EFFECT OF DIFFERENT VAT POLYMERIZATION TECHNIQUES ON PHYSICOMECHANICAL AND BIOLOGICAL PROPERTIES OF 3D-PRINTED DENTURE BASE

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AUTHOR DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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ABSTRAK

Penggunaan pencetakan tiga dimensi (3D) dalam pergigian untuk fabrikasi alas gigi tiruan sedang mendapat perhatian dalam beberapa tahun terkini. Sejauh ini, pelbagai teknologi dan bahan pencetakan 3D boleh digunakan untuk menghasilkan alas gigitiruan. Walaubagaimanapun, terdapat kekurangan pemahaman terhadap kesan kebolehcetakan, sifat-sifat mekanikal, fizikal, dan biologi alas gigitiruan 3D tercetak apabila dibuat dengan teknik polimerisasi vat yang berbeza. Kajian ini dijalankan untuk menjelaskan kesan teknik polimerisasi vat yang berbeza dalam pembuatan alas gigi tiruan. Dalam kajian ini, resi alas gigitiruan NextDent dicetak dengan teknologi stereolithography (SLA), pemprosesan cahaya digital (DLP), dan paparan cahaya kristal (LCD) dan mengalami prosedur pemprosesan yang sama. ANOVA satu hala dan ujian post hoc Tukey digunakan untuk menganalisis data secara statistik. Keputusan menunjukkan kekuatan lentur tertinggi ditunjukkan oleh SLA ($\mathbf{150.8 \pm 7.93\ MPa}$), diikuti oleh DLP dan LCD. Trend ini konsisten dalam ketahanan rekahan dan mikrokeras, dengan SLA menunjukkan kekuatan yang lebih tinggi, diikuti oleh DLP dan LCD. Perlu diperhatikan, penyerapan air dan kelarutan DLP adalah lebih tinggi secara signifikan ($\boldsymbol{p < 0.05}$) daripada kumpulan lain masing-masing ($\mathbf{31.51 \pm 0.92 \frac{\mu g}{mm^3}}$) dan $\left(\mathbf{5.32 \pm 0.61 \frac{\mu g}{mm^3}}\right)$. SLA menunjukkan kekuatan mekanikal keseluruhan tertinggi di kalangan semua kumpulan yang diuji, walaupun pada kadar pencetakan yang lebih perlahan, kerana keupayaannya untuk mencapai tahap penukaran yang lebih tinggi. Analisis morfologi permukaan tidak memperlihatkan perbezaan yang ketara setelah menjalani penggilapan mekanikal menyeluruh, menunjukkan struktur berlapis hanya wujud di permukaan luar. Walau bagaimanapun, penempelan *Candida albicans* yang paling tinggi juga ditemui dalam SLA ($\mathbf{221.94 \pm 65.80\ CFU/ml}$) mungkin disebabkan oleh kekasaran permukaan yang lebih tinggi di sepanjang lapisan berikutnya. Walau bagaimanapun, semua alas gigitiruan yang diperbuat dengan teknik polimerisasi vat yang berbeza tidak menunjukkan sebarang kesan sitotoksik terhadap Fibroblas Gingiva Manusia. Kesimpulannya, kajian ini mengesahkan bahawa resi alas gigitiruan NextDent yang direka untuk DLP boleh dicetak dengan pelbagai teknik polimerisasi vat yang berbeza dan semua kumpulan yang diuji memenuhi keperluan ISO kecuali kelarutan dalam air. SLA menunjukkan kekuatan mekanikal terbesar sementara DLP menunjukkan penempelan mikrob terendah.

ABTRACT

The utilization of three-dimensional (3D) printing in dentistry for denture base fabrication is rapidly gaining traction in recent years. To date, a wide range of 3D printing technologies and materials can be utilized for the fabrication of denture bases. However, there is a lack of understanding of the effect of printability, mechanical, physical, and biological properties of the 3D-printed denture base upon fabricating with different vat polymerization techniques. This study was carried out to elucidate the effect of different vat polymerization techniques in fabricating denture bases. In this study, the NextDent denture base resin was printed with stereolithography (SLA), digital light processing (DLP), and light-crystal display (LCD) techniques and underwent the same post-processing procedure. One-way ANOVA and Tukey's post hoc were used to analyze the data statistically. The results showed that the greatest flexural strength was exhibited by the SLA $(150.8 \pm 7.93\ \text{MPa})$, followed by the DLP and LCD. This trend was consistent in fracture toughness and microhardness, with SLA demonstrating superior strength, followed by DLP and LCD. Notably, the water sorption and solubility of the DLP are significantly higher $(p < 0.05)$ than other groups $(31.51 \pm 0.92 \frac{\mu g}{mm^3})$ and $\left(5.32 \pm 0.61 \frac{\mu g}{mm^3}\right)$, respectively. SLA demonstrated the highest overall mechanical strength among all tested groups, albeit at a slower printing rate, owing to its ability to achieve a higher degree of conversion. Surface morphology analysis revealed no discernible differences after undergoing thorough mechanical polishing, indicating that the layered structure was confined to the outer surface. However, the most *Candida albicans* adhesion was also found in SLA $(221.94 \pm 65.80\ \text{CFU/ml})$ probably due to its higher surface roughness along the successive layers. Nonetheless, all denture bases fabricated with different vat polymerization did not demonstrate any cytotoxic effect on the Human Gingiva Fibroblast. In conclusion, this study confirmed that the NextDent denture base resin designed for DLP can be printed with different vat polymerization techniques and all tested groups met the ISO requirement aside from the water solubility. SLA exhibited the greatest mechanical strength while the DLP showed the lowest microbial adhesion.

ملخص

في طب الأسنان لتصنيع قاعدة الأسنان يكتسب قوة جذب (3D) إن استخدام الطباعة ثلاثية الأبعاد سريعة في السنوات الأخيرة. حتى الآن، يمكن استخدام مجموعة واسعة من تقنيات ومواد الطباعة ثلاثية الأبعاد لتصنيع قواعد أطقم الأسنان. ومع ذلك، هناك نقص في فهم تأثير قابلية الطباعة والخصائص الميكانيكية والفيزيائية والبيولوجية لقاعدة طقم الأسنان المطبوعة ثلاثي الأبعاد عند التصنيع باستخدام تقنيات بلمرة الوعاء المختلفة. أجريت هذه الدراسة لتوضيح تأثير تقنيات بلمرة الوعاء المختلفة في تصنيع باستخدام NextDent قواعد أطقم الأسنان. في هذه الدراسة، تمت طباعة راتينج قاعدة طقم أسنان وتقنيات عرض الكريستال الضوئي ،(DLP) ومعالجة الضوء الرقمي ،(SLA) الطباعة الحجرية المجسمة (ANOVA) وخضع لنفس إجراءات ما بعد المعالجة. تم استخدام تحليل التباين الأحادي (LCD) SLA وتوكي اللاحق لتحليل البيانات إحصائيًا. أظهرت النتائج أن أكبر قوة انثناء أظهرتها وكان هذا الاتجاه ثابتًا في صلابة الكسر .LCDو DLP تليها ،$(\mathbf{150.8 \pm 7.93\ MPa})$ والجدير بالذكر أن امتصاص الماء .LCDو DLP قوة فائقة، يليه SLA والصلابة الدقيقة، مع إظهار $\left(\mathbf{31.51} \pm\right.$ من المجموعات الأخرى (P<0.05) أعلى بكثير DLP وقابلية ذوبان على التوالي. أظهر جيش تحرير السودان أعلى قوة $\left.\mathbf{0.92\,\frac{\mu g}{mm^3}}\right), \left(\mathbf{5.32 \pm 0.61\,\frac{\mu g}{mm^3}}\right)$ ميكانيكية إجمالية بين جميع المجموعات التي تم اختبارها، وإن كان ذلك بمعدل طباعة أبطأ، وذلك بسبب قدرته على تحقيق درجة أعلى من التحويل. كشف تحليل مورفولوجيا السطح عن عدم وجود اختلافات ملحوظة بعد خضوعه لتلميع ميكانيكي شامل، مما يشير إلى أن الهيكل الطبقي كان محصوراً في السطح الخارجي. ومع ذلك، تم العثور على أكثر التصاق للمبيضات البيضاء أيضًا في SLA $(\mathbf{221.94} \pm$ ربما بسبب خشونة سطحها العالية على طول الطبقات المتعاقبة. ومع $\mathbf{65.80}\ \boldsymbol{CFU / ml})$ ذلك، فإن جميع قواعد أطقم الأسنان المصنعة باستخدام بلمرة مختلفة لم تظهر أي تأثير سام للخلايا على الخلايا الليفية في اللثة البشرية. في الختام، أكدت هذه الدراسة أن راتينج قاعدة طقم الأسنان يمكن طباعته باستخدام تقنيات بلمرة مختلفة وأن جميع المجموعات التي DLP المصمم لـ NextDent أكبر قوة SLA بصرف النظر عن قابلية الذوبان في الماء. أظهر ISO تم اختبارها استوفت متطلبات أقل التصاق ميكروبي DLP ميكانيكية بينما أظهر.

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LIST OF UNITS OF MEASUREMENTS

Nanometre	nm
Millimetre	mm
Centimetre	cm
Milliwatt per centimetre square	mW/cm^2
Kilonewton	kN
Newton	N
Ground force	gf
Milligram	mg
Millilitre	mL
Microlitre	µl
Percentage	%
Megapascal	MPa
Gigapascal	GPa
Megapascal per metre square	MPa/m^2
Vicker hardness	HV
Microgram per cubic millimetre	$\mu g/mm^3$
Colony forming unit per millilitre	CFU/mL

LIST OF SYMBOLS

$\geq$	More than or equal to
$\leq$	Less than or equal to
℃	Degree Celsius
°	Degree angle
$\times$	Multiply
$\pm$	Plus minus
σ	Flexural strength
E	Flexural modulus
K_{max}	Fracture toughness
w_{sp}	Water sorption
w_{sl}	Water solubility
p	Significance level

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

3D	Three Dimensional
AM	Additive manufacturing
ANOVA	Analysis of Variance
AO	Acridine Orange
BHI	Brain Heart Infusion
Bis-EMA	Ethoxylated Bisphenol A Glycol Dimethacrylate
Bis-GMA	Bisphenol A-Glycidyl Methacrylate
C. albicans	Candida albicans
CAD	Computer Aided Design
CAD-CAM	Computer Aided Design- Computer Aided Manufacturing
CAM	Computer Aided Manufacturing
CFU	Colony Forming Units
CNC	Computer Numerical Control
CO_2	Carbon Dioxide
DC	Degree of Conversion
DLP	Digital Light Projection
DMD	Digital Mirror Device
DMEM	Dulbecco’s Modified Eagle’s Medium
FBS	Fetal Bovine Serum
FDA	Food and Drug Administration
FFF	Filament Fused Fabrication
FTIR	Fourier Transform Infrared Spectroscopic
HGFs	Human Gingival Fibroblast
HPLC	High-performance Light Chromatography
IPA	Isopropyl Alcohol
IR	Industrial Revolution
ISO	International Standard Organization
LCD	Liquid Crystal Display
LED	Light Emmiting Diode
MDA	Medical Device Authority
MMA	Methyl Methacrylate
MOH	Ministry of Health
MTT	3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl-2H-tetrazolium bromide
OD	Optical Density
PBS	Phosphate Buffer Saline
PFM	Porcelain-fused-to-metal
PMMA	Polymethyl Methacrylate
RPM	Revolution per minute

SD	Standard Deviation
SLA	Stereolithography
SLS	Selective Laser Sintering
SM	Subtractive Manufacturing
SPSS	Statistical Package for Social Science
TEGDMA	Triethylene Glycol Dimethacrylate
UDMA	Urethane Dimethacrylate
UTM	Universal Testing Machine
UV	Ultraviolet
VH	Vicker Hardness