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Research Article

Shear Bond Strength of Denture Teeth with Different Surface Treatment to 3D Printed Denture Base Material

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Abstract

Aims: The present study aimed to assess the shear bond strength of various types of prosthetic teeth and different surface treatments bonded to a 3D-printed denture base resin.

Materials and Methods: A 3D-printed denture base resin was used, and three types of denture teeth, acrylic, composite, and 3D-printed teeth, were tested. A total of 120 maxillary right central incisors were used, with 40 specimens for each tooth type. Each tooth type was divided into four subgroups based on surface treatment. The four subgroups were: control (no treatment), air abrasion, bur roughening, and dichloromethane (DCM) treatment. Shear bond strength testing was performed using a universal testing machine. The collected data were statistically analyzed using SPSS version 22.

Results: No significant difference was found among the three types of artificial teeth in terms of shear bond strength to the 3D-printed denture base. However, air abrasion and dichloromethane surface treatments significantly increased the shear bond strength for all types of teeth compared to the control groups.

Conclusion: The type of prosthetic tooth does not affect the shear bond strength to a 3D-printed denture base resin. However, shear bond strength can be enhanced by using air abrasion or dichloromethane surface treatments for all types of teeth.

Keywords: Bond strength; Denture base; Denture teeth; Surface treatment; 3D printing.

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INTRODUCTION

Full tooth loss has a significant impact on the articular region's esthetics, acoustics, and mastication, resulting in a lower quality of life for patients. The most practical treatment option is complete denture preparation, in which the edentulous person is provided a removable acrylic-based denture that acts as a replacement for all teeth and accompanying structures (1,2).

Artificial teeth are an essential component of prostheses. Many materials, including acrylic, composite, and porcelain, have been employed with varying degrees of success (3).

The most common issue affecting denture function is the separation of the prosthetic teeth from the denture. This issue may arise as a result of the excessive chewing force, which raises the risk of prosthetic tooth displacement (4). It is believed that tooth separation accounts for 22%-30% of denture repairs, with the front portion being the most prone to separation (5).

Dentures may be created utilizing computer-assisted design manufacturer (CAD/CAM) or add-on (3D printing), in addition to the traditional manufacturing of heat-cured and self-curing dentures. 3D printed dentures necessitate the printing of the acrylic denture base, followed by the bonding of the traditional or 3D printed denture teeth to the denture base with a bonding agent (6). Digital denture production technologies, for example, 3D printed, decrease the step of connecting the teeth to the denture base resin during the heat polymerization step to produce the ideal bond with cross linked polymer system.

According to a study, selecting the most appropriate accessory for acrylic dentures, teeth, and denture base resin may prevent prosthesis failure and associated repairs, which may save the patient time and money (7). There are a lot of modifications that may be done for the ridge lap portion of the artificial teeth, like Chemical or mechanical modification that has been done to increase or strengthen the contact between denture teeth and an acrylic resin denture base (8).

The mechanical preparation may be done to improve the bond strength by making roughening. This treatment removes the glaze from the tooth and enhances the bonding surface area by roughening the surface and creating grooves and holes. Chemical agents such as PMMA monomer, acetone, ethylene, dichloromethane (DCM), and non-polymerizing solvents such as chloroform or ethyl acetate could be used to treat the tooth surface(9). The shear bonding force test is the most common method of testing for determining the binding strength between prosthetic teeth and denture base (10).

MATERIALS AND METHODS

Preparation of (rectangular form) stone base

A plastic mold was used to prepare a stone base (18 mm thickness, 90 mm length, and 60mm in width). This plastic mold was placed on the surveyor table, which was placed and fixed in a position parallel to the horizontal plane (the zero plane). The dental stone was mixed according to the manufacturer's instructions and then poured into the plastic mold. The incisal portion of the central incisors was embedded in the stone (about 6 mm of the incisal edge) before setting in such a way that only the ridge lap of the artificial tooth appears outside the stone mixture, and the long axis of each incisor is perpendicular to the stone base with the aid of a dental surveyor using A surveyor's analyzing rod. By using this method, one incisor is placed at the center of the plastic mold, and four incisors are placed at the periphery of the mold. After setting the dental stone, the stone is removed from the plastic mold. By using this method, all the incisors were placed and fixed in standard position .8 Stone bases were prepared for the acrylic teeth, and 8 stone bases were prepared for composite teeth [11] as shown in Figure 1

Figure (1): the stone mold

Ridge lap surface preparation

A milling machine is used to prepare the artificial teeth, which allows only horizontal movement of the handpiece. The stone base was placed on the table of the milling machine and fixed on it by screws. The handpiece disk with a constant speed (4000 Rpm) was used to cut the ridge lap section of the synthetic teeth in one direction [12] as shown in Figure 2.

Figure (2): A milling machine used for cutting the ridge lap portion of synthetic teeth

Preparation of 3D-printed specimens

The 3D-printed denture base specimens were created in SketchUp Pro (2020) and saved as a Standard Tessellation Language file (STL). DentaBase3Dprint asiga (Australia) material is used for printing the specimens, and the file is then imported to the Asiga MAX UV 3d printer OMNI dental Australia) is used for printing the specimen.

The denture base samples are 5 mm in diameter and 2.5 mm in thickness, that resemble the thickness of denture base in accordance with ADA Specification No 12(2002), and the same printing cycle for the same setting and environment of room temperature to avoid any difference in the condition and to provide standardization for all samples.

3D printed teeth preparation

The virtual design of the 3D-printed resin teeth was obtained by scanning the right maxillary central incisor of the prefabricated surveyed tooth by using a dental scanner device (Ios hero U.S.A), then the scanned virtual design was saved and converted as STL file, and then printed by using (3D Temp resin sentrex turkey) (13).

Surface treatment

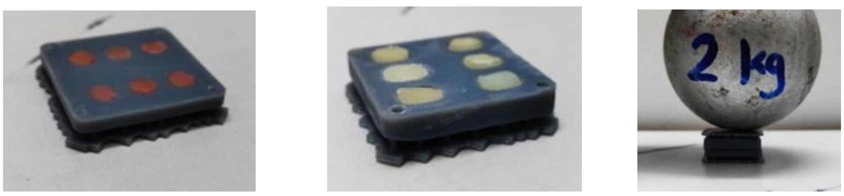
Surface treatment was performed for each tooth type. The ridge lap surfaces of the first subgroups were treated with Particles of alumina (Edelkorund, Germany), where the samples were placed for approximately 15 seconds in an air abrasion machine (Twinpen Dental Sand Cleaning Machine, Korea)

Roughening tooth surfaces with a straight, rounded end and a blue diamond bur (314.142.514 -882FG-014 Diamond Burs-verdent-poland) by using a handpiece that was placed on a surveyor in one direction was used for the roughening subgroups. The tooth was maintained parallel to the tooth surface for 5 seconds during the roughening technique.

The third group was treated with dichloromethane (DCM) (Central Drugs House, Delhi, India). DCM is applied using a small brush and then left for approximately 10 seconds before bonding the teeth to the 3D printed denture base specimen (9).

The specimen bonding

The index was constructed and stored as an STL file to regularize bonding of the tooth to the 3D printing DBR sample, and then printed using 3D printed material (sendrex\turkey 3D model) and 3D printed device (creality hongkong). Two indices were created: one for the teeth and one for the denture base sample. The teeth and denture base are then inserted into the index hole then a thin layer of 3Dprinted asiga material was placed on the ridge lap surfaces of the teeth [5] then the other index is placed over the first index and a load (2 kg) was placed over the index then the specimen of the tooth and denture base is returned to the curing machine for 45 minute[9] as indicated in Figure 3 (a, b, c).



A **B** **C**

Figure (3): bonding of the specimens: A-denture base material index. B-teeth specimen index. C-bonding of the two specimens

Shear Bond Strength

After completing the samples, each sample was embedded in a cylindrical plastic ring with a diameter of 1.4 cm and a height of 4 cm, is then placed over each sample and then poured with a mixture of cold-cured acrylic resin and left to set. The samples were then placed inside a special holder to test the shear bond strength. The bonding strength between the denture base and the prosthetic teeth was tested in shear mode at a cross speed of 1 mm/min using the universal testing equipment, as shown in Figure 4 (14,15).

Figure (4): Shear bond strength bonding machine

RESULTS

The Shapiro-Wilk test of normality was done to analyze the main study results data for the shear bond strength of 3D printed denture base, and the results showed that the data were parametric and normally distributed. Descriptive data for shear bond strength (Mpa) Table (1) shows the mean and standard deviation of the 3D-printed denture base for three different kinds of teeth and surface treatment.

Table (1): Descriptive statistics of 3D printed denture base

Descriptive Statistics				
		N	Mean	Std. Deviation
Acrylic	control	10	7.2153	2.05162
	Air-Abrasive	10	10.5073	3.51588
	DCM	10	8.4740	2.68530
	Bur-Roughening	10	6.1585	1.90820
3D printed teeth	control	10	7.2362	2.64332
	Air-Abrasive	10	6.7307	1.88197
	DCM	10	10.4693	4.66186
	Bur-Roughening	10	5.7983	.98734
Composite	control	10	5.7140	1.68075
	Air-Abrasive	10	4.8687	1.45164
	DCM	10	8.0549	2.35478
	Bur-Roughening	10	5.4754	1.14362
	Valid N (listwise)	10		

Effect of three types of teeth on shear bond strength

Statistical analysis of variance ANOVA was used to examine the effect of teeth (acrylic, composite, and 3D-printed teeth) on shear bond strength, and the results demonstrate no significant difference (P> 0.05) between teeth types, as shown in Table (2) and Figure (5)

Table (2): Statistical test of shear bond strength (MPa) among groups of teeth using one-way ANOVA

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between- Groups	15.239	2	7.619	1.630	.215
Within- Groups	126.191	27	4.674		
Total	141.430	29			

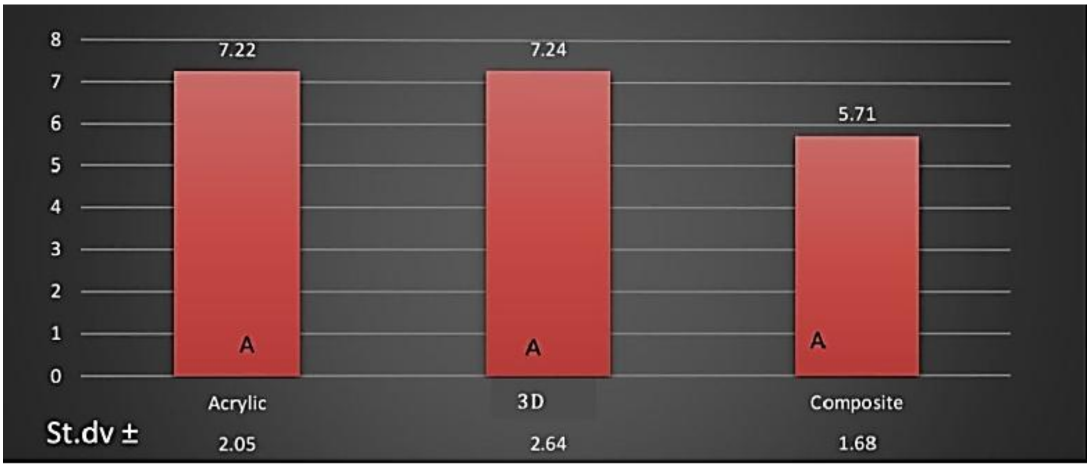


Figure (5): Duncan's multiple range test of three types of teeth bonded to a 3D printed denture base

Surface treatment effect on shear bond strength of acrylic teeth to 3D printed denture base material.

Statistical analysis of variance (ANOVA)was performed to evaluate the effect of (air-abrasive, bur-roughening and DCM) surface treatment on shear bond strength of acrylic and showed a significant difference ($P \leq 0.05$) between groups as shown in Table (3) Duncan's multiple range test between groups showed that the group bonded to Air-abrasive treated teeth and DCM treated teeth have a higher mean values when compared with control group and bur-roughening have no significant difference as compared with control group as shown in Figure (6).

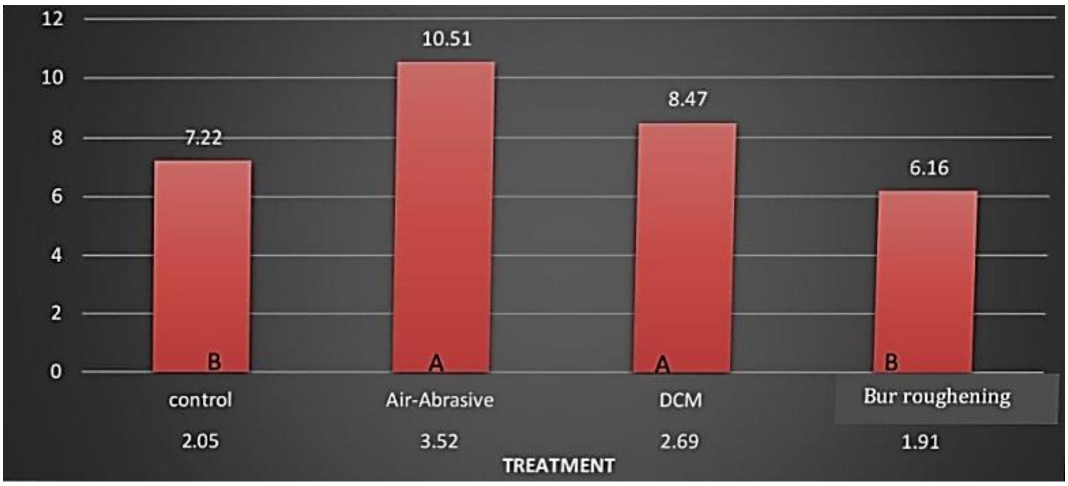


Figure (6): Duncan's multiple range test for surface treatment of acrylic teeth

Table (3): Statistical test of shear bond strength (MPa) among groups, surface treatment of acrylic teeth using one-way ANOVA

	ANOVA					
		Sum of Squares	df	Mean Square	F	Sig.
Acrylic teeth	Between Groups	104.865	3	34.955	5.099	.005**
	Within Groups	246.804	36	6.856		
	Total	351.669	39			

SOV=Source of variance. SS=Sum of Squares. Df =Degree of freedom. MS=Mean square. **highly significant at p≤0.05 MPa = mega pascal.

Surface treatment effect on shear bond strength of composite teeth to **3D printed denture base material**

Statistical analysis of variance (ANOVA)was performed to evaluate the effect of (air-abrasive, bur-roughening and DCM) surface treatment on shear bond strength and showed a highly significant difference (*P*≤0.05) between groups as shown in Table (4) Duncan's multiple range test between groups showed that the group bonded to DCM treated teeth have a higher mean values when compared with control group while air-abrasive group and bur roughening have no significant difference when compared to control group as shown in Figure (7)

Table (4): Statistical test of shear bond strength (MPa) among groups, surface treatment of composite teeth using one-way ANOVA

	ANOVA					
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Composite teeth	Between Groups	58.560	3	19.520	6.625	.001**
	Within Groups	106.065	36	2.946		
	Total	164.625	39			

SOV=Source of variance. SS=Sum of Squares. Df =Degree of freedom. MS=Mean square. **highly significant at p≤0.05 MPa = mega pascal.

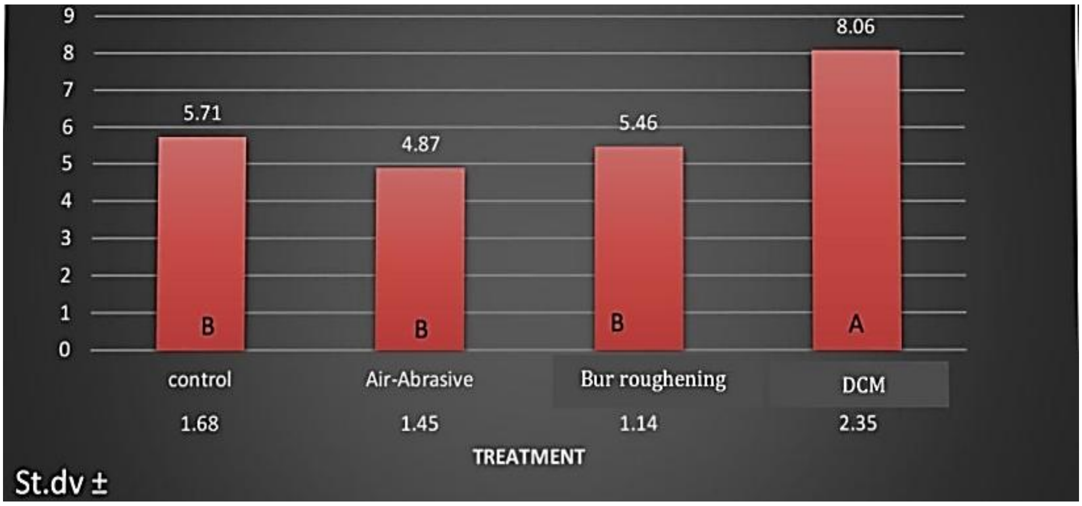


Figure (7): Duncan's multiple range test for surface treatment of composite teeth bonded to a 3D printed denture base

Surface treatment effect on the shear bond strength of 3D printed teeth to 3D printed denture base

Statistical analysis of variance (ANOVA)was performed to evaluate the effect of (air-abrasive, bur-roughening, and DCM) surface treatment on shear bond strength and showed a significant difference ($P \leq 0.05$) between types of surface treatment of 3D printed teeth, as shown in Table (5).

Duncan's multiple range test between groups showed that the group bonded to DCM-treated teeth has a higher mean value when compared with the control group, while the air-abrasive group and bur roughening have no significant difference when compared to the control group, as shown in Figure(8).

Table (5): Statistical test of shear bond strength (MPa) among groups of surface treatment of 3D-printed teeth using one-way ANOVA

		ANOVA				
		Sum of Squares	df	Mean Square	F	Sig.
3D-printed Teeth	Between Groups	123.600	3	41.200	4.958	.006**
	Within Groups	299.130	36	8.309		
	Total	422.730	39			

SOV=Source of variance. SS=Sum of Squares. Df =Degree of freedom. MS=Mean square. **highly significant at $p \leq 0.05$ MPa = mega pascal

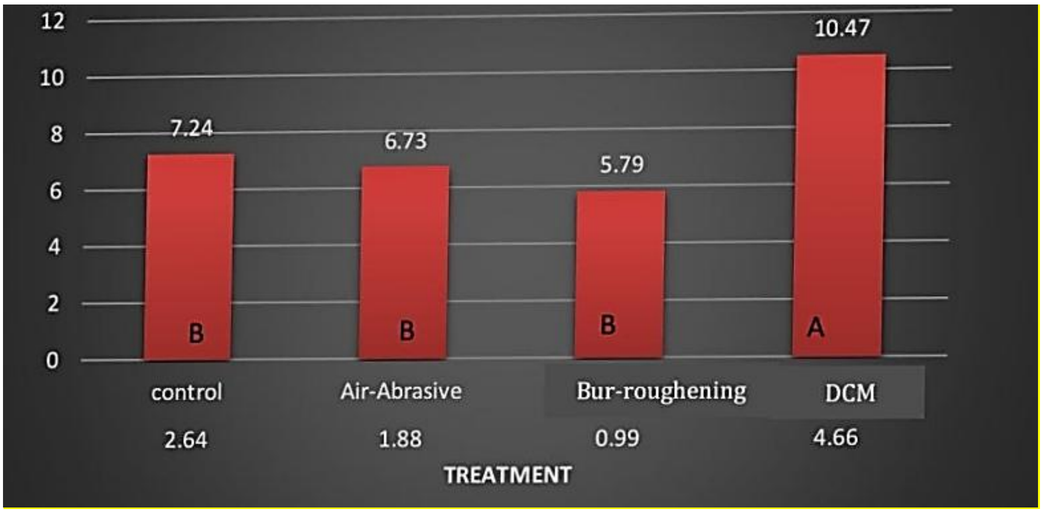


Figure (8): Duncan's multiple range test for surface treatment of 3D printed teeth

DISCUSSION

Our findings show that there is no significant difference in shear bond strength between the three types of denture teeth connected with 3D-printed DBRs. While the air abrasive and DCM surface treatment give an increase in the SBS.

The impact of three different types of teeth on the shear bond force when bonded to **the 3D printed denture base:**

The average SBS of all types of teeth is considerably equelled this means that there is no significant difference between them. This result is in agreement with Chung *et al* [6,] who found that the 3D printed resin teeth had fracture resistance and biomechanical pattern comparable to the conventionally prefabricated denture teeth.

This result is in disagreement with Goodacre *et al.* (16) and Choi *et al* (5), who find that the bonding of acrylic teeth to 3D-printed resin is inferior to that of conventional heat-cured acrylic bases. The interpretation of this result is explained by the fact that with 3D printing, the build direction (layer orientation) affects the mechanical properties of the dental restorative material. This is due to the nature of incremental layers in additive manufacturing technology, which can initiate crack propagation and lead to structural failure of the printed material. In an in vitro study, layer orientation was found to affect the compressive strength of 3D-printed composite material. Also, it is important to understand that the bond between the layers is weaker than that within the layer. This is explained by the number of residual stresses and porosities that accumulate during UV polymerization and material shrinkage. Al Harbi *et al* (17) and Ayman (18) found in their study that the attachment between the conventional prefabricated teeth and printed denture bases occasionally fails, indicating the need for the use of mechanical retention.

The effect of abrasive air surface treatment on the 3D-printed denture base for all **types of teeth**

Our study found that 3Dprinted denture base adhered to teeth with air abrasive surface treatment had high Shear bond strength in all tooth kinds. The roughness of the ridge surface of acrylic teeth causes glass breaking and increases the surface area available for bonding to the denture base, as expected. Air abrasion eliminates the tooth's saturated surface layer, exposing the underlying layer. As a result, the underlying layer has a high free surface energy, and the freshly alumina-blown resin surface has a higher free surface energy than the untreated surface. This may result in improved bond strength (20).

This finding is congruent with the findings of Boonpitak *et al* (21), who discovered that air abrasion treatment of the lap region of denture increased shear bond force regardless of polymerization type.

The effect of DCM surface treatment on the 3D-printed denture base for all types of teeth

Our findings show that DCM-bonded 3D-printed denture bases (CH_2CL_2, a biological solvent that may dissolve the polymer template of PMMA) have strong shear link strength in all kinds of teeth.

Dichloromethane increases the size of the dental acrylic resin's outer surface, permitting the polymerizable acrylic resin copolymer in the base to permeate into the synthetic teeth and form a considerable cross-linked polymer network. Enhanced bond strength may be due to the micro-roughness generated by the use of dichloromethane on tooth surfaces, which leads to improved mechanical maintenance.

This finding is consistent with Jain *et al* (22), who found that dichloromethane improves the dental bond strength of traditional and highly bonded acrylic teeth to 3 times the initial rate of untreated teeth. But it is inconsistent with Helal *et al* (9), who discovered that neither the surface of the treatment procedures enhanced SBS between the prosthetic teeth and the milled 3D printed denture base.

The impact of rough countenance treatment of all types of teeth on the dental **3D-printed denture base**

Our findings reveal that tooth roughness surface treatment has lower shear bond strength than dichloromethane and air abrasive surface treatments. The bond's fragility can be linked to the aggressiveness generated by the roughness of the diamond tooth, which results in microfissures on the surface, causing the bond to be readily lost during bond testing. This consequence is similar to the findings of Helal *et al* (9). The consequences of our study discovered that the diamond tooth surface roughness had a reduced shear bond strength value compared to the control.

CONCLUSIONS

Within the limitations of the current study,
It is possible to conclude that the shear bond strength can be enhanced for all types of teeth by using dichloromethane and air abrasive surface treatments, while the bur roughening surface treatment is not preferable for all types of teeth to 3D printed denture base.

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Authors' Contribution
Saleh H and Alnoori Akh completed the conceptualization, data curation, formal analysis, finding acquisition, investigation, resources, software, validation, visualization, writing- original draft, writing- review, and editing. Methodology, Project administration by Saleh H., Supervision, Visualization by Alnoori AKh.

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Ethical statement: This study was approved by the ethical committee of research in the College of Dentistry, with the approval number (**UoM.Dent.23/43**) on 31/5/2023.

Conflict of interest

The author declares that there are no conflicts of interest regarding the publication of this manuscript

Availability of data and materials: All data generated or analyzed during this study are included in this published article and its supplementary information files.

Declaration of Generative AI and AI-assisted technologies

During the preparation of this work, the authors used a grammar tool to improve the readability of the manuscript. The authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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قوة الترابط القصي لأسنان طقم الأسنان ذات المعالجة السطحية المختلفة مع مادة قاعدة طقم الأسنان المطبوعة ثلاثية الأبعاد

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2- فرع صناعة الاسنان، كلية طب الأسنان، جامعة الموصل، الموصل، العراق

الملخص

الأهداف: هدفت هذه الدراسة إلى تقييم قوة الترابط القصي لأنواع مختلفة من الأسنان الاصطناعية ومعالجات سطح راتنج قاعدة طقم الأسنان المطبوع ثلاثي الأبعاد. **المواد وطرائق العمل**: باستخدام راتنج قاعدة طقم الأسنان المطبوع ثلاثي الأبعاد، تم اختبار ثلاثة أنواع من أسنان طقم الأسنان (أكريليك، ومركب، ومطبوع ثلاثي الأبعاد). استُخدم 120 سنًا من القواطع المركزية العلوية اليمنى، 40 سنًا من كل نوع، وقُسِّم كل نوع إلى 4 مجموعات بناءً على معالجة السطح. تضمنت الدراسة أربع مجموعات فرعية: (المجموعة الضابطة) بدون معالجة، والصنفرة الهوائية، والتخشين باستخدام المثقاب، وثنائي كلورو الميثان (DCM). استُخدم جهاز اختبار عالمي لاختبار قوة الترابط القصي. أخيرًا، تم تحليل البيانات المُجمَّعة إحصائيًا باستخدام برنامج SPSS الإصدار 22. **النتائج**: لم يُلاحظ أي فرق ذي دلالة إحصائية بين الأنواع الثلاثة من الأسنان الاصطناعية في قوة الترابط القصي مع قاعدة طقم الأسنان المطبوعة ثلاثية الأبعاد، بينما أدت معالجة سطح الأسنان بالصنفرة الهوائية وثنائي كلورو الميثان إلى زيادة قوة الترابط القصي لجميع أنواع الأسنان مقارنةً بالمجموعات الضابطة. **الاستنتاجات**: إن استخدام أي نوع من الأسنان ليس له تأثير على قوة الترابط القصي لقاعدة طقم الأسنان المطبوعة ثلاثية الأبعاد، ولكن يمكننا زيادة قوة الترابط القصي باستخدام السفع الرملي ومعالجة ثنائي كلورو الميثان لجميع أنواع الأسنان.

الكلمات المفتاحية: قوة الترابط؛ قاعدة طقم الأسنان؛ أسنان طقم الأسنان؛ معالجة السطح؛ الطباعة ثلاثية الأبعاد..