UNIVERSIDADE DE BRASÍLIA
Faculdade de Ciências de Saúde
Departamento de Odontologia

Trabalho de Conclusão de Curso

Comparação das propriedades mecânicas de resinas de impressão para placas oclusais utilizando diferentes tipos de impressoras 3D

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Trabalho de Conclusão de Curso apresentado ao Departamento de Odontologia da Faculdade de Ciências da Saúde da Universidade de Brasília, como requisito parcial para a conclusão do curso de Graduação em Odontologia.

Orientador: Prof.° Dr. Rodrigo Antonio de Medeiros

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Dedico esse trabalho a Deus e a minha família, que sempre estiveram presentes em todos os momentos da minha formação.

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RESUMO

"Quando nos encontramos com um desejo que nada no mundo parece satisfazer,
a explicação mais provável é que fomos feitos para outro mundo"

C.S. Lewis

RESUMO

Objetivo. O objetivo desse estudo é avaliar as propriedades mecânicas de materiais de impressão 3D para confecção de placas oclusais, utilizando diferentes impressoras 3D e diferentes alturas de camada de impressão. **Métodos**. Noventa amostras retangulares, com dimensões de 64.3x10.3x3.3 mm, foram impressas e divididas em 9 grupos (G1 a G9) de acordo com o modelo da impressora 3D utilizada na sua fabricação (AnyCubic Mono X, Elegoo Mars 2 ou FlashForge Hunter) e a altura da camada de impressão (20, 50, ou 100 µm). As amostras foram então submetidas aos testes de microdureza superficial, resistência flexural e modulo de elasticidade. Os dados foram tabelados e analisados por testes Two-way ANOVA e Teste de Tukey, com o valor considerado estatisticamente significativo foi de 5%. **Resultados**. Os resultados apresentaram diferenças estatisticamente relevante, especialmente as amostras confeccionadas pela impressora AnyCubic Mono X, apresentando propriedades mecânicas mais consistentes do que as outras duas impressoras. **Conclusão**. Sistemas de impressão diferentes e diferentes alturas de camada podem interferir com as propriedades mecânicas de materiais de impressão 3D, influenciando assim na sua tomada de decisão clínica.

Palavras-chave: CAD-CAM; Bruxismo; Testes Mecânicos

ABSTRACT

Purpose. This study aimed to evaluate the mechanical properties of 3D-printed materials for occlusal splints using different 3D printers and printing layer thicknesses. **Methods.** Ninety rectangular samples, with dimensions of 64.3x10.3x3.3 mm, were manufactured and divided into nine groups according to the 3D printer model they were printed on (AnyCubic Mono X, Elegoo Mars 2, or FlashForge Hunter) and the layer thickness (20, 50, or 100 μm). The samples were subjected to superficial microhardness, flexural resistance, and elasticity modulus tests. The results were analyzed using two-way analysis of variance (ANOVA) and Tukey's statistical tests, with a significance level of 5%. **Results.** The results revealed statistically relevant differences, especially for the samples prepared using the AnyCubic Mono X 3D printer with a layer thickness of 20 μm, showing mechanical properties more consistent than those associated with the other two printers. **Conclusions.** Different printing systems and printing layer thicknesses can interfere with the mechanical properties of 3D-printed materials, thereby influencing clinical decisions.

Keywords: CAD-CAM; Bruxism; temporomandibular disorders; Mechanical Tests

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FOLHA DE TÍTULO

Comparison of mechanical properties of 3D printer resins for occlusal splints using different models of 3D printers

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INTRODUÇÃO

Disfunção Temporomandibular (DTM) é o nome dado para descrever problemas funcionais relativos às articulações temporomandibulares (ATMs), e estruturas correlacionadas, como músculos da mastigação[1,2]. Entre os diversos fatores etiológicos para a DTM estão: fatores ambientais, biológicos, psicológicos, biomecânicos e neuromusculares, que podem agir individualmente ou em conjunto para o desenvolvimento da DTM[1,3]. Os sintomas mais prevalentes em pacientes diagnosticados com DTM incluem, mas não estão limitados à: dores na mandíbula, dor articular, dor de dente (sem origem dentária), dor de ouvido, dor de cabeça e limitação funcional mandibular[4,5].

Os fatores analisados a fim de estudar a etiologia da DTM, segundo o modelo biopsicossocial, são fatores biológicos (predisposição genética ou bioquímica), fatores psicológicos (ansiedade, estresse, depressão, entre outros), e fatores sociais (cultura, comportamento familiar, condição socioeconômica, entre outros)[3]. Outro fator que pode contribuir para o desenvolvimento da DTM é o bruxismo[6]. O bruxismo é a atividade parafuncional dos músculos da mastigação regulados pelo sistema nervoso central[7], podendo ocorrer durante o sono ou durante a vigília, onde o contato dentário repetitivo ou sustentado é associado ou não com contração estática ou dinâmica da mandíbula[8].

Um dos métodos de tratamento dos sintomas da DTM e dos efeitos negativos do bruxismo é o uso de placas oclusais, sendo essa a abordagem mais comum para o bruxismo do sono[9]. A confecção ainda amplamente utilizada dessas placas é com o uso de resinas acrílicas com base em PMMA (polimetilmetacrilato). Nos últimos anos, surgiram novos métodos para a produção de placas oclusais, como a tecnologia de CAD/CAM, que consiste no projeto e fabricação com o auxílio de computadores e a materialização deste projeto pelo uso de materiais de manufatura de adição em impressora 3D[10] ou por fresagem de "blocos" ou "placas" de PMMA, com o uso de fresadoras odontológicas. Estudos recentes demonstram que esses métodos de fabricação mais novos são eficientes para produção de placas oclusais, devido aos materiais modernos e seus métodos de confecção[11].

A fabricação de placas oclusais por meio da manufatura aditiva, ou impressão 3D, é de grande interesse para a odontologia clínica, pela velocidade de sua fabricação, e por remover a necessidade do laboratório entre sessões clínicas. Com o surgimento de diferentes tecnologias de impressão 3D que utilizam técnicas de impressão e alturas de camada diversas, é pertinente a pesquisa quanto a diferenciação na viabilidade do uso dessas impressoras na prática odontológica e o impacto desses diferentes sistemas na qualidade do produto final.

Diversos trabalhos já demonstram que, quanto a fidelidade das peças e a acurácia das dimensões, os diferentes tipos de impressoras analisadas apresentam resultados semelhantes[12, 13]. Porém, existe uma escassez de trabalhos que comparem as propriedades mecânicas entre esses diferentes tipos de impressoras. Desta forma, o presente estudo busca avaliar as características de resistência dessas peças, não visando a recomendação de um método de impressão específico.

Os metódos de impressão selecionados para esse estudo foram: DLP (Digital Light Processing) que consiste em imagem emitida por um projetor de alta definição que é refletido por um espelho, e impressoras MSLA (Liquid Crystal Mask Technology) que faz uso de uma sequência de LEDs que emitem luz sobre uma tela LCD.

O objetivo do trabalho foi comparar as propriedades mecânicas do mesmo material para impressão de placas oclusais, utilizando impressoras 3D e com diferentes alturas das camadas de impressão. A hipótese do estudo é que diferentes impressoras e diferentes alturas de camada podem influenciar as propriedades mecânicas da resina utilizada para confecção de placas oclusais.

MATERIAIS E MÉTODOS

2.1 Confecção das amostras

As amostras, com dimensões de 64,3x10,3x3,3mm, foram confeccionadas pelas impressoras 3D FlashForge Hunter (DLP), AnyCubic Mono X (MSLA monocromática 4k) e Elegoo Mars2 (MSLA monocromática 2K).

A confecção das amostras foi feita com resina de impressão 3D (Resina Smart Print Bio Bite Splint, MakerTech Labs) para todas as impressoras, utilizando as configurações quanto ao tempo de polimerização encontrados por meio de teste de calibragem para impressão 3d, sendo o teste um retângulo de 15x20mm, impresso repetidamente com pequenas variações nos parâmetros de impressor, até que não houvesse divergência no tamanho definido no software e o encontrado nas peças. A tabela 1 apresenta os parâmetros obtidos. Para o processo de pós-cura da resina, todas as peças foram submetidas a lavagem com álcool isopropílico 100% no equipamento Wash and Cure (Hong Kong Anycubic Technology Co.) por 5 minutos e 30 segundos, e curadas em máquina de emissão UV (405nm) por 5 minutos.

A impressora Hunter apresenta uma configuração adicional comparada com as outras impressoras, sendo essa a Intensidade Luminosa. Esse parâmetro foi definido como 40%, de acordo com as recomendações do fabricante da resina.

Os grupos do estudo foram divididos de acordo com a impressora utilizada e altura de camada de impressão, sendo eles:

- Grupo 1 (G1) – impressora Mono X – altura de camada de 20µm (n=10);
- Grupo 2 (G2) - impressora Mono X – altura de camada de 50µm (n=10);
- Grupo 3 (G3) - impressora Mono X – altura de camada de 100µm (n=10);
- Grupo 4 (G4) - impressora Mars 2 – altura de camada de 20µm (n=10);
- Grupo 5 (G5) - impressora Mars 2 – altura de camada de 50µm (n=10);
- Grupo 6 (G6) - impressora Mars 2 – altura de camada de 100µm (n=10);
- Grupo 7 (G7) - impressora Hunter – altura de camada de 20µm (n=10);
- Grupo 8 (G8) - impressora Hunter – altura de camada de 50µm (n=10);
- Grupo 9 (G9) - impressora Hunter – altura de camada de 100µm (n=10);

As amostras foram então submetidas ao acabamento e polimento padronizados com discos de lixa de granulação #200, #600, e #1000 (Carbarnet; Buehler) e de granulação #800 e #1200 (microcut; Buehler) da mais granulosa para a menos granulosa, acoplados em máquina de polimento automático (AutoMet 250; Buehler) sob irrigação constante de água em 300rpm durante 30 segundos em cada face. Após, foi feita finalização com solução policristalina diamantada (MetaDi Supreme; Buehler) em todas as faces.

2.2 Teste de microdureza superficial Knoop

Os valores de microdureza Knoop foram determinados utilizando um aparelho microdurômetro (HMV-2T; Shimadzu Corp., Kyoto, Japão) com 25 gramas de carga por 10 segundos. Para cada amostra, três mensurações foram feitas.

2.3 Resistência flexural e módulo de elasticidade

No ensaio de resistência flexural por três pontos e módulo de elasticidade, cada amostra foi submetida ao ensaio de flexão na máquina de ensaio universal EMIC modelo DL 3000 (EMIC – Equipamentos e Sistemas de Ensaio Ltda., São José dos Pinhais, PR), com uma velocidade constante de 5mm/min, até ocorrer sua fratura.

2.4 Análise estatística

Two-way ANOVA foi realizado para verificar a diferença estatística entre os grupos para os testes de microdureza superficial, resistência flexural e módulo de elasticidade. Teste de Tukey foi utilizado para comparar os grupos com diferença estatística. Todas as análises estatísticas foram realizadas utilizando o software estatístico (SPSS Statistics 17.0; SPSS Inc., Chicago, Illinois). O valor de p menor que 0,05 foi considerado estatisticamente significante.

RESULTADOS

Os resultados do teste two-way ANOVA estão apresentados nas tabelas 2 (microdureza superficial), tabela 3 (resistência flexural) e tabela 4 (módulo de elasticidade).

Para o teste de microdureza superficial, após realização do teste de Tukey (tabela 5), notamos que não houve diferença estatística entre as impressoras para a altura de 20µm. Para a altura de 50µm, a impressora Mono X apresentou valores maiores, e para a altura de 100µm, a impressora Hunter apresentou valores menores. Quando comparamos as alturas de impressão para a mesma impressora, notamos que para a impressora Hunter, a altura de 100µm apresentou menores valores, e, para as impressoras Mars 2 e Mono X não houve diferença entre as alturas de impressão.

Para o teste de resistência flexural, após a realização do teste de Tukey (tabela 5), notamos que não houve diferença estatística entre as impressoras para a altura de 20µm. Para a altura de 50µm e 100µm a impressora Mono X apresentou maiores valores. Quando comparamos as alturas de impressão para a mesma impressora, notamos que para as impressoras Hunter e Mars 2 a camada de 20µm apresentou maiores valores. Para a impressora Mono X, não houve diferença estatística entre as alturas de camada.

Para o teste de módulo de elasticidade, após a realização do teste de Tukey (tabela 5), notamos que houve diferença estatística entre as impressoras para a altura de 20µm, sendo que a Mars 2 apresentou maiores valores. Para a altura de 50µm a impressora Mono X apresentou menores valores e, para a altura de 100µm a impressora Hunter apresentou menores valores. Quando comparamos as alturas de impressão para a mesma impressora, notamos que para a impressora Hunter, a altura de 50µm apresentou maiores valores. Para a impressora Mars 2 e Mono X, não houve diferença estatística entre as alturas de camada.

DISCUSSÃO

A hipótese do estudo foi aceita, visto que houve diferença estatística entre as impressoras utilizadas, e entre as alturas de camadas de impressão.

Quanto ao tipo de resina, existe uma baixa produção para resinas específicas para DLP ou SLA, já que o comprimento de onda para polimerização de ambas é o mesmo.

Dessa forma, a maioria das empresas opta por nomear suas resinas para impressão como universais. São necessário mais estudos para definir se a utilização de resinas vendidas como específicas para um modelo de impressão apresentam resultados superiores.

Em relação às alturas de camadas, os resultados mostraram que, de uma maneira geral, as propriedades mecânicas foram melhores em 20µm. Isso se justifica por camadas menores receberem mais energia proporcionalmente e acabarem tendo uma maior conversão de monômeros para polímeros[12]. O único teste que as os valores se mantiveram com o aumento da altura de camada foi microdureza superficial, exceto para a Hunter em 100µm. A microdureza parece estar mais associada ao material utilizado[9] e ao tratamento dado a superfície após sua cura, como acabamento e polimento[16]. A Hunter pode ter apresentado desempenho inferior em 100 µm pois forneceu menos energia, como será aprofundado adiante, e a máquina utilizada para aferir a microdureza penetrou até as porções menos polimerizadas da camada, diminuindo seu valor estatístico.

Um fato a ser atentado quanto ao resultado desse estudo é que a impressora Hunter apresentou perda nas qualidades mecânicas de forma generalizada quando as impressões eram feitas com a altura de camada de 100µm. Esse fato possivelmente está vinculado a quantidade energética entregue pela impressora. Como a Intensidade Luminosa, como recomendado pelo fabricante da resina, foi definida para 40%, é possível que pela altura da camada ser maior, a resina mais afastada da fonte de luz, durante a fotopolimerização, não tenha obtido o mesmo grau de conversão dos monômeros que suas camadas mais próximas da fonte de luz, diminuindo suas propriedades mecânicas[16]. Possivelmente, se um novo teste fosse feito utilizando uma Intensidade Luminosa maior para a Hunter, as impressões em 100µm estariam mais próximas do resultado encontrado para as outras impressoras. São necessários novos estudos, para que essa hipótese seja testada.

O mesmo fato supracitado, quanto a dificuldade de polimerização de camadas maiores e a interferência da potência da fonte de luz, pode explicar por que a impressora Mono X foi a única das analisadas que conseguiu manter um padrão de qualidade entre suas diversas camadas. Por ser a impressora com a fonte de luz mais potente, a saber, uma sequência de LED polimerizadores com potência nominal maior, (levando em consideração que a impressora Hunter possui fonte de luz similar, mas suas peças foram produzidas utilizando 40% de sua intensidade luminosa máxima), ela conseguiu obter uma polimerização mais regular em suas camadas nas diversas alturas. A maior taxa de conversão dos monômeros possivelmente influenciou positivamente nos resultados dessa impressora quando diferentes alturas de camadas foram utilizadas[9].

Vale salientar que diferentes resinas de impressão 3D possivelmente apresentarão resultados diferentes. A resina escolhida (Resina Smart Print Bio Bite Splint, MakerTech Labs) é recomendada pela fabricante para impressão de placas oclusais, mas a utilização de resinas que inicialmente têm outras indicações pode levar a resultados variados, como resinas para impressão de provisórios ou para restaurações definitivas[17].

Considerando os resultados obtidos pelo presente estudo, pacientes com bruxismo severo apresentam indicação para o uso de placas oclusais impressas com a altura de camada de 20-µm, em impressoras 3D com a fonte de luz mais potente, como a Mono X. Se a placa oclusal for indicada para paciente com DTM ou para proteção das coroas em pacientes sem o diagnóstico de DTM, podemos indicar o uso de placas oclusais impressas em 20-µm ou 50-µm, selecionando impressoras com fontes de luz potentes. Testes clínicos randomizados são necessários para confirmar esses achados.

As limitações do estudo estão contidas, mas não limitadas à: Utilização de apenas uma marca de resina, podendo resultados estatisticamente relevantes estarem sendo camuflados pelos problemas e vantagens inerentes da resina escolhida. Além disso, não foram realizados testes como grau de conversão, análise por microscopia eletrônica e estabilidade de cor.

Assim, se faz necessário o aprofundamento da pesquisa na área abordada pelo estudo, a fim de que uma base de dados maior possa ser criada e os resultados do presente trabalho possam ser confirmados ou refutados.

Implicações Clínicas

Além do avanço da pesquisa, as implicações clínicas incluem: auxiliar na decisão do profissional em qual sistema de manufatura aditiva possui os melhores resultados para o seu consultório, entregando para o paciente o resultado mais favorável e para o dentista o melhor custo-benefício. O trabalho também auxilia na tomada de decisão quanto a viabilidade da utilização de impressoras 3D no ambiente clínico, além do ambiente laboratorial.

CONCLUSÃO

Assim, levando em conta as limitações e os resultados da pesquisa, podemos chegar as seguintes conclusões: as propriedades mecânicas das resinas indicadas para impressão 3D de placas oclusais são influenciadas pelo modelo da impressora utilizada e pela altura de camada utilizada. A impressora Mono X e a altura de camada de 20-µm apresentaram os resultados mais consistentes e mais resistentes respectivamente, entre os parâmetros e impressoras comparadas nesse estudo.

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CONFLITOS DE INTERESSE

Os autores declaram não ter conflitos de interesse em relação à produção desse estudo

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ANEXOS

Tabelas

Table 1: Exposure time for each layer by printer and by thickness.

	Mono X	Hunter	Mars 2
20 µm	22 s for the eight bottom layers (first printed) and 1.5 s for the other layers	15 s for the eight bottom layers (first printed) and 2.5 s for the other layers	20 s for the eight bottom layers (first printed) and 2 s for the other layers
50 µm	30 s for the eight bottom layers (first printed) and 2.5 s for other layers	20 s for the eight bottom layers (first printed) and 4 s for the other layers	30 s for the eight bottom layers (first printed) and 3 s for the other layers
100 µm	40 s for the eight bottom layers (first printed) and 5 s for the other layers	35 s for the eight bottom layers (first printed) and 4.5 s for the other layers	35 s for the eight bottom layers (first printed) and 5 s for the other layers

Table 2: Two-way ANOVA results for each 3D printer model and layer thickness on superficial Knoop microhardness

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	***P***
Corrected model	52.110	8	6.514	2.302	.028
Intercept	13930.312	1	13930.312	4922.706	.000
Printer	30.178	2	15.089	5.332	.007
Layer thickness	0.225	2	0.113	0.040	.961
Printer X Layer thickness	21.706	4	5.427	1.918	.115
Error	229.214	81	2.830		
Total	14211.636	90			
Corrected total	281.324	89			

Table 3: Two-way ANOVA results for each 3D printer model and layer thickness on flexural strength

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	***P***
Corrected model	30026.432	8	3753.304	18.661	.000
Intercept	497419.348	1	497419.348	2473.115	.000
Printer	14128.120	2	7064.060	35.122	.000
Layer thickness	12604.895	2	6302.447	31.335	.000
Printer X Layer thickness	3293.417	4	823.354	4.094	.005
Error	16291.589	81	201.131		
Total	543737.369	90			
Corrected total	46318.021	89			

Table 4: Two-way ANOVA results for each 3D printer model and layer thickness on elasticity modulus

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	***P***
Corrected model	1795603.5	8	224450.441	5.328	.000
Intercept	164364728	1	164364728	3901.427	.000
Printer	871502.804	2	435751.402	10.343	.000
Layer thickness	216379.425	2	108189.712	2.568	.083
Printer X Layer thickness	707721.296	4	176930.324	4.200	.004
Error	3412480.38	81	42129.387		
Total	169572812	90			
Corrected total	5208083.91	89			

Table 5: Tukey test for superficial Knoop microhardness, flexural strength, and elasticity modulus.

Tests	3D Printer models	Layer thickness		
		20µm	**50µm**	**100µm**
Knoop hardness (kgf/mm^2)	Hunter	12.61 (1.83) Aa	11.4 (2.04) Aa	10.97 (1.26) Ab
	Mars 2	12.14 (2.2) Aa	12.59 (1.5) Aa	13.08 (1.65) Ba
	Mono X	12.65 (1.74) Aa	13.44 (1.31) Ba	13.06 (1.3) Ba
Flexural strength (MPa)	Hunter	83.66 (22.62) Aa	68.77 (15.49) Ab	45.66 (15.63) Ac
	Mars 2	86.91 (18.74) Aa	59.49 (14.79) Ab	48.42 (4.80) Ab
	Mono X	95.63 (8.59) Aa	95.35 (5.93) Ba	85.16 (10.55) Ba
Flexural modulus (MPa)	Hunter	1378.12 (182.10) Aa	1481.03 (175.11) Aa	1128.04 (286.87) Ab
	Mars 2	1581.96 (239.36) Ba	1465.01 (177.37) Aab	1397.58 (247.16) Bb
	Mono X	1211.24 (204.98) Aa	1198.45 (170) Ba	1321.11 (109.43) Ba

mean followed by the same upper-case letter on column and mean followed by the same lower-case letter on the same line do not differ to the 5% significance level (p<0.05) for the tukey test.

NORMAS DA REVISTA

JOURNAL OF PROSTHODONTICS
Implant, Esthetic, and Reconstructive Dentistry
AMERICAN COLLEGE OF PROSTHODONTISTS

JOURNAL OF PROSTHODONTICS

Instructions for Authors

(Revised January 2023)

SCOPE

The *Journal of Prosthodontics* promotes the advanced study, science, and practice of prosthodontics, implant, esthetic, and reconstructive dentistry. It is the official journal of the American College of Prosthodontists, the association that represents the dental specialty of prosthodontics. The *Journal of Prosthodontics* serves both researchers and practicing clinicians by providing a forum for the presentation and discussion of evidence-based prosthodontic research, treatment concepts, techniques, and procedures. The objective of the *Journal of Prosthodontics* is to facilitate the effective worldwide transmission of new and innovative prosthodontic-related research and knowledge. The journal publishes original scientific articles presenting information that is new and relevant to prosthodontics. Additionally, it publishes reports of innovative techniques and clinical treatments, systematic reviews of topics of interest to the field of prosthodontics, reviews of new instrumentation and products, new uses for existing material, digital technology advances related to prosthodontics, instructive clinical reports, editorials, and announcements of importance to the prosthodontic community.

MANAGING EDITOR

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ARTICLE TYPES ACCEPTED

Article type	Description	Abstract type	References	Figures and Tables (total combined)	Total Word pages*
Original Articles					
Research	Original research, in vivo or in vitro	**Structured**: Purpose, Materials and Methods, Results, Conclusions	No limit	8	10
Clinical report	Report of the presentation, treatment, and follow-up of an individual patient	Non-structured	30	10	10
Technique article	Describes a solution to a particular technical problem in clinical dentistry, in a numbered, step- by-step format	Non-structured	20	10	10
Other types					
Reviews	Systematic reviews preferred, contact the editor prior to submitting a non-systematic review	**Structured**: Purpose, Methods, Results, Conclusions	No limit	7	No limit

Letter to the Editor**	Report original data, discuss published articles, or present hypotheses	None required	15	2	4

*Text only (page count does not include title, references, tables, or figures)

**Letter to Editor policy:

While we will read and respond to all letters, we will only publish a select few. We are most likely to publish letters that deal with a controversial topic, advocate for the field of prosthodontics, or that take issue with research published in the *Journal of Prosthodontics*. While a letter may be critical, in order to be considered for publication, it must not be insulting. Criticism should be constructive, and arguments made should be appropriately referenced to previously published work.

Upon approval for publication, we will publish the letter in the next available print issue of the *Journal of Prosthodontics*. When written in response to an article published in the *Journal*, we will also give the author of the original article the opportunity to respond. If they choose to do so, we will attempt to publish the letter and response in the same issue.

MANUSCRIPT PREPARATION

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Element	**Description**
Font	12-point, Times New Roman or 10-point Arial
Line spacing	Double-spaced throughout
Margins	One inch (2.5 cm)
Page size	Letter (8 ½ x 11) inches
Page numbers	Yes; start with the title page as page 1, place on lower right-hand corner
Line numbers	Do not use

Required layout	**Title page**: separate file with complete list of authors, affiliations, and conflict of interest **Main Text file (Research & Reviews)**: Abstract & Keywords, Introduction, Materials & Methods, Results, Discussion, Conclusions, Acknowledgements (*optional*, *must be blinded for review*), References **Main Text file (Clinical Reports/Technique articles)**: Abstract, & Keywords, Introduction, Clinical Report (or Technique), Discussion, Conclusion/Summary, Acknowledgements (*optional*, *must be blinded for review*), References **Tables** can be placed at the end of the main text file or uploaded in a separate text file. Each table must be numbered and include a title/brief description. **Figures and Figure Legends** can be placed at the end of the main text file or uploaded
	as individual figure files. Captions/legends must be visible. **Multipart figures** must be submitted as one file with parts a, b, c, etc labeled. Use lowercase letters to delineate and cite figures. In text, and in figures use Fig 1a **Supplementary Material** (for online publication only) should be uploaded as a separate file(s).
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Figures	preferred: .tiff, .eps, .pdf
Videos	.mp4, .mov

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1) Full title of manuscript (sentence case).
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4) Authors' institutional affiliations including city and state (US authors) or city and country (non-US authors)
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6) If the work has previously been presented, the name, place, and date of meeting(s)
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Abstract page

An abstract is required for all manuscripts, with the exception of letters to the editor, and must precede the body of the manuscript. Abbreviations and references should not appear in the abstract. Research manuscripts must conform to the structured abstract format (see above).

Clinical reports and Technique manuscripts do not need a structured abstract. Following the abstract and on the same page, there should be several words not appearing in the title of the manuscript to be titled: KEYWORDS.

Text

Research manuscripts should include the following sections: Introduction (no header), Materials and Methods, Results, Discussion, Conclusion, Acknowledgements (optional), and References. Other manuscripts should begin with two to five introductory paragraphs. The remainder of the manuscript should be divided into sections preceded by appropriate headings (i.e., "Clinical report," "Technique," etc.).

The ***Introduction*** will include the following: a description of the problem that inspired the study and what distinguishes it from previous research that investigated the same problem; a brief discussion of relevant published material that addressed the same problem or that documents methodology used in the study; and the goal of the study, the purpose statement and null hypothesis.

The ***Materials and Methods*** section describes materials or subjects used and the methods selected to evaluate them, including information about the overall design, the nature of the sample studied, sample size, the type of interventions (or treatments) applied to the individual elements in the sample, and the principal outcome measure. All human subject research (including surveys) must include a statement of ethical or institutional review board approval in this section.

Statistical methodology and rationale for sample size determination must be included in this section.

Example: A power analysis was conducted to determine the sample size. The World Health Organization formula was used with 80% power and 0.05 level of significance, and it revealed that 10 specimens per group would be needed to detect the postulated effect size. A total of 120 specimens (40/flexural strength test, 40/impact strength test, and 40/surface roughness and hardness tests) were distributed in two groups.

Gad MM, Fouda SM, Abualsaud R, Aet al. Strength and surface properties of a 3d-printed denture base polymer. J Prosthodont 2021; https://doi.org/10.1111/jopr.13413

Example: The sample size was established using the effect size = 0.25 (medium) or 0.5 (large), a = 0.05, power = 0.8, and number of groups = 3. The results indicated that a total of 159 specimens (medium effect size) or 42 (large effect size) were needed for the fracture loading tests. The analysis showed that 14-53 specimens were needed for each group for the test, and therefore using 15 specimens/group, which is covered by the results of the G-power calculation, was considered appropriate.

Alberto Jurado C, Kaleinikova Z, Tsujimoto A, et al. Comparison of fracture resistance for chairside cad/cam lithium disilicate crowns and overlays with different designs. J Prosthodont 2021; https://doi.org/10.1111/jopr.13411

The *Journal of Prosthodontics* encourages authors to register clinical trials prior to submission at one of the registration sites listed below. The registration number and date of registration should be included in the Materials and Methods section. See “Reporting guidelines” on page 17 below for further details.

The ***Results*** section will be a clear statement of the findings and an evaluation of their validity based on the outcome of statistical tests. When reporting results of statistical tests, actual p values must be reported.

The ***Discussion*** section presents the research in its broader context, describes its clinical implications, identifies limitations or problems that emerged during the course of the study, characterizes the larger significance of the findings, and articulates any further questions remaining to be answered on the subject.

The ***Conclusion*** section includes only a brief and succinct summary of the findings. **Conclusions should be written in paragraph form, not as a numbered list.**

An ***Acknowledgment (optional)*** section to thank anyone who contributed to the manuscript, but is not a listed author (i.e., statistician, copyeditor, dental technician, photographer, artist). This text should be blinded for review, and can be added after acceptance.

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Authors are to use current prosthodontic nomenclature and are referred to the *Glossary of Prosthodontic Terms* (9th Edition) and the *Glossary of Digital Dental Terms* (2nd Edition) for accepted terminology.

Please cite these references as:

Glossary of Digital Dental Terms, 2nd Edition. J Prosthodont 2021; 30: 172-181.

https://doi.org/10.1111/jopr.13439

Glossary of Prosthodontic Terms (9th Edition). J Prosthet Dent 2017;117:E1-E105.
https://doi.org/10.1016/j.prosdent.2016.12.001

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Use the symbol × rather than the letter x as a multiplication sign.

Report the actual P values to 3 decimal places. For P values below 0.001 write P<0.001. Report results to 2 decimal places.

When reporting data with the ± sign, please use the spacing 123.45 ±6.78 µm.

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Use digits for most numbers appearing within the text, except at the start of a sentence, and when the use of the digit places unnecessary emphasis on the number; or when "one" is used as a pronoun.

Minimize the use of subheadings in the text.

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If English is not your native language, we suggest you have a native English speaker read and review the manuscript prior to submission. An English-speaking colleague can be an excellent resource. If you do not know someone who can help you, we recommend that you have your paper professionally edited for English language by a service such as Wiley Publishing's at http://wileyeditingservices.com.

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Number references consecutively in the order in which they are first mentioned in the text. Identify references in text, tables, and legends by superscript Arabic numerals.[1] Use the Vancouver reference style format. The titles of journals must be abbreviated according to the style used in the National Library of Medicine's - NLM Catalog: Journals referenced in the NCBI databases.

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Reference numbers should appear after punctuation marks, not before. Example: To date, zirconia dental ceramics have had an excellent clinical performance with a cumulative 5-year survival rate of 92.1% for zirconia-based all-ceramic single crowns,[1] and 90.4% for tooth-supported fixed dental prostheses.[2]

Where appropriate, please cite primary literature. Please also consult and cite as needed the **Glossary of Digital Dental Terms (2nd Edition)** and **Glossary of Prosthodontic Terms (9th Edition).**

Glossary of Digital Dental Terms, 2nd Edition. J Prosthodont 2021; 30: 172-181.

https://doi.org/10.1111/jopr.13439

Glossary of Prosthodontic Terms (9th Edition). J Prosthet Dent 2017;117:E1-E105. https://doi.org/10.1016/j.prosdent.2016.12.001

Article type	**Example**
Journal article, authors ≤ 6	Authors separated by commas – Family name and initials. Title of article. Abbreviated journal title. Publication year, month, day (month & day only if available);volume (issue):pages. [include DOI if no vol/iss avail) ***Example*** Choi S, Kim S, Chang, J-S. The neutral zone approach with CAD-CAM record bases. J Prosthodont. 2022;31(6):459-463
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Book	Masri R, Driscoll CF. Clinical Applications of Digital Dental Technology. John Wiley & Sons; 2015
Chapter in a book	Author(s) of chapter - Family name and initials. Title of chapter. In: Editor(s) of book - Family name and initials, editors. Title of book. edition (if not first). Place of publication: Publisher name; Year of publication. p. [page numbers of chapter]. ***Example***: Phoenix RD. Denture base resins: Technical considerations and processing techniques. In: Anusavice KJ, editor. Phillips' Science of Dental Materials, vol 1. 10th ed. Philadelphia, Saunders; 1996. P. 237-271.

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Website/Webpage [author/ organization responsible for the site, page title, URL, access date]	Author/organization's name. Title of the page [Internet]. Place of publication: Publisher's name; Publication date or year [updated date - year month day; cited date - year month day]. Available from: URL ***Example*** American College of Prosthodontics. PR tips: seven ways to promote your practice [Internet]. Available from: https://www.prosthodontics.org/practice-resources/practicemanagement/ Accessed 2/12/19

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Tables should be positioned following the references, not in the body of the manuscript. The tables should be numbered consecutively with Arabic numerals. Each table should be typed on a separate page with a brief, descriptive title. Include any necessary legends on the same page with the associated table. Do not submit tables as image files. Tables should be provided in a simple form, without style formatting and without use of color.

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The table below details typical images accepted by the *Journal of Prosthodontics*. Figures should be submitted after the tables (if included) or after the reference list (if tables not included), not in the body of the text. A descriptive figure caption should be included below each figure.

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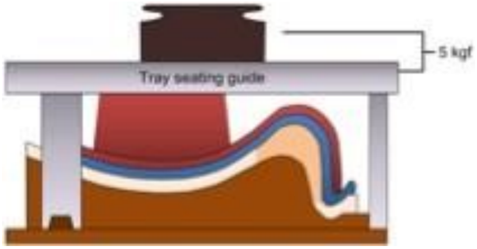
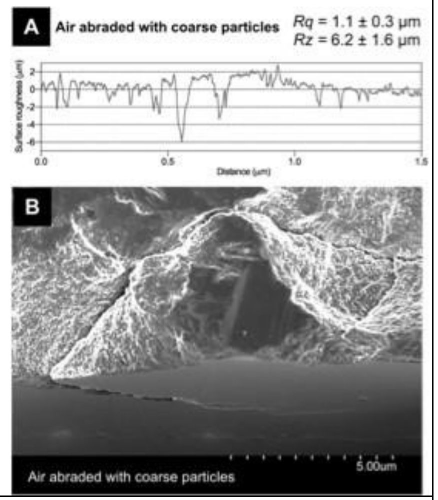
<tr><td>Example</td><td></td><td></td><td></td></tr>
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<tr><td>Notes</td><td>Guidelines apply to SEM images as well</td><td>For bar graphs, black and white images preferred</td><td>Include paneled images in one image file (i.e., do not submit Fig 1a and Fig 1b as separate files); label parts with lowercase letters.</td></tr>
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ETHICAL POLICIES Data sharing and bioethics

Human and other animal experiments

For original research manuscripts reporting experiments on animals, the corresponding author must confirm that all experiments were performed in accordance with relevant guidelines and regulations. The manuscript must include a statement identifying the institutional and/or licensing committee approving the experiments, including any relevant details regarding animal welfare, patient anonymity, drug side effects, and informed consent.

For experiments involving human subjects, authors must identify the committee (e.g., Institutional Review Board [IRB]) approving the experiments and include with their submission a statement confirming that informed consent was obtained from all subjects. All human studies must adhere to the principles set out in the Declaration of Helsinki (World Medical Association Declaration of Helsinki, published online October 19, 2013. doi:10.1001/jama.2013.281053).

It is the author's responsibility to ensure that a patient's anonymity be carefully protected and to verify that any experimental investigation with human subjects reported in the manuscript was performed with informed consent and following all the guidelines for experimental investigation with human subjects required by the institution(s) with which all the authors are affiliated. All identifying details (patient names and/or initials and name of specific hospital unit) should be removed from the text, tables, and/or radiographs or other figures. Patients should be assigned numbers instead. Identifying data should be removed from a manuscript unless important clinically or epidemiologically. Clinically and epidemiologically significant details include: race, sex, age, occupation, country or region of origin, and/or sexual orientation. Note that the same information must be given for each patient or group.

If any individual data is included, written consent for participation/publication must be given for each patient or group.

If any individual data is included (i.e., an identifiable full-face picture in a clinical report), written consent for participation/publication must be obtained from every individual whose data is included. A written statement attesting that the author has received and archived such written patient consent must accompany the manuscript. For research articles, if authors cannot obtain consent to publish individual data they may only provide summary results. Exclusions to this include:

- The patients are de-identified
- The patients are dead
- There has been a waiver granted by the Institutional Review Board (IRB).

Permissions Form: If identifying details must be retained, the author must attest they have informed consent from the patients (a signed permissions form), see Appendix A below.

Permissions must appear in English. In the case of a non-English speaking patient/author the permission should appear first in the native language with the translation to English below and the signature following both. If the patient cannot be located or refuses to consent to publication, the manuscript will NOT be published. In the event that the patient cannot provide consent due to death or legal incompetency (this includes photos of corpses) permission from the power of attorney is needed as well as proof of power of attorney. If the patient is a minor, a legal guardian must provide permission. Previous publication of news coverage does NOT eliminate a patient's right to privacy and does NOT negate the need for patient permission. This informed consent should be indicated in the text of the article (in the Methods section, if appropriate) or in the

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- U.S. National Institutes of Health Clinical Trials Registry - http://www.clinicaltrials.gov
- EU Clinical Trials Register - https://www.clinicaltrialsregister.eu
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Authors are required to disclose any possible conflicts of interest. These include, for example, patent, ownership, employment, stock ownership, consultancies, speaker's fee. Author's conflict of interest (or information specifying the absence of conflicts of interest) will be included on the title page of published articles.

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1. Substantial contributions to the conception or design or the work; or the acquisition, analysis, or interpretation of data for the work; AND
2. Drafting the work or revising it critically for important intellectual content; AND
3. Final approval of the version to be published; AND
4. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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When a large multi-author group has conducted the work, the group ideally should decide who will be an author before the work is started and confirm who is an author before submitting the manuscript for publication. All members of the group named as authors should meet all four criteria for authorship, including approval of the final manuscript, and they should be able to take public responsibility for the work and should have full confidence in the accuracy and integrity of the work of other group authors.

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- verbatim copying of >100 words of original material in the absence of any citation to the source material, or
- unattributed use of original, published, academic work, such as the structure, argument or hypothesis/idea of another person or group where this is a major part of the new publication and there is evidence that it was not developed independently.

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APPENDIX B: MANUSCRIPT SUBMISSION CHECKLIST

This submission checklist is provided to help authors in the final stage of submission. Following this checklist should ensure the editorial office does not return your manuscript to you prior to evaluation. A more complete description of each item is provided under the appropriate heading in the Information for Authors document.

Separate documents are submitted in the following order:

(1) title page, include any previous presentation and explanation of any conflicts of interest; (2) main text file (manuscript without author identifiers and without tracked changes) including a structured or standard abstract, keywords, body of the text, tables, figure legends;
(3) figures;
(4) supplementary files (if necessary)

Title Page

- ☐ Title
- ☐ Running head (abbreviated title) of no more than 60 character spaces
- ☐ Author(s) full name(s) written as First Name then Last Name, and academic degree(s), and the institutional affiliation(s) of the author(s) at the time of the study. An asterisk after an author's name and a footnote may indicate a change in affiliation. Department, Institution, Locations. (Example: Department of Prosthodontics, University of North Carolina School of Dentistry, Chapel Hill, NC)
- ☐ Disclosure of any presentation of this material, to whom, when, and where.
- ☐ Disclosure of financial support, including grant numbers
- ☐ Explanation of any conflicts of interest
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Manuscript Body

- ☐ No line numbers
- ☐ Statement is included in the Materials and Methods section that human experimentation has been approved by the local institutional review board or conforms to Helsinki Declaration
- ☐ Guidelines for the care/use of animals, approved by the institution, have been followed as indicated in the Methods
- ☐ Manuscript has been checked by a professional editor or a colleague fluent in English
- ☐ The body of **research manuscripts** includes the Introduction (no heading), Materials and Methods, Results, Discussion, and Conclusions headings

☐ The body of **clinical reports and technique manuscripts** includes the Introduction (no heading), Clinical Report/Technique, Discussion, and Summary headings

Abstract

☐ For Original Research Articles, and Review Articles, a structured abstract is included before the body of the manuscript followed by keywords

☐ For other manuscripts (e.g., Clinical Reports/Technique articles), include a conventional, unstructured abstract followed by keywords

Style guide

☐ Abbreviations: spell out the first time used. Example: Fixed partial dentures (FPDs); can be called "FPD" when used again; avoid abbreviations in the abstract

☐ Equipment and/or materials are identified in text by the manufacturer and city and state (US manufacturer) or city and country (non-US manufacturer). Example: (Whip Mix, Louisville, KY); (3Shape, Copenhagen, Denmark)

☐ Formatting of reported values, statistical tests conform to *Journal of Prosthodontics* author guidelines

References

☐ All references are numbered consecutively in the order they are cited in the text

☐ References are Arabic numerals (i.e., 1, 2, 3, etc) in superscript[1]

☐ References appear after punctuation marks.[1]

☐ All listed references have been cited in the text

Tables

☐ Tables are cited in numeric sequence in the text

☐ Tables should be submitted in Word

Figures

☐ Each figure is numbered with an Arabic numeral and cited in numeric sequence in the text (Fig 1).

☐ Photographs of recognizable persons require a signed release from the patient or legal guardian authorizing publication

☐ Figures should be submitted in PDF, JPG, EPS, or TIFF format

☐ Figures with multiple panels (Fig 1a, 1b) should be submitted as a single file

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Revisions

In addition to the above:

☐ A highlighted copy should be submitted showing all of the changes made throughout the manuscript; do not use the Word "Track Changes" feature

☐ Provide a separate file as a response to the reviewers and editors detailing the changes made or the changes not made, and why the author chose not to make the changes.

APPENDIX C: RESPONSE TO REVIEWERS TEMPLATE

Use this format to respond to reviewers and editors (the remarks in this template are an example only).

Response to Reviewer 1:

1) *The main findings in this manuscript bear a close similarity to other previously published work and I feel that they add little to the conclusions of that manuscript.*

Response: We respect the comment of the reviewer and appreciate their insight. However, we feel that the previous paper being referred to does differ from our current submission and that the current manuscript adds new data that continues to build upon the programmatic theme of our laboratory. (Discussion of differences in the two works has been redacted to shorten this document) **Text Change:** We have expanded our discussion to reflect these differences, see page 4.

2) *BSPII and osteopontin are well known to be produced by osteoblast-like cells in culture.*

Response: This is true. However, the results have been noted in standard 2D cultures. Very few studies have analyzed the expression of these proteins in 3D cultures as we have submitted. We have previously reported differences in spatial and temporal expression of BSPII in a 3D mandibular bovine model (Bone 1999). However we did not want to assume that expression in those models would also translate to the aggregate model we describe here. **Text Change:** None.

3) *It is not surprising that aggregate Size Correlated to Starting Cell Number, but perhaps "correlated" is the wrong word as there was no rigorous statistical treatment.*

Response: We appreciate the comment and have modified the text accordingly to state the size was associated with cultured cell number.

Text Change: Abstract, Results headings page 7 and 8.

Response to Reviewer 2:

1) *Typographic errors warrant author's attention.*

Response: Thank you.

Text Change: Proofread and corrected.