



T.C.

YEDITEPE UNIVERSITY

INSTITUTE OF HEALTH SCIENCES

DEPARTMENT OF PROSTHETIC DENTISTRY

**IN VITRO COMPARISON OF THE SHEAR BOND
STRENGTH FOR GLASS CERAMIC LAMINATE
VENEER MATERIAL BY THE USING OF TWO
DIFFERENT ADHESIVE SYSTEMS.**

MASTER THESIS

ASMA ELBADRI, DDS.

Istanbul-2021



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THESIS APPROVAL FORM

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DECLARATION

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree except where due acknowledgment has been made in the text.



13.09.2021

ASMA ELBADRI.

DEDICATION

This thesis is dedicated to my lovely family.



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First and foremost, praise and thanks to God, almighty, for his showers of blessing throughout my thesis research to complete the work successfully.

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LIST OF ABBREVIATIONS and SYMBOLS

Al ₂ O ₃	Alumina.
ADA	American Dental Association.
Bis-GMA	Bisphenol Glycidyl Gamma Methacrylate.
BOP	Bleeding on Probing.
CAE	Computer Aided Engineering.
CAD/CAM	Computer Assisted Design/Computer Aided Manufacturing.
CTE	Coefficient of Thermal Expansion.
D-LF	Dentin - GC veneer group.
D-V	Dentin - GC veneer group.
E-LF	Enamel-linkforce veneer group.
E-V	Enamel -GC veneer group.
ED-LF	Enamel-dentin linkforce veneer group.
ED-V	Enamel-dentin GC veneer group.
E	Standard Error.
FDPs	Fixed Partial Prostheses.
Ca ₅ (PO ₄) ₃ F	Fluorapatite.
ISO	International Organization for Standardization.
Li ₂ O–SiO ₂	Lithium Oxide-Silicon Dioxide.
Li ₃ PO ₄	Lithium Orthophosphate.
MgAl ₂ O ₄ .	Magnesium Aluminate.
SBS	Macro-Shear Bond Strength.
TBS	Macro-Tensile Bond Strength.

$\bar{x}$	Mean.
MPa	Mega Pascal.
mm	Millimeter.
μ SBS	Micro-Shear Bond Strength.
μ TBS	Micro-tensile Bond Strength.
μ PO	Micro- Push-out.
Max.	Maximum.
Min.	Minimum.
N	Newton.
%	Percent.
PFM	porcelain-fused-to-metal.
PLVs	Porcelain laminate veneers.
K ₂ O	Potassium Oxide.
PO	Push-Out.
Std. $\pm$	Standard Deviation.
E	Standard Error.
Skew.	Skewness.
Y-TZP.	Yttrium-Stabilized Zirconium.
ZrO ₂	Zirconium.

ABSTRACT (ENGLISH)

El Badri, A. (2021) In Vitro Comparison Of The Shear Bond Strength For Glass Ceramic Laminate Veneer Material By The Using Of Two Different Adhesive Systems. Yeditepe University, Institute of Health Science, Department of Prosthodontics, MSc Thesis, Istanbul.

The aim of this in vitro study is to evaluate the shear bond strength of the glass ceramic laminate veneer material cemented to prepared enamel, enamel- dentin complex and and dentin surfaces with the using of two different luting systems.

Sixty sound human premolar teeth were selected, and the teeth were divided randomly into 3 groups (n = 20). The teeth were prepared as three levels for bonding surfaces of enamel (E), dentine (D), and enamel–dentine complex (E–D). The glass ceramic (GC li si press, GC Co.) was prepared into discs of 4 mm in diameter and 1.5 ± 0.2 mm high. The discs were grounded with the adhesive paper to reaches 1.2 ± 0.1 mm. Each bonding surface was divided into two subgroups (n=10). The ceramic discs were adhesively luted by using light-curing cement (GC VENEER [V], GC Co) and dual curing cement (GC Linkforce [LF], GC Co) according to the manufacture's instructions. The samples were subjected to thermocycling with 5000 cycles (50C-150C) with 15 second dwell time, shear bond strength testing by using an Instron machine with a crosshead speed of 0.5mm/minute, and failure mode analysis using a stereomicroscope. Fir statistical analysis, the One-way ANOVA test and Student's t tests were used and the significance was evaluated at the $p < 0.05$ level. There was a statistically significant difference between the three groups, with the higher shear bond strength value in the (E) group ($32,49 \text{ MPa} \pm 6,95$), followed by the (ED) group ($22,02 \text{ MPa} \pm 3,43$) and the lowest value in the (D) group ($16,78 \text{ MPa} \pm 2,46$). There was no statistically significant difference between the two types of resin cements within the groups of the same adhesion surface, The mean shear bond strength values of the (GC-V) cement groups were equal to $23,14 \text{ MPa} \pm 7,7$, and for the (GC- LF) cement groups were equal to $24,39 \text{ MPa} \pm 8,45$. The shear bond strength of porcelain laminate veneers to 3 distinct tooth structures (enamel, dentine, and enamel–dentine complex) was impacted by the type of tooth structure.

Keywords: Porcelain laminate veneers, ceramic discs, Dentine exposure, Adhesives, shear bond strength.

ÖZET (TURKISH)

El Badri, A. (2021) İki farklı yapıştırma sistemi kullanılarak cam seramik laminaların dişlere bağlanma kuvvetlerinin in vitro değerlendirilmesi. Yeditepe Üniversitesi, Sağlık Bilimleri Enstitüsü, Protetik diş tedavisi Anabilim Dalı, Yüksek Lisans Tezi, İstanbul.

Bu in vitro çalışmanın amacı, hazırlanan mine, mine-dentin kompleksi ve dentin yüzeylerine simante edilen cam-seramik laminate veneer materyalinin iki farklı yapıştırma sistemi kullanılarak kesme bağlanma mukavemetini değerlendirmektir.

Çalışmamızda 60 adet insan premolar dişi kullanılmıştır ve diş örneği hazırlık kapsamlarına göre her grupta 20 adet diş olacak şekilde üç gruba ayrılmıştır ($n = 20$). Dişler mine (E), dentin (D) ve mine-dentin kompleksi (E-D) yüzeylerinin yapıştırılması için üç seviye olarak hazırlandı. Cam seramik (GC li si press, GC Co.) 4 mm çapında ve $1,5 \pm 0,2$ mm yüksekliğinde diskler halinde hazırlanmıştır. Her yapıştırma yüzeyi iki alt gruba ($n=10$) ayrılmıştır, seramik diskler, üretim talimatlarına göre ışıkla sertleşen rezin siman (GC VENEER [V], GC Co) ve çift aşamada sertleşen (GC Linkforce [LF], GC Co) üreticilerin önerdiği kullanma talimatlarına göre simante edilmiştir. örnekler, 15 saniye dwel süresi 5000 kez (5°C - 15°C) ile termal siklusa sokulmuştur. Evrensel test makinesinde diş yüzeyi ile seramik arasındaki birleşim noktasına bağlanma kuvvetlerinin değerlendirilmiştir. örneklerini birbirinden ayrılmış adezyon yüzeyleri stereo mikroskop altında incelenmiştir. Tek yön ANOVA testi ve Student's t testleri kullanılmıştır ve istatistiksel olarak sonuçlarımız $p<0.05$ seviyesinde değerlendirilmiştir. (E) grubundaki ($32,49 \text{ MPa} \pm 6,95$) daha yüksek kesme bağı mukavemet değerine sahip üç grup arasında istatistiksel olarak anlamlı fark vardı, bunu (ED) grubu ($22,02 \text{ MPa} \pm 3,43$) ve (D) grubundaki en düşük değer ($16,78 \text{ MPa} \pm 2,46$) izlenmiştir. Aynı yapışıklık yüzeyi grupları içindeki iki reçine siman türü arasında istatistiksel olarak anlamlı bir fark yoktur, (GC-V) ışıkla sertleşen rezin sima gruplarının ortalama kesme bağlanma mukavemet değerleri ($23,14 \text{ MPa} \pm 7,7$)'ye, (GC- LF) çift aşamada sertleşen grupları için ise $24,39 \text{ MPa} \pm 8,45$ 'e eşitti. Porselen laminat kaplamaların 3 farklı diş yapısına (emaye, dentin ve emaye-dentin kompleksi) kesme bağı mukavemeti diş yapısının tipinden etkilenmiştir.

Anahtar Kelimeler: Porselen laminat vener, seramik diskler, Dentin maruziyeti, Yapıştırıcılar, kesme bağı mukavemeti.

1. INTRODUCTION and PURPOSE

Esthetic or cosmetic dentistry has recently become one of the most important fields in the dental practice and has had significant advancement for several years. In recent years, the reason for the use of dental restoration is not only to restore the loss of dental tissues due to trauma or caries, but also to repair the form and correct the color of the teeth to enhance patient self-image and social acceptance.¹ Accordingly, in order to find the proper restorations which combine the essential strength and resistance needed for the function in the posterior region with the desired esthetic qualities in the anterior regions. It has therefore become necessary to improve new materials and techniques.²

Porcelain laminate veneers (PLVs), since their introduction in 1938 by Charles Pincus, have become an esthetic alternative to conventional all-ceramic and ceramic-metal crowns.^{2,3} Nowadays, it is possible for highly esthetic-demanding patients to improve their smile design with minimally invasive tooth preparation by using ultra-thin ceramic veneer materials and new adhesive technologies.⁴ By successful use of this technique, the esthetic dentist can painlessly transform the smiles of patients with conservative, relatively quick and long-lasting esthetic results.²

Many clinical trials of the veneers revealed good clinical results, including a 20-year survival rate of 91 %.⁵ The lengthy effectiveness of porcelain laminate veneers is influenced by a variety of variables, including: (1) Tooth structure. (2) Depth of preparation. (3) Thickness and type of porcelain materials. (4) Type of resin cement and dental adhesive system (5) The morphology of the teeth and patients' functional and parafunctional activities.^{1,6} As a result the success depends upon the the clinician ability to choose the proper materials and technique to harmonize with intraoral conditions and esthetic demands.⁷

Currently, ceramic laminate veneers can be fabricated by using several ceramic materials available on the market, such as lithium disilicate, feldspathic porcelain, and lithium disilicate reinforced with zirconia.⁸ Aside from the ceramic material utilized, the preparation process is critical for the lifetime of the product (PLVs) as it was reported

that a high failure rate of these restorations is associated with large exposed dentine surfaces.⁹ So, in order to decrease the stress in porcelain and maintain an optimal bonding with the (PLVs), The preparation must be entirely in enamel. However, during the laminate preparations, It is unavoidable that significant quantities of dentine will be exposed, especially along the proximal and cervical areas.¹⁰ There are few in vitro studies reporting dentine exposure's influence on the strength of bond in porcelain laminate veneers.^{11,12}

Despite the introduction of new adhesive methods, the bond strength of enamel to porcelain remains superior to dentin to .^{13,14} The challenges associated with bonding to dentine are more difficult to solve than those associated with bonding to “enamel”, due to the unique features of the “dentine” substrate.^{15,16} The used Adhesive systems play an important role in the long-term success of porcelain veneers. It is critical to cure the resin cement properly in order to retain the best “bonding” between the porcelain and the structure of teeth. Dentists choose light curing resin cement for the cementation of porcelain laminate veneers because it has a longer working duration and better color stability than dual or chemical curing resin cements.^{17,18}

Regardless of whether the clinical studies are the best approach to assess the performance of adhesive systems. The long-term clinical trials are challenging to conduct. As a result, the clinical behaviour of dental materials to be anticipated an in vitro testing methods are still widely utilized.¹⁹ The “shear” and “tensile” bond strength tests are the most often used laboratory procedures. They are used generally to assess the binding strength of adhesive systems to dental hard tissue surfaces.²⁰

The purpose of this in vitro study: (1) to assess whether the “shear bond strength” of the porcelain veneers to enamel is comparable with the shear bond strength of the porcelain veneers to “dentin” and “enamel–dentine complex”, which in some cases occurs due to dentin exposure during the preparation. (2) to assess whether the performance of “light-curing adhesive systems” and “dual-curing adhesive systems” are compatible with each other by evaluating the porcelain's shear binding strength to the tooth surface

The null hypothesis of this study is as follows:

- (1) There is no difference in the shear bond strength of the porcelain laminate veneers to enamel, enamel–dentine complex cemented, and dentin cemented with two different resin cements.
- (2) The shear bond strength value is not affected by the type of the used adhesive resin.
- (3) Type of adhesion tooth surface does not affect the shear bond strength values.



2. LITERATURE REVIEW

2.1. Dental Veneers:

A veneer is a tooth-colored layer that is placed to the surface of a tooth as an esthetic restoration for “localized” or “generalized defects” and “intrinsic discolorations”.²¹ The process of creating a veneer (regardless of the material used) and attaching it to an etched tooth surface is known as "laminating".²² To enhance the look of an anterior tooth, a laminate veneer is a less invasive alternative to full coverage restorations.²³ A porcelain laminate veneer is a thin porcelain shell that has been bonded to the tooth structure.²⁴

There is minimal distinction between a "laminate" and a "veneer" in cosmetic dentistry. In general, the distinction between laminate and veneers is that laminate is used to preserve color whereas veneer is used to modify color. Laminates are utilized to restore the natural color of a tooth. Whereas veneers are used to modify the originally colour of the tooth to create more natural-looking restorations.

In general terms; the difference between the laminate and veneers, as laminate used to Preserve the color, where the veneer used to change the color. On other hand, in cosmetic dentistry, laminates are used to restore the original color of the tooth, whereas veneers are generally used to modify the original colour of the tooth to construct a more naturally appearing restorations.²⁵

2.2. History of Dental Veneers:

The concept of using tooth-colored shells on anterior teeth was first proposed by Charles L. Pincus in the 1930s, when he used this technique to change the appearance of the anterior teeth to encourage distinct expression of personality and character, with a focus on actors throughout filming. However, the lifespan of the initial veneers was just for few hours, as there were no proven and tested well-attaching ceramic systems or

dependable adhesive bonding methods available at the time, as a denture adhesive powder was used to temporarily adhere thin veneers.²⁶ Buonocore et al.²⁷ in 1955 studies with the acid-etch process provided a straightforward approach to improve the adherence of acrylic filling materials to enamel surfaces. Bowen et al.²⁸ developed bonding materials using bisphenol glycidyl gamma methacrylate (bis-GMA). Around the same time, but in the “1970s” and with the invention of visible-light cured composites, it became possible for the dentist to adequately shape direct composite laminate veneers by conditioning these veneers with “ethyl acetate” or “methylene chloride” liquids and luting them into the surface of the teeth by a “resin composites”.^{22,29}

Although dental veneers had previously been discovered, they were brought to the public's attention in 1975 by Rochette et al.³⁰, who used porcelain laminate veneers to repair broken incisors using a silane coupling agent. Then, in the 1980s, porcelain laminate gained popularity because of its conservative character and advancements in the etching technique and new bonding technologies. Horn HR.²³ proposed the use of a light-curing luting resin agent in 1983 for potency and convenience. In the same year, Simonsen and Calamia.³¹ demonstrated that etching the interior surface of porcelain veneers allows for greater adhesion to etched tooth enamel than acrylic or composite resin. Following that, in 1984, Calamia supported his previous study by employing silane pre-treatment to improve the etched porcelain/luting resin bonding.³² Nicholls J.I.³³ discovered in 1986 that tensile stresses are primarily responsible for the dislodgement of veneers bonded using micro filled resin materials. In 1987, Heymann HO.³⁴ shown a clinical procedure for indirect composite resin veneers. Reid J.S.³⁵ in 1988 investigated the change in tooth color using veneers and discovered a technique to enhance the look of discolored teeth with naturally looking results rather than just hiding the discoloration.

Graber A.³⁶ conducted a comparison of “direct composite veneer” and “etched porcelain laminate veneers” in 1989, he believed that the direct bonding composite repair would be replaced by an etched porcelain restoration. Robert and Jankowski³⁷ described the provisionalization of porcelain laminate veneer (PLVs) using light cure acrylic resin in 1991. Rouse S.³⁸ in 1997, addressed conventional veneer preparations with interproximal expansions. In 2000, Dumfahrt and Herbert³⁹, conducted a retrospective

research of (PLVs) extending from 14 months to 127 months and assessed 191 (PLVs), concluding that (1) the expectation for PLV survival was 97% at 5 years and 91% at 12 years (2) the failure increased when the finishing line was in the filing materials (3) the success of veneers was impacted by the patients' occlusion condition (4) when the veneer margin was in dentin marginal integrity and discoloration were unsatisfactory (5) The dentin resin cement was the weakest bonding link; (6) when the veneers' margins were located on the gingival margin or sub gingivally, the papillary bleeding on probing (BOP) and recession were increased; and (7) wearing time had a significant effect on the surface of the porcelain, marginal integrity, and marginal discoloration.

In the same year, Peumans et al.¹ found that a positive outcome was reached when the preparation was completely in enamel and a proper surface treatment was given, and they also noted that the wide margin difference was relatively the primary defect of porcelain veneers. Bertil et al.⁴⁰ described the use of “Procera all ceram laminates” for the treatment of patients with stained teeth in 2001. Magne and Belser⁴¹ explained in details the use of a diagnostic mock-up for porcelain laminate preparation in 2004. Cherukara et al.⁹ in 2005 examined the efficiency of three clinical intra enamel preparation procedures (dimple, depth groove, and freehand) in 2005, and determined that there was no significant difference between the three groups in the preservation of the enamel. Zarone et al.⁴² (2006) stated that “chamfer preparation” is the most recommended for central incisors, Canines, on the other hand, benefit from "window preparation."

2.3. Advantages of Porcelain Veneers

The main advantages of porcelain veneers as following: (1) Due to the naturally appearing stable colour, smooth surface texture, and porcelain crystalline structure.⁴³ Furthermore, porcelain may be stained in different shades, allowing for color change, giving the dentist more flexibility in adjusting the final shade.⁴⁴ Highly acceptable bond strength. when compared to other veneering materials, the bonding of etched porcelain veneers to enamel is regarded to be the strongest, with bond strengths ranging from “17.9 to 22.1 MPa” for silane-treated etched porcelain veneers and just “6.2–9.7 MPa” for

composite resin veneers. (3) characteristic porcelain strength that allows reshaping of the teeth. Despite the fact that porcelain veneers are brittle, the restoration establishes significant "tensile" and "shear" strengths after it is bound to enamel.^{45,46} (4) The highly glazed porcelain surface has a reduced chance of plaque formation than any other veneer material due to its great biocompatibility with gingival tissues.⁴⁷ last for long time, Because bonded porcelain veneers create strong "tensile" and "shear" strengths while remaining in place, they are a good option. A five-year clinical trial of 186 porcelain veneers applied to 61 patients, for example, found a 98.4% survival rate.⁴⁸ Fradeani et al. discovered that 182 "porcelain veneers" had a 94.4 % chance of surviving after 12 years.⁴⁹ (5) Excellent wear and abrasion resistance,⁵⁰ and considerable resistance to staining, because porcelain has few gaps and imperfections that might collect stain under a microscope. When compared to composite resin veneers, They are more resistant to the negative effects of solvents such as drugs, alcohol, and cosmetics.⁵¹ Much less prone to absorb oral fluids than other materials, as water absorption by resin veneers causes physical characteristics to deteriorate over time, increasing the risk of wear.^{50,52} (6) Laster retention on the surface, Composite resins need to be polished often since they lose their shine over time, but porcelain can keep its glazed appearance for the lifetime of the restorations.(7) Because the radiolucency of the porcelain is equivalent to that of natural tooth structure, radiological access to regions that would otherwise be covered by radiopaque restorations is possible.⁴⁴

2.4. Disadvantages of Porcelain Veneers

The main disadvantages of porcelain veneers as following: (1) Difficult to repair. "Porcelain veneers" can be repaired by using composites, but the repairs are not long-lasting because the veneers tend to stain at the margin of "composite resin" and "porcelain". On the other hand, Kimmich and Stappert 2013 mentioned that porcelain can be repaired using "hydrofluoric acid" for 1 min or by using the "Co Jet system" to create surface roughness porcelain intra orally.⁵³ The veneers are then "silanated" and covered with an "unfilled resin layer", followed by a colour matched composite repair. However, the disadvantages of time and complexity, as well as the repair's unlimited endurance,

remain. (2) Difficult to modify the color once bonded in position. Irreversible preparation. Unlike direct composite resin bonding, which requires little or no preparation. (3) The highly fragile and complicated to manufacture and manage for the dental technician leads to increasing time and cost. Technical challenges in avoiding excessively contoured restorations and achieving closely fitting porcelain/enamel margins. Because the edge is fragile and difficult to complete.⁴⁴ (4) Consequently, “stannous fluoride paste” should be avoided with any porcelain materials. It is advisable to avoid “air-polishing prophylaxis systems”. In addition to that, dental hygienists should avoid the use of ultrasonic scalers in periodontal treatment particularly in the areas around “gingival margins”.⁵⁴

2.5. Indications of The Porcelain Veneers

Ceramic laminate veneers are used for three reasons: tooth discolouration that is resistant to a variety of bleaching techniques, the need for substantial alteration in the form of the anterior area, and the restoration of anterior teeth that have been destroyed.⁴¹ Classic veneer indications are listed in **(Table 1)**

Table 1: Classic veneer indications according to Magne and Belser.

Type I	Moderate tooth discolorations/ color corrections: Tetracycline Fluorides Amelogenesis imperfecta
Type II:	Anatomical malformations/corrections of position: Type IIa: Conoid teeth Type IIb: Diastemata Type IIc: Incisal edge lengthening
Type III:	Extensive damage/changes in form: Type IIIa: Extensive coronal fractures Type IIIb: Congenital and acquired malformations

Porcelain veneers' capacity to alter and conceal the teeth makes them a suitable technique for a variety of clinical circumstances, along with those listed below. (1) Mild to moderate discolorations in the teeth which are not responsive to vital bleaching, such as fluorosis, staining by tetracycline, and teeth darkened by age or devitalization.²² Furthermore, Veneers can help with widespread mild anterior tooth discolouration caused by amalgam "shine-through".⁵⁵ (2) Surface defects, such as small cracks in the enamel due to "aging", "trauma", or "chewing of ice", may cause weakening and dark discoloration of the enamel. In some cases, porcelain veneers can cover the discoloration while also strengthening the teeth. (3) Replacing the "missing" or "fractured parts" of the teeth.⁵⁶ (4) Diastemas Closing one or several gaps between the teeth., and enhancing the look of "rotated" or "mal-positioned" teeth. People with generally healthy teeth who avoid orthodontic treatment might benefit from veneers that provide the appearance of straight teeth. (5) Short teeth are elongated to give a more aesthetically pleasing look of straight teeth. (6) Elongation of short teeth to create a more aesthetic appearance.⁵⁵ (7) Teeth that are "mal-occluded" or have periodontal problems. "Porcelain veneers" can be used to repair or alter anterior teeth's lingual surfaces, in order to create greater guiding. Furthermore, porcelain veneers can be utilized to reshape interproximal embrasure gaps in cases of gingival tissue recession. (8) The congenitally missing lateral incisor. When the lateral incisors are congenitally absent, porcelain veneer can aid when the cuspid emerges next to the central incisor by generating a distinct coronal shape of the cuspid that mimics the form of the lateral incisor. Because the cuspid is frequently overly wide, this procedure may need to be coupled with veneers on the central incisors to achieve a more optimal ratio in the relative percentage of the teeth. (9) The treatment of wear in the anterior teeth. If no significant length increase is required. To restore the appearance, colour, or performance of the teeth, porcelain veneers can be bonded to the remaining tooth structure. Porcelain veneers can even be utilized to restore the teeth which harmed by the symptoms of "anorexia nervosa" or "bulimia", assuming the parafunctional behaviour is under control. (10) unsatisfactory colour of functionally sound ceramic-metal or all ceramic crowns.⁵⁵ This procedure is performed using the same steps used for preparing the conventional veneer. Because the expense of this treatment is almost the same as that of a new crown, it should be reserved for patients who refuse to have their complete "crown" or extended "fixed dental prosthesis" replaced.⁵³

2.6. Contraindications For Porcelain Veneers

The ceramic laminate veneer contra indicated in the following situation: (1) Patients with “bruxism” or “parafunctional habits” such as pencil chewing or ice crushing may place excessive stress on the “porcelain veneers”. (2) Little Enamel Available for Bonding. Ideally, the veneer periphery should be in enamel for better adhesion and more critically, to adhere the veneer to the tooth surface.⁵⁷ Furthermore, bonding to dentin are often less effective and reliable than bonds to enamel. So that If the tooth or teeth are composed mainly of dentin and cementum, the preferable treatment are more extended veneer restorations or crowning with the using of high strength ceramics.^{57,58} (3) Some sorts of occlusions may cause issues. “Class III” and edge to edge bites are examples of this. Nonetheless, in these circumstances, reshaping the lower incisors and “building out” the upper incisors may be used. (4) Because primary teeth and teeth that have been excessively “fluoridated” may not etch successfully, extra-aggressive roughening of the "enamel/dentin surface" using an air abrasion in conjunction with good bonding chemicals may be necessary to produce a good veneer.⁵⁹

2.7. Preparation Design of Laminate Veneers

The desire to enhance the laminate veneers survival rate was driven not only by various attempts to improve the materials, but also by the introduction of new preparation designs into the field of “porcelain laminate veneers”. There are four distinct common preparation designs, as stated in the literature.^{60–63} (**Figure 1**): (1) “window preparation”: in which the incisal edge is preserved as the tooth is prepared. (2) “Feather preparation”: It involves the bucco-palataly preparation of the incisal edge without the reduction of the incisal edge. (3) “Bevel preparation”: The incisal edge of the tooth is constructed bucco-palataly, with a little decrease of the incisal edge of the tooth of around one millimeter (0.5-1mm). (4) “Incisal overlap preparation”: The veneer preparation was extended to the palatal surface as the tooth was prepared bucco-palataly with the incisal edge reduced by roughly one millimeter (2mm).

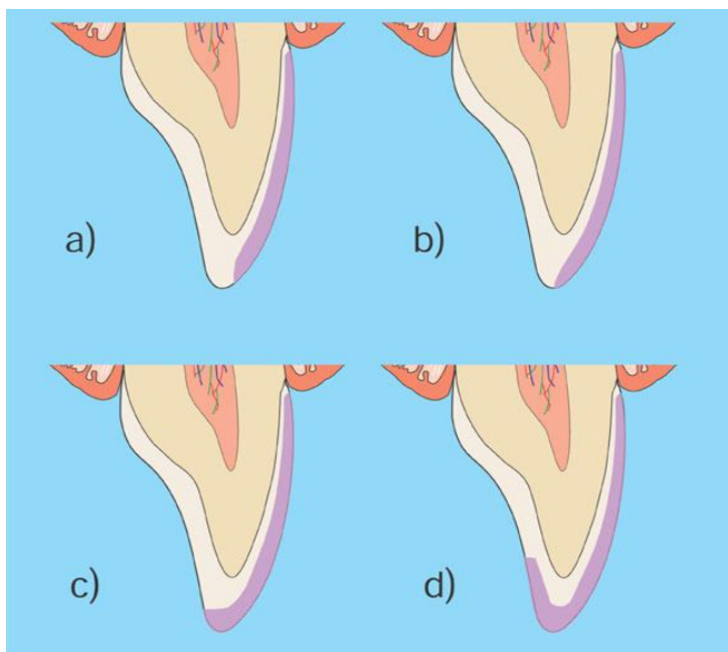


Figure 1: Showing common veneer preparations a) window b) feather c) bevel d) incisal overlap.⁶⁴

2.8. Influence of Preparation Design on The Survival of Dental Veneers

Unfortunately, clinical trials examining the long-term survival of “dental veneers” according to preparation designs are considered to be limited, owing to the presence of several factors that might impact the life of the veneer treatment if assessed clinically.^{1,62} As a result, several in vitro investigations were conducted to assess the influence of pre-treatment design on veneer long term survival. Despite the fact that these in vitro studies could not provide insight into actual clinical circumstances, they might provide clinicians with guidelines for further clinical research.⁶⁵

Some preparation design requirements are highly recommended in most literatures and in vitro research, such as limiting the preparation to just involve the enamel, which is regarded a significant component for bonding strength and a longer-lasting outcome.^{1,66–68 1,66–68} The maintenance of interproximal contact, as explained by greater enamel and tooth structure preservation, is another suggestion in different literatures.^{58,68–70}

In some cases, such as with misaligned teeth and diastema closure, the clinician must extend the reduction to the interproximal area in order to get a better esthetic result.^{71,72} Furthermore, several publications advocate a labial decrease of 0.4-0.7 mm for “ceramic veneers”.^{43,73,74} The most effective support for the restoration appears to be incisal overlap preparation, which distributes occlusal pressures across a greater surface area. The incisal third receives a lot of occlusal force during the window preparation, which might cause the restoration to fracture. In addition, when the incisal edge is decreased, incisal translucency is improved.^{60,62,71,75} However, whether adding a “chamfer finish line” or having a “shoulder finish line (butt joint)” is preferable is debatable. According to Troedson and Dérand¹¹ and Zarone et al.⁷⁶, a “palatable chamfer finish line” is necessary for the restoration to withstand occlusal loading stress.

Likewise, Castelnovo et al.⁶⁰, claimed that a “chamfer finish line” did not improve the restoration's lifespan. They also stated that veneers with a “butt-joint” end line might give more than one way of insertion. However, having one insertion path might be beneficial since it prevents the veneer from shifting during final cementation. Finally, the study concluded that an overlap preparation with “chamfer end line” did not reduce the treatment's lifespan or predictability.

Furthermore, the force biting for the anterior teeth is regarded as low (100–200 N).⁷⁷ In the absence of a clear, well-studied “clinical trial”, the choice of preparation design is primarily based on the clinician's decision, however “incisal overlap” may always be used to restore the guidance of the anterior area.⁷⁸

2.9. Dental Ceramics

Ceramic is a non-metallic inorganic substance that is fired at a high temperature to achieve desired mechanical and optical characteristics. Ceramics must meet particular criteria to be utilized in everyday dentistry, including appropriate toughness to survive fracture propagation, sufficient mechanical strength to withstand occlusal pressures, and predicted in vivo performance exhibiting long-lasting and durable properties.⁷⁹

For more than a century, ceramics have been the foundation of aesthetic dentistry. Ceramics were first utilized mostly for “porcelain jacket crowns”, “denture teeth”, and “partial covering” in the naturally occurring feldspathic form. Since the invention of aluminous porcelain by John McLean in the mid-1960s, there has been ongoing improvement in “strength”, “aesthetics”, and “manufacturing processes”, resulting in a variety of possibilities for professionals to choose from.⁸⁰

2. 9. 1. Classification of Dental Ceramics

The most recent classification for dental ceramics was created after the American Dental Association (ADA) classified resin-matrix materials as "ceramics" since they exhibit ceramic-like characteristics and should not be neglected in any system of classification.⁸¹ Dental ceramics are categorized by Gracis et al.⁸² into three groups depending on the existence of particular properties in their formulation, as shown in **(Figure 2)**: “glass-matrix ceramics”, “polycrystalline ceramics”, and “resin-matrix ceramics”.

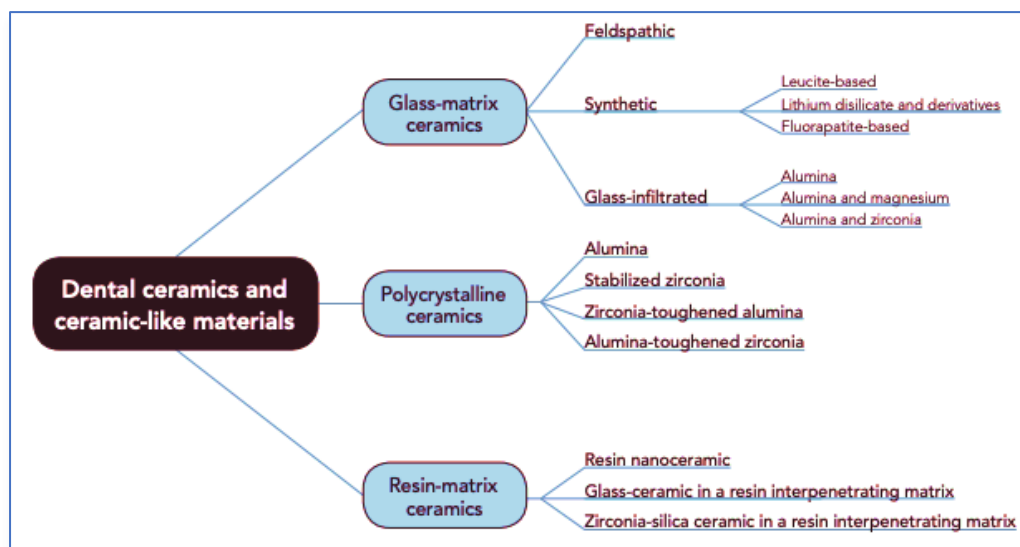


Figure 2: Overview of the proposed classification system of all-ceramic and ceramic-like materials by Gracis et al.⁸²

2. 9. 2. Glass Matrix Ceramics

They are non-metallic inorganic multiphase ceramics that are mostly made of a residual glass phase with precisely distributed crystalline phases.^{82 82} Glassy ceramics are often made by precisely crystallizing the glass and dispensing it uniformly throughout the “glass phase”, or alternatively, one or more crystals can be embedded in the structure.⁸³

2.9.2.1. The History of Dental Glass–Ceramics

Humans since long time recognized the medicinal and cosmetic important of tooth replacements. Ancient Egyptians utilized bovine teeth for esthetic tooth replacement. Dental ceramic materials were created in the 18th century as esthetically pleasing dental restorations.⁸⁴ The first two United States patents for “porcelain–fused–to–metal (PFM)” restorations composed of gold alloy and feldspathic porcelain were awarded in 1962. As a result, “PFM restorations” have become the popular choice for multiple teeth repair. In spite of the wide range for using the “PFM restorations”, The use of metals inside the oral cavity had a number of drawbacks, including biological incompatibility and veneering layer chipping due to the different in “coefficient of thermal expansion (CTE)” between the veneering porcelain layer and the metal framework expansion (CTE) between the veneering porcelain layer and the metal framework.⁸⁵

All ceramic restorations have been offered on the market since the 1980s. Because of its outstanding mechanical characteristics, “yttrium-stabilized ZrO₂ (Y-TZP)” has grown in favour. However, because Y-TZP has a low translucency, To make visually appealing restorations, a veneering layer is required.⁸⁶ Even though chipping is still an issue, the invention of “monolithic restorations” with enhanced strength and translucency has propelled the growth of multi-layered dental restorations.

Dental glass ceramics are very appealing to both dentists and patients because of its outstanding “physical” and “chemical” qualities, such as the good aesthetically appearance, low heat conduction, sufficient strength, nontoxicity with dental tissues,

resistance to wear, and chemical resistance.⁸⁷ In 1984, Corning incorporation was the first to who manufactured dental replacement with glass ceramics.⁸⁸

Many attempts were made to strengthen the glass ceramics, with dispersion strengthening being one of the most well-known approaches. The first particle filler utilized to strengthen dental glass ceramics was Leucite, which has a strength properties of 138 MPa.⁸⁹ Currently, lithium disilicate is added to create the most extensively used, hardest, and strongest dental ceramics. The glass ceramic contains approximately 70% of its volume in interlocked rod-like lithium disilicate crystals with “flexural strength of 350 MPa” and “fracture toughness of 2.9 MPa m^{1/2}.”⁹⁰

2.9.2.2. Microstructure of Glass–Ceramic

To be more specific, the word "glass" refers to a state of matter in which the atoms or molecules are arbitrarily oriented, indicating that the glass materials are amorphous **(Figure 3a)**. **(Figure 3d)** depicts a glass in a Li₂O–SiO₂ system with somewhat brighter contrast droplets embedded in a darker contrast glass matrix.⁹¹ The metastable immiscibility in a binary Li₂O–SiO₂ system causes the glass phase to separate into droplet-like zones of Li-rich phase and SiO₂-rich glass matrix.⁹¹

Ceramic materials are mostly composed of crystalline grains with a few glass phases present at grain boundaries **(Figure 3c)**. **(Figure 3f)** depicts the microstructure of zirconia toughened alumina ceramic, in which ZrO₂ grains (light contrast) and Al₂O₃ grains (dark contrast) are connected by grain boundaries.⁹² Glass–ceramics, on the other hand, are thought to represent a distinct class of materials comprised of at least one crystalline phase embedded in a glass matrix.

The crystallinity ranges from 30% to 70%, with two types of interfaces: one between the crystalline phases and the other between the crystalline phase and the glassy matrix. **(Figure 3e)** shows the microstructure of a lithium disilicate glass–ceramic with the glassy phase removed by acid etching, leading in a rod-like Li₂Si₂O₅ crystalline phase with a length of 3 to 6 μm.

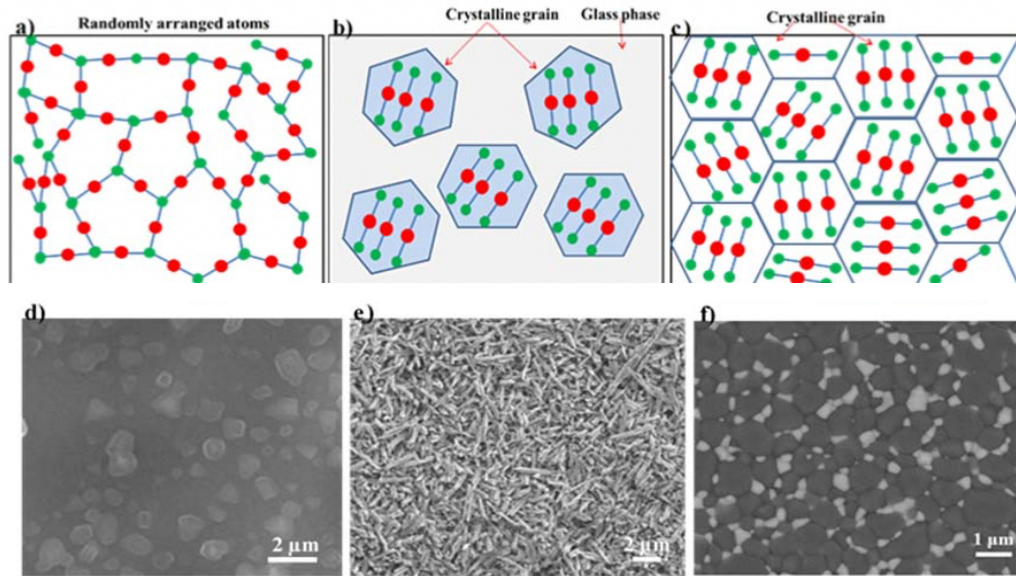


Figure 3. Microstructure differences between glass, glass ceramic, and ceramic.⁹³

2.9.2.3. The Commercially Available and Newly Developed Dental Glass Ceramic Materials

- **Feldspathic Ceramics**

These types of ceramics are known as conventional ceramics and are made up of three primary components: quartz, feldspate, and kaolin, with “silica dioxide” serving as the fundamental component. The primary components of feldspars are “silica dioxide (60-64%)” and “aluminum oxide (20-23%)”, which are modified in various methods to produce glass that may be utilized in restorations.^{94,95}

Feldspathic porcelain has poor mechanical characteristics, with “flexural strengths ranging from 60 to 70 MPa”.^{94 94} As a result of its high glass content, it is regarded to be more prone to fail under “mechanical stress”; thus, (CLVs) constructed from feldspathic porcelains get their toughness from a suitable bond combined with a stronger enamel base.⁹⁶ It is feasible to achieve a veneer layer of not more than 0.5 mm with Feldspathic porcelain. The existence of at least 50 % enamel, 50 % of the substrate

being enamel, and at least 70 % the margin should be in sound enamel are optimal situations for the success of the feldspathic veneers.⁹⁶

Traditionally, feldspathic ceramic was made by using “refractory dies” to support the condensed ceramic layers (layering technique).²³ Despite the fact that this approach allows integrated layers to be controlled well by the dental technician, leading to a “natural-looking restoration”, it is considered a technically sensitive treatment.⁹⁷

The machined feldspathic ceramics are now accessible in chairside CAD/CAM (computer assisted design/computer aided manufacturing) to address these challenges in the manufacture of feldspathic porcelain laminate veneers.⁹⁸ When compared to ordinary feldspathic porcelain, the machinable feldspathic porcelain, Vita Mark II (Vita Zahnfabrik, Bad Sackingen, Germany), was introduced in 1990 for the CEREC 1 system (Siemens AG, Bensheim, Germany), with enhanced strength and finer grain size (4 µm).⁹⁹ It is made up of 60% - 64% SiO₂ and 20% - 23% Al₂O₃ and may be etched with “hydrofluoric acid” to produce mechanical retention to “adhesive resin cement”. Despite the fact that this product is monochromatic, it is available in a number of colors, including the traditional line Vita shades, Vitapan 3D-Master shades, VITABLOCS Esthetic Line, and bleached shades.¹⁰⁰ To address the visual drawbacks of a monochromatic restoration, a multicoloured ceramic block (VITA Triluxe Bloc, VITA Zahnfabrik) was added to create a multilayer three-dimensional component. It features a black opaque inner base layer, a neutral zone in the middle, and a translucent outer layer.¹⁰¹

The use of feldspathic porcelain in the manufacture of ceramic laminate veneer will permits the considerable results. 1) The repair of the original colour of teeth even when a thin coating of material is used, 2) cheap technical cost as opposite to other ceramic. 3) better mechanical retention after “hydrofluoric acid etching” and with sufficient enamel. 4) outstanding bonding properties with other ceramic systems.¹⁰²

▪ **Synthetic Glass Ceramics**

When compared to “feldspathic porcelain”, “synthetic glass ceramics” offer superior mechanical fracture resistance, resistance to excessive heat, and resistance to corrosion. This increase in mechanical characteristics is dependent on the interaction between the “crystals” and “the glassy matrix”, and the size and number of crystals.¹⁰³

Depending on the chemical composition and the position of the implanted crystals in the matrix, either opaque or transparent glass ceramics will be introduced. The inclusion of appropriate fillers that are spread uniformly throughout the glass, such as leucite and lithium disilicate, increases the strength of glassy ceramics.¹⁰⁴ Because of their exceptional optical characteristics and acid sensitivity, “leucite” and “lithium disilicate” reinforced ceramics are recommended for veneers fabrication.¹⁰⁵

As the glass matrix is penetrated by micron-sized crystals of “leucite” and “lithium disilicate”, resulting in a densely packed “glass matrix”, the flexure strength of a “glass-based ceramics” increases depending on the form and volume of the included crystals.⁹⁵

• **Leucite Glass-Ceramics**

Traditionally; “Leucite glass-ceramics” were created by crystallizing leucite in the same ternary phase system “(SiO₂–Al₂O₃–K₂O)” as traditional feldspathic material, but with a higher K₂O concentration of not more than 12 wt. %. To increase the biomechanical qualities of the materials, “leucite glass-ceramics” have a 35–45 % of their volume composed of 1–5 μm of random densely distributed crystals in a glassy matrix.¹⁰⁶ “VITA VMK 68 (VITA Zahnfabrik, Bad Säckingen, Germany)” were launched in the late 1960s as the first powder liquid system utilized in metal ceramic repair. “IPS Empress (Ivoclar Vivadent, Schaan, Liechtenstein)” was created in the early 1990s to solve the problem of shrinkage in powder liquid systems, along with the development of the “lost wax press technique” as a new “processing method” for “ceramic restorations”.¹⁰⁴

It is composed of 50-55 % “leucite crystals” with an index of refraction not far from that of feldspathic ceramics. Furthermore, “leucite reinforced ceramics” have a faster etching rate than base glass, resulting in a strong micromechanical bond by providing micro features for resin cements to enter within.¹⁰⁷

Another leucite reinforced ceramic “IPS ProCAD (Ivoclar Vivadent)” was launched in 1998 for use with the “CEREC inLab system (Sirona Dental Systems, Bensheim, Germany)” with a more refined particle sizes and available in a variety of colors including “bleached shade” and an “esthetic block line”.¹⁰⁰

- **Lithium Disilicate Glass Ceramic**

Lithium disilicate glass ceramic is a well-known synthetic glass-ceramic based on the “SiO₂–Li₂O system” that is composed of rod-like randomly located “lithium disilicate crystals” at higher concentrations of up to 70% with lower concentrations of “lithium orthophosphate (Li₃PO₄) crystals” disperse within the glass matrix.¹⁰⁸ The higher concentration of “crystalline phase”, It is made up of finely interlocked lithium disilicate crystals 5 mm long and 0.8 mm wide, and the interlocking matrix of this “synthetic glass ceramic” result in significantly higher strength of approximately 350 MPa and fracture toughness of 2.5 MPa m^{1/2} when compared to “feldspathic porcelain”.⁸⁷

The thermodynamic expansion difference between “lithium disilicate crystals” and the “glassy matrix” causes compressive pressures out at the crystals, which may be responsible for fracture resistance and enhanced strength. Multiple fracture deflections are caused by the alignment of the crystal after heat pressing the lithium disilicate glass ceramic. In 1998 IPS Empress 2 (Ivoclar Vivadent) was introduced as true glass ceramics with a “lithium disilicate” crystal content of 70%.¹⁰⁹

The translucency of dental materials is influenced by a number of things, including (1) the crystalline/glass phase ratio, (2) the difference in refractive index value between these phases, (3) the special morphology of crystals, (4) pores of the grain

boundaries, (5) the component of the second-phase, (6) additives, and (7) light scattering from the surface. When the two phases have completely different refractive indices, high crystallinity is generally coupled with high opacity. As a result, the remarkable translucency of “lithium disilicate glass-ceramics” is due to the refractive index matching around the “crystal phase” and the “glass matrix”.¹¹⁰

Long-term clinical investigations revealed that the crowns constructed from anterior and posterior IPS Empress 2 have high survival rates (95.5 % for 10 years). Clinical success of three-unit IPS Empress two-unit fixed partial prostheses (FDPs) is mostly restricted by failure of the bulk fracture in the area of the connection, especially when the size of connection is smaller than the required specifications (about 70 % survival rate after 5 years 20).¹¹¹

The pressable lithium disilicate ceramic is intended for construction of monolithic “inlays”, “onlays”, and “posterior crowns”, as well as a core material for “crowns” and “3-unit FDPs” in the anterior area. In 200, Ivoclar Vivadent introduced IPS e-max press (Ivoclar Vivadent) as an modified “press-ceramic material” compared to IPS Empress ceramic. It gains improved physical attributes and translucency and gain different crystal volume. The refractive index of IPS e-max press ceramics are more translucent than IPS Empress and IPS Empress II ceramics due to the different in refraction index.¹⁰⁴ crowns (96,6% after 3 years),¹¹² “monolithic inlay retained FDPs” (100% after 4 years),⁹⁵ and “full crown retained FDPs” (93% after 8 years).¹¹³

A lithium disilicate glass ceramic (IPS e.max CAD, Ivoclar Vivadent) has recently been developed for the (CAD/CAM) processing technologies. A two-stage crystallization technique is used to these milled lithium disilicate blocks. During the first stage, the precipitation of “lithium disilicate” crystals resulting in a glass ceramic with range of 0.2 to 1.0 mm of crystal size, roughly 40% volume lithium metasilicate crystals, and a “flexural strength” of 130 to 150 MPa. This allowing for more less complicating machining and easier intraoral modification. After milling at 850 °C in vacuum, the final crystallization process occurs, with dissolution of the meta-silicate crystal phase and crystallization of the “lithium disilicate”. This technique also transforms the pre-crystallized block's blue shade to the necessary tooth shade, resulting in a glass ceramic

with a small size of the grain about 1.5 μ m and the inclusion of 70% “crystal volume” in a “glass ceramic”, after milling at 850 °C in vacuum resulting in final crystallization process with dissolution of the meta- silicate crystal phase and crystallization of the “lithium disilicate”. This technique also changes the blue shade of the pre-crystallized block to the desired shade, yielding a glass ceramic with a small grain size of roughly 1.5 μ m and a crystal volume incorporation of 70% in a glass ceramic.¹¹⁴

The CAD/CAM-processed lithium disilicate glass ceramic has a “flexural strength” of 360 MPa. It is approved for “anterior or posterior crowns”, “implant” “crowns” “inlays”, “onlays”, and “veneers”. Preliminary clinical trials on single crowns revealed a good survival rate (100 % after 2 years).¹¹⁵

Celtra Duo (Dentsply Sirona, York, PA) is one of the market's newest “lithium silicate-based ceramics”. It is a zirconia-reinforced lithium silicate containing around 10% “zirconium oxide”. According to the company, the high mechanical strength is due to the smaller ceramic crystal size and ultrafine microstructure. Celtra Duo lithium silicate-based ceramics are recommended for crowns and bonded partial crowns. They are offered as pressable or machined blocks.¹¹⁶

Another newly introduced lithium silicate-based ceramic is “GC Initial LiSi Press (GC Co., Tokyo, Japan)”. They are characterized by multi-layered rod-shaped and platelet-shaped crystals with approximately equal length and a high aspect ratio to form this special interlocking microstructure. This leads to excellent mechanical and optical properties.¹¹⁷ This unique interlocking microstructure distinguishes the GC Initial LiSi Press from other lithium disilicate ceramics (**Figure 4**). The multi-layered structure of lithium disilicate (LS2) crystals in the Initial LiSi Press is due to epitaxial growth on heterogeneous nuclei produced by additional nucleating chemicals.¹¹⁸ Furthermore, the high optical characteristics of this material result from a linear well-organized crystalline structure, which improves the transmittance of these materials.¹⁰⁸

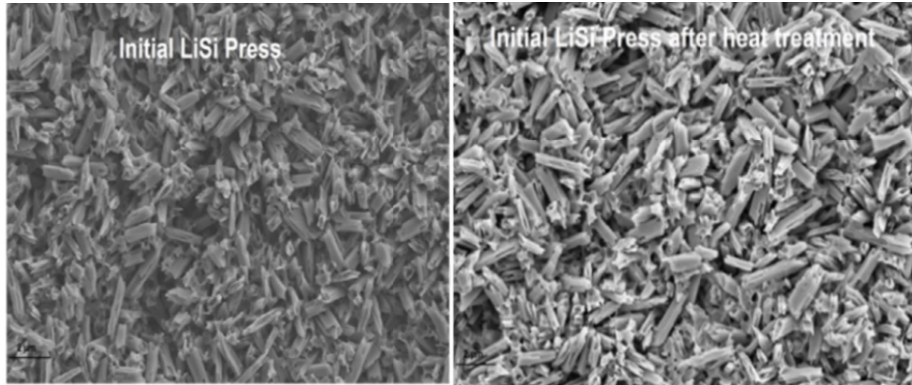


Figure 4: Showing the unique microstructure of initial li si press ceramic before and after heat treatment.

- **Fluorapatite-Based Ceramics** (eg, IPS e.max Ceram, ZirPress, Ivoclar Vivadent)

This veneer porcelain material is made of “fluorapatite crystals” in an “aluminosilicate glass” and may be placed over the core to produce a restoration with its final shade and shape. Fluorapatite is a kind of calcium phosphate that contains “fluoride ($\text{Ca}_5(\text{PO}_4)_3\text{F}$)”. Flexural strength increased to over 360 MPa, which is around three times that of IPS Empress.¹¹⁹ The presence of fluorapatite crystals contributes to optical features and the (CTE). So that it matches both “pressable” and “machinable” lithium disilicate ceramics.¹²⁰

- **Glass-Infiltrated**

- **Alumina (eg, In-Ceram Alumina, Vita)**

The firstly introduced glass-infiltrated partially sintered alumina ceramic (In-Ceram). It was introduced in 1989. It used a slip-casting technique, which included the formation of skeleton by densely packed alumina particles (70–80 wt %), followed by another firing at 1100 °C for 4 hours, which included the infiltration of lanthanum glass to fill the porosity and increase the strength.¹²¹ The inserted alumina particles were classified as “elongated big grains” (10 to 12 μm long and 2.5 to 4 μm broad), “faceted grains” (1 to 4 μm diameter), and “round grains” (less than 1 μm diameter). In-Ceram

ceramic has exceptionally high flexural strengths, which are three to four times that of conventional ceramics.¹²²

- **Alumina and Magnesium (eg, In-Ceram Spinell, Vita)**

In-Ceram Spinell, developed in 1994. It produced in the same way as in-ceram, but with the addition of porous magnesium aluminate (MgAl_2O_4) as the core material to improve optical characteristics. the translucency increased to approximately 25%. However, this increase in translucency comes at the price of their strength.¹²³

- **Alumina and Zirconia (eg, In-Ceram Zirconia, Vita)**

In-Ceram Zirconia is a variation of In-Ceram Alumina in which the zirconia oxide is introduced to the Al_2O_3 core to improve the ceramic's strength. According to the manufacturer, it is made up of “ Al_2O_3 (62%), ZnO (20%), La_2O_3 (12%), SiO_2 (4.5%), CaO (0.8%), and other oxides (0.7 %)”.¹²⁴

2. 9. 3. Dental Ceramics Processing Techniques

Processing procedures have a stronger relationship with clinical success or failure of dental ceramics. The technique of processing either improves or diminishes the final qualities. There are several ways for processing various ceramic materials. For dentistry can be roughly characterized as follows:

2.9.3.1. Powder/Liquid Building

Combining ceramic powder with a special liquid is considered as the ordinary processing technique. The process involves the construction of a core from either ceramic or metal. This occur by manual handling of the powder/liquid ceramic slurry condensed by using a brush or spatula is the condensation method. The slurry is vibrated to remove excess exclude the liquid to the surface. In this method it is critical to remove any voids which may results in weak restoration.

The built-up ceramics are then burned at a special temperature. This process is known as sintering, in which the moisture is removed during the process. When the firing temperature is reached, the particles connect at the fusion point, leading to densification by viscous flow. To account for densification or shrinkage throughout the fire cycle, restorations are frequently "over-contoured" by 25%.¹²⁵

2.9.3.2. Slip Casting

This manufacturing process begins with the slip casting of a porous core. Which then subsequently "sintered" and "infiltrated" with a lanthanum-based glass. Resulting in a network formed of a glassy phase and a crystalline architecture. This crystalline structure "(12 Ce-TZP-Al₂O₃)" could be made of "alumina (Al₂O₃)", "spinel (MgAl₂O₄)", or "zirconia-alumina".¹²⁶ This method yields restorations with fewer processing faults and greater robustness than typical feldspathic porcelain.¹²⁵

2.9.3.3. Hot-Pressed Ceramic

In the late 1980s, the "hot-pressed" ceramic fabrication procedure was devised, allowing the technician to manufacture the prosthesis in wax.¹²⁵ The restoration is often done by using lost-wax technique, the same method for constructions of metal prosthesis lost-wax method. As a result, a wax pattern of the desired core or repair is produced, and refractory die materials are purchased. The wax is subsequently scraped away and a mold is formed. The mold is filled with a high-temperature ceramic ingot (block). Pressable ceramics are another name for this type of restoration. This method is often referred to as the "hot-pressing technique", since it relies on the application of externally pressure at temperatures that are quite high to accomplish the restoration.^{127,128} One advantage of the hot-pressing technique is that most fabrication stages, such as investing, wax elimination, and casting, are familiar to dental professionals. The heat-pressing process is used to create two main, highly filled glass ceramic restorations. Ceramics based on leucite and lithium disilicate.⁸⁷ Lithium disilicate was the secondary generation of the materials to employ this technique in 2006. A popular approach is to wax the repair to

full shape and then hot press it to produce a restoration. To make mamelons, the incisal region is then trimmed down. Following that, different incisal porcelains are applied.¹²⁹

2.9.3.4. CAD/CAM

In the mid-1990s, Nobel Biocare company the first company which introduced the idea of a “CAD/CAM” substructure for ceramic materials. The core was composed of 99.9% “alumina”, with a coating formed of feldspathic materials.¹²⁹ By allowing a computer to scan, plan, and mill a full-contoured restoration “CAD/CAM technology” improved machinable ceramic production.¹³⁰

The first one involves the electrical deposition of the material’s powder above a special die layer by layer using electricity.¹³¹ This technique is known as additive or prototyping. The other technique which is the most used involves the use of hard blocks of ceramics from which the restoration is milled and is known as the subtractive technique. As an example of this technique, the milled lithium disilicate, which first originated as lithium metasilicate and then heated to a high temperature (820°C) to transform this form into the final form of the disilicate material. This process will change the colour and the strength of the material to the desired final restoration..¹³²

2.10. Adhesion to Glass–Ceramics

The long-term survival of “glass–ceramic restorations” is rely on the selection of the optimal treatment plane based on the individual clinical indication and the application of a specific procedure for adhesive luting agents.¹³³

As a result, the clinician should be aware of the unique properties of each glass–ceramic material, such as differences in chemical component and the material's unique microstructure.¹³⁴

2.10.1. Acid sensitivity of Glass–Ceramic Materials

The dental ceramic materials have been divided into two categories based on their sensitivity to etching with hydrofluoric acid on their surface. They are either “acid sensitive” (mainly glass and particle-filled glass ceramics) or “acid resistant” (polycrystalline ceramic).¹³⁵ Glass ceramics acid sensitivity is due to their high glass content, which is frequently dissolved or removed during the etching process to generate micromechanical retentive structures that improve adhesive adhesion.¹³⁶

However, “etched acid-sensitive” (glass or mainly glass) ceramics have a unique structural analysis of the etched surface. They show different surface patterns based on specific “microstructure” and “composition”, which is determined by the concentration, etching time, and etching agent type utilized.¹³⁷

2.10.2. Hydrofluoric Acid Etching

The solution of “hydrogen fluoride” is known as hydrofluoric acid (HF). It has a weak and stable hydrofluoric bonding as compared to other acids for example (HCl etchant).¹³⁸ In 1983, Horn et al.²³ and Calamia et al.³¹ suggested using hydrofluoric acid to etch the interior surface of feldspathic veneers in order to provide more stable bonding in 1983. The (HF) works by selective reaction with the glassy matrix of the ceramics to reveal “(SiO₂)”, resulting in topographic changes on the ceramic's surface¹³⁹, thereby creating a micromechanical retention when incorporated with a resin cement.¹⁴⁰ Prior to the application of the “silane coupling agent”, the roughness created by ceramic surface etching improves the available surface area for bonding and the surface energy,¹⁴¹ As a result, the surface area and the energy free surfaces will be raised, reducing the contact angle and encouraging bonding agent infiltration, enhancing resin–ceramic bonding by increasing resin cement wettability.¹⁴²

The effect of etching dental ceramic is determined by a number of variables, including (1) the substrate composition (2) surface topography (3) etching duration.^{143,144} Many in vitro experiments have been conducted based on these parameters, showing the influence of various combinations of “hydrofluoric acid” concentrations and etching

protocol on the bond strength between “glass–ceramics” and the luting agents.^{140,143,145} The acid sensitivity of glass ceramics varies owing to differences in “chemical composition” and “microstructure”. physicians should be aware with the particular bonding process technique for each glass ceramic type. As a result, numerous investigations have found that excessive etching reduces the flexural strength of many glass–ceramic composites.^{146–148} As a result, utilizing the correct timing and concentration of hydrofluoric acid is critical for optimal results . A timed using of 5–10 % “hydrofluoric acid” on the interior surface of the glass laminate veneer can be used for chairside ceramic etching. **(Table 2)** Illustrates the manufacturer's instructions suggestions for the use protocol for each type of glass ceramic with recommendations for clinical uses for each type of material.¹³⁴

Table 2: The manufacturers' recommended surface treatment is based on the glass–ceramic (acid-sensitive) composition.¹³⁴

Ceramic type	Commercial name (brand)	Clinical indications	Surface treatment
Feldspathic	Vitablocs Mark II (VITA)	Veneers, inlays, onlays, anterior and partial crowns, overlay veneers for multiunit frameworks	5% HF ^a for 60 s + silane
	Vita PM9 (VITA)	Layered veneers; overlay veneers for multi-unit frameworks	
Leucite enhanced	IPS Empress Esthetic and IPS Empress CAD (Ivoclar Vivadent)	Veneers, inlays, onlays, anterior and posterior crowns	5% HF ^a for 60 s + silane
Lithium disilicate based	IPS e.max Press and IPS e.max CAD (Ivoclar Vivadent)	Veneers, inlays, onlays, anterior and posterior crowns, anterior and posterior implant abutments; three-unit bridges up to premolars; overlay veneers for multiunit frameworks	5% HF ^a for 20 s + silane
	LiSi Press (GC)	Occlusal veneers, thin veneers, veneers, inlays, onlays, anterior and posterior crowns, crown on top of an implant abutment, three-unit bridges up to the second premolar and placed on top of an implant abutment	5–9% HF ^a for 20 s + silane
Nano-fluorapatite glass–ceramic	IPS e.max Ceram (Ivoclar Vivadent)	Layered veneers, veneering of Y-TZP frameworks and lithium disilicate substructures	5% HF ^a for 20 s + silane
Fluorapatite glass–ceramic	IPS e.max ZirPress (Ivoclar Vivadent)	Veneers, pressing over Y-TZP frameworks	5% HF ^a for 20 s + silane
Zirconia- reinforced lithium silicate ^b	Vita Suprinity (VITA)	Veneers, inlays, onlays, anterior and posterior crowns	5% HF ^a for 20 s + silane
	Celtra DUO (Dentsply)		5% HF ^a for 30 s + silane
Feldspar ceramic network reinforced by a polymer network ^b	Vita Enamic (VITA)	Minimally invasive reconstructions, non-prep veneer/table top, inlays, onlays, anterior and posterior crowns	5% HF ^a for 60 s + silane

2.10.3. Silanization with Silane Coupling Agents

Silane Coupling Agents, also known as bifunctional tri-alkoxy silanes, have two chemically functional end groups, “alkoxy” and “C–C”. These groups can be linked to materials with either inorganic or organic content. For this special property, the silane agents could be involved in the ceramic cementation procedure as it will provide excellent bonding with both luting resins and the etched ceramic surface.¹⁴⁹

So, when the silane agents are applied to the ceramic surface, they act by improving the wettability of the surface in order to enhance the chemical bonding. This dual reaction occurs when the non-hydrolyzable functional group ends with a "C–C bond", reacts with the monomers in the composite resin to produce a double bond and the hydrolysable alkoxy group (e.g., methoxy–O–CH₃) reacts with the hydroxy group on the surface of the ceramics.¹⁵⁰

The application of "silane agents" should be in a thin layer, as too thick a silane will result in cohesive bond failure, while too thin a film would result in a complete bond between the silanized ceramic surface and the cement resin. We can adjust the necessary thickness of the silane (approximately 20–100 nm) by varying the saturation of the silane solution, the time required for curing, and temperature. Unfortunately, "siloxane" linkages are easily damaged by liquids at the interface between the luting resin and the luting ceramic surface. The aging techniques, storage in liquids, and thermal cycling protocols have been observed to be detrimental to the "siloxane–ceramic connections."¹⁵¹ Because of the resin's water permeability, the connection between “silane” and “resin composite” is likely to fail with time.¹⁵² Many studies have shown that using just silane on ceramic surfaces did not result in acceptable binding strength due to inadequate mechanical retention.^{153–155}

2.10.4. Adhesion to Tooth Substrates

The endurance of indirect restorations is governed not only by the appropriate and adequate ceramic surface treatment, but also by the quality of bonding between the resin cement to tooth surfaces.¹⁵⁶

Adhesive solutions are currently classified into two types depending on the way of creating and dealing with the smearing layer, which is mainly formed after the preparation of the tooth surface, and the mechanism of adherence to the surface. The first type, the "total-etching adhesive system", involves a total etch and rinse phase, then priming and adhesive resin application in a three-step technique, or a total etching, then one step primer and adhesive resin application, which is generally presented in one bottle in a technique known as two-step total-etching adhesive. The second approach incorporates a non-washing acidic monomer used as a self-etching agent which used as etching and priming agent for both the enamel and the dentine surfaces at the same time. Followed by the application of adhesive resin material this technique knowing as two-step self-etching adhesive. Recently, the "self-etching priming systems" were upgraded to include all-in-one adhesives which combine etching, priming, and adhesive efficiency in one process.¹³⁴

The recently developed "self-etching" technologies simplify restoration operations, save time, and eliminate the requirement for acid etching prior to application, considerably lowering method sensitivity. Despite the fact that self-etching systems simplify restoration operations by saving time and eliminating the etching phase.¹⁵⁷ Many investigations have found that some "all-in-one adhesives" have a comparatively poor bond when compared to other "two-step total-etching methods".¹⁵⁸ Since the turn of the century, "self-adhesive universal luting materials" have been invented for the market in order to minimize method sensitivity while also saving time.¹⁵⁹

Nonetheless, an in vitro study conducted by Rohr & Fischer¹⁵⁹ stated that "conventional technique" cementation had superior long term success when compared to "self-adhesive cements", demonstrating bond failure of the restorations cemented with self-adhesive cement and emphasizing that etching of the enamel and priming are critical for a "successful bonding procedure". Furthermore, they discovered that when the enamel

surface was etched, the “bond strength” values for all of the resin cements which tested in this research were much higher than when no “pre-treatment” procedure was used.

According to Van Meerbeek et al.¹⁶⁰ in 2004, elective enamel etching is a critical step in indirect ceramic restorations since it considerably enhances marginal adaption. In 2016, Federlin et al.¹⁶¹ demonstrated an improvement in the rates of survival for etched enamel surface bonded to crowns with self-adhesive resin for up to 6.5 years in 2016. Dentin adhesion is more prone to failure in the area of the contact such as "enamel–resin cement" or "ceramic–resin cement." A hybrid layer is generated as a result of the micromechanical link between resin "cement" and "dentin," on which a low-viscosity resin will infiltrate and polymerize into the collagen fibril network.¹⁶²

To obtain a hybrid layer using the “total-etching approach”, the dentin is pre-treated with an “acidic chemical”, followed by “priming” and the “application of a low-viscosity resin cement”. Alternatively, only self-etching adhesive methods can modify and integrate the smear layer into the hybrid layer.¹⁶³ Importantly, the bonding to tooth substrate is considered to be a technique sensitive and should be applied in accordance the manufacturer’s instructions.¹³⁴

2.10.5. The Effect of Resin Cements on The Adhesion of Glass Ceramics

Because the cement will adhere the “ceramic restoration” to the “tooth substrate”, the choice of cement and luting process is recognized as one of the most critical factors impacting the clinical life of “indirect restorations” (supporting material). Because glass ceramics have low “tensile” and “flexural” strengths, composite resin adhesive cementation should be employed to strengthen the glass ceramic restorations”.^{164,165}

When the silica based ceramics are luted with resin composite, they give high strength restoration with longer intraoral survival as compared to other traditional luting agents.^{166,167} The resin luting agent is low in organic filler composite materials, which are modified in different ways to produce low viscosity cementing agents.¹⁶⁸

2.10.5.1. Classification of Resin Cement

The resin cements are classified into two categories based on method of activation and way of interaction with dental tissue (1) resin cements used with “conventional” or “self-etching” adhesives; and (2) “self-adhesive cements,” which can be used “directly” without the need for tooth conditioning before cementation.¹⁶⁸ According to the activating process, the luting cements can be classified into: (1) chemical curing (2) light-curing (3) dual-curing resin cements.

The luting cements are categorized into three types based on the activation process: (1) “chemical curing” cements (2) “light-curing” resin cements (3) “dual-curing” resin cements. Light activation has the advantage of allowing for extended period of clinical work than the other dual or chemical curing materials.¹⁶⁹ Another important property of these materials for aesthetic restorations is their better colour consistency when compared to “dual-polymerizing cements”. The modest modification of “dual curing cement” caused by the oxidation of the tertiary amines found in dual cements as auto polymerizing reaction enhancers.¹⁷⁰ Therefore, for the glass (CLVs) the light way of polymerization is preferred for the cementation.¹⁷¹

The “chemical” and “physical” qualities of resin cements have a major impact on the clinical effectiveness of indirect restorations. These properties include: (1) the ability to improve the endurance of the connection between the “restorative material” and the “tooth surface”. (2) “tensile” and “compressive” strength (3) suitable “elastic modulus” (4) biocompatibility (5) suitable shade (6) excellent viscosity, which is controlled by the ratio of the filler in the material, as it affects the thickness and fit of the restoration.^{172,173}

In terms of resin cement thickness, various studies have shown the increase in stress on the cementing surfaces as the cement thickness increases. The optimal cement layer thickness it should be not more than 50 μm because it provides good connection to the glass ceramic than a cement layer above 50 μm .¹⁷⁴ Furthermore, a film thickness of 50 μm was shown to be more suited for the stress failure loads of “feldspathic crowns” than crowns cemented with a thickness of 500 μm .¹⁷⁵ As a result, an appropriate resin-

bonding technique should be used to increase the efficiency of indirect esthetic restorations and the fracture resistance of the dental ceramic.^{105,176,177}

2.11. Laboratory Bond Strength Testing Methods

The prosthesis in the oral environment is subjected to complex degradation factors because it is influenced by the force of mastication in the form of "shear", "tensile", "compressive", and "flexural" forces. Furthermore, the replacement is surrounded by saliva and is impacted by the PH, temperatures, and chemistries of the meals and beverages. As a result, a variety of laboratory testing methodologies have been developed in an attempt to imitate oral circumstances and, as a result, "clinical bonding performance" may be expected. Regardless, no one laboratory test can accurately predict the effectiveness of "clinical resin-ceramic bonding".¹⁷⁸

There are two ways for measuring bond strength: in vitro methods and clinical trial evaluation of bond durability. The techniques of measuring bond strength in the laboratory are further classified as static tests, in which the specimen is fixed while the load is applied, and dynamic tests, in which the specimen is in a "dynamic condition". Static tests are further subdivided into "macro" and "micro" based on the size of the bonding region, with "macro-bond tests" applied to areas bigger than 3 mm² and micro-bond tests done to areas as tiny as 1mm² or less.¹⁷⁹

2.11.1. Static Macro-Test Methods

They are divided into shear, tensile, and push-out test methods.

2.11.1.1. Macro-Shear Bond Strength (SBS) Test

The "SBS test" considered as an effective test technique for the evaluation of the materials bond strength.¹⁸⁰ Bowen reported this test technique for the first time in 1965.¹⁸¹ This technique involves the assessment of the maximum loading which the materials can withstand before the occurrence of bond breakage and specimen fracture (**Figure 5**). The SBS test is popular in businesses and research organizations since it requires no

additional specimen processing following the bonding technique, making it the simplest and quickest method.¹⁸² However, with new adhesives with increased bond strengths, “cohesive failures” in surface were commonly seen, affecting the validity of the data acquired with this test technique.¹⁸³

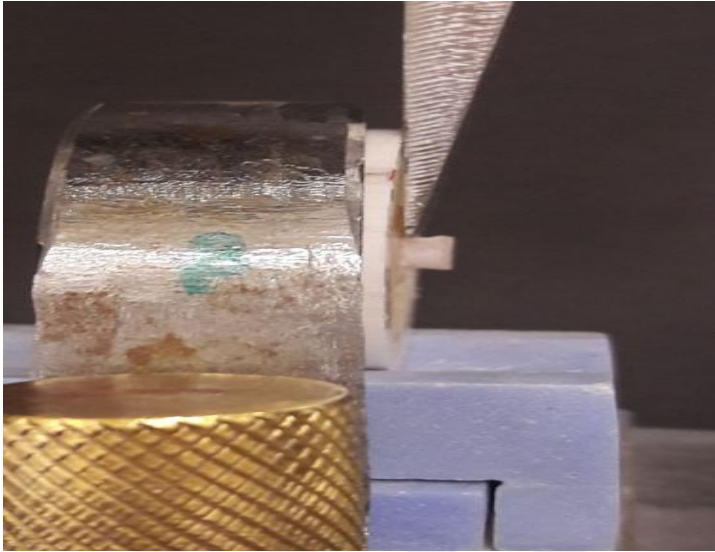


Figure 5: Setup for a shear bond strength test.¹⁸⁴

2.11.1.2. Macro-Tensile Bond Strength (TBS) Test

The TBS test is a far less often utilized test. It denotes the bond strength of cement to other hard materials such as ceramics and metal alloys.¹⁸⁵ The TBS tests examines the strength of bonding by amore customized manner of stress distribution, so in turn , give a more accurate results as compared to the other testing methods.¹⁸⁶ The load is applied on either side of the test specification.¹⁸⁷ In this testing method the specimens should be applied in a perpendicular manner. Otherwise, bending stresses will occur. As a result, either “active” or “passive” gripping procedures should be used to link the test specimen to the “mechanical testing equipment”. **(Figure 6).**

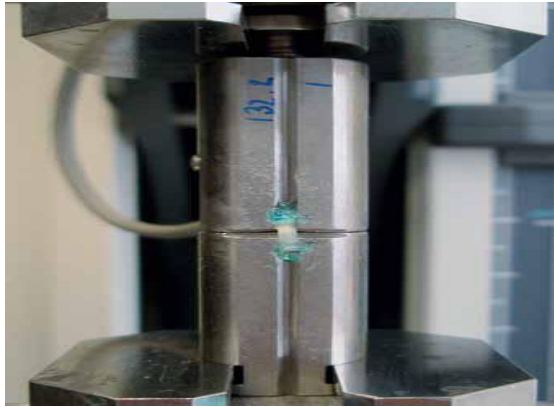


Figure 6 : Attached ends of a test specimen for tensile bond strength testing.¹⁸⁴

2.11.1.3. Push-Out (PO) Test

A Push-Out (PO) method was utilized especially for the assessment of dentine bond strength. The approach is extremely beneficial for assessing the adherence of root canal sealers as well as the retention of “posts luted in root canals”. The PO test gives the examiner ideas about the stress formed between both the cement dentin and cement post connections.¹⁸⁸). It provides more precise estimation on the influence of various adhesives on “bond strength” than the typical “shear bond test” since it involves curing composite extraction (**Figure 7**). “PO test”, on the other hand, has never been acknowledged as a “universal bond strength test technique”, mostly due to the time-consuming specimen processes.¹⁸⁹

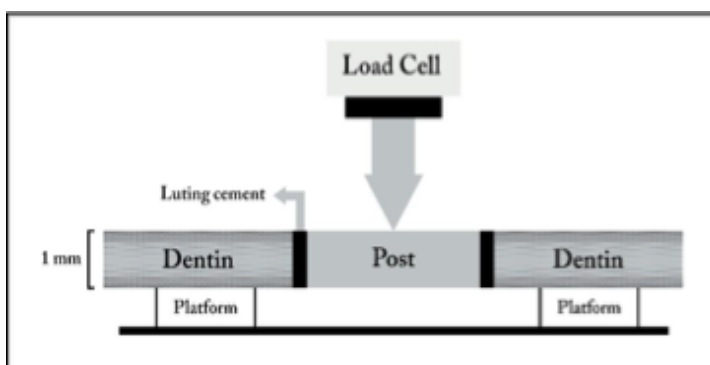


Figure 7: The push-out bond strength test is illustrated schematically

2.11.2. Static Micro-Test Methods

They are divided into micro-shear, micro-tensile, and micro-push-out test methods.

2.11.2.1. Micro-Shear Bond Strength (μ SBS) Test

In 2002, the (μ SBS) test was established.¹⁵⁵ It enables the examination of small tooth regions. As with micro-tensile testing, we can fabricate different specimens from one tooth through special dividing technique. however, this may result in a small areas of cracking in the specimens.¹⁹⁰

2.11.2.2. Micro-Tensile Bond Strength (μ TBS) Test

Sano et al.¹⁹¹ pioneered this test procedure, which includes attaching adhesive material to the occluding surfaces of the teeth, which is subsequently coated with by composite resin. The specimen is sectioned in the longitudinal direction several times to produce multiple specimens. This sectioning was performed using a diamond saw. Then the species is preserved in water. into numerous serial parts with "a slow-speed diamond saw" after cure and storage in water. (**Figure 8**). This method is considered technique critical as it requires complex specimen preparation with the possibility of dehydration of some specimens.^{192,193}

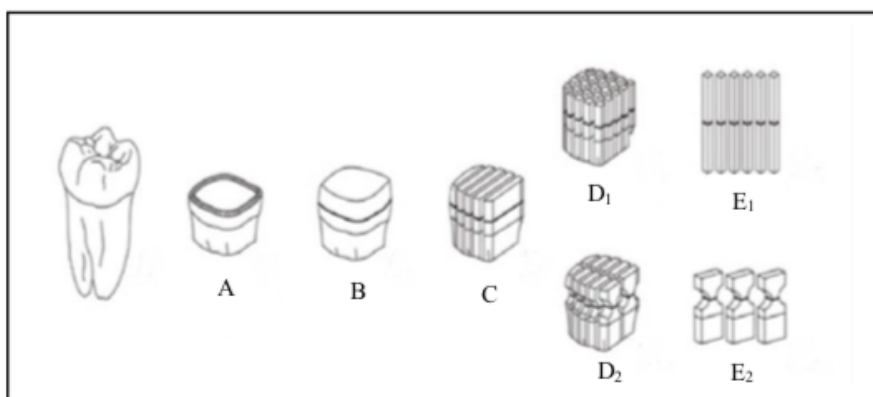


Figure 8. The collection of specimens for the micro-tensile bond strength test is shown schematically. (A) Exposure of dentin by removing the occlusal surface of the tooth; (B) Bonding process at the tooth surface and fabrication of composite resin blocks (C) (The specimen has been vertically sectioned into numerous serial sections; (D1, E1) Non-trimmed specimens (stick-shaped); (D2, E2) Trimmed specimens.

2.11.2.3. Micro- Push-Out (μ PO) Test

The bonding strength of luted fibre posts is measured using the “(μ PO) test”. It is considered as another type of push test as it uses dentine specimens of approximately 1 mm².¹⁹⁴ Castellan *et al.*¹⁹⁵ the “POS” and “TBS” strategy yielded higher values than “standard pull-out” and “push-out” procedures. Nevertheless, more research into the “PO” technique is required.

2.11.3. Dynamic Tests (Fatigue Tests)

This method is not commonly used as it involves an abrupt loading technique which is considered to not represent the true situation in the mouth as this abrupt force does not happen commonly. Because of the complexity and the length of the procedure, nowadays it is seldomly used. In addition to that, it is not suitable for testing enamel because it is difficult to detect in fatigue mode. On the other hand, it may be used in dentine testing.¹⁹⁶

2.12. Thermal Cycling

Thermal cycling is a commonly used artificial aging technique in which the specimens are generally exposed to a number of cycles ranging from 1000 to 100,000 by using temperature values between 5 and 55 °C.^{197,198} The concept of thermal cycling is to act by generating a stress at bonding surfaces as a result of discrepancy in the coefficient of thermal expansion.¹⁹⁹ According to Galea & Darvell,²⁰⁰ 10,000 cycles equals one year of clinical function, and “500 cycles” is considered to be a small number and ineffective for studying long-term bonding effectiveness.

Many studies reported the effect of thermocycling in bond strength decreasing in between the resin cement and ceramic material. However, another study confirmed the role of thermal cycling for the improvement in the bond strength regardless of the kind of the used resin cement and this attributed to the relatively “short number of cycles

(6000)", so that insufficient storage time and fatigue exposure might enhance the degree of cement conversion, thus, resulting in a higher bond strength.²⁰¹ Nevertheless, the application of thermal cycling in dentin bonding studies considered as in suitable factor in assessing the bond between the resin and dentin.²⁰²

2.13. Mechanical Loading

This method is utilized significantly less frequently in bonding assessments as compared to other techniques. One research found that mechanical application of the load to the cement with "60 N for 20 times" did not reduce the strength of the bond between the resin luting agent and the examined ceramic material. During the testing procedures, some of the specimens failed during the loading and should have been removed from the assessment. Another research found that specimens which were exposed to 1,400,000 cycles of loading exhibited a substantial reduction in resin–ceramic bonding strength. Because of the scarcity of research, no conclusions can be drawn on whether fatigue testing affects the endurance of the "resin–ceramic bond".²⁰³

3. MATERIALS and METHODS

This study was conducted at Yeditepe University Faculty of Dentistry, Department of Prosthodontics, to evaluate the shear bond strength of a heat pressed glass ceramic laminate veneer material cemented to prepared enamel, enamel-dentin complex and dentin surfaces by the use of two different luting resins. All teeth that were planned to be used in this study were collected after taking approval from the Yeditepe University Ethic Committee of Clinical Research (Approval No: 1416 \ 07.04.2021). The "power analysis" was done using the G*Power tool to establish the sample size for the current study, and the number of samples identified for Power: 0.80 and 0.05 was calculated as a minimum of n=9 (total 54) for each group.

3.1. The Materials Used in This Study

The lithium disilicate glass ceramic material, GC Initial Li Si Press by (GC Co., Tokyo, Japan) (**Figure 9**), was selected for this study and provided by the manufacturer as a heat pressed ingot. The two used cements were light-curing G-CEM Veneer (**Figure 10**) and dual curing G-CEM LinkForce luting resins by (GC Co., Tokyo, Japan) (**Figure 11**) for etching and bonding agent application for the teeth. We used Total etch gel from "(Ivoclar Vivadent, Schaan, Liechtenstein)" and "G-Premio BOND from (GC Co., Tokyo, Japan)" respectively (**Figure 12, 13**). For etching and silanization of the ceramics, we used 9% Porcelain Etchant from (Ultradent Products, Inc, USA) and G-Multi PRIMER from (GC Co., Tokyo, Japan) respectively. (**Figure 14, 15**). The materials used in this study are described in detail in (**Table 3**).



Figure 9: GC Initial Li Si Press (MT-A1).



Figure 10: G-CEM veneer resin cement.



Figure 11: G-CEM LinkForce resin cement.



Figure 12: Total etch (37% phosphoric acid etching)



Figure 13: G-Premio BOND.



Figure 14: hydrofluoric acid gel (Ultradent Products, Inc, USA).



Figure 15: G-Multi PRIMER.

Table 3: The materials used in the study.

Materials	Manufacturer	Composition	LOT Number
GC li si press	(GC Co., Tokyo, Japan)	70% Lithium disilicate crystals with low concentration of lithium orthophosphate (Li ₃ PO ₄) dispersed in glass matrix.	1708041
G-Cem LinkForce	(GC Co., Tokyo, Japan)	Base paste: Urethanedimethacrylate (UDMA) 20-25%, dimethacrylate 5-10%, stabilizer <0.5% material Catalyst paste: UDMA 20-25%, bis-EMA 5-10%, dibenzoyl peroxide <1%, butylated hydroxytoluene <0.5%	2010061
G-CEM VENEER	(GC Co., Tokyo, Japan)	(octahydro-4,7-methano-1H-indenediyl) bis (methylene) bismethacrylate 1,3,5-Triazine-2,4,6-triamine, polymer with formaldehyde Urethane Dimethacrylate (UDMA) 2,2'-ethylenedioxydiethyl dimethacrylate 2-(2H-benzotriazol-2-yl)-p-cresol	0211241
G-Multi PRIMER	(GC Co., Tokyo, Japan)	Ethanol Methacryloyloxydecyl Dihydrogen Phosphate (MDP) Methacryloyloxydecyl dihydrogen thiophosphate (MDTP) γ -Methacryloxypropyl tri	2010091
G-Premio BOND	(GC Co., Tokyo, Japan)	Acetone Water 4-Methacryloxyethyl trimellitate anhydride (4-MET) Phosphoric ester monomers (MDP & MDTP) Methacrylate monomer Silicon dioxide	2010151
Ultradent Porcelain Etch	Ultradent Products, Inc, Usa	9% buffered hydrofluoric acid	BK7Y6
Total etch	Ivoclar Vivadent, Schaan, Liechtenstein	37% phosphoric acid	Y25896

3. 2. Selection Criteria of The Teeth:

Sixty sound human premolars extracted due to orthodontic or periodontal causes were used for this study. The selected teeth were free of cracks, fractures, caries and used within six months of extraction as recommended by ISO standards (ISO /TS 11405:2015).

3. 3. Preparation of Teeth Specimens:

The teeth specimens were stored in 1 % chloramine T-trihydrate (Merck KGaA, Darmstadt, Germany) stored at room temperature for about one week to avoid dehydration and bacterial growth until the "laboratory procedures" were conducted. The teeth were next scaled with a hand tool "(Scaler H6/H7; Hu-Friedy, Chicago, IL)" and brushed with a brush with a nonaromatic pumice at 6000 rpm (No: 9640.204.060; Komet, Gebr Lemgo, Germany) until they were visibly clean (**figure 16**). Under the light of a magnifying glass, the cleaned specimens were examined for any pre-existing small fractures. With a diamond covered precision saw (Micromet 5114; Buehler, IL, USA), the tooth specimens were dissected in a horizontal direction about 2 mm below the (CEJ) with cooling in the water (**Figure 17**). The coronal sections of tooth specimens were embedded in auto polymerizing acrylic resin "(Meliodent; Heraeus Kulzer GmbH, Hanau, Germany)", with 2 mm of the facial surface layers remaining outside the resin material (**Figure 18**).



Figure 16: sixty premolar teeth specimens.



Figure 17: A. The diamond coated precision saw (Micromet 5114; Buchler, IL, USA) / B the tooth fixed in the machine 2 mm below the CEJ before sectioning.

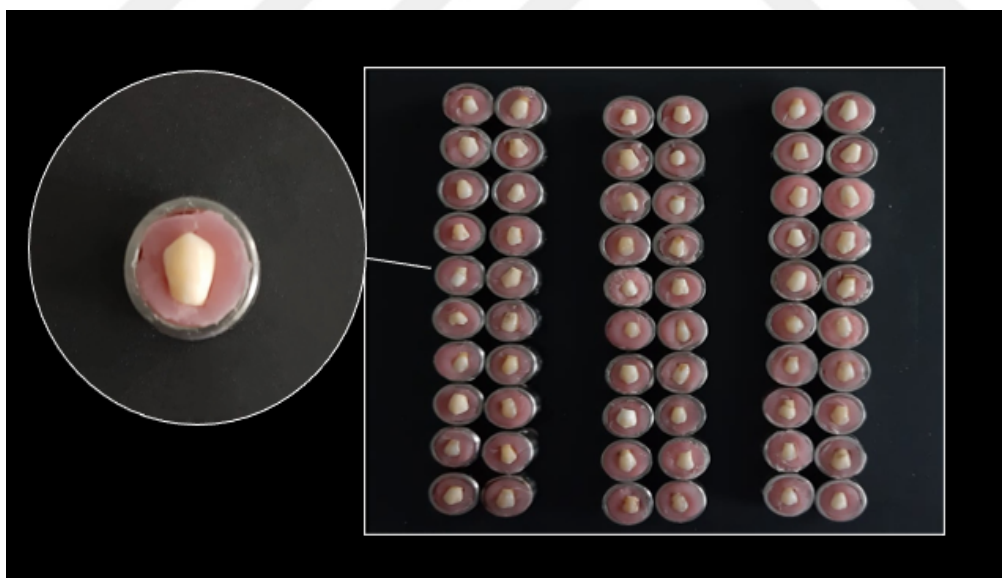


Figure 18: The teeth sectioned and mounted in the acrylic resin.

3. 4. Assignment of Experimental Groups:

The 60 number specimens were divided according to extent of preparations into three groups, with 20 samples for each group:

Group E: represent teeth surface preparation in enamel only.

Group ED: represent teeth surface preparation in Enamel-Dentin complex.

Group D: represent teeth surface preparation completely in dentin.

Then each group further divided into two subgroups according to the used adhesive systems (E-V, E-LF) (ED-V, ED-LF) (D-V, D-LF) as illustrated in the (Figure 19).

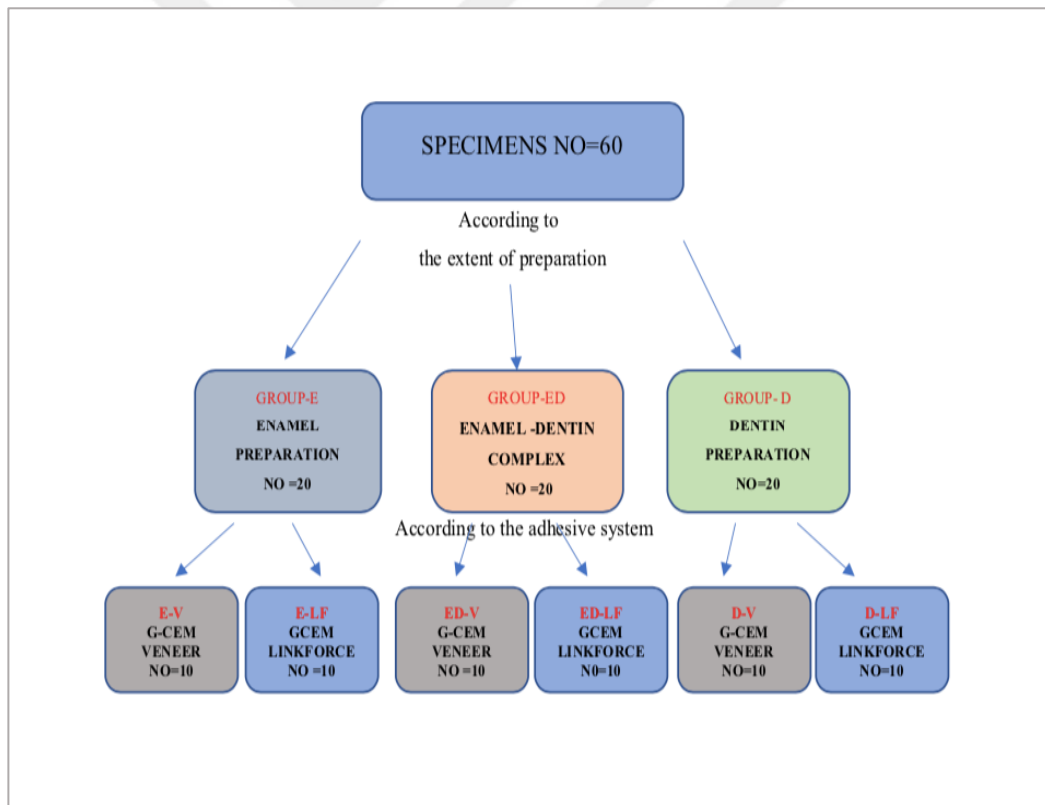


Figure 19: Experimental Groups (Study Design).

3. 5. Preparation Enamel:

For (Group E), three horizontal grooves of approximately 0.5 mm on the buccal surfaces of the teeth for orientation of the depth, using a triple wheel bur (Triple Wheel Diamond, DIA.TESSIN, Switzerland) mounted on a high-speed hand piece. The prepared grooves are then painted with a water-insoluble pen (**figure 20**) (**Figure 21**), To obtain a flat preparation surface completely on the enamel with a diameter of approximately 5-6 mm in diameter, the tooth structure in between the depth grooves was removed with a flat diamond bur. Then the teeth preparations were advanced by using "100, 400, and 600 grit Silicon Carbide Papers (English Abrasive, London, England)" on a polishing machine with water cooling "(Phoenix Beta Grinder \Polisher, Buehler, Germany" (**Figure 22**) Specimen preparations were maintained until the complete removal of the tooth structures between the painted grooves and the obtaining of a completely flat surface for luting the porcelain discs to the center of the buccal surface (**Figure 23**).

3. 6. Preparation of Enamel-Dentin Complex:

For this group (Group ED), the preparations were continued as for the Enamel group with guided preparation by grinding with "100, 400, and 600 grit Silicon Carbide Papers (English Abrasive, London, England)" until the occurrence of exposure to the dentin on the cervical area of the buccal surface and until this exposure reached the center of the buccal surface, so that we obtained a flat surface available for bonding of porcelain discs, nearly the upper half in dentin and the lower one in enamel (**Figure 24**).

3. 7. Preparation of Dentine Group:

In (Group D), the preparation was carried out in the same way as for enamel-dentine, with additional grinding with abrasive papers "100, 400, and 600 grit Silicon Carbide Papers (English Abrasive, London, England)" until a completely flat surface of about 5-6 mm in diameter was obtained entirely in the dentin, occupying the center of the tooth specimens (**Figure 25**).

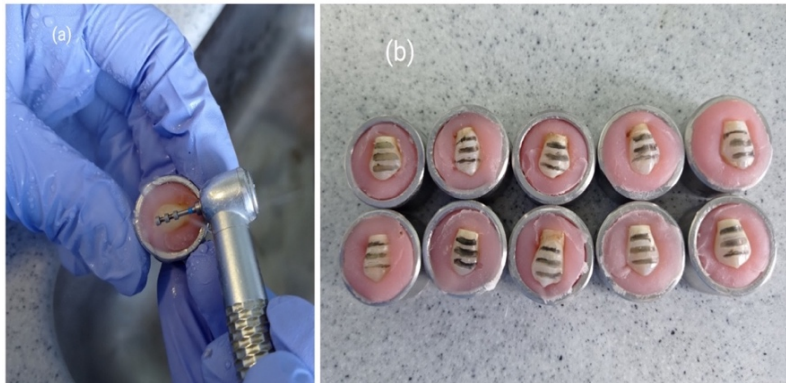


Figure 20: (a) Preparation of depth orientation grooves, (b) The preparation grooves painted with in soluble pen.

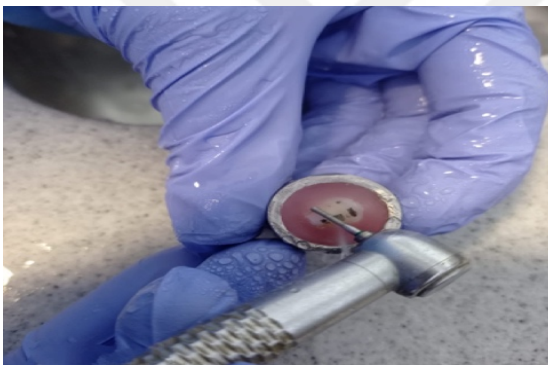


Figure 21: The removal of tooth structure with flat diamond bur.

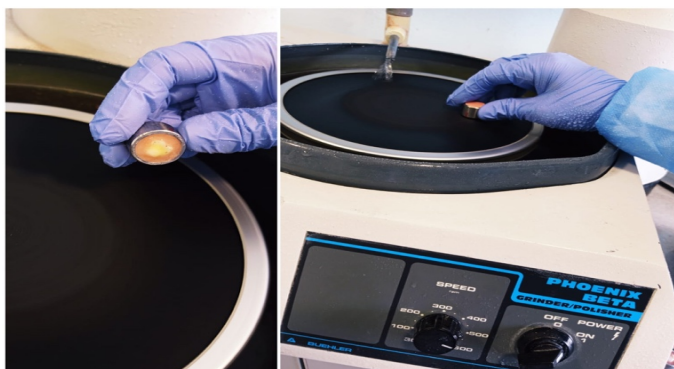


Figure 22: Grinding of the teeth specimens to provide a flat surface using Phoenix Beta Grinder \Polisher, Buehler, Germany.

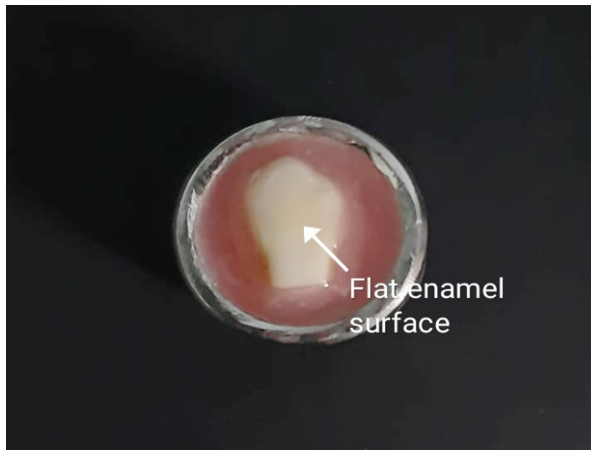


Figure 23: Preparation of enamel surface.



Figure 24: Preparation of enamel- dentin complex surface.



Figure 25: preparation of dentin surface.

3. 8. Fabrications of Porcelain Discs:

The required dimensions of the porcelain disc were drawn using "computer aided design (CAD) and computer aided engineering (CAE) programs" (Solid Work, Dassault Systèmes, France). This design was installed as a PDF file in the Mill-box Directory Program (**Figure 26**). After the design was completed, the specimens were prepared in wax (fusion ceram wax block) by the CAD-CAM machine (Dentifa Pro2) (**Figure 27**). Then the attained wax specimens are invested in SILVADENT investment (silvavent dr. böhme & schöps GmbH, Germany) (**Figure 28**) and then they were permitted to burnout in a furnace (Electra, Keith Company, USA) at temperatures of 850 °C for 30 minutes. The investment and an ingot GC initial li si Press were sent to the furnace "(EP 3000; IPS Empress, Ivoclar Vivadent, Schaan, Liechtenstein)" and pressed automatically (910 °C, 60 min) (**Figure 29**). After the specimens were allowed to cool down, they were sandblasted with 70 microns of aluminum oxide in the Renfert Basic Master sandblasting unit. The thickness of the specimens was checked using a Digimatic caliper (Mitutoyo company, Japan) at 1.5 ± 0.2 mm in thickness (**Figure 30**). All of the porcelain discs were then polished with silicon carbide abrasive paper of "grits 400, 600, and 1200 (English Abrasive, London, England)" until they reached a thickness of about 1.2 ± 0.1 mm. (**Figure 31**).

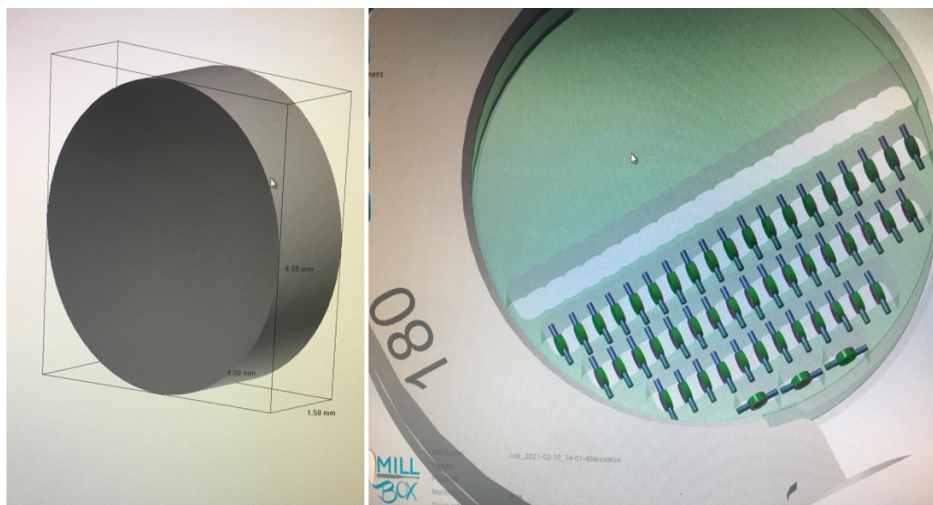


Figure 26: The design of porcelain discs using CAD-CAE program.



Figure 27: wax preparation of the porcelain in CAD-CAM machine.



Figure 28: Investment procedure for the wax specimens.



Figure 29: Pressing procedure for GC li si press ingots.

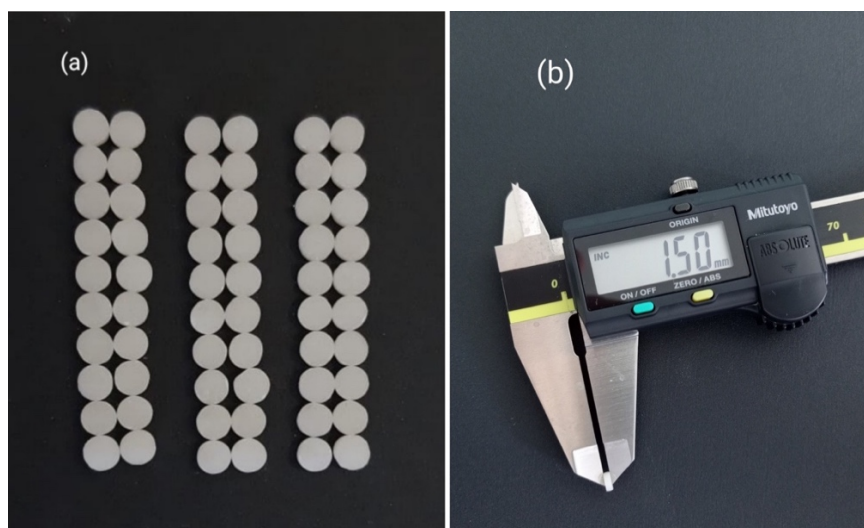


Figure 30: (a) The obtained porcelain discs. / (b) Checking of the ceramic disc thickness with Digimatic caliper.



Figure 31: (a) Phoenix Beta Grinder \Polisher, Buehler, Germany.\ (b) Polishing of the porcelain discs.

3. 9. Bonding Procedure

According to the study's design, the ceramic discs were cemented to the prepared buccal surfaces of the teeth. Specimens of groups E-V, ED-V and D-V were bonded with "light cure resin cement" G-CEM Veneer, while specimens of groups E-LF, ED-LF and D-LF were bonded with "dual cure resin cement" G-CEM LinkForce. According to manufacture instruction, by using a LED source (WOODPECKER LED.B, Gullin Woodpecker Medical Instrument Co., Ltd. China) (**Figure 32**). The two resin cement bonding techniques are outlined and discussed in (**Table 4**).



Figure 32: LED- light curing machine.

Table 4: Description of the bonding procedures.

Surface treatments	G-CEM Veneer	G-CEM LinkForce
Total etch technique <u>Enamel and Dentin:</u> 35-37% phosphoric acid gel (GC ETCHANT) for 20 seconds, rinse for 5 seconds and gently dry. <u>Porcelain:</u> hydrofluoric acid gel (5-9%) for 20 seconds to the inner surfaces of the restoration.	preparation of the tooth surface: 1. Apply G-Premio BOND. 2. Wait for 10 seconds. preparation of the restoration: 1. Apply G-Multi PRIMER 2. Dry with an air syringe.	preparation of the tooth surface: 1. Apply G-Premio BOND 2. Leave undisturbed for 10 seconds. 3. Dry with an air syringe. • For 5 seconds. 4. Light cure for 10 seconds (halogen/led700mw/cm2) preparation of the restoration: 1. Apply G-Multi PRIMER 2. Dry with an air syringe.

2. 9. 1. Acid Etching and Silanization Of Porcelain Discs:

A 9% buffered hydrofluoric acid gel (Ultradent Products, Inc, USA) were applied to the prepared buccal surface of the porcelain discs for not more than 20 seconds. The surface was then sprayed with water and dried. Then a coat of silane coupling agent (G-Multi PRIMER, GC Co., Tokyo, Japan) was applied with an applicator brush (**Figure 33**), uniformly wetting the prepared surfaces of the porcelain discs and drying them with an air syringe.

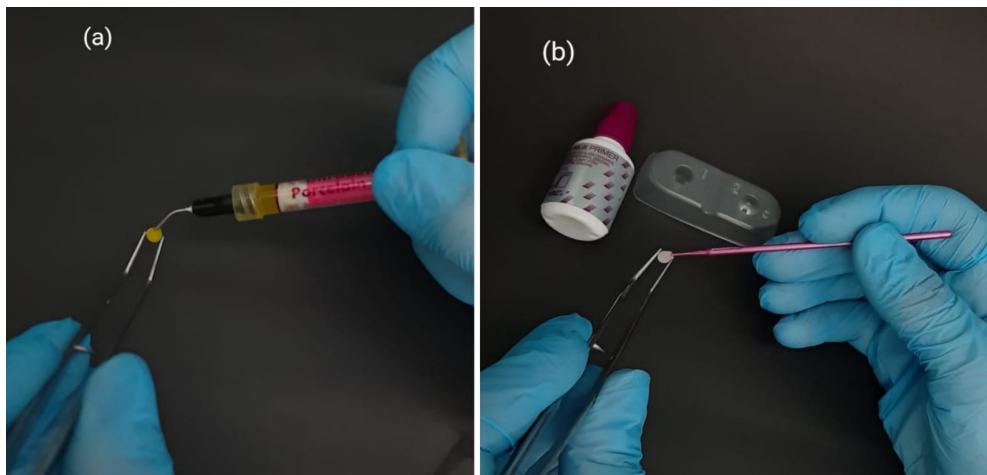


Figure 33: (a) etching of the porcelain luting surface. / (b) the application of silane coupling agent.

2. 9. 2. Etching and Bonding of The Teeth Specimens:

The surfaces of the teeth that had been prepped were etched with a total acid etching technique using 37% phosphoric acid "(Ivoclar Vivadent, Schaan, Liechtenstein)" for 20 seconds, washed for 5 seconds with water spray, and gently dried with an air syringe (**Figure 34**). Then the etched surfaces were coated with a bonding agent (G-Premio BOND, GC Co., Tokyo, Japan) for 10 seconds, and left undisturbed. Then the air syringe was used for drying for 5 seconds, and finally light cured for 10 seconds (**Figure 35**).

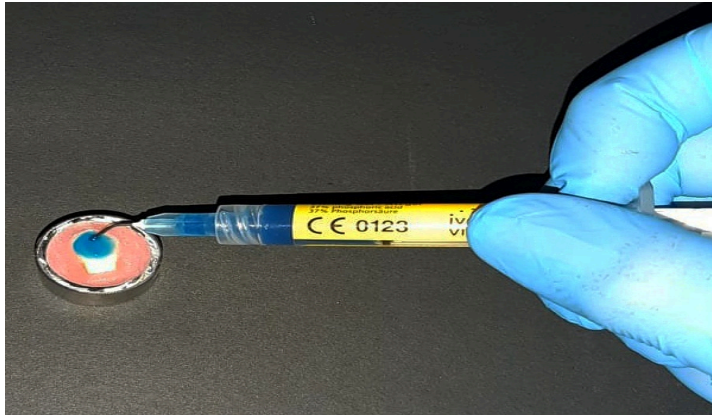


Figure 34: etching of the tooth surface with hydrofluoric acid.

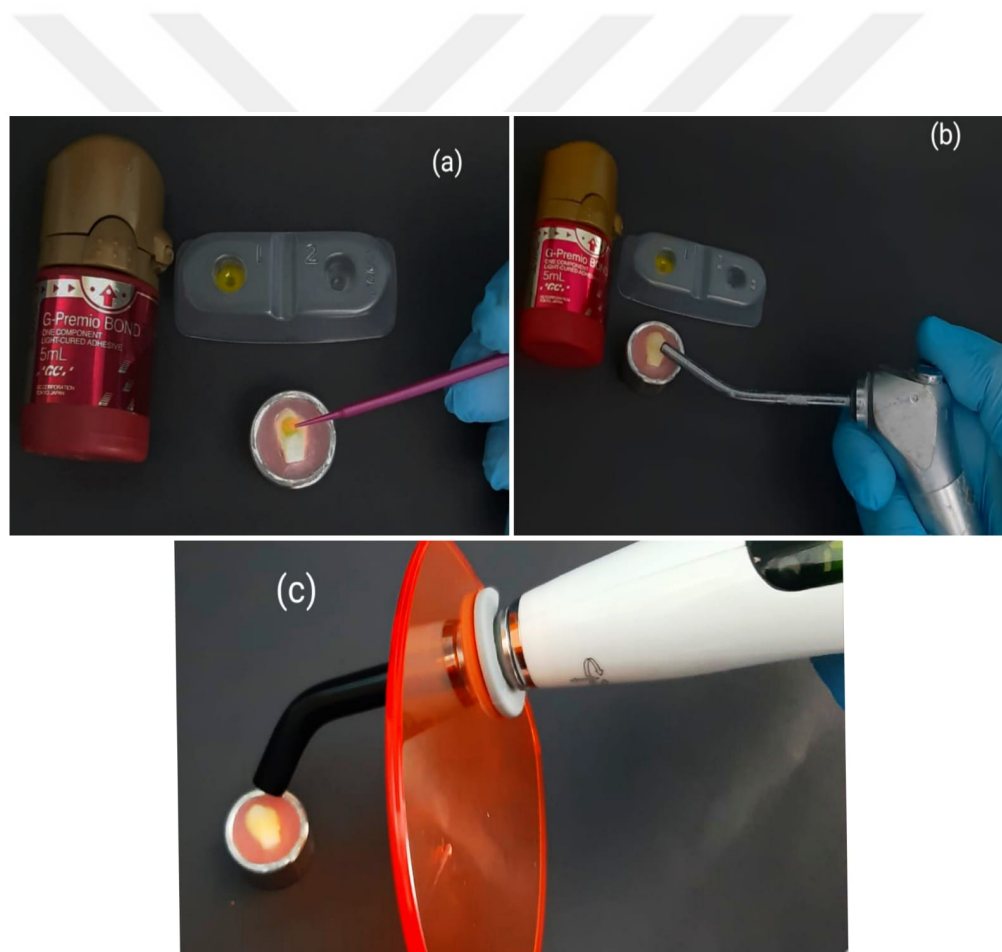


Figure 35: The application of bonding agent.

2. 9. 3. Cementation of Porcelain Discs:

Adhesive tapes with circumferential holes of roughly 4-mm in diameter were used to demarcate the bonding region. The ceramic discs were all cemented right in the middle of the holes with light finger pressure using a glass slab for 2 min. Extra cement was removed using a disposable micro brush and a high-powered LED light (1200 mW/cm²) used on cement interfaces from four distinct sides (occlusal, mesial, distal, and cervical). For 10 seconds on each side, use an LED source (WOODPECKER LED.B, Gullin Woodpecker Medical Instrument Co., Ltd., China) (**Figure 36**).

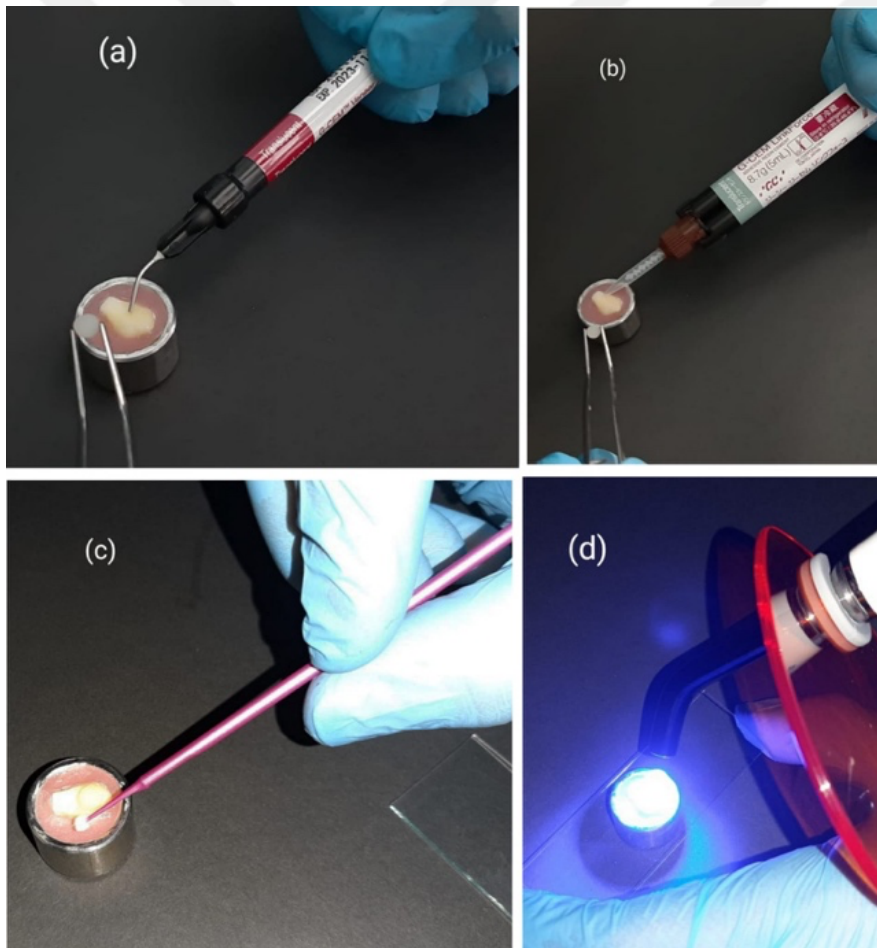


Figure 36: (a), (b) The cementation with G CEM veneer and G CEM Linkforce. / (c) removal of cement excess. / (d) light curing.

2. 10. Thermocycling Procedure:

The samples were exposed to a thermocycling procedure (**Figure 37**) using a thermocycling machine (Salibrus Technica, Turkiye): “5000 cycles, between 5 0C and 55 0C, with a dwell duration of 15 seconds at each temperature” and a transfer period of 10 seconds from one bath to the other. Six months of clinical function is equal to 5000 cycles.

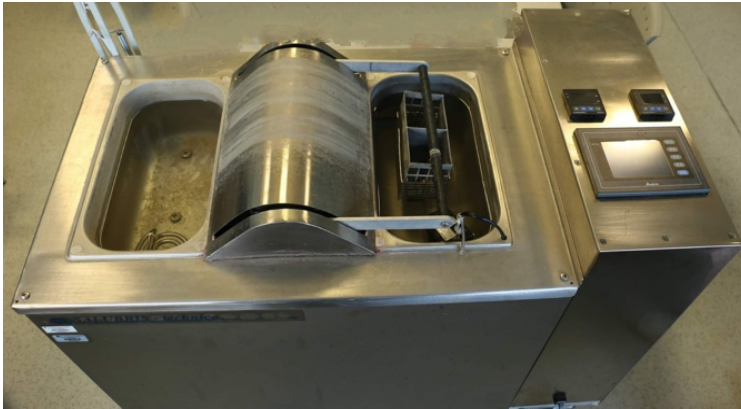


Figure 37: Thermal cycling machine salibrus technical, turkiye.

3. 11. Shear Bond Strength Testing:

The shear bond strength test was carried out using a universal testing machine (Model 3345, Instron Crop., Norwood, MA, USA) (**Figure 38**). At a cross head speed of 0.5 mm per minute. The stainless-steel knife apparatus is positioned perpendicular to the tooth surface/ceramic disc junction. The samples were all loaded until they failed. And once the fracture force was measured, the failure force was measured in newtons (N), and the unit was converted to MPa using the following equation:

$$\text{Shear bond strength (Mpa)} = \text{load (N)} / \text{surface area of the disc (mm}^2\text{)}$$

Where surface area of the disc = $\pi \times d^2 / 4$.

d = the exact diameter of the bonding surface.



Figure 38: The samples fixed in the universal testing machine.

3. 12. Failure Analysis

In order to determine the failure mode of the samples, after the shear testing procedures, all fractured samples were analyzed using a stereomicroscope at a magnification of 12 x. (Model 73446, Carl Zeiss Surgical GmbH, Oberkochen, Germany). The failure modes are categorised as follows:

- 1) Adhesive failure occurred between the "porcelain" and the "tooth surface" within the bonding interface.
- 2) Cohesive failure occurred between the "tooth structure" and the "resin cement".
- 3) Mixed failure [partial adhesive failure between the "porcelain" and the "tooth surface" and/or "resin cement" mixed with partial cohesive failure in the tooth structure and resin cement (less than 40% in the bonding region)].

3. 13. Statistical Analysis

For statistical analysis in this study, we selected the IBM SPSS Statistics 22 (IBM SPSS, Türkiye) program. The Kolmogorov-Smirnov and Shapiro Wilks tests were used to establish the parameters' appropriateness for the normal distribution, and it was determined that the parameters were suitable for the normal distribution. The impact of group and surface treatment interaction on shear bond strengths was assessed using the Two-way ANOVA test, and Tamhane's T2 test was employed since the variances of the groups were not homogenous in the post-hoc analysis. The Univariate tests included the one-way ANOVA and Student's t tests. The significance was determined at the p 0.05 level.

4. RESULTS

To evaluate the influence of preparation extent and the type of luting cement on the values of the shear bond strength of GC li si press glass ceramic laminate veneer material, The shear bond strengths (SBS) of several types of prepared tooth surfaces and ceramics were comparatively evaluated. Descriptive statistics of continuous data were presented as mean ($\bar{x}$), standard deviation (Std. $\pm$), minimum (Min.), maximum (Max.), standard error (Se) and skewness (skew.) values. Normal distributions were evaluated with the use of the Kolmogorov-Smirnov and Shapiro Wilks tests and determined that all the variables were normally distributed, with skewness values within ± 1 (**Table 5**).

Table 5: Descriptive statistics.

Groups	n	$\bar{x}$ (MPa)	Std. $\pm$	Min. (MPa)	Max. (MPa)	Se	Skew.
Enamel- GC Veneer (E-V)	10	31,00	7,03	22,76	42,55	2,22	0,150
Enamel -GC Link Force (E-LF)	10	33,97	6,89	24,29	44,64	2,18	0,055
Enamel Dentin complex- GC Veneer (ED-V)	10	22,05	3,91	11,75	25,59	1,24	-1,007
Enamel Dentin complex - GC Link Force (ED-LF)	10	22,00	3,07	16,75	26,85	0,97	0,198
Dentin -GC Veneer (D-V)	10	16,37	2,32	13,2	19,89	0,74	0,047
Dentin- GC Link Force (D-LF)	10	17,19	2,65	12,86	20,16	0,84	-0,498

The two-way ANOVA test (**Table 6**) revealed a statistically significant difference between the three sets of adhesion surfaces (Enamel, Enamel-Dentin complex, and Dentin) in the values of the (SBS) ($p = 0.000$). On the other hand, within the groups of similar adhesion surfaces, the test revealed no statistically significant difference ($p = 0.312$). This means that the type of cement didn't affect the bond strength values within the groups of the same adhesion surface.

Table 6: Evaluation of the effect of included parameters on the shear bond strengths.

	Type III Sum of Squares	Df	Mean Square	F	P values
Adhesion surfaces	2557,33	2	1278,66 5	57,154	0,000*
Cement type	23,264	1	23,264	1,04	0,312
Adhesion surfaces *Cement type	24,060	2	12,03	0,538	0,587

Two- way ANOVA Test

** $p < 0.05$*

Detailed explanations of the above-mentioned results are as seen in the tables below.

Table 7: Means of Shear bond strengths based on the adhesion surface and cement type.

	Groups	Shear bond strength values $\bar{x} \pm SD$ (MPa)	P values
Adhesion Surfaces	Enamel	32,49±6,95	¹ 0,000*
	Enamel-dentin complex	22,02±3,43	
	Dentin	16,78±2,46	
Cement type	GC Veneer	23,14±7,7	² 0,312
	GC Link Force	24,39±8,45	

¹One-way ANOVA Test

²Student t test.

* $p < 0.05$

According to **(Table 7)**, the "one-way ANOVA test" reported a statistically significant difference between the groups of different adhesion surfaces (E, ED, D) in terms of (SBS) ($p = 0.000$). The mean (SBS) of enamel groups was equal to 32,49 MPa with a standard deviation of $\pm 6,95$, which is statistically significantly higher than the Enamel-Dentin complex groups and Dentin groups ($p_1 = 0.000$, $p_2 = 0.000$).

The mean (SBS) of "Enamel-dentin complex" groups was equal to 22,02 MPa with a standard deviation of $\pm 3,43$ which is also statistically significantly higher than Group Dentin groups with a mean (SBS) of 16,78 MPa and a standard deviation of $\pm 2,46$ ($p = 0.000$).

The student T test indicated that there was no statistically significant difference between the two types of cementing agents within the groups of the same adhesion surface according to the (SBS). The mean (SBS) values of the GC Veneer cement groups were equal to 23,14 MPa with a standard deviation of $\pm 7,7$, and for the GC Link Force cement groups were equal to 24,39 MPa with a standard deviation of $\pm 8,45$.

Table 8: Shear bond strength values (MPa) of individual groups in the resin cement groups.

	Resin cement type	
Adhesion surface	Veneer $\bar{x} \pm SD$ (MPa)	Link Force $\bar{x} \pm SD$ (MPa)
Group E	31 $\pm$ 7,03	33,97 $\pm$ 6,89
Group ED	22,05 $\pm$ 3,91	22 $\pm$ 3,07
Group D	16,37 $\pm$ 2,32	17,19 $\pm$ 2,
P values	0,000*	0,000*

Oneway ANOVA Test

**p<0.05*

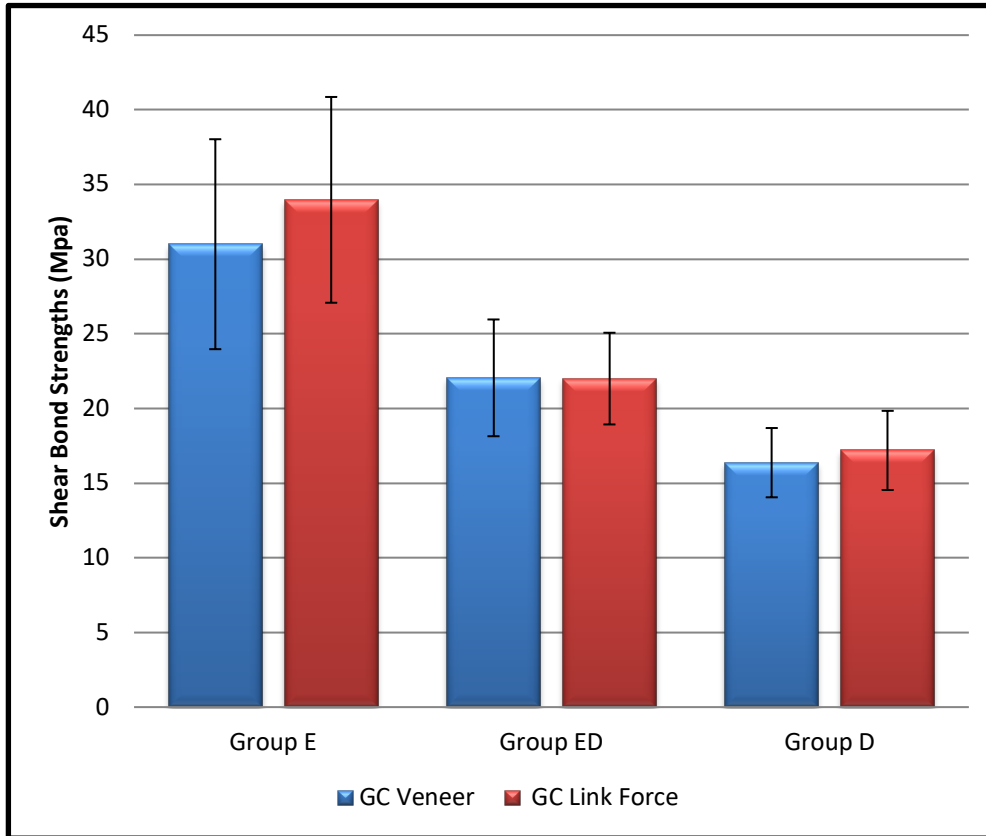


Figure 39: Bar -chart for the different adhesive surfaces with the two resin cements.

According to **(Table 8)** and **(Figure 39)**, when GC Veneer cement was used, a significant difference in (SBS) ($p = 0.000$) was detected between the groups. The mean (SBS) of Group E was statistically significantly higher than Group ED and Group D ($p_1 = 0.010$, $p_2 = 0.000$). The mean shear bond strengths of Group ED were also statistically significantly higher than Group D ($p = 0.004$).

When GC Link Force cement was utilized, a statistically significant difference in (SBS) was detected between the groups ($p = 0.000$). The mean (SBS) of Group E was statistically significantly higher than Group ED and Group D ($p_1 = 0.001$, $p_2 = 0.001$). The mean shear bond strengths of Group ED were also statistically significantly higher than Group D ($p = 0.005$).

Table 9: Shear bond strengths of individual cement type in groups.

	Resin cement type		
Groups	GC Veneer $\bar{x} \pm SD$ (MPa)	GC Link Force $\bar{x} \pm SD$ (MPa)	P values
Group E	31 $\pm$ 7,03	33,97 $\pm$ 6,89	0,354
Group ED	22,05 $\pm$ 3,91	22 $\pm$ 3,07	0,977
Group D	16,37 $\pm$ 2,32	17,19 $\pm$ 2,65	0,474

Student t test

**p>0.05*

According to student T test in **(Table 9)**:

In Group E, there was no statistically significant difference between the two used luting resin cements according to the (SBS). (p = 0.354).

In Group ED, there was no statistically significant difference between the two used luting resin cements according to the (SBS). (p = 0.977).

In Group D, there was no statistically significant difference between the two used luting resin cements according to the (SBS). (p = 0.474).

According to the findings from the failure mode test which was collected in **(Table 10)**, 73.3 % of the failure modes were adhesive, % were cohesive, and 20% were mixed. In the group of enamel adhesive surfaces, the ceramics which were cemented with

GC Veneer Cement demonstrated 70% adhesive and 30% mixed failures, while the ceramics cemented with GC Linkforce cement demonstrated 60% adhesive, 10% cohesive and 30% cohesive failures. In the group of enamel dentin complex adhesive surfaces, the ceramics which were cemented with GC Veneer Cement demonstrated 70% adhesive, 10% cohesive and 20% cohesive failures, whereas the ceramics cemented with GC Linkforce cement demonstrated 90% adhesive and 10% cohesive failures. In the group of dentin adhesive surfaces, the ceramics which were cemented with GC Veneer Cement demonstrated 70% adhesive and 30% cohesive failures, while the ceramics cemented with GC Linkforce cement demonstrated 80% adhesive, 10% cohesive and 10% cohesive failures.

Table 10: Mode of failure distribution of the groups.

Groups	Adhesive Failure	Cohesive Failure	Mixed Failure
G E-V	7 (70%)	0 (0%)	3 (30%)
G E-LF	6 (60%)	1 (10%)	3 (30%)
G ED-V	7 (70%)	1 (10%)	2 (20%)
G ED-LF	9 (90%)	1 (10%)	0 (0%)
G D-V	7 (70%)	0 (0%)	3 (30%)
G D-LF	8 (80%)	1 (10%)	1 (10%)
Total	44 (73.3%)	4 (6.7%)	12 (20%)

5. DISCUSSION

In this in vitro study, we used the extracted human premolar teeth to assess the impact of dentin exposure during the preparation of dental laminate veneers, and the type of adhesive systems used for the cementation on the (SBS) values of the (CLVs). Although “well-conducted randomized controlled clinical trials” are regarded the optimal approach for examining the quality of newer systems in the assessment of dental materials, there are numerous restrictions that prevent this type of research from being used routinely. ^{204–206} These tests are difficult to standardize due to factors such as examiner variability, changes in the substrate over time, the cooperativity of the patient during the long trial period, and failed recollection. ²⁰⁴. Furthermore, clinical studies are expensive and time-consuming. Therefore, it is critical to realize that when adopting the viewpoint that dental materials develop dramatically, their clinical performance should be assessed in a simple, fast, and more reasonable manner. ^{206,207}

Durability and quality are desirable qualities that must be allocated by any material, but the longevity of contemporary dental materials in the oral environment restricts their long-term efficacy. Nonetheless, these characteristics must be achieved. ²⁰⁸ The materials used in restorative procedures must be able to tolerate a hostile environment that varies from patient to patient. Uncontrollable factors like as mastication power, occlusal habits, dietary variables, humidity, and temperature changes can all shorten the lifespan of materials. ²⁰⁹

The benefits of laboratory testing in general include: (1) the rate at which data about a certain characteristic or property may be collected, (2) the often used test methodology's relative simplicity (3) the capacity (and requirement) to measure a single parameter while controlling all other factors, (4) the capacity to compare the performance of a new materials and techniques (5) the ability to evaluate many experimental groups at the same time (within specified restrictions) inside a single research setup. (6) must be

able to rely on low-cost, basic test procedures. A laboratory test's ultimate goal should be to collect data in order to anticipate the final clinical outcome.¹⁷⁹

So that; a diverse techniques could now be utilized to assess the bond efficiency of the used adhesives systems to both “enamel” and “dentin” substrates.¹⁸⁰

In-vitro bond strength measurement tests are used all over the world to assess the bonding efficiency of various adhesive techniques to the tooth structure. In addition, adhesive system bond strength testing is thought to be a strong predictor of dental restoration longevity.²¹⁰ So, the appropriate bond-strength test should be easily performed without complicated and sensitive procedures with acceptable quickness. The bond strength may be tested statically using either a “Macro- or Micro-test” setup, Furthermore, adhesive system bond strength testing is thought to be a good predictor of the lifespan of dental restorations. With a bond area more than 3 mm². The Macro-bond strength can be measured using "shear," "tensile," or a "push-out" method. The (SBS) technique is without a doubt the most frequently employed.¹⁸⁰ . In 35 % of journal studies on bond strength, the (SBS) was employed. Because the (SBS) test requires no extra specimen processing after the bonding procedure, it is widely used in businesses and other research organizations. On the other hand, (TBS) technique is less often employed to evaluate the bond strength between the luting agent and the hard structures like the ceramic materials and the metal alloys.^{185,186}

A push-out method was also used, specifically to gradually evaluate the resistance of bonds between the dentin and the adhesive agent to the fatigue.²¹¹ A push-out approach, on the other hand, has never been recognized as a universal bond-strength test methodology, owing to the more complex specimen preparation required as well as the longer testing period. This method, on the other hand, seems to be quite useful for determining the retention of luted posts in root canals.^{212,213}.

Because they are simple to perform and need little equipment and specimen preparation, the (SBS) has been the most commonly used to test the bond strength of dental materials.¹⁸⁰ In vitro models can correctly estimate the durability of dental

materials by examining mechanical and structural degradation factors during physiological ageing process.

Even though; the laboratory (In-vitro) testing could not precisely represent the clinical situation as the degree of the humidity and the encountered stress during the intra oral life. They could to some degree mimic the ecology of the oral cavity by the using of different aging technique for the teeth and the dental restorative materials. There are several technique could be used in the laboratory to artificially aging the teeth and dental materials, thermal aging is one of the most commonly utilized in laboratory studies and is well-known in the research world. ²¹⁴

Several research investigations have been conducted using heat cycling regimes to study the characteristics of dental materials. ²¹⁵⁻²¹⁹ After the release of Gale and Darvell's review ten years ago ²⁰⁰, many research had been used thermal cycling and mechanical stress to imitate the situation in the clinic. The expansion and contraction strains caused by heat cycles in the oral cavity might generate deteriorating stresses between the tooth substrate and the dental restorative material. Many research discovered that, depending on the kind of adhesive, thermocycling decreased binding strength to enamel and dentin. ²²⁰ Burke et al.¹⁸⁰ analysed the bond testing procedures used in “102 published studies and discovered that 82% of the publications did not include information on whether the specimens had underwent thermal cycling”. The thermal cycling, if indicated, the most commonly used values vary from 100 cycles to 500 cycles, with a temperature difference ranging from 5 C⁰ to 55 C⁰.

According to the (ISO) TR 11450 standard (1994) ²²¹, the thermocycling regimen of “500 cycles in water between 5 and 55°C” is the most suitable artificial ageing way, as many investigations have been conducted in accordance with the ISO standard. However, this quantity of cycles is most likely insufficient to create a true ageing impact according to Gale and Darvell.²⁰⁰ More recent studies have applied a variety of thermocycles, including approximately 1500 cycles between 10 and 50 °C after 3 months of storage Trites et al.²²², 500 cycles between 5 and 55°C Bishara et al.²²², and 6000 cycles between 5 and 55°C Faltermeier et al.²²³ In this study, we used “5000 cycles” based on

Yap et al. findings, as they reported that 5000 thermal cycles were identical to 6 months of oral life with function. Harper et al.²²⁵ concluded that a more than 15 seconds dwell time was unsuitable, as the patient with vital teeth cannot withstand for a long time the direct contact with hot and cold. For this reason, we used a “dwell time of 15 seconds” in our study.

For this study we decided to use the human teeth as a substrate and excluded the usage of “bovine teeth”, as the “human teeth” specimens considered to be preferable for in vitro dental research because they allow the study hypothesis to be tested in a more clinically relevant substrate.²²⁶ Many in vitro studies were done to compare between “human” and “bovine teeth” when used as a substrate in (SBS) tests. Lopes et al.²²⁷ stated that the use of “bovine teeth” instead of “human teeth” for laboratory tests of the (SBS) is considered partially unrealizable because the value obtained from the test does not depend only on the used substrate but depends mainly on the used adhesive agents. Titley et al. demonstrated that bovine primary incisor enamel and dentin are viable alternative test substrates for human primary enamel and dentin if the bovine dentine is not conditioned with 37 % orthophosphoric acid. Ruttermann et al.²³⁵ claimed that; the use of “bovine teeth” instead of “human teeth” for laboratory tests of shear bond strength testing is only partially suggested as a replacement for “human teeth”, because the (SBS) test on “bovine teeth” yields different quantitative findings than the “human substrate”.

The ultimate goal of a properly constructed ceramic restoration is the proper bonding of the material to the tooth substrate, which in turn increases the life span of the restoration in the mouth. The bond strength of the material to the tooth structure can be controlled by various parameters, including the selected surface treatment protocol in the form of choosing the appropriate type and concentration of the etching agent and the selection of the proper luting agent suitable for the individual situations. However, for long term success of (PLVs) several factors can be impacted by several factors, such as the type of the adhesion structure (enamel or dentine), the used preparation design, the type and film thickness of the used porcelain, the used luting agent and adhesive type, the shape of the teeth, and the type of patient occlusion.^{1,230}

Alenezi et al.²³¹ conducted a recent systematic analysis of the literature to evaluate the survival of the (PLVs) constructed in patients for the last 25 years. They came to the conclusion that the anticipated probability of prolonged survival of PLVs was 95.5 % over a 10-year period. The most prevalent kind of failure is veneer fracture preceded by debonding. The debonding most often occurs following a few years of the cementation procedures. The veneer constructed from ceramic other than feldspathic ceramic and without incisal coverage failed at a higher rate than the others.

Fracture is one of the most usual reasons of “PLV” total failure. One possible cause is that ceramic materials have low ductility, which is a known problem that contributes to fracture formation.²³² Furthermore, because veneering porcelains lack a core material, they may be more prone to breakage under mechanical stress. Another issue would be the shrinkage during the polymerization of the adhesive agent, leading to the concentration of stress failure at the adhesive layer.²³³ The preparation design for PLV restorations is categorised based on the kind of incisal edge. The two most common preparation designs are incisal bevel (IB) and incisal overlap (IO) terminating in a palatal chamfer. Both approaches allow for better incisal area characterisation and PLV sitting. However, there is disagreement over which preparation design is superior²³⁴ and just a few clinical trials have compared their efficacy.²³⁵

Many in vitro investigations concluded that more preservative teeth restoration can be obtained by PLVs as compared to other in direct restoration modality.²³⁶ The tooth preparation for PLVs is critical for good function and esthetics. Thus, care should be made to finish this preparation fully in the enamel^{70,230}, because if the preparation is done fully in the enamel, It is thought to maintain proper bonding with PLV and reduce stress in the porcelain. Furthermore; the preparation procedure utilized has an influence on the durability of the restoration; for example, significant failure rates of PLVs have been related to dentin surface exposure, as a result, PLV preparation must be done meticulously⁷⁰.

Despite the introduction of new adhesive methods, many studies revealed a challenging bonding of PLV to the dentine surface in spite of the introduction of new

adhesive materials and techniques. The estimated reason for this may be the low-rigidity of the dentine surface, which is more sensitive to stresses during loading, increasing the likelihood of fractures as compared to PLVs bonded to enamel.^{237,238} Other reasons include the dentine substrate's specific properties, which include changes in tubular structure, decreased inorganic content, and the outward flow of intratubular fluid.¹³ The aforementioned dentin difficulties are thought to be connected to debonding, which is another of the most prevalent complications with “PLVs”, although debonding can also occur as a result of inadequate adhesion.²³⁷

In many studies, it was not feasible to fully verify the impact of dentin extension in the PLV preparations, since this was rarely reported in details. Furthermore, while the presence of “dentin” or “enamel” in the preparation is generally detected visually, it is not always possible to discriminate between the two²³⁷.

Although excessive exposure of dentin surfaces was related to increased failures in PLVs²³⁹, a considerable dentin exposure is required during preparation, particularly in the cervical and proximal regions, to compensate for minor malposition and/or discolouration¹⁰. Aside from anatomical causes, age-related attrition and tooth erosion increased enamel shrinkage. As a result, minimally invasive tooth preparation within the enamel is extremely difficult⁹.

Using "0.5 mm porcelain veneer" as an example, to replicate the natural curves of the tooth, it was decided that the preparation depth could not be adjusted as a particular measure. The depth of the preparation should follow the anatomical contour of the teeth with a value of "0.3 to 0.7 mm". Currently, the ceramic veneer preparation should be no more than 0.3 mm in the cervical area. Not more than 0.5 mm in the middle of the tooth, and not more than 0.7 mm in the incisal edge area. Theoretically; this anatomical preparation technique may enable tooth preparation within only enamel, owing to the different enamel thickness in different zones of the tooth, However, this may be difficult to achieve. Cherukara et al.³⁸ in their pilot study, evaluated the efficiency of three clinical approaches in creating an intra-enamel preparation, namely "dimple", "depth groove", and "freehand", as well as the connection between dentin exposure and overpreparation

above the typically suggested depth of preparation of 0.5 mm. They found that we can make preparations confined to the enamel, when the preparation depth ranges from 0.4 to 0.6 mm, with exception to the cervical areas, even if the preparation is done by the most conservative depth limiting technique. and concluded that a fifth of the prepared labial surface was exposed dentin. The anatomical explanation for this was uncovered by data from Ferrari et al.⁴³, as they concluded that the average thickness of enamel at the cervical third varied from 0.3–0.4 mm, by measuring the enamel thickness at the incisal third, medium third, and cervical third of 114 anterior teeth.

Other variables that might impact the long-term performance of porcelain laminate veneers are the kind and thickness of porcelain materials because of their physical characteristics. “lithium disilicate ceramics” has gained favour among ceramic systems for anterior esthetic restorations.²⁴² “Lithium disilicate” is a silica-based ceramic material with outstanding esthetic, translucency, strength, resistance to wear, and their ability to withstand chemicals effects.²⁴³ Clinicians have access to a wide range of adhesive system materials and techniques for the cementation of lithium disilicate ceramics to the teeth surfaces, which vary according to the special clinical requirements for the restoration in order to enhance the efficiency of aesthetic restoration.

The ability of a luting agent to withstand functional loads during the life of a restoration is a critical criteria for an acceptable luting agent.²⁴⁴ Adequate polymerization is critical for resin luting materials to have appropriate physical characteristics and clinical efficacy. The low rate of transformation from monomer to polymer and the excessive number of resulting double bonds are considered the main causes of the complete polymerization of the luting agent. This in turn reduces the physical properties of the luting agent by increasing its dissolution in water.²⁴⁵

The luting materials are essential for the durability of (PLV) restorations.²⁴⁶ Peumans et al.¹⁶⁰ stated that the most prevalent causes of PLV failures are the shrinkage of the resin cement, increase in temperature and mechanical forces. Furthermore, it has been observed that (PLVs) failures can develop as a result of the application of inappropriate luting agents.

Several factors, including optical features, the method of resin activation, the quality of the used curing machine ²⁴⁷, the film thickness of the material, may influence resin polymerization and, as a result, cement selection. ²⁴⁸ Light-curing or dual-curing activation can be used for veneer cementation. Light-curing cements allow the material to set by a polymerization technique under special light. The set-on-command feature of these materials, as well as the limitless working time it gives, is a significant benefit. ¹⁶⁹

The main undesired feature of the dual curing cements is their colour changes with advancement in time. This feature might compromise the aesthetic features of the restoration, especially if applied under a thin veneer layer. ^{249,250} So that, the clinicians prefer light-curing luting resins over dual-cured luting resins for the cementation of porcelain veneers because they have better color stability. ²⁵¹ However, the lack or reduction of light irradiance caused by the ceramic material's thickness, or low translucency may decrease the quality of the polymerization process. ²⁵² To solve this issue, a cement with both chemical and light activation processes was introduced. In these materials, special ingredients are included in order to initiate the polymerization reaction even in the absence or reduction of light. ^{252,253} This feature slows the setting process to permit adequate working time for finishing the restration. ¹⁶⁹

In order to obtain an ideal ceramic-tooth structure bond, a good bond should be obtained between the cementing agent and both the ceramic and the tooth structure. ²⁸ To achieve strong bond strength, the luting agent must be cured optimally. ²⁵⁴ Furthermore, the polymerization rate of the luting resin impacts their mechanical characteristics and, as a result, the restoration's survivability. ²⁵⁵ A sufficient amount of light is necessary to sustain proper polymerization of the material. ²⁵⁶

Ilie and simon ²⁴⁴ stated that; even with the dual curing cements, the maximum achievable hardness was not attained until a curing period of 15 seconds, and the high intensity curing unit was able to cure through ceramics up to 2 mm without reducing luting composite hardness.

Öztürk et al.¹⁷ in their in vitro study, which was conducted to compare the more effective luting protocol for ceramic restoration as they compared micromechanical characteristics between the light and dual-curing cements. They concluded that the performance of the dual curing cement is superior to the light cured one. Also, the mechanical characteristics of the luting resins are influenced by the ceramic thickness and the used luting resin and the curing period with a minimum curing time of 20 seconds is required.

The findings of the present study encourage the rejection of the first null hypothesis, which states that there is no difference in the form of (SBS) between glass (CLV) Material cemented to enamel (E), dentine (D), and enamel–dentine complex (ED) by the use of two distinct luting resin. Although the (E) surface preparation groups showed no statistically significant difference between the two subgroups (E-V & E-LF), they did have higher (SBS) values than the (ED) and (D) groups. In the same way, the (ED) subgroups (ED-V & ED-LF) and the (D) subgroups (D-V & DLF), no significant difference was found between the two cements within the groups. Although the (ED) groups showed lower (SBS) values as compared to the (E) groups, they exhibited higher (SBS) values than the (D) groups. So, from the results of our study, we can say that, despite advancements in adhesive methods, Bonding porcelain restorations to “enamel” remains preferable than bonding to “dentine”.

In accordance with our findings in this study, Abo-Hamar et. al.²⁵⁷ in their in vitro study in which they used the (SBS) test with and without thermocycling, to compare the bonding efficiency of five cementing agent to both the enamel and dentin, reported a superiority of enamel bonding to dentin bonding. They also conclude that the thermal cycling procedure had no effect in the (SBS) values of dentin groups but enamel groups it had a major effect on the (SBS) values of two from five used resin cements. They attributed the degree of thermocycling effect to a number of variables, such as the difference in “heat conductivity” and “coefficient of thermal expansion” between the tooth substrate and the restoration versus the initial bond strength between the used luting material in the study and the tooth substrate, which resists any generated thermal stresses. Bair et. al.⁷² compared five different resin cements regarding the strength of

bonding to the "dentine" and "enamel" surfaces of extracted teeth by cementing 140 stainless steel cylinders to prepared "enamel" and "dentine". The specimens were kept in water for 24 hours without being subjected to any sort of thermocycling process, and they reported that the bond strength values were impacted by the kind of tooth substrate in terms of enamel and dentine, with dentin having a lower bond strength than enamel. In the same way, Naumova et al.²⁵⁸ investigated the (SBS) of five different luting resin to human "enamel" and "dentine" under varied storage conditions. After being ground flat, teeth were polished with sandpaper to reveal "enamel" or "dentine." Steel cylinders were treated and cemented to the teeth. (SBS) was determined after specimens were maintained in three distinct conditions before being thermo-cycled. They discovered that the different tooth surfaces, "enamel" or "dentine," influence the (SBS) of the tested resin cements by luting with steel, with the bond strength to "enamel" vastly superior in all resin cements. They also discovered that specimen storage conditions have no effect on the bond strength to "enamel", but hydrothermal stress may change the bond strength to dentin.

Although the results of these studies supported our findings regarding the superiority of bonding to enamel as compared to dentin, they did not address the idea of dentine exposure. In addition to that Bair et. al.⁷² and Naumova et al.²⁵⁸ used steel cylinders instead of ceramic materials for bonding.

On the other hand, öztürk et al.²³⁰, Ge et al.²⁵⁹ and Blunck et al.²⁶⁰ studied the impact of dentin exposure on the survival of (CLVs). As öztürk et al.²³⁶ used an extracted human teeth, to evaluate the (SBS) of (CLV) materials to three different surfaces (enamel, dentin, and enamel dentin), luted with three different resin cements, and their conclusion supported our results, as they reported a significance difference in the (SBS) values between the different surfaces with highest (SBS) values in "enamel" groups and lowest shear bond strength values in "dentine" groups. Ge et al.²⁵⁹ investigated the effects of adhesive surface type "(all-enamel, all-dentin, or half-dentin-half-enamel)" and (CLV) thickness on the stresses required to produce early and "catastrophic porcelain veneer failure". The (CLV) specimens of variable thicknesses were cemented to the prepared human incisors with various "enamel" and "dentine" tooth substrates. Then the specimens subjected to thermal cycling and loaded until failure. They concluded that (CLV) bonded

to the mixed substrate (half-enamel-half-dentin) were much weaker as compared to those bonded to enamel substrate. Blunck et al.²⁶⁰ evaluated the effect of five preparation methods and two distinct porcelain thicknesses on the integrity of veneer margin and fracture resistance of (CLV) following in vitro thermal and mechanical loading, as they randomly assigned eighty human central incisors to ten groups, with five preparation design namely: “non-prep”, “minimally invasive (exclusively enamel-bonded)”, “semi-invasive (50 % bonded in dentin)”, “invasive (100 % in dentine)”, “semi-invasive with two additional class III composite resin restorations”, and “invasive with two additional class III composite resin restorations”. Leucite ceramic veneers were designed in two thicknesses (0.2–0.5 mm and 0.5–1.2 mm), adhesively luted, thermo-cycled, and mechanically loaded. They concluded that; After three million mechanical load cycles, all groups demonstrated high levels of excellent margin qualities. In addition to; Thin veneers with considerable "dentine exposure" had a statistically higher failure risk than veneers that luted fully in enamel and veneers of increasing thickness with minimal dentin exposure.

Even though Ge et al.⁷⁴ and Blunck et al.⁷⁵ tested the effect of dentin exposure on laminate veneer preparation by tests other than (SBS) testing, which is the used test in our study, they also concluded that the exposure of dentin affects the long-term survival of ceramic veneers, but the degree of this effect depends on the degree of this exposure. This gives us a hint to study the additional effects of dentine exposure on the veneer survival by using other testing methods than (SBS) in order to improve the bond behaviour of porcelain to dentine.

The results of our study contradicts the findings of Lafuente et al.²⁶¹ who compared the bonding behaviour of four distinct resin cements to enamel and dentin. They found that the type of the tooth substrate had no influence on the values of the bond strength, although there was a substantial difference in the bonding between the used resin cements in their study. This may be addressed by the fact that different testing methods were used, as he used tensile strength testing.

According to the results of the descriptive statistical data from our study, no significant statistical difference was found between the two used resin cements within the same adhesion surface. For all adhesion surface types (enamel, dentin and enamel dentin complex), there was found no statistical significance difference in the (SBS) values between the light curing GC-V (GC Veneer) cement and the dual curing GC-LF (GC-Linkforce) cement. Because the findings of this investigation showed that the influence of preparation surface type on (SBS) was substantially larger than the effect of resin cement type, the second null hypothesis could be approved.

In agreement with our findings. Hikita et al.²⁶² used a different adhesive resin systems to evaluate their bonding quality to both human enamel and dentine substrates and they concluded that with all the used resin cement the (SBS) values were compatible.

The kind of adhesion surface had a major effect on the (SBS) in this study. When the (SBS) values of the three examined adhesion tooth surfaces were evaluated, there was a significant difference between the "enamel", "enamel–dentine complex", and "dentine" adhesion surfaces. As a result, our findings support the rejection of the third null hypothesis, which states that the type of adhesion tooth surface does not affect the shear bond strength values.

It has been confirmed by Eick et al.⁶⁵ and Pekkan et al.⁶⁶, that to compensate adequately for the stress caused by polymerization shrinkage in the resin cement, the adhesion to dentine should have a (SBS) of at least 17 MPa and the adhesion to enamel should have a (SBS) of at least 20 MPa.

This study's findings indicated that, the mean (SBS) values of the (E) groups were (31±7,03 MPa) for E-V group and (33,97±6,89 MPa) for E-LF group, the (SBS) values of the (ED) groups were (22,05±3,91 MPa) for ED-V group and (22±3,07 MPa) for ED-LF, while for (D) groups the (SBS) values were (16,37±2,32 MPa) for D-V group and (17,19±2 MPa) for D-LF group. For (E) and (ED) groups the mean (SBS) values were above 20 MPa. In this case, and in accordance with öztürk et al.²³⁰ finding, the dentine exposure if occurred during the (CLV) preparation should not extend to more than half

of the prepared adhesion surface. The bonding survival of the (CLV) could be obtained even if dentine exposure occurred during the preparation. However, the more the exposure of the dentine, the lower the (SBS) of the porcelain. As a result, It has been suggested that all preparation margins for “(PLV) restorations” be in sound enamel.²⁶³

Many studies assessing (PLVs) in vitro in the dental literature have shown these restorations to be very successful. According to Andreasen et al.²⁶⁴ and Stokes and Hood²⁶⁵ the extracted human teeth restored by (PLVs) could maintain to some extent their intrinsic strength. Furthermore, Magne and Douglas^{266 272} stated that teeth restored with (PLVs) can exhibit mechanical characteristics comparable to undamaged teeth when dentine adhesives are applied appropriately. In their clinical study, Arif et al.²⁶⁷ demonstrated that (PLV) restorations are an effective conservative treatment option for enhancing the aesthetics of anterior teeth.

The failure mode categorization used in this study was comparable to Scherrer et al.²⁶⁸ In all of the mixed failures, the tooth substrate and resin cement are mostly a part (less than 40%) of the overall adhesion area. All cohesive failures were seen in the tooth substrate, and when the fractured tooth substrate was in major portions (40 % or more), it was classed as a cohesive failure. Adhesive failure occurs when there is a failure in adhesion between the tooth substrate and the bonded material, even though very small amounts of adhesive resin (less than 10 %) remain observed on the tooth surface. In our study, when the failure modes were analyzed using the previously described classifications, it was observed that the most common pattern of failure was adhesive, followed by mixed mainly cohesive, followed by cohesive failure. Also; we observed that all the mixed or cohesive failures were in the tooth and/or cement, not the ceramic substance. This interfacial failure in dentine and/or resin with minor cohesive fractures may be connected to the adhesive's capacity to resist defect propagation, such as crack development or peeling resistance from the substrate. According to Scherrer et al.²⁶⁸, regardless of the performed test method, the presented "mixed failure" configuration most often does not specify the degree of "cohesive failure" or the involved material, whether it be dentine, adhesive or restorative material. Although many authors observed actual minor interfacial failure “cohesive fractures” in cement or the dentin substrate.

Although Della Bona et al.¹⁴¹ stated that the “cohesive failure” of the specimen's base is an intrinsic characteristic of the geometry of the (SBS) test system, and that the (SBS) technique is insufficient for measuring the luting resin adhesive efficiency to ceramic. But in our study the cohesive failure was seen in only 4 samples with 6.7% of all the groups, which means a low incidence rate, with main adhesive failure with 73.3% followed by mixed failure of 20%.

Pashley et al.¹⁸¹ and Thomsen & Peutzfeldt²⁶⁹ outlined the variables that predispose to cohesive failure. Which include; the extracted tooth's structural characteristics, the extracted tooth becomes more brittle after a long period of waiting, weakness of the adhesion surface following the acid etching process, the breakdown of adhesion interfaces, and development of a weak and insufficient hybrid layer.

The (SBS) values for all groups in our investigation were found to be extremely satisfactory, this might be connected to the use of the same adhesive system and resin cement by the same manufacturer. Rather of mixing and matching an adhesive system from one manufacturer with a resin composite from another As a result, equivalent bond strength testing of similar "adhesive/composite combinations" is achievable.²⁷⁰

6. CONCLUSION

Within the scope of this study, the following conclusions are drawn:

1. The shear bond strength of the porcelain laminate veneers to the three different types of dental structures (enamel, dentine, and enamel–dentine complex) was influenced by the type of tooth structure (enamel, dentine, and enamel–dentine complex).
2. During the preparation of the ceramic laminate veneer, the clinicians should preserve the enamel as much as possible as they can, as the bond strength will decrease when the amount of dentine exposure increases.
3. According to the results of our study, dentine has the lowest shear bond strength value, so porcelain laminate veneer restorations should not be cemented to dentine alone.
4. The shear bond strength of the porcelain laminate veneer restorations was unaffected by the kind of resin cement used in this study – dual-cure or only light-cure.

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8. APPENDICES

8.1. Ethical Committee Declaration.



Sayı : 37068608-6100-15- 2120
Konu: Klinik Araştırmalar
Etik Kurul Başvurusu hk.

08/04/2021

İlgili Makama (Aasma El Badri)

Yeditepe Üniversitesi Diş Hekimliği Fakültesi Protetik Diş Tedavisi Prof. Dr. Ender Kazazoglu'nun sorumlu araştırmacı olduğu **"İki Farklı Yapıştırma Sistemi Kullanılarak Cam Seramik Laminaların Dişlere Bağlanma Kuvvetlerinin İn Vitro Değerlendirilmesi"** isimli araştırma projesine ait Klinik Araştırmalar Etik Kurulu (KA EK) Başvuru Dosyası(2145) kayıtlı Numaralı KA EK Başvuru Dosyası, Yeditepe Üniversitesi Klinik Araştırmalar Etik Kurulu tarafından 07.04.2021 tarihli toplantıda incelenmiştir.

Kurul tarafından yapılan inceleme sonucu, yukarıdaki isim belirtilen çalışmanın yapılmasının etik ve bilimsel açıdan uygun olduğuna karar verilmiştir (KA EK Karar No: 1416)

Prof. Dr. Turgay Çelik

Yeditepe Üniversitesi
Klinik Araştırmalar Etik Kurul Başkanı