ISSN: 2458-8989

Natural and Engineering Sciences

NESciences, 2025, 10 (1): 56-68 doi: 10.28978/nesciences.1613417

Additives Versus Subtractive Fabricated Techniques and Materials Types and their Impact on the Fracture Resistance of Ceramic Crown

Zahraa A. Salman [1*], Nadia H. Hasan [2], Aous A. Abdulmajeed [3]

[1*] College of Dentistry, University of Mosul, Mosul, Iraq.
E-mail: zahraa.22dep18@student.uomosul.edu.iq

[2] College of Dentistry, University of Mosul, Mosul, Iraq. E-mail: nadiahameed@uomosul.edu.iq

[3] College of Dentistry, University of Mosul, Mosul, Iraq. E-mail: aabdulmajeed@vcu.edu

Abstract

Because of the evolvement of digitalized dentistry and the need of a restoration that is fixed, there has been an introduction of many materials related to 3D printing in today's market. The purpose of this study is to evaluate the resistance of fractures by comparing materials of ceramic which are of four kinds and they are zirconia-reinforced lithium disilicate, also Emax cad, and IPSS emax as well as 3Dprinting nanoceramic. Methods: 24 crowns were prepared (6sample for each type of the material) used in the study. And undergone artificial ageing before testing using the universal testing machine. Submission of results in SPSS for tests like Kruskal-Wallis as well as nonparametric test proved the difference in each material of ceramics and it differed at $p \leq 0.05$ whereas in the methods used there is no such difference. The material which showed a resistance for fractures with a high value was the samples of ZLS which was about 1473.1 and the material which showed a resistance for fractures with a low value was the Emax cad and it was about 1013.7. To conclude, Value of Fracture resistance can have an impact because of the kind of material whereas there is no significant impact because of the preparation method.

Keywords:

Zirconia-lithium silicate, 3D printing, CAD-CAM, fracture.

Article history:

Received: 18/10/2024, Revised: 18/12/2024, Accepted: 07/01/2025, Available online: 31/03/2025

Corresponding Author: Zahraa A. Salman, E-mail: zahraa.22dep18@student.uomosul.edu.iq

Introduction

Variations in the capability of resisting fractures can be because of reasons like shape of the luting cement for the tooth, void fraction of the crown and its thickness and certain flaws that are large, defects in the material, void fraction, or a void in cements present in occlusal region in ceramic crowns i.e. near to internal surface determine tensile stress which accounts for the type of material, the method through which the preparation of crown took place and also any failure that was caused (Rosentritt et al., 2017 ; Malbašić, 2021). To assess if the restoration will be efficient enough for a long period of time, the check of resistance of fractures is a significant factor as well as an essential feature for any restoration in dental field. Factors like resistance of cracks, method of fabrication and the roughness of surfaces can be responsible for the damage caused to the structure during mastication which can cause fracture of the restored part (Ashour et al., 2024).The establishments in literature prove that one of the main reasons for a failure in the ceramics after many dental procedures done in oral cavity is because of fracture and this is because of loads that are repeated in the mouth of the patient which can be an influence on the crown's reliability in a long-term perspective (Elraggal et al., 2022).

SM (Subtractive Manufacturing) of designs developed with the aid of computers and CAD-CM (Computer-aided manufacturing) has helped in the development of a technology that is mature and also helped in ceramic restoration production which are fit to be used in clinics. But there are many limitations in SM for example, risks like introduction of micro-cracks while milling, wastage of material, the requirement of replacement for tools that are worn out, as well as less reproduction of geometrical surfaces as depicted by the size of tools used in milling and also the functioning of axes of CNC (Computer Numerical Control) machines (Revilla-León et al., 2020). Advantages that the AM (additive manufacturing) has as compared to the SM is factors such as saving materials, manufacture of details that are highly intricate and have geometries that are complex. In recent times, ceramic fabrication in dental clinics have been making use of AM. The definition "a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies" was given by The American Society for Testing and Materials (Al Hamad et al., 2021; Sadid-Zadeh et al., 2021). The microhardness of a surface can be improved by mechanical treatment of the surface of zirconia which has AL2O3(Riyadh & Nayif, 2020). And this has the ability to get affected by the kind o material utilized. (Maha & Nayif, 2013) and also get affected by the use of material like cement (Shackori et al., 2024) and the application of force. Hence, this study is for the evaluation of resistance of fractures by comparing materials of ceramic which are of four kinds and they are zirconia-reinforced lithium disilicate, also Emax cad, and IPSS emax as well as 3Dprinting nanoceramic where the fabrication takes place using methods of 3 types called press technology, CAD-CAM as well as 3D printing (Jalili et al., 2021). The comparative analysis sheds light on how material composition and production methods influence the durability and mechanical performance of dental ceramics in clinical applications (Bita et al., 2021). Prior research suggests that the high-strength properties inherent to zirconia-reinforced lithium disilicate render it more resistant to fracture under stress compared to conventional options like IPSS emax or even newer innovations like nanoceramics produced via 3D printing (Kumar & Rao, 2024). However, advancements in digital manufacturing through CAD-CAM technology present potential for improved precision and optimized strength outcomes across a range of ceramic types. Likewise, the pressing technique has historically demonstrated reliable consistency in producing ceramics with homogeneous structural integrity. By including novel approaches such as 3D printing alongside traditional methods, this investigation provides valuable insights into how emerging technologies might rival or complement established ones in delivering enhanced restorative solutions tailored for various clinical scenarios. Ultimately, understanding the interplay between material properties and manufacturing techniques contributes to advancing patient-specific restorations with superior durability and longevity.

Methods Implemented and Materials Used

Design of the Study: Figure 1 depicts that Artificial ageing was performed on the samples in this study which was later divided.

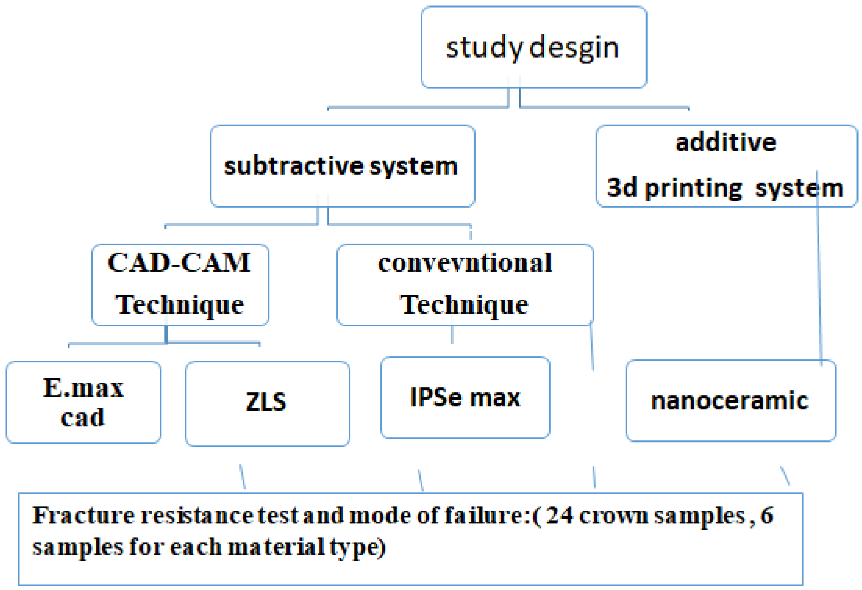

Figure 1. Workflow design

Sample Tooth Preparation

Twenty-four intact first upper premolars extracted for orthodontic reasons in ages between (12 and 16) will be used in this study to make crowns from IPSemax, Emax CAD, 3D nanoceramic and ZLS, Collection of extracted teeth will be performed according to ethical approval cod (UoM.Dent.24/1047)and will be stored in 0.1% thymol solution during study procedures to prevent dehydration The teeth will be allocated in the study groups based on the average similarity in crown dimensions using digital Vernier (Abbood & Al-Hashimi, 2016).

The mounting of the teeth was done by cold cure acrylic with retentive ring of PVC (polyvinyl chloride) that has a height of 1.4cm and a diameter of 2cm and this was made use of as mould. With the support of surveyor (Marathon-103; Seayang, Korea) the mould had each tooth mounted on it and to make sure that the tooth positioned in the mould is vertical, there has been a use of clamp, which is in the arm that moves vertically in the surveyor, to hold the teeth (Silveira et al., 2020). When the positioning of the tooth's axis is implemented in a correct manner, the mould will have an acrylic resin poured onto it and before it attains the point where it takes the texture of a dough, the insertion of the tooth in the mould's center is done in a longitudinal direction to a depth of 2mm in approximation in the junction of apical till cemento-enamel which is depicted in Figure 2. To avoid polymerization of resins because of overheating post the polymerization done in the initial stage, samples are immersed into distilled water (Kollmuss et al., 2016).

A silicone index using heavy body rubber base silicone impression material was prepared, the impressions were taken for each premolar to obtain a silicon index before preparation then the impression was cut into two halves vertically to obtain a side view for the preparation as shown in figure (2 B and C)(Ziwei & Han, 2023).

Preparation of teeth in a standardized manner for entire groups was implemented under spray water, with the aid of a surveyor from dental lab (Marathon-103; Seayang, Korea) and diamond bur taper of 6° (No.856; Intensive SA, Switzerland) which is depicted in Figure 2D.

Indicating depth marks was done on the tooth surface by using the bur (Figure 2E) these marks were linked together to complete the preparation by diamond bur (No. 5850-018; Brasseler USA, Savannah, GA) (Figure 2F)the bur runs all around the tooth and changes the bur direction according to the part of tooth being prepared to make tooth smaller in size without over reduction and the preparation done according to measurement shown in figure (2G) and Traditional groups of crown were made ready which had a shoulder finish line of 1mm at CEJ. To ensure cutting efficiency, as replaced after every single tooth preparation.

Scanning Procedures and Restoration Design

For scanning the tooth which is prepared, intra oral scanner is utilized and after that the image will be sent to STL file which is otherwise known as standard tessellation language file which is an important aspect of techniques called milling systems and also 3D printing whereas for the traditional method, a template made of wax which is an imitation of the crown is created with the help of three dimensional printers (Holtsky)(Shenzhen Creality 3D Technology Co, Ltd., which is a manufacturing company of three dimensional printers of the Chinese origin started in 2014), and then templates of this are utilized to acquire crowns of lithium disilicate which is pressed (IPPSSe max) which is done by using pressing techniques and application of lost wax as per the instructions of the manufacturer. In this process, the templates of wax are corrected using wax sprue(IPS Multi Wax Pattern Form A; Ivoclar Vivadent) and the wax is obtained.(IPS Press VEST Pre-mium; Ivoclar Vivadent) It will be placed in oven (KaVo EWL 5645; KaVo, Kloten, Switzerland) and the template which has been vested will be subjected to heat until it reaches a rate of melting of about 5 degree Celsius per minute from the temperature of room till 850 degree Celsius and would be held till 60min to acquire the mould and the mould obtained will be injected with lithium-disilicate ceramic (IPS e.max Press Ivoclar Vivadent). After this, by placing the ring in a pressing furnace, it is entirely burnt (Programat EP 5010 Ivoclar Vivadent) in a rate of 60 degree Celsius per minute which ranges between 700 degrees Celsius until 898 degrees Celsius which is held for approximately 25 minutes. After the process had cooled down, the crowns are acquired in a careful manner and by the air abrasion particles (Germany/Renfert GmbH No. 1594105) they are cleaned for 3 whole minutes. The glazing if surface will be done with the aid of IPS e.max Fluorescence Glaze, (IPS e.max CAD Crystall/Shades, Stains and Glaze/ Ivoclar Vivadent) and then they are placed inside the sintering-oven yet again and about 6 crowns are created with the help of such a technique.

While to obtain the ceramic crown of the group E.max CAD/CAM (IPS emax CAD (LT A2, Ivoclar Vivadent, Schaan, Liechtenstein) and ZLSDental CAD/CAM system (Yenadent) used to prepare a crown sample depending on (STL)file prepared firstly on the same dimension.

After the completion of the process of milling by the machine, the separation of crowns is done in a careful manner and after their removal from blanks of Emax, every crow's margin was provided with adjustments with the help of a diamond bur which is fine in texture and shaped like a football (379-023 M-HP) and this is done to have all the excess removed. Crowns of E.max were put in a firing tray and as per the instructions of the manufacturer, they are sintered by being subjected to a temperature that is significantly high for 25 minutes in Zetain Sintering Furnace(400-860°C). The outer surface of crowns of e max cad was first finely grounded, then polished, post which they are cleaned and dried and as the final step, glaze firing Is implemented on it. This technique was implemented to prepare six crowns from E. max cad.

For ZLS crowns also STL file was made before by the cad-cam system to prepare six crowns and the sintering of the crowns was done by a Zetain sintering furnace between (0-1530°C) and six crowns made.

For the ceramic samples of the group 3D printing nano ceramic samples also STL file, the crowns were designed by AutoCAD program Before the process began using Printer Phrozen Mighty 8K, utilised vat photo polymerization technique for the process of three-dimensional printing. Initially, the resin is in the form of liquid but after it is subjected to light, certain chemical reactions take place which makes it solid in nature which ends in the development of an object which is solid, the procedure started by heat resin bottle in a hot water jar. This is important to use all resin in the bottle and to mix all nanoceramics in the product. Put water 1L-1.2L inside a water heater and make it boil, when the water boils machine will stop, so put a whole bottle inside the water heater. Wait 5-10min, shake well for 30sec - 1min hard put the resin in a tank of 3D printing machine and start the print. After print, it is cleaned with the help of 96% of a solution of ethanol using a bath which is ultrasonic and unheated for 3 min (ultrasonic cleaner power 30 -35 watts), Resin residues can also be removed using a brush immersed in 96% ethanol and just after alcohol clean, wash via tap water 5- 10 sec and spray alcohol for final clean and immediately clean via pressured air. Post-curing**,** Remove the support structure with the help of a cutting wheel and a material of blasting glass bead of 50 µm with a maximum pressure of blasting of about 1.5 within a duration of 3 min. Check for fit and finish the objects. Finishing and contouring can be performed using a carbide cutter or diamond grinding stone(No.PH-1011). Finally, twenty–four crowns were obtained by three different techniques (Figure 3).

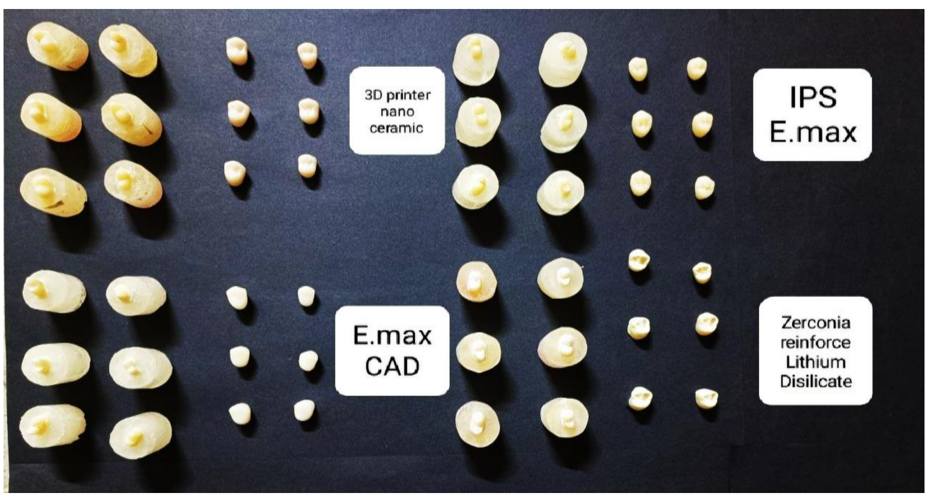

Figure 3. The prepared crowns

Cementation Protocols

The procedure of conditioning for the ceramic restoration's inner surface changed with respect to different groups. In IPS Emax group, with the help of hydrofluoric acid of 5%, etching is performed for the 20s and this is for the creation of surface that is rough which is carried out by having the glassy matrix dissolved which helps in an increase of surface energy and area which again increases the rate of wetting with the help of bonding agent, (IPS ceramic etching gel.; Ivoclar Vivadent) post which spraying of water is done, and an air-drying which is oil-free. The application of air-abrasion for inner parts takes place in other groups like ZLS, E.max cam and 3DP (Rocatec Plus 30 µm, 2.5 bar, 3M ESPE, Seefeld, Germany). For every group of restoration, the intaligo surface will be modified with a saline (Monobond Plus; Ivoclar Vivadent) are often air dried in a gentle manner post the 60s. With phosphoric acid of about 35%, the teeth structure is etched (it is the material of reference in the technique of etching with acid of enamel and dentine, which gives a surface for both the tissue's adhesion in an optimal way). For ceramic etching or glass etching, the hydrofluoric acid is used for 30s. (Ultraetch; Ultra dent, Utah, USA) post which it is sprayed with water(30s) for the removal of grease from surface or biofilm residues and then is air dried with an oil free method. For a standardized cementation technique, during the time of cementation a pressure of occlusal cementation which is like a pressure from the fingers of a dentist was given in a uniform and even manner. A pressure of 49N was applied by the device in the mode of compression for about 5 minutes (Zlatanovska et al., 2019) for the purpose of having the crowns cemented. Then the margins of crown are subjected to blue LED of a device of light cure (coltolux 75) for a time period of 20 sec as advised and then any material which is in excess amount is removed. An adhesive system (Mobo bond Plus; Ivoclar Vivadent) will be implemented on the surface of the tooth as well as intaglio restoration surfaces which is air-blown in a gentle manner. The adhesive cementing of restorations takes place with the help of a resin cement A2 which is of the dual curing type (Variolink Esthetic DC; Ivoclar Vivadent). The application of light curing happens right after the excess cement is removed.

Artificial Aging

All the twenty-four crowns that were prepared will undergo ageing with the aid of a thermos cycling unit (Dorsa, Iran) of cycles of a count of 5000 ranging from 5 to 55°C and a dwell time of 30s, which corresponds to approximately 1 year of intraoral use (Øilo & Gjerdet, 2013).

Testing of the Crowns

Fracture Resistance Test

The strength of fracture of any material depicts the load or stress it can bear to a maximum point before the occurrence of a fracture. It is property of mechanics which is crucially significant because of its ability to segregate the resistance of the materials to failure with a set of loading modes as well as applied forces (Thillaigovindan et al., 2019). One of the stress tests specified by ISO is the fracture resistance test. It is recommended as an easy, accurate, and dependable if the placement of specimens is inside UTM (University Testing machine) (AGS-X, Shimadzu, Kyoto, Japan) for the purpose of a test to check its resistance to fractures where a force which was highly compressive was applied at a speed rate of 1mm per minute with a modified bar in round shape which had 4mm as diameter and 0.5 mm per minute as its speed. In parallel to the axes of teeth that are long, a metal bar is placed and its is kept opposite to the surface of restoration that is occlusal. Newton (N) was used as the unit to record maximum load required for fracture of every crown. All recorded data have been gathered and tabulated to be statistically analyzed.

Result

The Effect of Technique

To determine the relation between the preparing technique and fracture resistance value of the samples prepared from four different materials, the data were collected and submitted to a normality test so non-parametrical analyses were done a descriptive statistic including data's standard deviation and mean will be obtained from (Table 1).

Table 1. Description and statistical analysis including standard deviation and mean

			N	Mean ±Std. Deviation
Preparing Technique	Subtractive system	Conventional Technique	6	1336±11
		CAD-CAM Technique	12	1243±240
	Additive system	3Dprinting Technique	5	1184±10

Regarding how effective the technique is on values of resistance of fractures in the crowns prepared from four different ceramics materials, A difference in the techniques is evident from the test of Kruskal-Wallis that between techniques where $p \leq 0.001$ (Table 2).

Table 2. Kruskal-Wallis's result showed how effective the preparation method on value of resistance of fracture

			Mean ±Std. Deviation	Test value	P value
Fracture resistance value	Subtractive system	Conventional Technique	1336±11	2.16	0.34
		CAD-CAM Technique	1243±240		
	Additive system	3D printing	1184±10		

There is no significant between techniques about the fracture resistance value.

The Effect of Material Used: To determine the relation between the material and fracture resistance value of the crown prepared from four different materials (IPSSe max, ZLS, Emax cad,3Dnanoceramic). The data were collected and submitted to a normality test so non-parametrical analyses were done (Table 3).

Table 3. Description of analysis of statistics including standard deviation and mean for fracture resistance

	Material	N	Mean	Std. Deviation
Fracture resistance value	E.max cad	6	1014±18	18
	IPS E.max	6	1336±11	11.3
	nanoceramic	5	1184±10	9.7
	ZLS	6	1473±13	13

Regarding how effective the material is on the value of resistance of fractures of crowns of four different ceramics materials, A difference in the techniques is evident from the test of Kruskal-Wallis that between techniques where $p \leq 0.001$(Table 4).

Table 4. Kruskal-Walli's result showed the effect of the preparing technique on fracture resistance value

	Materials	**Mean ±Std.Dev.**	Test value	p-value
Fracture Resistance value	E.max cad	1014±18	21.6	0.001**
	IPS E.max	1336±11		
	nano ceramic	1183±10		
	ZLS	1473±13		

For the identification of the importance level which was acquired, a test of multiple range by Dunn depicted that the value of mean of the ZLS crowns was significantly higher than E .max cad (Figure 12).

Failure Mode

Failure mode of the restoration can be classified into the following: Type I crown's Adhesive failure Debonding without the failure of fracture mode type II the crown's Cohesive failure Fracture without loss of adhesion i.e., displacement type III crown's mixed failure i.e., Cohesive-adhesive Fracture with loss of adhesion i.e., displacement (Figure 4)

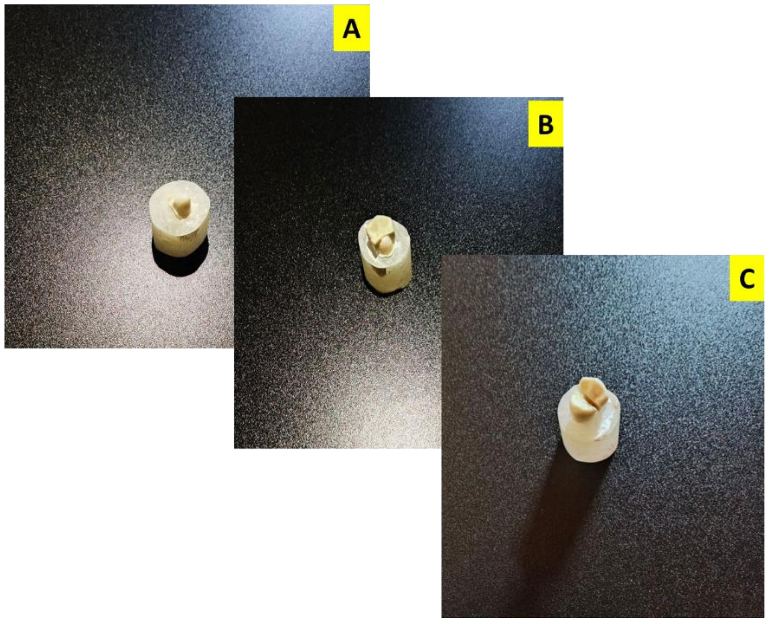

Figure 4. Failure mode (A)adhesive failure(B) cohesive failure(C)mixed

Discussion

One of the major reasons why restorations fail is because of getting fractured post the clinical use. These ceramic crown failures can be depicted either as many fragments or the crown's complete fracture and the structure of the tooth as well. Also, ceramic materials in dental sector are subjected to mechanical and thermal conditions in oral cavity (Seung-Mi, 2005). Hence, resistance of fracture of a material is described as the heaviest thing a material can bear before it gets fractured. (Alsarani, 2023).

Even so, there was on significant between techniques for the impact of the procedure on the value of resistance of fractures the samples prepared by conventional had the highest value (1336.3) and the 3Dprinting technique was the lowest one (1183.8), the highest fracture resistance for conventional technique may be because of applying pressure from external point at temperatures that are high while sintering with the traditional procedure. The glass ceramics which are heat-pressed have a few properties which was reported in the study previously, and these are the material's mechanical properties that undergoes changes and which have similar compositions of chemicals because of their structure attributed to an increased, and more uniform distribution of the leucite phase (Taha et al., 2018; Lien et al., 2015).

During manufacturing process called AM, parameters for processing like direction of deposition, also temperature as well as having the angle of contact changed between the layer of solid that is deposited and the material layer which lies next to it can result it damaging the bond which the layers of deposits have and this can have an impact on the content that is void which has a negative impact on the resistance to fractures and with that the kind of material that is selected as well as the parameters used in processing can have an impact on printed restoration's mechanical properties.

For the material's impact on the value of resistance to fractures, crowns developed from ZLS had the highest value (1473.1) and E. maxed was the least(1013.7), the highest fracture resistance of the ZLS crowns may be because of adding zirconia of up to 10% in ceramic called lithium silicate, a new creation of ceramic which consists of lithium silicate as its significant phase of crystalline in a matrix that is vitreous also combined with crystals of zirconium oxide which behaves like nucleating agent, making the entre structure of ceramic through crack interruption(Taha et al., 2018). The incorporation of 10% zirconia which is completely dissolved in the glass phase proposing a homogenous ultrafine crystalline microstructure provides this material with high strength. It was expected that the addition of zirconia to lithium disilicate ceramics would improve their fracture resistance. When zirconia for 10% is dissolved in the phase of glass, a crystalline microstructure which homogenous and ultrafine gives the material a strength of high value. The expectation was that adding zirconia in lithium silicate will make them better and strong in resistance to fractures. (Mostofi, 2016). The lowest value for E. max CAD may be due to that E .max cad the crack could enable propagation into the matrix glass and also it might be significant to have the cycle of crystallization revised according to manufacturer’s suggestion for E.max CAD, and this is because the surfaces that are fractured did not seem to be crystallized completely. It is in the glass and crystal’s interface where the propagation of crack is demonstrated to take place which results in the creation of fractures that are intergranular. (Muralidharan, 2024). From the inspections of the crowns by the naked eye we found the fracture resistance failure Figure 5.

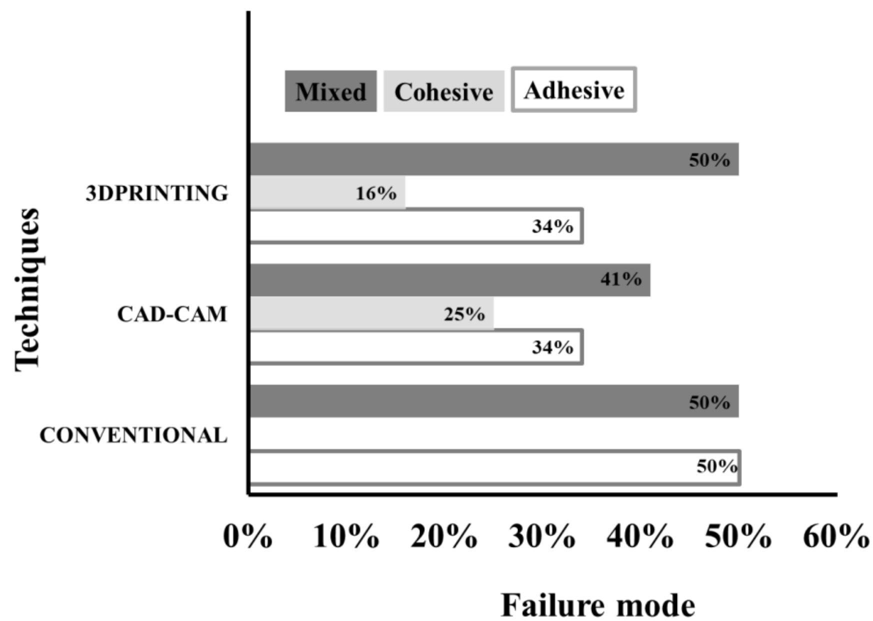

Figure 5. Bar graph for the failure mode of the techniques

The conventional technique had the highest adhesive failure may be due to the least surface roughness which makes the cement interlocking difficult and is one of the possible causes of adhesive failures. The 3D printing which uses resin using a conversion which is of a higher degree and consists of a low number of double bonds such as C=C which are accessible easily, which are essential for creation of new bonds that are covalent with the help of resin cement, so this may explain why the 3D technique had the least adhesive failure (Padma et al., 2017)

The adhesive failure of E.max cad which was at the highest and they were attributed to crystals filled in the matrix glass which were non- homogenous as well as in the shape of a needle and grained finely. Because of the micro structure of the material, the ZLS has very low adhesive failure. The reason behind a bond with higher value of strength between resin cement as well as ceramics of glass is because of the significant mechanism where molecules of silane have a reaction with water which leads to the formation of groups of silanol (-Si-OH) which are derived from groups of methoxy (-Si-O-CH3). After that the groups of silanol react in a continuous manner with surface of ceramic glass which results in the formation of a network of siloxane

(-Si-O-Si-O-). Along with that, pretreatment with silane helps in the formation of a layer which is functional and uniform and which is essential for resin's adhesion to the substrate of glass. After that, the ends which are monomeric of silane undergoes a reaction with composite resin groups that are methacrylate with the aid of a process called polymerization that is free-radical in nature, and this is as the monomers of silane have bonds of C=C. Hence, silane helps to bridge resin cement which is composite and the substrate of glass. A bond of higher strength is formed between resin and substrate of glass by polymerization of methacrylate monomer and silane as well as methacrylate monomer and a different methacrylate monomer. As an end result, resin cement's component is utilized as a significant factor which has an impact on the strength of bonding in restorations of ceramics and which also has an impact on the strength of fracture of the material. (Donmez et al., 2024; Elsayed et al., 2020) (Figure 6).

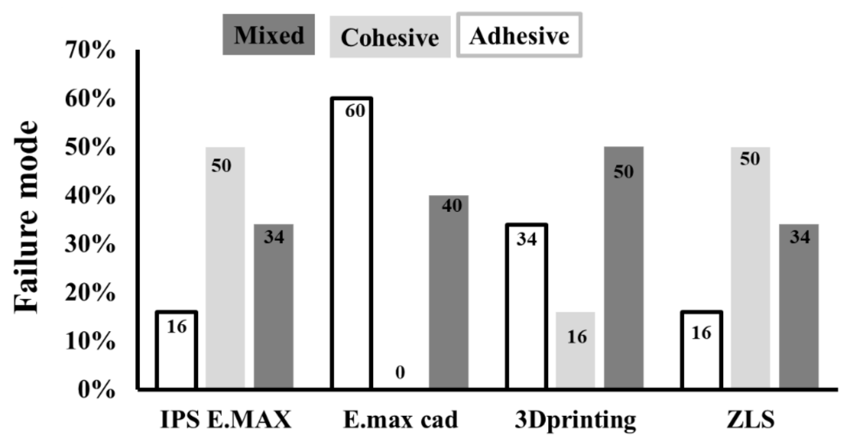

Figure 6. Clustered column graph for the failure mode of materials

Conclusion

In summary, the analysis of the interplay between material composition and preparation techniques in relation to fracture resistance has yielded noteworthy insights. The type of material employed plays a pivotal role in determining the fracture resistance value, signifying that variations in material properties can significantly influence the durability and performance of dental crowns. Conversely, the findings suggest that the specific techniques utilized in the preparation of these crowns do not exert a measurable impact on their fracture resistance, indicating that factors beyond the preparation method may be more critical in ensuring the longevity and reliability of dental restorations. This distinction underscores the necessity for practitioners to prioritize material selection when aiming to enhance the resilience of dental crowns, while also suggesting that a standardized approach to preparation techniques may suffice, as they do not adversely affect the structural integrity of the final product. Thus, future research and clinical practices should focus on optimizing material choices to achieve superior fracture resistance, ultimately improving patient outcomes in restorative dentistry.

References

Abbood, MH, & Al-Hashimi, RA (2016). In vitro comparative assessment of composite nanoleakage using various dentine surface treatments. *Journal of the College of Dentistry, University of Baghdad*, *325* (3955), 1-7.

Al Hamad, K. Q., Al-Rashdan, R. B., Al-Rashdan, B. A., & Baba, N. Z. (2021). Effect of milling protocols on trueness and precision of ceramic crowns. *Journal of Prosthodontics*, *30*(2), 171-176. https://doi.org/10.1111/jopr.13245

Alsarani, M. M. (2023). Influence of aging process and restoration thickness on the fracture resistance of provisional crowns: A comparative study. *The Saudi Dental Journal*, *35*(8), 939-945. https://doi.org/10.1016/j.sdentj.2023.07.017

Ashour, A. M., El-Kateb, M. M., & Azer, A. S. (2024). The effect of two preparation designs on the fracture resistance and marginal adaptation of two types of ceramic crowns using CAD/CAM technology (In vitro study). *BMC Oral Health*, *24*(1), 1065. https://doi.org/10.1186/s12903-024-04742-4

Bita, S., Balouch, A., & Mohammadian, T. (2021). Determination of lethal concentration (LC50) of silver nanoparticles produced by biological and chemical methods in Asian seabass fish. *International Journal of Aquatic Research and Environmental Studies*, *1*(2), 7-12. https://doi.org/10.70102/IJARES/V1I2/2

Donmez, M. B., Çakmak, G., Yılmaz, D., Schimmel, M., Abou-Ayash, S., Yilmaz, B., & Peutzfeldt, A. (2024). Bond strength of additively manufactured composite resins to dentin and titanium when bonded with dual-polymerizing resin cements. *The Journal of Prosthetic Dentistry*, *132*(5), 1067-e1. https://doi.org/10.1016/j.prosdent.2023.04.003

Elraggal, A., Aboushelib, M., Abdel Raheem, I. M., & Afifi, R. R. (2022). Effect of surface treatments on biaxial flexural strength, fatigue resistance, and fracture toughness of high versus low translucency zirconia. *BMC Oral Health*, *22*(1), 412. https://doi.org/10.1186/s12903-022-02431-8

Elsayed, M., Sherif, R., & El-khodary, N. (2020). Fracture resistance of Vita suprinity versus IPS e. max CAD vonlays restoring premolars (An in vitro study). *Int J Appl Dent Sci*, *6*(3), 734-41. https://doi.org/10.22271/oral.2020.v6.i3k.1029

Jalili, S. H., Motallebi, A. A., Noghani, F., Rahnama, M., Seifzadeh, M., & Khodabandeh, F. (2021). Amino acids profile changes of silver carp (Hypophthalmichthys molitrix) skin hydrolysate during hydrolyzing by Alcalase. *International Journal of Aquatic Research and Environmental Studies*, *1*(2), 29-37. https://doi.org/10.70102/IJARES/V1I2/4

Kollmuss, M., Kist, S., Goeke, J. E., Hickel, R., & Huth, K. C. (2016). Comparison of chairside and laboratory CAD/CAM to conventional produced all-ceramic crowns regarding morphology, occlusion, and aesthetics. *Clinical Oral Investigations*, *20*, 791-797. https://doi.org/10.1007/s00784-015-1554-9

Kumar, R., & Rao, P. (2024). Intelligent 3d Printing for Sustainable Construction. *Association Journal of Interdisciplinary Technics in Engineering Mechanics*, *2*(3), 22-29.

Lien, W., Roberts, H. W., Platt, J. A., Vandewalle, K. S., Hill, T. J., & Chu, T. M. G. (2015). Microstructural evolution and physical behavior of a lithium disilicate glass–ceramic. *Dental materials*, *31*(8), 928-940. https://doi.org/10.1016/j.dental.2015.05.003

Maha, A. M., & Nayif, M. (2013). The effect of indirect veneering materials as light interpose on microhardness of dual cured resin cements. *Al-Rafidain Dental Journal*, *13*(2), 290-295.

Malbašić, V. (2021). The Strategy of Management and Utilization of Mineral Raw Materials in The Republic of Srpska Through the Globalization Era. https://doi.org/10.7251/afts.2021.1325.017M

Mostofi, K. H. (2016). Evaluating the effect of upside and downside slope on flow hydraulic in cylindrical overflows by using Flow 3D software.

Muralidharan, J. (2024). Innovative Materials for Sustainable Construction: A Review of Current Research. *Innovative Reviews in Engineering and Science*, *1*(1), 16-20. https://doi.org/10.31838/INES/01.01.04

Øilo, M., & Gjerdet, N. R. (2013). Fractographic analyses of all-ceramic crowns: a study of 27 clinically fractured crowns. *Dental Materials*, *29*(6), e78-e84. https://doi.org/10.1016/j.dental.2013.03.018

Padma, S., Umesh, S., Asokan, S., & Srinivas, T. (2017). Bite force measurement based on fiber Bragg grating sensor. *Journal of biomedical optics*, *22*(10), 107002-107002. https://doi.org/10.1117/1.JBO.22.10.107002

Revilla-León, M., Methani, M. M., Morton, D., & Zandinejad, A. (2020). Internal and marginal discrepancies associated with stereolithography (SLA) additively manufactured zirconia crowns. *The Journal of prosthetic dentistry*, *124*(6), 730-737. https://doi.org/10.1016/j.prosdent.2019.09.018

Riyadh, M., & Nayif, M. (2020). Evaluation of different zirconia surface treatments on their microhardness. *Al-Rafidain Dental Journal*, *20*(2), 273-282. https://doi.org/10.33899/rden.2020.166475

Rosentritt, M., Hahnel, S., Engelhardt, F., Behr, M., & Preis, V. (2017). In vitro performance and fracture resistance of CAD/CAM-fabricated implant supported molar crowns. *Clinical oral investigations*, *21*, 1213-1219. https://doi.org/10.1007/s00784-016-1898-9

Sadid-Zadeh, R., Sahraoui, H., Lawson, B., & Cox, R. (2021). Assessment of tooth preparations submitted to dental laboratories for fabrication of monolithic zirconia crowns. *Dentistry Journal*, *9*(10), 112. https://doi.org/10.3390/dj9100112

Seung-Mi, J. (2005). Dimensional stability of impression body using silicone index tooth tray impression system. *The Journal of Korean Academy of Prosthodontics*, *43*(5), 622-632.

Shackori, M., Hasan, N., Qasim, A., & Abdulmajeed, A. (2024). Evaluate the Shear Bond Strength for Alkasite in Comparison with other Esthetic Restorative Materials. *Al-Rafidain Dental Journal*, *24*(1), 109-119. https://doi.org/10.33899/rdenj.2023.141870.1216

Silveira, R. C., Cruz, L. O., Marcondes, C., Rodrigues, D. C., Carolyna, D., & Freitas, R. D. (2020). Influence of types of designs of dental structure preparations for a esthetic treatments with ceramic laminates–literature review. *Int J Recent Scic Res*, *11*(03), 37901-10.

Taha, D., Spintzyk, S., Sabet, A., Wahsh, M., & Salah, T. (2018). Assessment of marginal adaptation and fracture resistance of endocrown restorations utilizing different machinable blocks subjected to thermomechanical aging. *Journal of Esthetic and Restorative Dentistry*, *30*(4), 319-328. https://doi.org/10.1111/jerd.12396

Thillaigovindan, R., Rai, R., Mishal, M., & Priya, T. (2019). Recent advances in ceramics—a review. *World J Pharm Res*, *8*, 515-24.

Ziwei, M., & Han, L. L. (2023). Scientometric Review of Sustainable Land Use and Management Research. *Aquatic Ecosystems and Environmental Frontiers*, *1*(1), 21-24.

Zlatanovska, K. A., Dimova, C., Gigovski, N., Korunoska-Stevkovska, V., & Longurova, N. (2019). Fracture localisation of porcelain veneers with different preparation designs. *Open Access Macedonian Journal of Medical Sciences*, *7*(10), 1675. https://doi.org/10.3889/oamjms.2019.323