al. (2019)	Varseowax Splint, Ortho Rigid (3D-Printed) Ortho Rigid 3D-Printed)	117.2 ± 0mpa 75.0 ± 12.0 mpa	Probase Cold, Orthocryl (Conventional) Ceramill Splintec (milled)	88.3 ± 10.1 mpa 102.6 ± 7.3 mpa 104.0 ± 10.4 mpa	140 specimens, 64×10×3.3 mm N=10	Flexural Strength	Polyamide-based and nonacrylic light-polymerizing materials showed higher flexibility than PMMA-based materials.	CAD-CAM and conventional PMMA-based resins
				VOLUMETRIC LOSS AND WEAR				
Gökçen Ateş et al. (2024)	Dental LT Clear Resin v2, Formlabs	Volume loss: AMH: 0.46±0.07 mm³	Heat-polymerized PMMA (control)	Volume loss: CM: 0.51±0.05 mm³	240 specimens (Ø10×2 mm)	Wear behavior	SMB (ceramic-reinforced PEEK) showed the lowest volume loss and depth of wear across all antagonists tested.	SMB (ceramic-reinforced PEEK)
Anastasiia Grymak et al. (2022)	Freeprint Splint 2.0	Volumetric loss: 204.59 ± 25.67 mm³	Vertex Rapid (heat-cured)	Volumetric loss: 17.22 ± 9.23 mm³	126 specimens, Ø45×12 mm	Wear behavior, volumetric loss	CAD-milled resins had the best wear resistance, followed by heat-cured and 3D-printed materials.	CAD-milled Ceramill a-splint
Nathaniel C. Lawson et al. (2024)	Keysplint Soft, nightguard Flex 2, smileguard, keysplint Hard, nightguard Firm 2 (Keystone Industries, sprintray, Desktop Health)	Volumetric wear (mm³): keysplint Soft (0.289 ± 0.057), nightguard Flex 2 (0.252 ± 0.042), keysplint Hard (0.028 ± 0.011);	Ceramill A-Splint (Amann Girrbach), Eclipse Prosthetic Resin, Excel Formula Heat Cure Denture Base Material, Erkoloc-Pro Thermoforming Disc	Volumetric wear (mm³): Ceramill A-Splint (0.041 ± 0.017), Eclipse Prosthetic Resin (0.013 ± 0.003);	N=8 per material; block specimens: 8 × 4 × 4 mm	Investigates the wear resistance of flexible and rigid 3D-printed occlusal device materials compared to milled and conventionally processed occlusal device materials	Rigid 3D-printed occlusal device materials had similar wear resistance to milled and conventionally processed materials, whereas flexible 3D-printed materials exhibited significantly	Ceramill A-Splint (Amann Girrbach) and keysplint Hard (Keystone Industries)

							more wear. There was a strong negative correlation between hardness and wear resistance (r=-0.93).	
SURFACE EVALUATION								
Anastasiia Grymak et al. (2021)	Freeprint Ortho, keysplint Soft	Surface gloss: 75.24±3.74 GU	Vertex Rapid Simplified	Surface gloss: 77.08±3.52 GU	3 specimens per group (40×40×3 mm)	Polishability, surface roughness	Vacuum-formed materials showed the highest polishability; 3D-printed materials had lower gloss pre-polished.	Vacuum-formed materials (Proform splint)
Verena Hickl et al. (2022)	Luxaprint Ortho Plus, keysplint Soft	ΔE: 2.82 (coffee, 4 weeks), Gloss: 62–114 GU	Optimill crystal clear (milled)	ΔE: 5.31 (coffee, 4 weeks), Gloss: 75–117 GU	58×8 specimens, Ø10×2 mm	Color stability, gloss, roughness	Milled and 3D-printed materials showed superior color and gloss stability after storage.	Luxaprint Ortho Plus (color stability)
Fabian Huettig et al. (2017)	Varseowax Splint	Ra: 0.06 ± 0.007 µm, Pt: 99.1 ± 21.5 µm	Palapress (powder-liquid PMMA)	Ra: 0.062 ± 0.01 µm, Pt: 111.4 ± 18.5 µm	10/group, Ø19.5×3.7 mm	Polishability, wear resistance	Subtractive resins showed statistically better polishability and wear resistance than 3D-printed.	Subtractive (innoblanc polycarbonate)
Sabina Noreen Wuersching et al. (2022)	Luxaprint Ortho Plus, keysplint Soft	Surface roughness Ra: 0.95 µm	Astron clearsplint (milled PMMA)	Surface roughness Ra: 0.72 µm	5 groups, complete splints	Bacterial adhesion, biofilm formation	Milled PMMA had the smoothest surface and lowest biofilm growth; thermoplastics showed highest adhesion.	Astron clearsplint
Mona Gibreel et al. (2022)	IMPRIMO LC Splint, keysplint Soft	Wear depth: 55.7 ± 4.2 µm (keysplint)	Paladon 65	Wear depth: 27.5 ± 2.4 µm	36 specimens, 10×15×2 mm	Two-body wear,	Flexible 3D-printed materials showed higher wear compared to PMMA-based resins.	Paladon 65
Marisol Reyes Sevilla et al. (2018)	Printed PMMA	Wear depth: 55.7 ± 4.2 µm	Conventional PMMA	Wear depth: 75 ± 5.2 µm	4 groups, 10×3 mm discs	Wear resistance against composites	Printed PMMA showed lower wear rates compared to conventional PMMA; antagonist material had minimal influence.	Printed PMMA
Ahmet Orgev et al.	AM-1, AM-2 (Additive	1.38 ± 0.08 mm (Cameo Surface	SM-1, SM-2 (Subtractive	1.35 ± 0.06 mm (Cameo Surface	Different additive and subtractive	Surface stability of occlusal devices	AM-2 and SM-1 were found to be more	AM-2 and SM-1

(2024)	Manufacturing)	Stability)	Manufacturing)	Stability)	methods compared		reliable alternatives for occlusal devices	
Halenur Bilir et al. (2023)	Freeprint Splint 2.0 (DETAX gmbh & Co. KG)	AMM: 0.168 ± 0.006 µm	Promolux HC (Merz Dental gmbh) (Conventional manufacturing method)	CMM: 0.083 ± 0.006 µm	N=60 per method (SMM, AMM, CMM); 15mm diameter, 3mm thickness	Examines the surface roughness of occlusal splints produced by subtractive, additive, and conventional methods with different polishing techniques	Chairside polishing was more effective than laboratory polishing. AMM group had the highest roughness, while CMM had the lowest. Surface roughness after polishing remained below the clinical threshold of 0.2 µm.	Conventional manufacturing method (Promolux HC)
Philipp Simeon et al. (2024)	Dental LT Clear (Formlabs), luxaprint Ortho Plus (DMG), V-Print Splint (VOCO)	Wear depth (mm): DLP1 (0.94 ± 0.16), DLP2 (0.82 ± 0.10), SLA1 (2.53 ± 0.49);	Milled PMMA (Zirlux Splint Transparent)	Wear depth (mm): 0.61 ± 0.11;	N=160; wear test: 80,	Examines the wear resistance propertie of SLA- and DLP-printed occlusal splint materials, considering different printing orientations	Milled splints exhibited significantly higher wear resistance and flexural strength than all 3D-printed splints. Printing orientation had a minor effect, but SLA1 showed anisotropy in flexural strength, with 90° oriented specimens performing best.	Milled PMMA (Zirlux Splint Transparent)
Marcel Reymus et al. (2020)	Freeprint Splint	Trueness deviation: 135.49 ± 7.10 µm	Proart CAD Splint	Trueness deviation: 67.69 ± 2.16 µm	90 specimens	Accuracy, trueness, precision	Milled splints showed higher trueness, while 3D-printed ones had better precision in vertical positioning.	Proart CAD Splint
Sarah Ribeiro Cruz-Araújo et al. (2025)	Cosmos Splint, Yller	104.29 ±9.71 mpa	Conventional translucent thermopolymerizable acrylic resin	107.63 ±8.77 mpa	10 samples per group, 65 × 10 × 3.3 mm	Accuracy and mechanical properties of occlusal splints	No significant differences in flexural strength between 3D-printed and conventional resin	No significant difference
Andrew B. Cameron et al. (2023)	Keysplint Soft (3D-printed)	Asiga (P1): 0.05 ± 0.01 mm (0°), 0.10 ± 0.03 mm (90°); Rapid Shape (P2): 0.11 ± 0.01 mm (60°), 0.13 ± 0.02 mm (90°)	Programill 7 (milled PMMA)	0.03 ± 0.005 mm	10 samples per group (occlusal splints)	Trueness of intaglio surface	Build orientation influenced trueness. 0° was best for Asiga, 60° for Rapid Shape. Milled splints were the most accurate.	Programill 7 (milled PMMA)

Bardia Saadat Sarmadi et al. (2024)	Dental LT Clear (SLA), luxaprint Ortho Plus (DLP1), V-Print Splint (DLP2)	RMSE (trueness): SM ±0.15 mm, DLP1 ±0.25 mm, SLA ±0.32 mm; RMSE (precision): DLP1 highest at 0° build angle, SLA highest at 30°-45° build angles	Subtractive manufacturing (SM) occlusal splints (milled Zirlux Splint Transparent PMMA)	RMSE (trueness): ±0.15 mm (SM); RMSE (precision): highest accuracy in SM, followed by DLP1 and SLA	N=192 occlusal devices; SLA, DLP1, DLP2 in 5 build angles; milling used for SM	Examines the impact of build angle and artificial aging on the accuracy of SLA- and DLP-printed occlusal devices	Subtractive manufacturing showed the best accuracy, followed by DLP1 and SLA. Build angle significantly affected trueness and precision, with SLA showing the most dimensional changes after aging.	Subtractive manufacturing (milled Zirlux Splint Transparent PMMA) had the best accuracy and precision
Ahmet Orgev et al. (2023)	Keysplint Hard (Keystone Industries)	Trueness (RMS error in mm): 3D-printing (M2): 0.05 ± 0.02 mm; 3D-printing (Cares P30): 0.24 ± 0.09 mm	Milled PMMA (Ceramill A-Splint, Amann Girrbach) and Heat-polymerized acrylic resin	Trueness (RMS error in mm): Milling (M Series): 0.04 ± 0.01 mm; Milling (DWX-51/52D): 0.04 ± 0.01 mm	N=60 total; 10 per manufacturing method; occlusal splints scanned for precision and trueness	Examines the effects of different manufacturing technologies (3D printing, milling, heat-polymerization) on the surface accuracy of CAD-CAM occlusal splints	Milled PMMA splints had the best accuracy, followed by CLIP 3D-printing. DLP 3D-printing had the lowest accuracy and highest deviations in both intaglio and cameo surfaces.	Milled PMMA (Ceramill A-Splint, Amann Girrbach) and CLIP 3D-printed splints (M2)
				TENSILE STRENGTH				
Hegerstrøm Haugli et al. (2023)	Freeprint Splint 2.0, Dental LT Clear	48.5 ± 3.4 mpa (Tensile Strength, freeprint)	Heat-cured PMMA	13.3 ± 0.7 mpa (Tensile Strength, Clearsplint)	50 samples, biocompatibility assessment	In vitro biocompatibility study of digitally materials	Autopolymerized resins had better biocompatibility than some 3D resins	Autopolymerized resin
Jan Raffael Rosello Jimenez et al. (2023)	FRE, LUX, VPR (Dimethacrylate resins)	40-50 mpa (Tensile Strength)	CLE, KEY (Methacrylate resins)	12.3-13.3 mpa (Tensile Strength)	Varied across storage conditions	Mechanical properties and aging of occlusal splint materials	Dimethacrylate resins exhibited superior tensile strength, modulus of elasticity, and hardness	Dimethacrylate resins (FRE, LUX, VPR)
				FRACTURE RESISTANCE				
Anna-Maria Lutz et al. (2018)	Fotodent Splint	Fracture resistance: 2286±499 N	Temp Basic (CAM)	Fracture resistance: 3398±435 N	3 groups, 32 samples	Fracture resistance, wear behavior	Milled resins had the highest fracture resistance; 3D-printed resins showed high material loss.	CAM (milled Temp Basic)
Cristian Abad-Coronel et	3D-printed splint (Resin Splint)	1489.9 ±99.8 N (Fracture resistance)	Conventional Acrylic Splint	1303.9 ±90.7 N (Fracture resistance)	Multiple splint types compared	Comparison of fracture resistance of occlusal splints	Milled splints had highest resistance (3051.2 ±179.07 N),	Milled Splint

al. (2023)							printed flexural (1943.4 ±281.21 N) outperformed conventional and standard printed splints	
Leila Perea-Lowery et al. (2019)	Nextdent Ortho Rigid	Bond strength: 5.2 ± 0.9 mpa	Thermoplastic foils	Bond strength: 2.1 ± 0.5 mpa	8 per group, 20×10×2 mm	Bonding properties	3D printed thermoset splints showed higher bond strength with autopolymerizing resins than thermoplastics.	3D printed thermoset splints
BIOLOGICAL PROPERTIES								
CELL VIABILITY								
Vivien Biege et al. (2021)	Dental LT Clear Resin, Freeprint Splint	Cell viability: 1.01 (polished samples)	Palaxpress (conventional)	Cell viability: 0.98	36 discs, Ø12×1.5 mm	Biocompatibility, polishing effects	Polishing improved cell viability; unpolished printed resins showed cytotoxicity.	Polished Dental LT Clear Resin
Julia Guerrero-Gironés et al. (2022)	Keysplint Soft, Freeprint Splint	Cytotoxicity: Freeprint Splint (*p<0.001)	Orthocryl	Cytotoxicity: Moderate	40 discs, Ø6×2 mm	Biocompatibility, cytotoxicity	Freeprint Splint showed significant cytotoxicity compared to other tested materials.	Keysplint Soft (most biocompatible)
Lennart Wedekind et al. (2021)	Sheraprint-ortho plus	MMA elution: 7.47 µmol/l in water	SHERAORTHOMER (conventional PMMA)	MMA elution: 8768 µmol/l	16 discs, Ø6×2 mm	Residual monomer elution	3D-printed resins had lower elution in water; conventional PMMA showed the highest monomer elution.	Sheraeco-disc PM20 (milled PMMA)
Maximilian Kollmuss et al.(2024)	Keysplint Hard (KR), keysplint Soft (KF), V-Print Splint (VR), V-Print Splint Comfort (VF), nextdent Ortho Rigid (NR), nextdent Ortho Flex (NF)	Cell viability (hgf-1, hok): KF, NR, and NF eluates led to significant reduction in cell viability; TR, TF, and KR eluates had the highest cell viability.	Tizian Blank PMMA (TR), Tizian Flex Splint Comfort (TF)	TR and TF showed the least cytotoxic response, with the highest cell viability among tested materials.	N=4 independent experiments per cell line; entire occlusal splints were used for extraction	Examines the in vitro cytotoxic and inflammatory response of gingival fibroblasts and oral keratinocytes to 3D-printed oral splints	3D-printed resins caused a slight reduction in hgf-1 viability and glutathione levels. NR, KF, and NF showed the highest cytotoxic response. There was no strong inflammatory response.	Tizian Blank PMMA (TR) and Tizian Flex Splint Comfort (TF) exhibited the least cytotoxicity.

ANTIMICROBIAL								
Joanna Weżgowiec et al. (2024)	3D-printed Dental LT	Biocompatibility tests (MTT, LDH, Presto)	Heat-cured Villacryl	Biocompatibility tests (MTT, LDH, Presto)	15 samples per group	Cytotoxicity and biocompatibility	3D printing is a safe alternative for intraoral appliances, but heat-cured Villacryl showed a significant mitochondrial activity decrease	3D-printed Dental LT
Merve Özarslan et al. (2023)	Freeprint Ortho	Biofilm: 0.97±0.03 × 10^5 CFU; Eugenol inhibition: 92.39%	Thermoplastic (vacuum-formed)	Biofilm: 0.89±0.01 × 10^5 CFU	4 groups, 5×10×2 mm	Biofilm, antibiofilm effects	Eugenol showed the highest antibiofilm effect across all groups; thermoplastic had lower adhesion.	Eugenol-treated surfaces

*The study did not present the standard deviation data necessary for meta-analysis, therefore it was not included. Authors in bold are tabulated in more than one property.

Table 4. RoBDEMAT analysis for the included studies

	D1: Bias in Planning and Allocation			D2: Bias in Specimen Preparation		D3: Bias in Outcome Assessment		D4: Bias in Data Treatment and Reporting	
Author	**Control Group**	**Randomization of sample**	**Sample size rationale and reporting**	**Standardization of samples and materials**	**Identical experimental conditions across groups**	**Adequate and standardized testing procedures and outcomes**	**Blinding of the test operator**	**Statistical analysis**	**Reporting study outcomes**
Valtteri O. E. Väyrynen et al. (2016)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Fabian Huettig et al.(2017)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Anna-Maria Lutz et al.(2018)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Marisol Reyes Sevilla et al. (2018)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Samer M. Alaqeel et al. (2019)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Leila Perea-Lowery et al. (2019)	Sufficiently reported/adequate	Not applicable	Insufficiently reported	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Vladimir Prpic et al.(2019)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Mayra Torres Vasques et al. (2019)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Constantin Berli et al.(2020)	Sufficiently reported/adequate	Not applicable	Insufficiently reported	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Marcel Reymus et al.(2020)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Marcel Reymus et al.(2020)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Anastasiia Grymak et al. (2021)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Vivien Biege et al.(2021)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Lennart Wedekind et al. (2021)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Christian Wesemann et al.(2021)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Anastasiia Grymak et al.	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate

(2022)									
Julia Guerrero-Gironés et al.(2022)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Verena Hickl et al.(2022)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Mona Gibreel et al.(2022)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Sabina Noreen Wuersching et al.(2022)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Merve Özarslan et al.(2023)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Cristian Abad-Coronel et al. (2023)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Jan Rafael Rosello jimenez et al.(2023)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Junichiro Wada et al.(2023)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Halenur Bilir et al.(2023)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Andrew B. Cameron et al. (2023)	Sufficiently reported/adequate	Not applicable	Not reported/not adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Insufficiently reported	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Yousif A. Al-Dulaijan et al. (2023)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Danielly Mendonça Guimaraes et al.(2023)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Otavio Marino dos Santos Neto et al.(2023)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Insufficiently reported	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Ahmet Orgev et al.(2023)	Sufficiently reported/adequate	Not applicable	Not reported/not adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Gökçen Ateş et al.(2024)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Ahmet Orgev et al.(2024)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Joanna Weżgowiec et al.(2024)	Sufficiently reported/adequate	Not applicable	Insufficiently reported	Sufficiently reported/adequate	Sufficiently reported/adequate	Insufficiently reported	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Ketil Hegerstrøm Haugli et al. (2024)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Thiago Carvalho de	Sufficiently	Not applicable	Sufficiently	Sufficiently	Sufficiently	Sufficiently	Not	Sufficiently	Sufficiently

Sousa et al. (2024)	reported/adequate		reported/adequate	reported/adequate	reported/adequate	reported/adequate	applicable	reported/adequate	reported/adequate
Joanna Weżgowiec et al.(2024)	Sufficiently reported/adequate	Not applicable	Insufficiently reported	Sufficiently reported/adequate	Insufficiently reported	Insufficiently reported	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Maximilian Kollmuss et al. (2024)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Bardia Saadat Sarmadi et al. (2024)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Tina Maleki et al.(2024)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Philipp Simeon et al.(2024)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Nathaniel C. Lawson et al. (2024)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Klara Janjić et al.(2024)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate
Sarah Ribeiro Cruz-Araújo et al.(2025)	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Sufficiently reported/adequate	Not applicable	Sufficiently reported/adequate	Sufficiently reported/adequate

6. Artigo 2

Laboratorial evaluation of photosensitive resins for additive manufacturing of occlusal splints with an affordable LCD printer

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ABSTRACT

Objective: This study aims to assess the physical, mechanical and biological properties of photosensitive resins used in additive manufacturing (AM) to produce occlusal splints with an affordable LCD printer.
Methods: Specimens from three photosensitive resins (ND: NextDent Ortho Rigid, CS: Cosmos Splint, PS: Prizma Bio Splint) were printed using an LCD printer (Anycubic Photon Mono SE (Anycubic, Shenzhen, Guangdong, China); and compared with controls of thermo polymerizable resin (TR: Triunfo) and auto polymerizable polymethyl methacrylate (AR: Fast). The following properties were evaluated according to ISO standards: flexural strength, elastic modulus, Knoop microhardness, surface roughness, water sorption, solubility, and cell viability. Additionally, dimensional accuracy was measured. Specimens were subjected to cell viability testing using L929 cells for up to 14-day and simulated aging protocols for up to 1-year for flexural strength. Statistical analysis was performed using SigmaPlot 12.0 software (Systat Software, Inc., United States) (p=0.05).
Results: The results showed that, initially, all photosensitive resins exhibited flexural strength similar to TR, with values higher than the AR resin. CS resin exceeded the minimum ISO value (65 MPa) after 30 days, reaching the highest flexural strength and modulus of elasticity after 360 days, respectively of 106.0 (95.3-106.8) MPa and 4.2 (4.1-4.4) GPa. The other photosensitive resins, ND and PS, presented lower strength than CS and AR after one year, but were similar to the TR control. In terms of hardness, only ND was similar to the TR control, while the other photosensitive resins had lower hardness than both controls. ND and CS showed lower water sorption and solubility, similar to the TR control. In contrast, PS had higher sorption 32.2% (31.5-33.6) and solubility 8.35% (7.96-9.16) than the other photosensitive resins but was similar to the AR control. Cell viability of the ND resin remained above 70% at all times evaluated, while the CS and PS resins and the TR obtained cytotoxic performance at 14 days. Regarding surface roughness, the photosensitive resins achieved the smoothest surfaces after polishing, which was not similar to the controls.
Significance: The performance of photosensitive resins varied when printed with an affordable LCD printer and was generally comparable to the thermopolymerized resin (TR) control. Among the photosensitive resins, ND presented higher cell viability and mechanical stability when printed with an LCD printer.

Keywords: Occlusal Splint; Additive Manufacturing, Three-Dimensional Printing, Photosensitive Resins.

1. INTRODUCTION

Occlusal devices play a crucial role in the multidisciplinary management of bruxism and orofacial pain by protecting both teeth and the temporomandibular joint (1). This device should be used as prescribed by the dentist, typically at night, in most cases, during extended periods of high stress, based on individual needs (2). It must withstand intense occlusal forces, requiring durability and resistance to ensure long-term effectiveness. This provides professionals with a solution to meet therapeutic and dental protection demands, especially in cases of bruxism and joint dysfunction (3). Photosensitive resins have played a fundamental role in the modernization of dentistry in additive manufacturing (AM) techniques, especially in the production of individualized devices such as occlusal splints (4). These resins, formulated to meet clinical requirements, enable the production of precise devices adapted to the individual anatomy of patients, improving fit and comfort (5).

The conventional method to manufacture occlusal splints involves manual molding and the use of auto-polymerizable Polymethylmethacrylate (PMMA), which is a labor-intensive process dependent on the technician's skill ((6). Moreover, the conventional technique requires more adjustments than additive manufacturing technique, which increases the time until installation in the patient (7).On the other hand, AM makes the process more efficient, optimizing time and reducing waste, allowing for more modern and customized dental care tailored to each clinical case(8).

Three-dimensional printers for AM rely on stereolithography (SLA) and digital light processing (DLP) technologies, which differ mainly in the way they cure the resin (9). In DLP-printed models, the printing layers are not fully polymerized during printing, so the models need to undergo a post-curing process with ultraviolet light (10). While direct light processing (DLP) is the most widely applied AM method for 3D printing (11). Some cost-effective options have emerged, such as SLA-LCD printers. LCD printers are more affordable and use a liquid crystal display to block the light from LEDs, making them more cost-effective, but with lower light intensity compared to DLP (12). Although LCD printers are popular for their affordability, there are still limitations in the variety of resins and the physical and biological performance of these materials, especially when compared to auto-polymerizable PMMA resins and thermo polymerizable resins (13).

LCD technology, although still little explored in the manufacture of occlusal splints, has shown promising potential in dentistry due to advantages such as lower cost, higher printing speed, and the ability to cure entire layers at once (14). Studies indicate that LCD printers are effective in the production of dental models and prostheses, with good precision and surface quality (15). Although there are no specific studies on occlusal splints with this technology, the use of LCD has been highlighted in other dental areas, suggesting that it can bring similar benefits, especially considering the need for customization and mass production of devices (14).

Therefore, the success of an occlusal splint manufactured by AM depends on the accuracy of digital scanning (16), the choice of resin (17), an adequate design (18), and quality printing to avoid rough surfaces (19). Post-printing processes of curing and polishing are also essential to ensure comfort and durability, guaranteeing that the device is effective and comfortable for the patient (20). Furthermore, to evaluate the effectiveness of the properties that lead to the resistance and safety of the resins used in the additive manufacturing of occlusal splints, it is essential to carry out tests of their physical and biological properties according to established ISO standards. Thus, this study aims to evaluate the physical and biological properties of photosensitive resins for AM used in the production of occlusal splints with an affordable LCD printer, and to compare them with traditional materials such as thermo polymerizable resin and auto-polymerizable PMMA. The hypothesis postulated is that the photosensitive resins printed with an affordable LCD printer would have a similar flexural strength, elastic modulus, Knoop microhardness, surface roughness water sorption, water solubility, and cell viability than conventional materials used for occlusal splints.

MATERIALS AND METHODS

2.1. Materials used and guidelines

Three photosensitive resins were evaluated: Next Dent Ortho Rigid, Cosmos Splint and Prizma Bio Splint. The controls included thermo polymerizable resin (TR: Triunfo) and auto-polymerizable PMMA (AR: Fast). The experimental setup of the study, including the evaluated resins, printing and post-curing procedures, and specifics of the examined properties, are illustrated in Figure 1 and Table 1. The types of materials and chemical compositions of the tested resins as provided by the manufacturers, along with the polymerization techniques, are outlined in Table 2. All resins were handled following the standards suggested by the manufacturers.

The 3D models were created using specific free and open-source software (TinkerCad, Autodesk, United States, www.tinkercad.com). The specimens of thermo polymerizable resin and auto-polymerizable PMMA were fabricated using stainless steel or silicone molds (Reflex, Yller Biomateriais, Brazil). To assess the physical properties of the resins utilized in the production of occlusal splints, the following experiments were carried out: flexural strength, elastic modulus, Knoop microhardness, surface roughness, accuracy evaluation, water sorption, and solubility. Furthermore, cell viability assays were performed to evaluate the biological properties of these materials

2.2. Evaluation of flexural strength and elastic modulus before and after aging

The analysis of flexural strength and elastic modulus was performed according to ISO 4049:2019(21). Ten specimens were prepared for each group (64x10x3mm). One group was tested immediately, while another was stored in water at 37 ± 1°C for approximately 2 hours before flexural testing. The remaining specimens were categorized into groups (n=10) for long-term evaluation and kept in water at 37 ± 1°C for 30, 90, 180, and 360 days before flexural testing. The flexural strength of the specimens was measured using a MBio2 universal testing machine (EMIC, Biopdi, Brazil). Each specimen was placed in a 3-point bending fixture made of steel with a span of 20 mm and was tested using a load at a speed of 1±0.3 mm/min and a 1 kN load cell).

2.3. Knoop microhardness

Three specimens (10mm in diameter and 1 mm in thickness) were prepared for each group. All specimens were first polished using a Twist-Gloss Diamond Spiral Polisher (American Burrs, Brazil) for up to 1 min per face. The Knoop microhardness was measured for each specimen using the microhardness tester (Future-Tech Corp FM-700, Tokyo, Japan). A load of 50g/force was applied through an indenter with an interval of 10 seconds, in 3 equidistant points of the specimen, and the average microhardness was calculated for each specimen. The procedure was carried according to ISO 20795-1:2019(22).

2.4. Accuracy evaluation

To evaluate dimensional accuracy 3D printed samples, rectangular bars (64 × 10 x4 mm) were obtained for each experimental group (n=4). Accuracy was calculated by comparing the measured dimensions of each bar to the virtually designed dimensions (64x10x4 mm) of the 3D design. Physical measurements of each dimension (length, thickness, and width) were obtained using a digital caliper (Digital Caliper 150mm 500-196-30 - Mitutoyo), having a precision of 0.01 mm. Specimen length, thickness, and width were measured at three points (two at a 1-mm distance from each specimen end and one in the center), and the average value was assigned to each specimen. Measurements were performed in areas where no printing supports were added. To quantify the accuracy for each dimension, the following formula was used: $A = (MV - RV / RV) \times 100$ where "A" corresponds to accuracy, "RV" to the virtual reference value, and "MV" to the analog, measured value. The value of "A" was obtained in percentage and corresponds to the percentage of dimensional error from the measured value compared to the reference one. The absolute values of accuracy were used for statistical analyses.

2.5. Surface roughness

Surface roughness (Ra) was evaluated using a digital roughness gauge (SJ-201; Mitutuyo, Tokyo, Japan) with a resolution of 0.01 µm operated at room temperature. The specimens (n = 3, 64x10x3mm) for long-term evaluation and kept in water at 37 ± 1°C for 30, 90, 180, and 360 days before, were subjected to an initial measurement before polishing, and a second measurement after polishing. Polishing was carried out simultaneously on all test specimens after the aging period. A Twist-Gloss Diamond Spiral Polisher (American Burrs, Brazil) was used for up to 1 minute per side during the polishing step. Three measurements were taken for each specimen, and the roughness value (Ra, µm) for each sample was calculated as the arithmetic average of the three readings.

2.6. Evaluation of water sorption and solubility

Ten specimens (5 mm in diameter and 1 mm in thickness) were prepared for each group (ISO 10477:2018)(23). The specimens were weighted after 24 hours of polymerization until a stable initial mass (m1) was reached. The samples were then stored in 20 ml of water at 37 ± 1ºC for 7 days. After this period, the specimens were individually washed and dried with absorbent paper until no visible moisture remained. The specimens were then shaken in the air for 15 seconds and weighed again after 1 minute (m2). Following this, the specimens were reconditioned in an oven until the mass loss for each was less than 0.1 mg per 24-hour period, and the final mass was recorded (m3). Water solubility (WSL = [(m1 – m3)/m3] x 100) and sorption (WSR = [(m2 – m3)/m3] x 100) were calculated as percentages of the original mass.

2.7. Assessment of cell viability

Cell viability assessment was performed following ISO 10993-5:2021(24) using L929 mouse fibroblasts. The cells were cultured in Dulbecco's Modified Eagle Medium (DMEM) supplemented with 10% fetal bovine serum (FBS), 2% L-glutamine, 100 U/mL penicillin, and 100 mg/mL streptomycin. Fibroblasts were maintained in DMEM and incubated at 37°C in a humidified atmosphere with 5% CO_2 until sub-confluence was reached. The cells were seeded at a density of $2x10^4$ cells per well in 96-well plates and incubated under 100% humidity and 5% CO_2 at 37°C. After 1, 7, and 14 days, eluates from 24-well plates containing one specimen per well (6 mm diameter, 1 mm thickness) with 1 mL of medium were collected. The eluates (200ul) were then applied to the cells in the 96-well plates for 24 hours. Following incubation, cell viability was evaluated using the MTT assay (Sigma, USA). After 4 hours of incubation at 37°C in the dark, the blue formazan precipitate formed in the mitochondria was solubilized with 200 µL of DMSO per well. Absorbance was measured at 540 nm using a spectrophotometer (Thermo Fisher Scientific, USA). The untreated group (cell control) was considered as 100% viable.

2.8. Statistical analysis

Data were analyzed using SigmaPlot 12.0 software (Systat Software, Inc., United States). The normality and homogeneity of sample variance were assessed with the Shapiro-Wilk and Levene tests. Flexural strength and cell viability were evaluated using Two-Way ANOVA followed by Tukey's post-hoc test. Hardness and accuracy were analyzed using One-Way ANOVA followed by Tukey's post-hoc test. Surface roughness was evaluated considering data before and after polishing with Two-Way Repeated Measures ANOVA test followed by Tukey's post-hoc test. Water sorption and solubility were assessed with the Kruskal-Wallis test followed by Tukey's post-hoc test. A significance level of 5% was considered.

3. RESULTS

3.1. Flexural strength and Elastic Modulus

Table 3 presents the flexural strength (MPa) and elastic modulus (GPa) of different resins (ND, CS, PS, TR, and AR) over 0, 30, 90, 180, and 360 days. Initially, all photosensitive resins were statistically similar to TR and with higher flexural strength than AR. Initially, regarding elastic modulus the photosensitive resins were similar to TR and AR controls. In general, the flexural strength of ND and PS decreased over time ($p<0.05$), and CS exceeded the ISO minimum value recommended for occlusal splints (65 MPa) only after 30 days. After one year, CS resin had the highest flexural strength and elastic modulus than the other photosensitive resins and TR, and was statistically similar to AR. Besides, the other photosensitive resins were comparable to TS in terms of flexural strength.

3.2. Knoop microhardness

Figure 2 presents the Knoop microhardness (KHN) of different resin groups. The results indicate that AR has the highest microhardness of 23.11 KNH (± 4.09), while CS and PS exhibit the lowest hardness respectively of 7.26 KNH (± 2.43) and 11.1 KNH (± 3.7). ND and TR showed statistically similar hardness, with significant differences from the other groups ($p<0.05$).

3.3. Accuracy

Figure 2b-c shows the accuracy in each dimension of the different resins printed entirely on the same LCD printer and with the same printing parameters described in Table 1. Differences were revealed in the accuracy of the three resins, evaluated in terms of length for the ND resin, showing a positive average accuracy, being greater than the size designed for the length (0.6%) with a low standard deviation (0.262), indicating reasonable consistency. Width and thickness have averaged close to zero, suggesting acceptable accuracy with greater variability in thickness according to the standard deviation (1.848). These results indicate no variations in dimensional accuracy for width and thickness between the different materials tested.

3.4. Surface roughness assessment

Figure 3 shows the surface roughness before (a) and after (b) polishing (Ra). Before polishing, in general AR exhibited the highest surface roughness across all time points, while CS and PS had lower values, indicating smoother surfaces. After polishing, all resin groups showed a significant reduction in surface roughness, with ND and CS achieving the smoothest surfaces and AR maintaining relatively higher roughness values even after polishing. Statistical analysis reveals significant differences in roughness both before and after polishing ($p<0.05$), highlighting that polishing effectively reduces surface irregularities, but the effectiveness varies depending on the resin type.

3.5. Sorption and solubility

Table 4 presents the median and interquartile ranges for water sorption (%) and solubility (%) of all groups. For water sorption, PS showed the highest values (32.2%) that were statistically similar to AR control (24.1%). CS and ND showed similar water sorption to TR and lower than AR and PS ($p<0.05$).

Regarding water solubility, PS and AR also exhibited the highest solubility respectively 8.35% and 7.07%. Besides, it was found a similar solubility for ND, CS and TR, which were also lower than PS and AR ($p<0.05$).

3.6. Cell viability

Figure 4 illustrates the cell viability (%) of L929 fibroblasts for different resin groups over 24 hours, 7 days, and 14 days, with the dotted line at 70%

representing the ISO 10993-1:2021(24) threshold for non-cytotoxic materials. ND consistently maintained cell viability above 70% across all time intervals. In contrast, the cell viability of CS, PS, and TR decreased after 14 days ($p<0.05$) and were below 70%, suggesting potential cytotoxic effects with prolonged exposure. These results indicate that ND could be more suitable for applications requiring long-term biocompatibility, while CS and PS may have limitations in this regard.

4.Discussion

This study evaluated the physical and biological performance of three commercial brands of photosensitive resins, such as ND (NextDent Ortho Rigid, NextDent), CS (Cosmos Splint, Ylller) and PS (Prizma Bio Splint, Makertech Labs), for AM of occlusal splints printed with an affordable LCD printer. The results showed that some photosensitive resins had comparable or even superior performance to traditional materials based on the tested properties. In the initial flexure, the photosensitive resins presented performance equal to the thermo polymerizable resins and superior to the auto-polymerizable resins. After aging (1-year), the ND and PS resins maintained flexural strength similar to the TR resins, while the CS resin outperformed the other 3D resins and presented performance similar to the AR resin. Regarding hardness, the ND resins presented results similar to the TR resins, while the CS and PS resins showed lower hardness than the TR and AR resins. In relation to sorption, the ND and CS resins presented results similar to the TR resin, while PS presented a greater sorption, similar to the AR. In terms of solubility, the ND and CS resins had similar solubility to the TR resins, while PS showed greater solubility, similar to the AR. Besides, photosensitive resins presented lower roughness than the TR and AR resins after polishing. Furthermore, regarding cytotoxicity, the ND resin stood out for not being cytotoxic, being the best among the 3D resins, while the CS and PS resins showed cytotoxic effects after 14 days, with results similar to the TR resins. Thus, considering that in all evaluated properties some photosensitive resins presented comparable results to the controls used, the hypothesis postulated was partially accepted.

The tested resins were compared to ISO 20795-1:2013(22), which requires a minimum value of 65 MPa for optimal performance. Initially, several resins met or exceeded this limit, with ND and PS resins exhibiting the highest flexural strength values, that was similar to the TR control. However, the performance of these resins declined over time, especially during the aging process. On the other hand, the conventional AR resin, despite starting with lower flexural strength values compared to the other resins, demonstrated greater stability over time. After 360 days, AR maintained flexural strength values closer to the 65 MPa required by the standard, standing out for its durability. The aging process, including hydrolytic deterioration and thermal degradation, significantly impacts the longevity of dental composites (25). The results of the present study align with these findings, as the flexural strength of the resins decreased over time. In a previous study (26), the decrease in flexural strength of DLP-printed materials with aging was also observed, with the results falling within the same range observed in our study. Initially, the additive manufacturing resins showed promising mechanical properties, with results similar to the TR resin and superior to AR. However, there was significant variation in the performance of the additive manufacturing resins after aging. After 360 days, the ND and PS resins, which initially showed the best results, experienced a reduction in flexural strength, equaling TR. In contrast, the CS resin, which initially performed similarly to the other additive manufacturing resins, showed an increase in flexural strength over time, outperforming the other resins and equaling AR.

When compared with the market controls, which follow the standards established by ISO 20795-1:2013(22), the results of the photosensitive resins are aligned with the conventional resins available on the market, showing that despite the variations, they still maintain performance within an acceptable range for dental applications (27). This comparison highlights the need to consider the effects of aging when choosing materials for dental prosthetics, as the durability and stability of mechanical properties over time are crucial for treatment success (3). The mechanical properties found were consistent with those of previous studies comparing conventional PMMA resins with photosensitive resins printed with DLP, SLA, and LCD printers (28). Similar ranges of flexural strength were reported, suggesting that both manufacturing methods produce comparable results (29). However, a study (30) found that conventional resins (Heat-cured

PMMA (Villacryl) exhibited higher flexural strength after aging compared to additive manufacturing resins, reinforcing deleterious impacts from aging on the mechanical properties of 3D printed materials.

In relation to hardness, the photosensitive resin ND demonstrated similar hardness to the TR control, while the CS and PS resins showed lower results than the oR and AR controls. Post-curing processing has been shown to significantly affect the hardness and strength of 3D resins (31), and due to this, we used a standardized post-cure as required by the manufactures. The post-curing process, especially with UV light exposure, has been shown to significantly increase the hardness of 3D printed resins, improving their mechanical properties over time. Studies indicate that proper post-polymerization treatment can make 3D resins comparable to or even superior to conventional resins in terms of hardness, with additional benefits in wear resistance (27,32–34).

Artificial aging has also been reported to degrade the mechanical properties of 3D printed resins. One study (30) found that 3D printed resins, although initially exhibiting high Shore D hardness, experienced significant reductions in hardness after 90 days of storage in water. These findings highlight the need to improve 3D resins to ensure better durability and long-term stability in environments subject to humidity and temperature fluctuations.

Regarding surface roughness, the photosensitive resins showed significant superiority over the thermo polymerizable and auto-polymerizable controls before and after polishing. Before polishing, CS and PS exhibited lower surface roughness (Ra) than the controls, resulting in smoother surfaces compared to TR and AR, with AR showing the highest initial roughness. After polishing, all resins showed a significant reduction in roughness, with the photosensitive resins, particularly ND and CS, achieving the smoothest surfaces. On the other hand, the controls TR and AR maintained relatively higher roughness than the additively manufactured ones, with AR still showing the highest roughness. The analysis also indicates that surface roughness is crucial for bacterial adhesion. According to studies (35), photosensitive resins such as ND and PS present greater surface roughness before polishing compared to thermo polymerized and auto-polymerizable controls, requiring more rigorous polishing to reach Ra values below 0.2 µm and avoid bacterial adhesion (36). The literature highlights the relationship between surface roughness and initial bacterial growth in 3D printed devices, suggesting that greater roughness facilitates bacterial colonization, especially in occlusal splints (37). However, with adequate polishing, most of the tested materials can reach roughness values below the critical limit of 0.2 μm, significantly reducing bacterial adhesion (36). Previous research (38,39) corroborate this relationship between roughness and biofilm formation, with greater adhesion to bacterial growth on rougher surfaces, which can be problematic for devices worn for long periods in the oral cavity. In contrast, thermo polymerizable and auto-polymerizable materials such as PMMA have a denser and less porous structure, making them less susceptible to bacterial adhesion, especially after polishing (37).

Water sorption in materials produced by additive manufacturing using an LCD printer was higher than the AR control and similar to the TR control in our study, as also found in previous results with other printers (3,40). Although the PS resin exhibited the highest water sorption values, the results were similar to the AR control. On the other hand, the ND and CS resins showed lower sorption than the other groups, being similar to the TR control. Regarding water solubility, PS and AR exhibited the highest solubility, being statistically similar, while the ND and CS resins showed lower solubility values, similar to the TR control. Layer thickness and post-polymerization influence both the sorption and solubility of printed materials, likely related to the degree of conversion of molecules into polymers (41). The solubility of materials directly influences important properties of occlusal devices. Materials with high solubility tend to release more residual monomers, which can compromise biocompatibility and induce cytotoxic effects on gingival fibroblasts, as well as promote wear and reduce mechanical strength over time (3,42). On the other hand, materials with low solubility exhibit greater dimensional stability, less release of toxic compounds, and better maintenance of mechanical and surface properties, resulting in increased clinical durability (30,40).

The dimensional accuracy of photosensitive resins was analyzed to assess the impact of using an LCD printer. The results obtained in the evaluation of dimensional accuracy showed a difference between the materials, with only ND resin showing a statistical difference in length, indicating reasonable accuracy for these materials. For width, no differences were found between the resins, as indicated by the absence of different letters in the columns. The same applies to thickness, where, despite variations in the average values, no statistically significant differences were found between the resins, confirming that accuracy errors in thickness do not vary significantly between the materials. The dimensional accuracy of resins printed with technologies such as SLA, DLP and LCD can be influenced by several factors, including printing orientation, storage time and post-curing strategy. Another study revealed that ND resin, used with DLP technology, showed good performance in length accuracy, but significant variations occurred in thickness, especially when compared to PS resin, which showed greater deviations (43). Similarly, another study observed that for devices printed with LCD technology, the 70-degree printing orientation showed better accuracy, although there were no significant differences in terms of trueness between the 0, 45, and 70-degree orientations (14). These studies demonstrate that although the accuracy of the resins is adequately good in various printing orientations, the choice of printing technology and post-processing parameters, such as post-curing strategy and artificial aging, play a crucial role in the dimensional stability and long-term mechanical properties of the resins. The choice of 45-degree angulation in our study was based on previous studies (44,45) and should be considered when evaluating these properties when selecting the material for clinical applications of occlusal devices.

Cell viability assay in photosensitive resins for additive manufacturing is crucial, as printing parameters and post-curing time can make the printed part toxic to the oral environment if the correct standards are not followed (42). In our evaluation, with the LCD printer, following the described post-curing procedure and cell viability methodology, the CS resin presented the lowest cell viability among all resins (Figure 4), with significant difference ($p \leq 0{,}05$) among the other resins at the same time points. According to ISO 10993-2021(24), a minimum cell viability of 70% is required for a material to be considered non-cytotoxic. As seen in Figure 4, ND resin was the only one that did not exceed this limit at every time-point. In general, 3D printing resins, except CS, presented cell viability results similar to those of conventional resins, this outcome is consistent with another study that evaluated by cytotoxic assay of fibroblasts in materials for occlusal splints with different surface treatments on a DLP printer (46). After 14 days, there was a decrease in cell viability in CS and PS resins, similar to TR resin. This can be explained because additive manufacturing resins contain monomers in their composition that, if not fully converted into polymers during printing or post-curing, can make the printed part potentially toxic to cells in contact with free monomers (47). In contrast, conventional self-curing forms showed lower cell viability compared to thermo polymerizable forms, which have higher monomer conversion due to the heat and pressure applied during polymerization. No other studies were found that evaluated cell viability at different times. Given that the resins exhibited changes in cell viability at different time points, it is crucial to evaluate cell viability not only at the initial stage but also over a prolonged period, as occlusal splints are worn by patients for prolonged periods (42)

The limitations of this study also encompass the absence of an analysis of variables such as the impact of polishing on the mechanical properties of materials, the influence of post-curing procedures on the dimensional accuracy of impressions, and the variability of material properties based on impression angulation. These aspects could potentially affect the results obtained. We limited the variables to provide an initial overview regarding the physical and biological properties of photosensitive resins printed with an affordable LCD printer. Additional research is required to assess these variables. Another notable limitation is the lack of specific ISO standards for certain parameters tested in the photosensitive resins used in the additive manufacturing of occlusal splints. The research was based on general standards for evaluating the physical properties of occlusal splints or the biological properties of dental materials, which are not specific for additive manufacture. Thus, the absence of a universal set of guidelines for the biological and mechanical properties of materials used in the additive manufacture of dental devices limits the comparison and standardization of results. Besides, our study did not consider the variation in properties depending on the type of 3D printer used, which could influence the results, since different technologies such as SLA, DLP, and LCD may have different curing and detailing characteristics, directly impacting the final quality of the photosensitive resin. Another key point is the absence of a long-term cost-benefit analysis, considering not only the physical and biological properties but also the economic viability of adopting these resins on a large scale in dentistry, specially considering the benefits of using an affordable LCD printer. Finally, the durability of materials over time, including resistance to environmental factors such as temperature and humidity, has been studied to a limited extent, and additional studies on the impact of different clinical conditions on the longevity of devices are also needed to gain a more comprehensive understanding of their effectiveness. However. our study was found that some photosensitive resins printed with LCD printer can achieve similar physical, mechanical, and biological performance to thermo polymerizable or auto polymerizable polymethyl methacrylate resin for occlusal splints.

5. Conclusion

The performance of photosensitive resins varied when printed with an affordable LCD printer and was generally comparable to the thermo polymerized resin (TR) control. Cosmos Splint (Yller) demonstrated the highest flexural strength after one year, and all photosensitive resins had lower roughness than the controls after polishing. Besides, Next Dent Ortho Rigid (NextDent) showed higher cell viability after 14 days than other photosensitive resins, and hardness, water sorption, and solubility similar to TR control. Among the tested resins, Next Dent Ortho Rigid exhibited the most favorable combination of physical, mechanical, and biological properties under the evaluated printing parameters.

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Figure 1

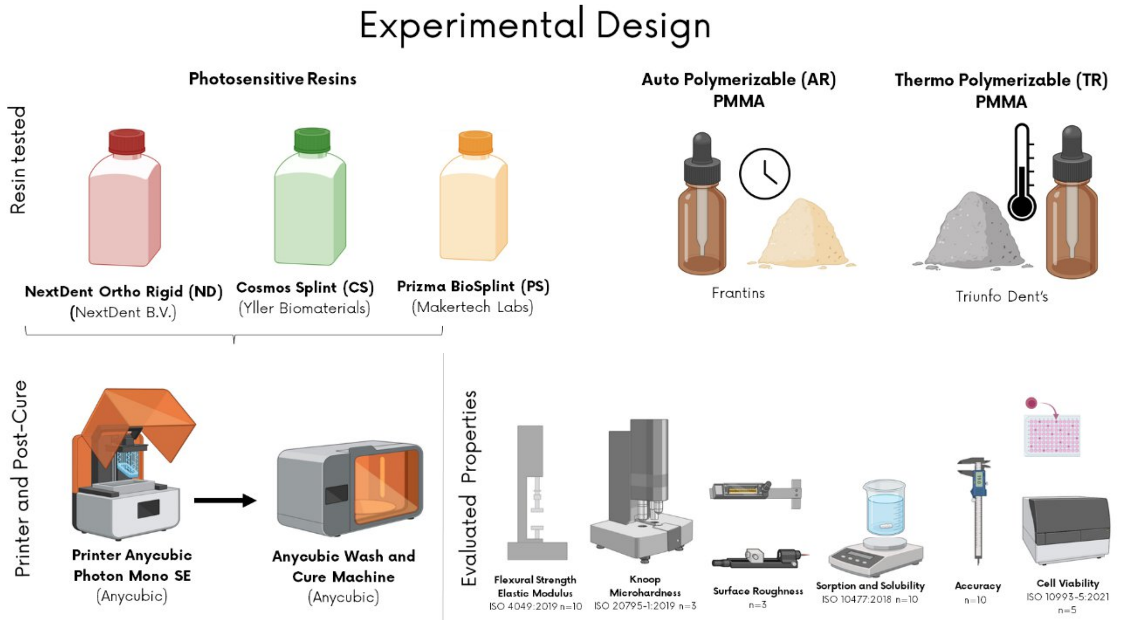

Figure 1. Experimental design of the study with tested resins, including printing and post-curing processes for photosensitive resins. The figure also details the evaluated properties, corresponding standards, and the number of sprecimens tested). Created with the assistance of BioRender(www.biorender.com).

Figure 2

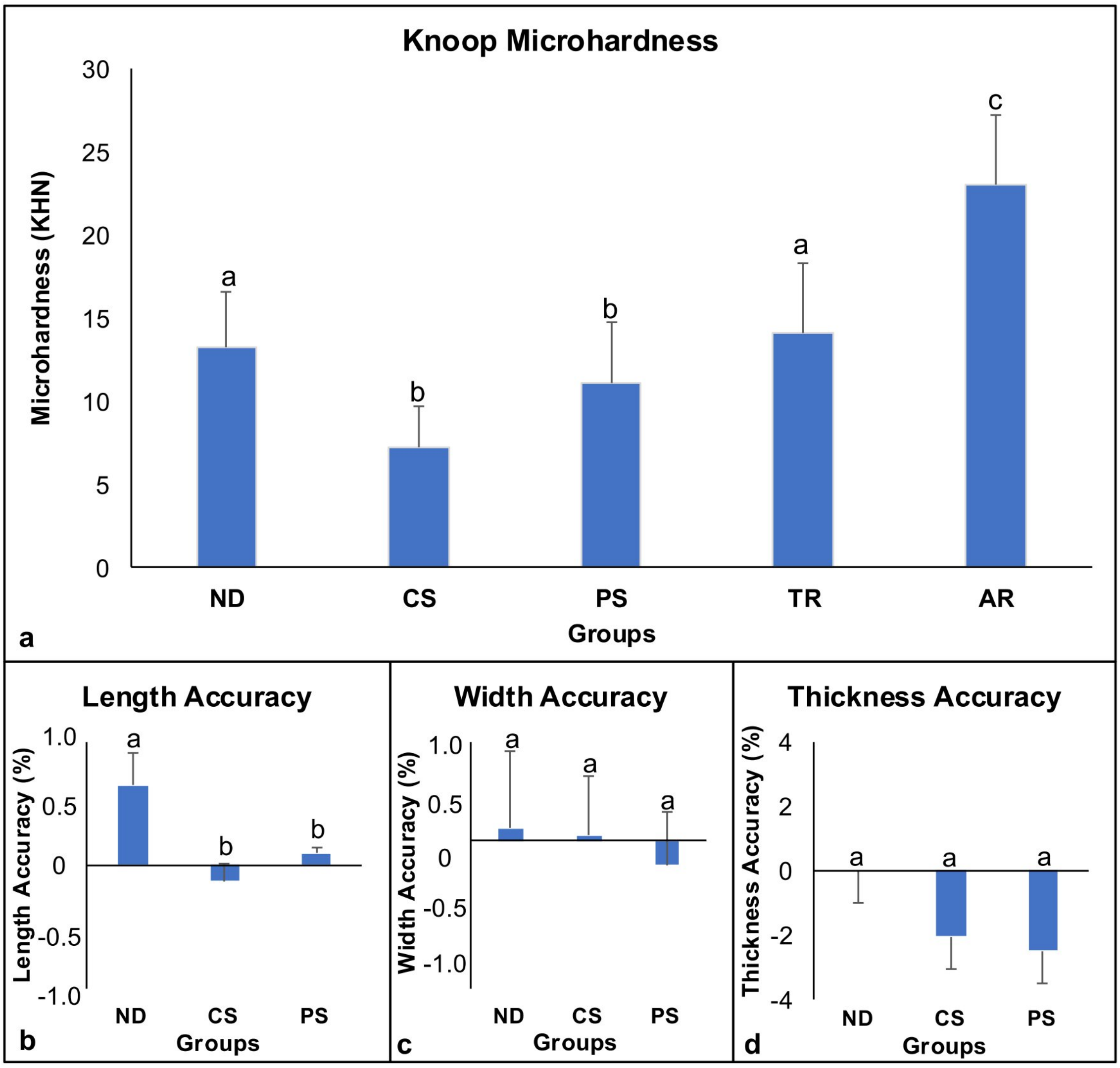

Figure 2. a. Knoop hardness of all tested groups. Accuracy results represented as percentage error from the original reference value, considering b. length, c. width, and d. thickness. Different letters indicate statistically significant differences between materials (p<0.05). ND: NextDent Ortho Rigid, CS: Cosmos Splint, PS: Prizma BioSplint, TR: Thermo polymerizable, AR: Auto polymerizable.

Figure 3

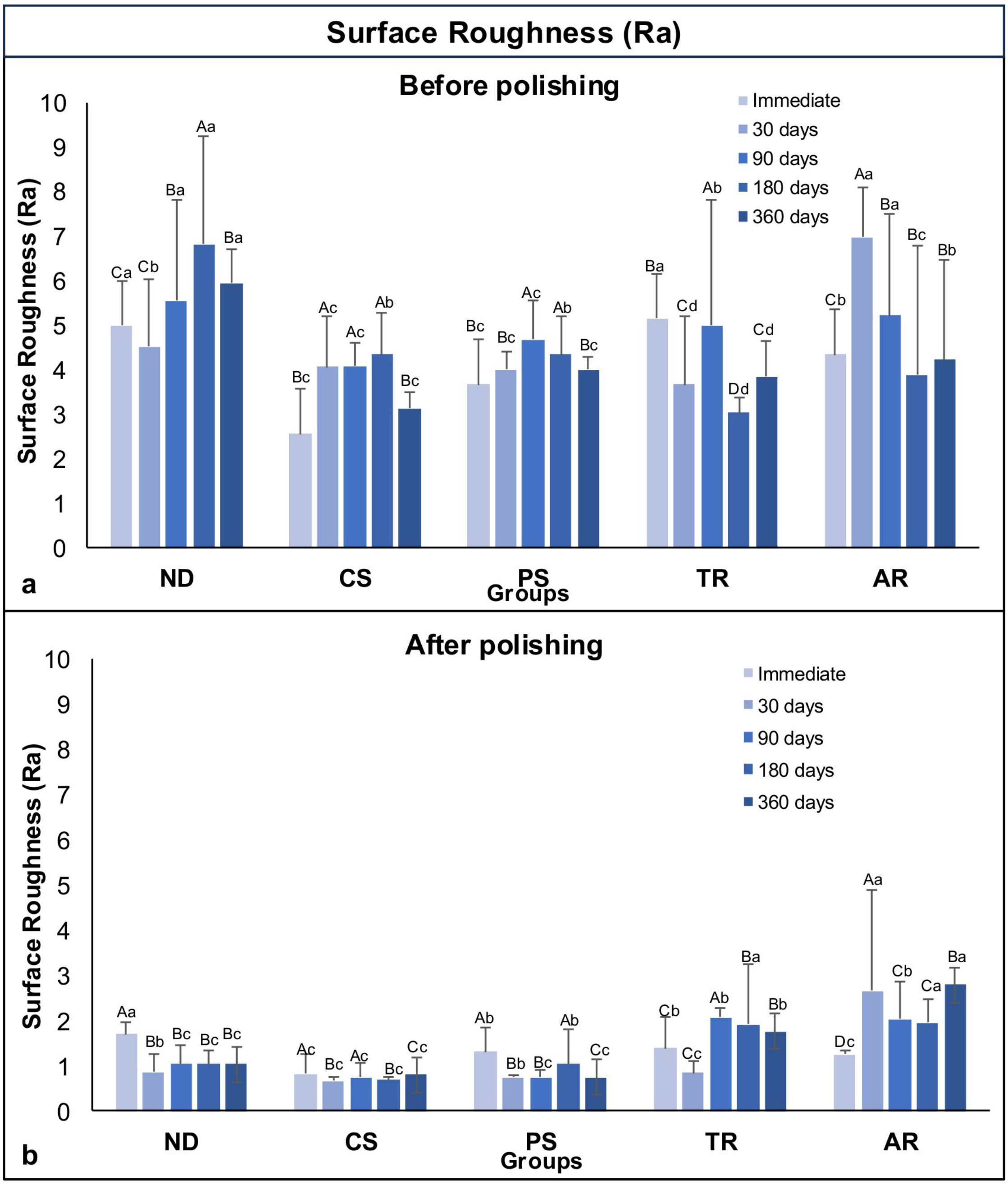

Figure 3. Surface Roughness (Ra) (a) before polishing and (b) after polishing. Different capital letters in the same resin group indicate statistically significant differences between time intervals($p<0.05$) and different lowercase letters in the same time interval indicate statistically significant differences between resins at the same period ($p<0.05$). Mean and Standard Deviation are shown for parametric statistics using the Two-Way Repeated Measures ANOVA test followed by Tukey's post-hoc test. ND: NextDent Ortho Rigid, CS: Cosmos Splint, PS: Prizma BioSplint, TR: Thermo polymerizable, AR: Auto polymerizable.

Figure 4

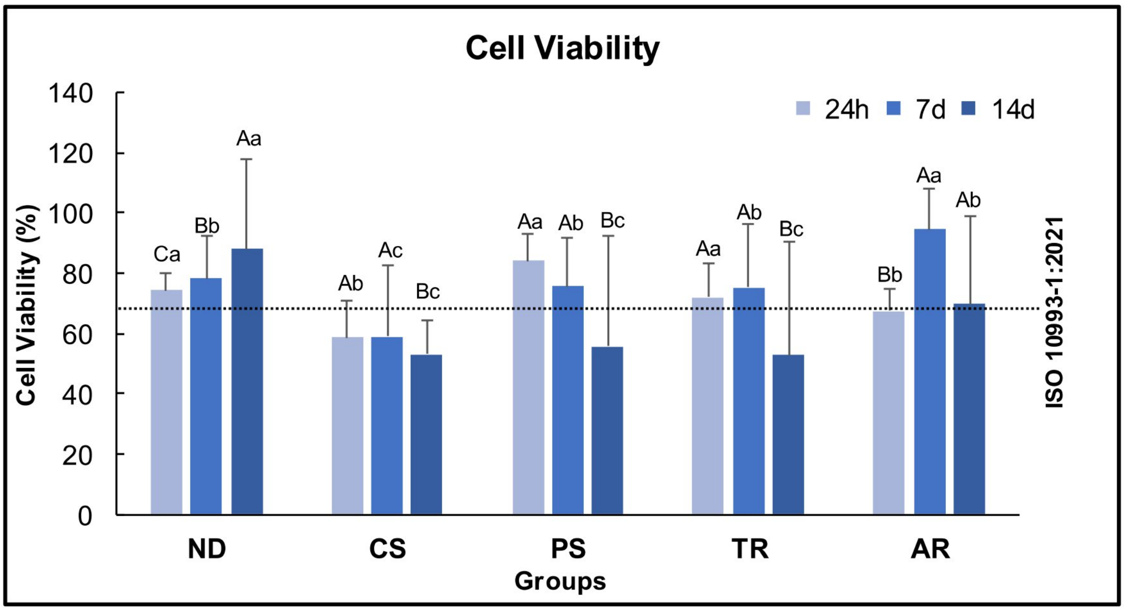

Figure 4. Cell Viability of L929 Fibroblasts after 1, 7, and 14 Days. Different capital letters in the same resin group indicate statistically significant differences between time intervals($p<0.05$) and different lowercase letters in the same time interval indicate statistically significant differences between resins at the same period ($p<0.05$). The line represents the ISO 10993-1:2021(24) recommended parameter of at least 70% cell viability for a non-cytotoxic material. ND: NextDent Ortho Rigid, CS: Cosmos Splint, PS: Prizma BioSplint, TR: Thermo polymerizable, AR: Auto polymerizable.

Table 1 - Main characteristics of resins used, including types, brands, manufacturers, specimen preparation, and post-curing processes.

Resin Type	Commercial Brand	Manufacturer	Preparation of specimens	Post-curing process
Photosensitive resins	ND: NextDent Ortho Rigid Shade: Blue (Lot: XG144N01) CS: Cosmos Splint Shade: Colorless (Lot: 00012250) PS: Prizma Bio Splint Shade: Colorless (Lot: 210823)	NextDent B.V., Netherlands Yller Biomaterials, Brazil Makertech Labs, Brazil	The resins were printed using the following parameters: • Printer: Anycubic Photon Mono SE (Anycubic, Shenzhen, Guangdong, China); LCD-Based SLA technology • Wavelength: 405nm • Printing angle: 45° angle • Layer thickness: 50µm • Normal exposure time: 2.5s • Off time: 1s • Bottom exposure time: 60s • Bottom layers: 8	5-minute cleaning with 99.5% isopropyl alcohol solution, followed by 30 minutes of UV curing using the *Anycubic Wash And Cure Machine* (Anycubic, Shenzhen, Guangdong, China)
Thermo polymerizable	TR: Triunfo Shade: Colorless (Lot:1832)	Triunfo Dent's, Brazil	According to manufacturer's instructions. Briefly, the powder and liquid components were mixed in the recommended ratio. Made at the temperature and pressure indicated by the manufacturer. The specimens were prepared by directly applying the mixture into the prepared molds.	Not performed.
Auto-polymerizable	AR: Fast Shade: Colorless (Lot: 8518)	Frantins, Brazil	According to manufacturer's instructions. Briefly, the powder and liquid components were mixed in the recommended ratio (3:1, powder to liquid), and the specimens were prepared by directly applying the mixture into the prepared molds.	Not performed.

Table 2 – Materials tested, chemical compositions and polymerization reported by to the manufacturers

Material	Composition according to the manufacture	Polymerization
ND: NextDent Ortho Rigid	7,7,9(or 7,9,9)-trimethyl-4,13-dioxo3,14-dioxa-5,12-diazahexadecane1,16-diyl bismethacrylate; 2-hydroxyethyl acrylate; Acrylic acid, monoester with propane-1,2-diol; ethylene dimethacrylate; 2-hydroxyethyl methacrylate; diphenyl(2,4,6-trimethylbenzoyl) phosphine oxide; Reaction mass of Bis(1,2,2,6,6-pentamethyl-4-piperidyl)sebacate and Methyl 1,2,2,6,6-pentamethyl-4-piperidylsebacate	Light-curing (UV or visible light)
CS: Cosmos Splint	Oligomers, monomers, photoinitiators, stabilizers, and pigment.	Light-curing (UV or visible light)
PS: Prizma Bio Splint	Acrylated and Triacrylated Monomers, Amorphous Silica, Fillers, Methacrylated Oligomers, Diphenyl (2,4,6-trimethylbenzoyl)-phosphine oxide	Light-curing (UV or visible light)
TR: Triunfo	Ethanol, 2,2'-[(1-methylethylidene)bis(4,1-phenyleneoxy)]bis-, diacetate; benzyl-phenyl-barbituric acid; silane-treated silica; (1-methylethylidene)bis(4,1-phenyleneoxy-2,1-ethanediyl)(1-phenyleneoxy-2,2'-ethoxyethanediyl)bis-acetate; tert-butyl 3,5,5-trimethylperoxyhexanoate	Thermo polymerizable
AR: Fast	Powder Resin: Polymethyl methacrylate, Benzoyl Peroxide and Biocompatible Pigments Liquid: Methyl methacrylate, Ethylene glycol methacrylate - EDMA, Inhibitor and Fluorescent	Auto-polymerizable

Table 3 – Median and Interquartile Ranges of Flexural Strength (MPa) and Elastic Modulus (GPa)

Test (n=10)	Resin	Median and Interquartile Ranges 0 days	Median and Interquartile Ranges 30 days	Median and Interquartile Ranges 90 days	Median and Interquartile Ranges 180 days	Median and Interquartile Ranges 360 days
Flexural Strength (MPa)	ND	72.9 (61.3-89.3)^{Ad}	99.1 (81.1-108.3)^{Ba}	86.0 (58.5-120.5)^{Ac}	60.0 (50-69.3)^{Bb}	62.5 (60.0-77.5)^{Bb}
	CS	55.5 (46.7-64.9)^{Ab}	97.5 (84.5-104.8)^{Ab}	92.0 (66.0-106.8)^{Ab}	82.5 (63.5-90.0)^{Ab}	106.0 (95.3-106.8)^{Aa}
	PS	75.4 (61.9-79.5)^{Ab}	80.5 (73.3-92)^{Ab}	80.0 (56.0-94.8)^{Aa}	66.0 (55.5-78.5)^{Ba}	58.0 (49.0-85.8)^{Ba}
	TR	66.4 (61.2-69.4)^{Aa}	55.0 (53.3-57.5)^{Ca}	67.5 (65.0-73.8)^{Ab}	51.0 (46.0-54.8)^{Ca}	57.0 (54.0-62.8)^{Bb}
	AR	47.0 (41.3-50.7)^{Bb}	57.5 (53.5-6.5)^{Cb}	77.0 (66.5-86.0)^{Aa}	56.0 (40.0-62.8)^{Ca}	71.5 (67.5-73.2) ^{Ac}
Elastic Modulus (GPa)	ND	2.4 (2.2-2.6)^{Ac}	2.2 (2.1-2.3)^{Ac}	4.3 (4.2-4.4)^{Ba}	2.4 (2.3-2.4)^{Ac}	3.7 (3.5-3.8)^{Bb}
	CS	2.7 (2.6-2.9)^{Ac}	2.6 (2.5-2.6)^{Ac}	5.1 (4.7-5.2)^{Aa}	2.9 (2.7-2.9)^{Ac}	4.2 (4.1-4.4)^{Ab}
	PS	2.5 (2.2-2.6)^{Ac}	2.0 (1.8-2.0)^{Bc}	4.0 (3.5-4.4)^{Ca}	2.2 (2.0-2.2)^{Cc}	3.4 (3.2-3.7)^{Cb}
	TR	1.9 (1.8-2.1)^{Ab}	2.1 (2.0-2.2)^{Ab}	3.8 (3.5-4.1)^{Ca}	2.2 (2.1-2.3)^{Bb}	3.3 (3.0-3.5)^{Ca}
	AR	1.5 (1.4-1.6)^{Ac}	2.3 (2.0-2.4)^{Ac}	4.2 (3.7-4.4)^{Ca}	2.4 (1.7-2.6)^{Cc}	3.1 (2.9-3.3)^{Cb}

Flexural Strength (MPa): Different capital letters in the same column indicate statistically significant differences between resins, and different lowercase letter in the same line indicate statistically significant differences at each time interval ($p<0.05$). Median and Interquartile Ranges are shown for parametric statistics using the Two-Way Repeated Measures ANOVA test followed by Tukey's post-hoc test.

Elastic Modulus (GPa): Different capital letters in the same column indicate statistically significant differences between resins, and different lowercase letter in the same line indicate statistically significant differences at each time interval ($p<0.05$). Median and Interquartile Ranges are shown or non-parametric statistics using the Two-Way Repeated Measures ANOVA test followed by Tukey's post-hoc test.

Table 4 – Median and Interquartile Ranges for Water Sorption and Solubility Test Results.

Resin	**Water Sorption (%)** (n=10)	**Water Solubility (%)** (n=10)
ND	14.6 (14.0-15.1)^{B}	3.56 (2.73-3.94)^{B}
CS	13.7 (13.6-14.0)^{B}	2.63 (1.73-3.13)^{B}
PS	32.2 (31.5-33.6)^{A}	8.35 (7.96-9.16)^{A}
TR	17.3 (17.0-18.7)^{B}	3.01 (2.79-4.20)^{B}
AR	24.1 (22.9-24.6)^{A}	7.07 (5.86-8.09)^{A}

Water Sorption (%) and Solubility (%): Different letters in the same column indicate statistically significant differences between resins ($p<0.05$). Median and Interquartile Ranges are shown for non-parametric statistics using the Kruskal-Wallis test followed by Tukey's post-hoc test.

7. Considerações Finais

As considerações com base na revisão sistemática apresentada são de que resinas impressas em 3D apresentam uma alternativa promissora aos materiais convencionais, oferecendo vantagens significativas em personalização e eficiência de produção, bem como custos reduzidos. No entanto, sua segurança biológica e desempenho mecânico dependem de processos de pós-processamento e controle rigoroso das condições de fabricação. Embora as resinas fotossensíveis ainda fiquem atrás dos materiais tradicionais baseados em PMMA em propriedades mecânicas como dureza e resistência à flexão, os avanços nas tecnologias de impressão 3D e o pós-processamento adequado podem melhorar seu desempenho mecânico e biológico, tornando-as uma opção viável para aplicações clínicas específicas, como talas oclusais. Além disso, a seleção de materiais e métodos para a fabricação de talas oclusais deve equilibrar propriedades físicas, mecânicas e biológicas com precisão clínica, durabilidade e viabilidade técnica e econômica. Em conclusão, este estudo demonstrou que as resinas fotossensíveis usadas na impressão 3D para talas oclusais geralmente exibiram propriedades físicas, mecânicas e biológicas inferiores em comparação aos materiais PMMA convencionais.

No trabalho experimental as considerações finais são de que o desempenho das resinas fotossensíveis variou quando impressas com uma impressora LCD acessível e foi geralmente comparável ao controle de resina termo polimerizada (TR). Cosmos Splint (Yller) demonstrou a maior resistência à flexão após um ano, e todas as resinas fotossensíveis apresentaram menor rugosidade do que os controles após o polimento. Além disso, Next Dent Ortho Rigid (NextDent) apresentou maior viabilidade celular após 14 dias do que outras resinas fotossensíveis, e dureza, sorção de água e solubilidade semelhantes ao controle TR. Entre as resinas testadas, Next Dent Ortho Rigid exibiu a combinação mais favorável de propriedades físicas, mecânicas e biológicas sob os parâmetros de impressão avaliados.

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9. Apêndices

9.1 Checklist PRISMA

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	#34
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	#35
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	#36
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	#37
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	#37
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	#38
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	#60
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	#56
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	#56
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	#37
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	#38
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	#39
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	#39
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	#38
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	#38
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	#38
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	#39
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	#39

Section and Topic	Item #	Checklist item	Location where item is reported
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	#40
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	#39
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	#40
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	#40
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	#40
Study characteristics	17	Cite each included study and present its characteristics.	#62-#66
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	#78-#80
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	#67-#77
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	#45
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	#39
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	#41
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	#67-#77
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	#78-#80
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	#45
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	#46
	23b	Discuss any limitations of the evidence included in the review.	#50
	23c	Discuss any limitations of the review processes used.	#51
	23d	Discuss implications of the results for practice, policy, and future research.	#51
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	#37
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	#37
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	#37
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	#51
Competing interests	26	Declare any competing interests of review authors.	#51

Section and Topic	Item #	Checklist item	Location where item is reported
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	#51

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

9.2 Certificado ENPOS 2023

MINISTÉRIO DA EDUCAÇÃO
UNIVERSIDADE FEDERAL DE PELOTAS

A Universidade Federal de Pelotas, certifica que

MARCELO PEREIRA BROD

Apresentou o trabalho **"INFLUÊNCIA DE DIFERENTES TEMPOS DE CURA NA RESISTÊNCIA A FLEXÃO DE UMA RESINA DE IMPRESSÃO 3D PARA PROVISÓRIOS: ESTUDO PRELIMINAR IN VITRO"** no **XXV Encontro de Pós-Graduação**, da 9ª Semana Integrada de Inovação, Ensino, Pesquisa e Extensão, realizado na UFPel, no período de 20 a 24 de novembro de 2023. O referido trabalho possui o(s) seguinte(s) autor(es): **BBROD, Marcelo Pereira; SILVA, Paula Fernandes; RAMOS, Tatiana da Silva; DA ROSA, Wellington Luiz de Oliveira; BOSCATO, Noéli**, sob orientação do(a) Prof.(a) **Noéli Boscato**.

Pelotas, 30 de novembro de 2023.