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In-vitro Evaluation of the Effect of Two Surface Treatment Techniques and Three Adhesive Systems on the Shear Bond Strength of Aged Composite Resin Repair

MSc MASTER'S THESIS

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APPROVAL

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DECLARATION

I declare that this thesis has been composed solely by myself and has been written by me and has not been submitted for any pervious degree and that, to the best of my knowledge and acceptance, it contains no material previously published or written by another authors, except where due acknowledgement has been made in the text.

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LIST OF ABBREVIATION

2-HEMA	2-hydroxylethyl methacrylate.
10-MDP	10-Methacryloyloxydecyl Dihydrogen Phosphate.
A1 sub-group	Diamond bur treament + total-etch adhesive
A2 sub-group	Diamond bur treatment + self-etch adhesive with selective
A3 sub-group	Diamond bur treatment+ self-etch adhesive.
A4 sub-group	Diamond bur treatment+ universal adhesive with selective etch.
A5 sub-group	Diamond bur treatment+ universal adhesive.
AFRs	Annual Failure Rates.
ANOVA	Analysis of Variance.
B1 sub-group	Air-abrasion+ total-etch adhesive
B2 sub-group	Air-abrasion+ self-etch adhesive with selective etch.
B3	Air-abrasion + self-etch adhesive.
B4	Air-abrasion+ universal adhesive with selective etch.
B5	Air-abrasion + universal adhesive.
BHT	Butylated Hydroxytoluene.
Bis-GMA	Bisphenol-A and Glycidyl Methacrylate.
BPDM	Biphenyl Dimethacrylate.
CQ	Camphorquinone.
DC	Degree of Conversion
EBPADMA	Ethoxylated bisphenol-A dimethacrylate**.**
HL	Hybrid Layer.
IRCS	Indirect Composite Resin.
LED	Light Emitting Diode.
MDP	Methacryloyloxydecyl Dihydrogen Phosphate monomer.
µm	micrometer.
Mpa	Megapascal.
MPTS	3-methacryloxypropyltrimethoxysilane.
NCTD	Non-Carious Tooth Defects**.**
nm	nanometer.
NPG-GMA	N-pherylglycine glcidyl methacrylate.
PMMA	Polymethyl Methacrylate.
PPD	1-Phenyl-1,2-Propanedione.

PSI	Pounds per Square Inch.
SBS	Shear Bond Strength.
SPSS	Statistical Package for the Social Sciences.
SD	Standard Deviation.
SE	Self-Etch.
SEM	Scanning Electron Microscopy.
TBS	Tensile Bond Strength.
TEGDMA	Triethylene Glycol Dimethacrylate.
UA	Universal Adhesive.
UDMA	Urethane Dimethacrylate.

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ABSTRACT

Aml, S. (2018). In-vitro Evaluation of the Effect of Two Surface Treatment Techniques and Three Adhesive Systems on the Shear Bond Strength of Aged Composite Resin repair. Yeditepe University, Institute of Health Science, Department of Restorative Dentistry MSc thesis, Istanbul.

Purpose of study: this study assessed the influence of two surface treatment techniques with three different adhesive systems on the shear bond strength of repaired aged composite resins.

Materials and methods: Ninety composite cylindrical shaped specimens (8mm × 4.5mm) were fabricated from Estilete Sigma Quick shade A2 composite in transparent Teflon mold, polished with 2500 grit carbide paper and kept in distilled water for 24 hours. Subsequently, the samples were aged with thermocycling for 10,000 cycle. Then, the specimens were separated into two main groups in relation to surface treatment (each group of 45 samples); diamond bur treatment and air abrasion with 50µ aluminum oxide then each group was divided according to the adhesive system with different application protocols into five subgroups (N = 9); total-etch two-step adper single bond 2, self-etch two-step SE clearfill bond and universal G-perimo bond. Following the application of bonding agents, the samples were repaired with the same composite type and shade. The initial shear bond strength was measured, and finally values were statistically analyzed.

Results: The mean shear bond strength values of the Bur treatment group (14,38±2,34) was found to be significantly higher than that of the air abrasion group (12,29±1,84) and There was a statistically significant difference in shear bond strength MPa between the subgroups (p: 0.000, $p < 0.05$). The shear bond strength of the total etch adhesive sub-group was found to be statistically significant and lower in Mpa values than that of the other sub-groups regardless of the surface treatment.

Conclusion: During aged composite repair procedures, both the surface treatment and adhesive agent application had an effect on the shear bond strength, with the high value of shear bond strength obtained from a combination of bur treatment with clearfill SE bond or G-primo bond.

Keywords: surface treatment, repair of aged composite resins, adhesive systems.

ÖZET

Aml, S. (2018). İki Değişik Yüzey Hazırlığı ve Üç Farklı Adeziv Sistem Uygulamasının Yaşlandırılmış Kompozitlerede Yapılan Tamir İşleminin Makas Kuvvetlere Dayanımının İn Vitro İncelenmesi. Yeditepe Üniversitesi Sağlık Bilimleri Enstitüsü. Restoratif Diş Tedavisi Anabilim Dalı. MSc Tez. İstanbul.

Çalışmanın amacı: İki değişik yüzey hazırlama ve üç farklı adeziv sistem kullanılarak, yaşlandırılmış kompozitlerde yapılan tamir işleminin, makas kuvvetlere karşı gösterdiği dayanımın in vitro olarak incelenmesidir.

Gereç ve Yöntem: Çalışmada, 90 adet 8 mm çapında 4,5 mm yüksekliğinde silindirik kompozit (Estilete Sigma Quick) bloklar şeffaf kalıp yardımı ile hazırlandı. Hazırlanan örnekler, 2500 gritlik silikon karbid zımpara kağıtları ile zımparalanıp 24 saat distile suda bekletildikten sonra 10000 termosiklus döngü süresiyle yaşlandırma işlemine tabii tutuldu. Yaşlandırma işlemi tamamlandıktan sonra, yüzey hazırlama şekline göre örnekler önce iki gruba (yüzeyin mekanik olarak elmas aşındırıcı ile hazırlandığı ve air abrazyon ile hazırlandığı), ardından da uygulan adezivin türüne ve uygulama şekline göre beş alt gruba ayrıldı. Yüzey pürüzlendirme işlemi elmas aşındırıcı ya da air abrazyon (50 µm alüminyum oksit püskürtülmesi) ile yapıldıktan ve farklı adezivler değişik şekillerde hazırlanan yüzeylere uygulandıktan sonra 2 mm çapında 2 mm yüksekliğinde şeffaf kalıp yardımıyla kompozit uygulanarak tamir işlemi gerçekleştirildi. Hazırlanan örnekler 24 saat distile su içinde bekletilip Universal Test Cihazı'na bağlanarak makas kuvvetlere dayanım testine tabii tutuldu. MPa olarak elde edilen bağlanma dayanımı verileri istatistiksel olarak analiz edildi.

Bulgular: Çalışma sonuçlarına baktığımızda, en iyi bağlanma değerlerini yüzey hazırlığının elmas aşındırıcılar kullanılarak mekanik pürüzlendirme yapılmış ve Universal Adhesive uygulanmış grupta (16,5 ± 0,79 MPa) elde edilmiştir. Elmas aşındırıcı ile yapılan mekanik pürüzlendirmeden sonra self – etch adhesive uygulanmış grupta ise 15,91 ± 1,15 MPa lık bir bağlanma görülmüştür. Yüzeyin, hem mekanik hem de air abrazyon ile pürüzlendirildiği ve iki basamaklı total etch sisteminin kullanıldığı gruplarda daha düşük bağlanma değerleri elde edilmiştir.

Sonuç: Elmas aşındırıcılar ile mekanik pürüzlendirme yapılan gruplarda, yüzey hazırlığının air abrazyon ile yapıldığı gruplara göre daha yüksek bağlanma değerleri elde edilmiştir.

Anahtar Kelimeler: Kompozit rezin, adeziv sistemler, kompozit tamiri**,** Yüzey Hazırlığı.

THE OBJACTIVE AND BACKGROUND

Improvement in adhesive technologies greatly affects recent concepts in restorative dentistry with the goal of conserving sound tooth structure and declining the number of interventions required (1).

Using composite resin in restorative dentistry has significantly improved due to the advance in curing systems, bonding procedures, physical and chemical modifications in their compositions. However, failure of composite restorations still happens (2). Because of this reason, for a long time, the defective restoration replacement has been considered as the most recorded treatment procedure in most of dental clinics, and it is considered as a major part of oral health care in adult patients (3). Since the replacement procedures would lead to more destruction in the remaining sound structure as well as increasing in cavity size, repair procedure is a good choice to avoid more damage to the sound tooth structure and to reduce the total price of dental management (4).

Repair of composite restorations is often accomplished by the application of fresh composite over the old composite (5). Because of a diminished number of accessible C=C bonds in old composite, which is important to react with the new composite, and also due to water sorption; the repair of old composite might be extremely challenging (4).

Defective restoration repairs are mainly performed months or years after their first application in the patient's mouth. Through this period of time, the restoration is subjected to the oral environment, which leads to the decrease in free-radical activity and more water sorption (6). For these causes, the aging process of composite materials before repair procedures has an essential role in the assessment of bond strength of composite resin repair (7).

During in-vitro studies, the aging of composite resin materials has been achieved through a various methods, which include storage and /or boiling in water, sodium chloride or citric acid solutions and thermocycling. Thermocycling is commonly used during repair procedures for the aging of composite resins. Throughout different studies, the number of cycles used were altered and there is no agreement on which number of thermal cycles produce the worst case or most clinically related situations (7).

For enhancement of the repair bond strength of aged composite, different surface treatment modalities have been used, which include bur roughening, phosphoric acid or hydrofluoric acid etching, air abrasion, sandblasting with silica coated particle and silanization. Recently, there has been a high attention upon the use of laser as a surface treatment in the repair procedure (7, 8, 9). Although there is a high number of studies about the effectiveness of different surface treatments, none of them might be suggested as a universally suitable repair technique (10).

Moreover, intermediate bonding agents would improve the strength of the repaired composite and enhance bonding significantly between aged composites and new composite layers, as the bonding agent penetrates deeper within the irregularities generated by the surface pretreatment, and also by direct chemical reaction with remaining C=C bonds present on the surface of aged composite resin (11).

Therefore, the purpose of this study was to examine the influence of different adhesive application protocols together with two surface treatment methods on the shear bond strength of aged composite repair. The null hypothesis was that the surface pretreatment and the type of adhesive system could not enhance the repair bond strength of aged resin composite.

INTRODUCTION

Dental decay is still the most frequent and widespread biofilm-related oral disease, causing the tooth tissue destruction by acidic attack from cariogenic bacteria (12, 13). Restorations are normally essential to replace the hard tooth tissue, which have been destructed by dental decay. Nevertheless, hard tooth structure loss also occurs from other non-carious tooth defects (NCTD), such as abfraction, abrasion, erosion lesions or tooth fracture. Furthermore, teeth with a developmental disorder or intrinsic discoloration like dental fluorosis and enamel hypoplasia, might need restorations to re-establish their esthetic and functional properties. Thus, the treatment plane of (NCTD) might be dependent not only on the necessity to restore lost tooth structure, but also to prevent additional damage to remaining sound structure (14).

The critical aim of dental restorative materials is to return the functional, biological and esthetic features of healthy tooth structures. Gold and amalgam restorative materials, which have a long report of clinical success, have been utilized as dental restorative materials for more than 100 years, mainly in molar teeth, due to their high mechanical properties, which resemble the natural teeth. On the other hand, these metallic materials are not esthetic, and one of the important requirements of esthetic dentistry is to restore anterior teeth and any extraorally visible parts of posterior teeth, with restorative material that has the same color and shade as that of the adjacent tooth surface, while restoring the functional properties (15).

2.1. Dental Composite Resin:

The introduction of resin-based composite materials to the field of restorative dentistry was one of the most important contributions in the last century. Currently, esthetic dental restorations are becoming more and more common than metallic restorations (16).

2.1.1. Historical Evolution of Dental Composite:

Dental Composite resins have been developed and used in the restorative dentistry to reduce the acrylic resin's drawbacks that substitute silicate cements, (which was the only esthetic material used in the 1940s). There have been significant evolutions in filler, bonding and curing methods of esthetic restorations along the past 55 years (17, 18). (Figure 2.1)

Solubility problems with silicate cement led to unfilled acrylic systems development, which is based on the polymethyl methacrylate monomer (PMMA). There has been an extreme contraction of methyl methacrylate monomer during a polymerization process, which causes gap formation. Also, PMMA was not strong enough to stand the occlusal force. Therefore, inorganic fillers, essentially silica particles were added. In retrospect, the earliest PMMA materials were named as (unfilled acrylics material) (19).

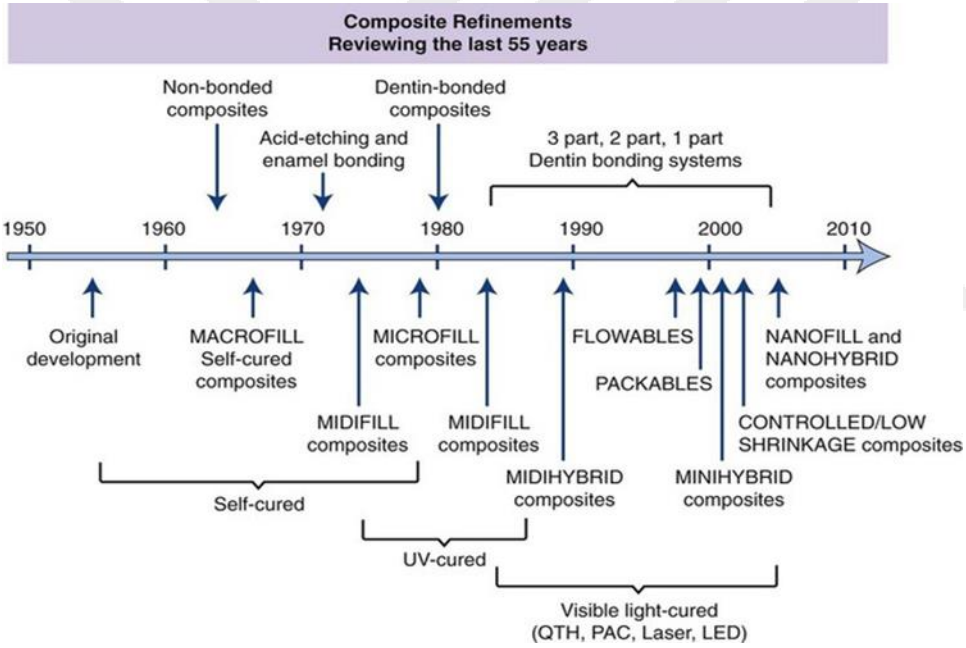

Figure 2.1: Evolution of dental composite resin from 1950 to 2010 (Figure obtained from a book of Phillips' Science of Dental Materials' 12th Edition, 2013).

Methylmethacrylate-based matrix was supplemented with (Bis-GMA). It is a disfunctional monomer created by the reaction of Bisphenol-A with glycidyl methacrylate. Another related disfunctional molecule used is urethane dimethacrylate (UDMA). (Bis-GMA) and (UDMA) both of them are highly viscous. For clinical causes, they are thinned by another disfunctional monomer, which is triethylene glycol dimethacrylate (TEGDMA) with a much lower viscosity (20).

Furthermore, the interfacial bonding between the organic phase (Bis-GMA) and the inorganic phase has an essential role to obtain a full advantage of composite resin formulation. Silica particles are covered by mono-molecular layer of silane coupling agents. One end of these molecules is able to bond to hydroxyl groups, which is present at the surface of the silica particles, and the other end has the ability to co-polymerize with monomer's double bonds within the matrix phase (21).

The early developed composite was chemically cured, which require the base to be mixed with the catalyst part, and difficulties with the proportions, mixing procedure and color stability may be happened (22). From 1970, composite materials started to be polymerized with electromagnetic radiation. At first, an ultraviolet light source with 365nm output was used to offer the necessary light energy, because of their iatrogenic effect and their shallow polymerization, and then it has been replaced by a visible-light source with (427-491nm) output, which is used nowadays and is undergoing continuous evolution (23).

2.1.2. Formulation of Dental Composite Resin:

Resin-based composite materials are very complex mixtures which contain three chemically-different phases: organic (resin matrix), in-organic (filler) phase and a coupling agent with an initiator and inhibitor system (20, 24).

2.1.2.1. Organic (Resin Matrix) Phase:

The organic phase involves a mixture of different polymerizable monomers, for example, Bis-GMA and/or UDMA as well as of different adjustments of these molecules with C=C double bonds, which, translated to the strongly cross-linked polymer with C-C bonds after free radical activation with photoinitiators (25, 26).

Bis-GMA is a long-chain monomer of two methacrylate groups that presents for cross-linking polymerization. However, because of its large size, its high viscosity; it reaches the gel point of photopolymerization rapidly, resulting in a relative low degree of conversion (27). Furthermore, the high viscosity limits the filler loading capacity of dental composites (28).

TEGDMA is a low-molecular weight monomer which is used as a diluent monomer for Bis-GMA. TEGDMA improves the molecular mobility during the polymerization procedure and slows down the gel point of photo-polymerization due to its low viscosity. Bis-GMA controls the final DC through monitoring the diffusion-controlled termination procedure. Composite formulations with a higher percentage of TEGDMA usually show high DC and allow elevation of filler loading, but also demonstrate higher polymerization shrinkage (25).

Ethoxylated bisphenol-A dimethacrylate (EBPADMA) and Bis-EMA are other base monomers used in some dental composite brands, which are a more hydrophobic analog of Bis-GMA, with low viscosity and more flexible structure than Bis-GMA formulation (29). Dental composites based on EBPADMA often demonstrate a lower polymerization shrinkage than the original Bis-GMA/TEGDMA resins (27).

2.1.2.2. Inorganic (Filler) Phase:

The inorganic phase consists of fillers which are mainly quartz, silica or ceramic. The polymerization shrinkage, water absorption and coefficient expansion are diminished with high filler content. However, the compressive and tensile strength, modulus of elasticity and wear resistance are generally increased with high filler percentage (30). Sometimes the shape of the inorganic particle determines the filler percentage within the composite formulations. In a study of different types of composite that contain a per-polymerized fillers, were shown to have the lowest filler content as well as the lowest hardness and flexural strength. Composites with round filler particles had the highest filler content, and these were related to the higher strength and hardness. For hybrid composites which have mixed filler particles, there was no linear connection between filler content and flexural strength (30). A study of seventy two restorative materials concluded that the filler volume had an essential effect on the mechanical properties (31).

The most common fillers used in composites are lithium aluminum silicates, silicon dioxide and boron silicates. For many composites, the heavy-metals such as barium, zinc, strontium, aluminum or zirconium which are opaque metals, have partially replace the quartz particles. Currently, the research is on new materials, such as calcium metaphosphate, which cause less wear on the opposing teeth as they are less harder than the glass ones (32).

2.1.2.3. A Coupling Agent and Initiator:

It is significant to bond filler particles to the resin matrix. And these bonds permit more flexible polymer matrix to transfer the stress to the higher modulus filler phase. The coupling agent with functional groups allow the chemical bond between the two phases of the composite (17, 19).

A standard coupling agent is 3-methacryloxypropyltrimethoxysilane (MPTS) with two ends; one end bonded to the hydroxyl groups of silica particles and the other end copolymerizing into the polymer matrix (17, 19, 25).

Autocured composite resin materials generally disappeared from clinical practices in the 1980s, due to the acceptance of the light-cured materials (21). Most of the composite types are light-activated, either as the entirely polymerization initiator or in a dual cure formulation containing a chemically cured part. The most commonly used photoinitiator system is camphorquinone (CQ), which is accelerated by a tertiary amine, mainly as an aromatic one. Some of marketable formulations have contained other photoinitiators, such as 1-phenyl-1, 2-propanedione (PPD), bisacylphosphine oxide and monoacylphosphine oxide (lucirin TPO) (33, 34).

2.1.2.4. Inhibitors:

The function of inhibitors is to avoid an accidental polymerization of monomers. The inhibitors have two main roles; to ensure adequate working time and to extend the resin's storage time, as the inhibitors have a strong reactivity with free radicals (17).

If the material is not saved from any light source such as short exposure to room light, a free radical is formed, subsequently, the inhibitors react with these free radicals faster than the reaction of free radical with the monomer. This process inhibits chain propagation before the radical is able to initiate polymerization (17).

2.1.2.5. Optical Modifiers:

Dental composites must have visual shading and translucency similar to the corresponding properties of tooth structure to achieve a natural appearance. Shading is obtained by adding various pigments. Usually, they involve a minute amount of metal oxide particles. For example, the translucency and opacity of the composite are modified by adding an opacifier. However, if an unnecessary amount of opacifier is added, too much light might be reflected, and the observer then perceives that the restoration is too white (17).

2.1.3. Composite Resin Polymerization:

There are three stages for the polymerization process: initiation, propagation and termination (35). Direct composite restorative materials usually contain the camphoroquinone (CQ) as a photoinihiator and a tertiary amine as a co-initiator (36). Generally, the blue light (450-550 nm) is used to activate CQ, which subsequently changes to an excited triplet state. After that the excited CQ reacts with a co-initiator to produce free radicals, which are molecules with unpaired electrons that initiate the polymerization procedure (activation and initiation stages). By starting the reaction between this reactive radical and monomer molecule, an active center is formed and propagates the polymerization procedure (34).

During the polymerization process, both the propagation and termination reactions are diffusion-controlled (37). The termination stage, which represents the process of two radicals that react and bind together to terminate each other, and even at low degree of conversion is diffusion-controlled and it slows down with the formation of a network. Then, there is an elevation in concentration of the free radicals, which subsequently enhance the polymerization rate, and this situation is named as autoacceleration. This process is essential for dental composite resins, as it leads to a rapid curing on clinically satisfactory time scales. When compared to termination reaction, the propagation includes the reaction between a mobile methacrylate monomer and a polymeric radical. As the polymer vitrifies, the propagation stage is slowed down and the polymerization process is ended, and autodeceleration occurs. This process results in residual, unreacted methacrylates, which remain in the composite restorations (38).

2.1.4. Classification of Dental Composite Resin:

Composite resin could be classified in different manners. Numerous authors have established their classifications according to different criteria.

2.1.4.1. Classification According to the Size of Filler Particle:

The composite resin was developed according to the size of filler particle from a large size particle to a nano-sized particle (Figure 2.2).

2.1.4.1.1. Traditional (Large Size Particle) Composite:

These composite resins were generally used in the end of 1960s and early 1970s. They were about 70% filled with glass or quartz particles and were chemically cured. The average filler particle diameter was about 15µm. The main weakness of these resins was the bond between the organic matrix and the dispersed inorganic large filler particles (39). Therefore, it has a low wear resistance, creating a rough surface that might enhance plaque accumulation (40).

2.1.4.1.2. Small (Fine) Particle Composite:

This kind of composite contains filler particles of 1 to 5µm in diameter and about 70% to 80% by weight (40). Some composite brands of these types might have a minute quantity of silica to enhance their condensation (41). The wear resistance and handling properties of these types improves when the filler content increases. Most of these resins are light cured. In contrast to the traditional composite resins, they produce a smoother surface with better color stability and higher strength. Despite that, they are still not suitable for most of the esthetic anterior restorations, as the large filler particle size decline their polishability (39).

2.1.4.1.3. Microfilled Composite:

This type of composite resin was introduced to provide the requirement for an esthetic, more polishable restoration. These composites have a very fine particle size, mainly of colloidal silica (0.04µm), that are scattered within a resin matrix. There are restrictions in the volume of filler particles that can be loaded within the matrix due to the large surface area of these fillers (42).

The major drawback of this composite type is the low equality of the bond between the filler particles and the chemically cured matrix, which might enhance the restorations' wearing process. The mechanical and physical properties of these composites are lower than that of traditional composites, as these composites are compromised 40% to 80% by the volume resin matrix, leading to a higher degree of water sorption, a higher coefficient of thermal expansion and diminished elastic modulus. So the microfilled composite is the resin of choice to restore teeth with smooth surface caries (class III and class V) and are avoided in stress-bearing situations (42).

2.4.1.4. Hybrid and Microhybrid Composites:

This type of composite resin consist of a silicon dioxide filler with particles size varying from 0.04 up to 0.1µm, and glass filler particles size ranging from 0.4 to 0.6 µm (400 to 600 nm). These composites develop a rough surface, decreasing their suitability for esthetically demanding cases. On the other hand, they have high physical properties that make them suitable for stress-bearing situations. Hybrid resins have slightly larger filler sizes than the microhybrid resins, and generally perform in the same manner (17, 43).

2.1.4.1.5. Nanofilled Composite and Nanohybrid Composite:

The utilization of nanotechnology in the field of restorative dentistry has led to enhancement in physical, mechanical, esthetic and optical properties of dental resin. Currently, these nanocomposites work as universal filling materials for both anterior and posterior teeth (44).

These composites are of two types; nanohybrid type and nanofill type. The nanofill composites are made from a mixture of; nanomers, which are nano-sized mono-dispersed, non-aggregated silica filler particles in the size ranging from 20 to 75nm and nanoclusters, which are clusters of mixture of silica nanomeric and zirconia silica particles (44, 45).

These composites are characterized by better dispersion and low polymerization shrinkage as the smaller size of their particles permits a higher filler capacity (about 79%), which has adequate distribution within resin matrix and tends to increase the interfacial area between the filler and the matrix. The nano-sized filler particles have superior hardness and strength, together with adequate esthetic properties (shade, texture, translucency and gloss retention) and less biodegradation (46).

Nanocomposites have high mechanical properties, such as a high flexural, compressive and tensile strength, together with high modulus of elasticity, greater hardness, wear resistance and fracture toughness (45). Also, they have low tendency for crack formation and propagation due to the reduction in interparticle distance between the nanofillers. The decrease in the whole content of the organic matrix with strong interfacial connection among the filler particles and the resin matrix, lead to decreased polymerization shrinkage (47). Since the nanohybrid has the least amount of organic matrix, they permit lower rate of polymerization shrinkage than that of nanofill composites. Clinically, it exhibits lower tendency for micro-fracture formation together with better marginal seal and color stability (46).

Nanofiller also provides an improvement in the most important properties which are optical and esthetic properties. There is a significant increase in the polishing ability, color stability, accuracy of shade selection and it permits very good finishing and gloss retention for the final restoration (48).

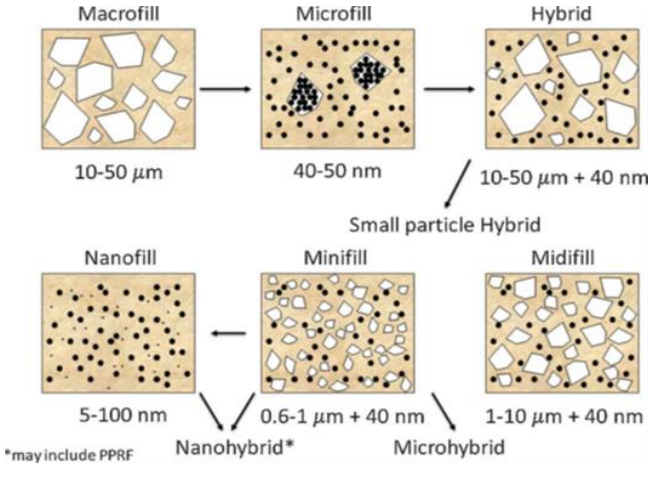

Figure 2.2: Development of composites resins according to filler particles size (Figure is obtained from Ferracane JL. Resin composite-State of the art. Dent Mater, 2011).

2.1.4.2. Classification of Composites by Manipulation Characteristics:

2.1.4.2.1. Flowable Composites:

It is named as a flowable composite due to their low viscosity and capability to be syringed into prepared cavity with a needle tip. To make a composite of low viscosity or flowable, two processes must be accomplished; increased particles size and decreased filler amounts (49).

These resins, typically have the capability to flow easily, spread constantly with adequate adaptation to cavity configuration, which gives the proper dental features. In contrast, the mechanical properties of this composite have been reduced such as a lower flexural strength, low wear resistance with higher rate of polymerization shrinkage. Flowable composites have numerous utilizations, such as a liner material, to block small undercuts, as an indirect or direct pulp capping material and also, it can be used under composite fillings as a stress breaker which help in reduction of polymerization shrinkage stress of overlying composite (49).

2.1.4.2.2. Condensable (Packable) Bulk-Fill Composites:

This type of composite resin contains a high amount of filler particles with the addition of elongated fibrous fillers which are about 100µm in length with rough textured surfaces or branched geometries, that tend to interlock and resist flow, these type can be packed, carved and handled similar to amalgam as well as being able to be light cured in thick layer of up to 5mm (50).

The viscosity of condensable composite resin is greater than that of hybrid composite and their physical properties are as good as hybrid composites. When the physical and mechanical properties are examined, they are identical to the natural teeth. These properties permit firm interproximal contact with easier condensation in class II cavity (50). These composites provide another advantage, as the restoration can be cured as a one piece, and as a deep polymerization is possible because of their high densities. On the other hand, the main disadvantages of this composite type are their poor esthetic and polishing properties, because of the limited shade selection and also the incorporation of air bubbles during condensation (17, 51).

2.1.4.3. Classification According to Curing Methods:

2.1.4.3.1. Self-Curing (Chemical Curing) Composites Resin:

Self-curing composites are most commonly available as a two past system, consisting of a catalyst and a base material. One portion contains a benzoyl peroxide initiator, and another portion has an aromatic tertiary amine accelerator. When these two components are effectively mixed, the polymerization process is chemically activated (52). One of the difficulties associated with chemical activation is that, during mixing the air might be incorporated into the mix, leading to the formation of pores that weaken the structure and entrap oxygen, which might cause the inhibition of the polymerization process. An additional disadvantage of this curing method is that after the two components had been mixed the operator has no control over the working time (53).

2.1.2.4.3.2. Light Activated (Photochemical Activated) Composite Resin:

With the addition of photochemical initiators, composite resins can be polymerized with either ultraviolet or visible light. Photochemical initiators such as diketones, have been found to initiate the polymerization process by absorbing a visible light in the range of 420 to 450 nm. Both the ultraviolet and visible light activated composites offer many advantages over the self-curing ones, including extended working time, less porosity, and better resistance to wear or abrasion. The ultraviolet light has several disadvantages, one of a primary concern is the potential health hazard to both dentist and patients. Furthermore, practical disadvantages exist with ultraviolet light generators, requiring several minutes as a warm up time before being fully operable, and the intensity of the light source gradually decreases in strength with use (53).

Visible light activated systems provide numerous advantages over ultraviolet light systems; the health hazard is virtually eliminated; no warm up time is required for proper operation; the composite resin material is cured in less time; from 20 to 30 seconds, according to the thickness and shade of composite. There is no decrease in the strength of the light source, because the output is constant until the bulb burns out. Visible-light system has greatly simplified the use of composite resins for restoration and other innovative applications (54).

2.1.5. Properties of Dental Composite

2.1.5.1. For Current Material:

Dental composite resins in recent times have an appropriate mechanical properties, which permit their use in all regions of the oral cavity. However, the concern is still present when the composite resins are used in great stress locations, particularly in patients with parafunctional problems such as clenching and bruxism, the concern is especially for wear and fracture of the restoration. The wear is regarded to be a less important difficulty for nowadays materials when compared to the composite used in decayed ago, because of improvement in the filler particle's size which greatly diminished the amount of abrasive wear. On the other hand, when used in a large prepared cavity, especially in numerous teeth in the same side, or when used to restore cusps, the wear of these materials still has important attention (55).

Generally, mechanical properties are commonly dependent on the filler loading; the composite with high amount of fillers being the strongest, stiffest, and toughest. This is not unexpected, as this shift is expected by the role of mixtures for dental composite resins. Nevertheless, it is helpful to make a comparison between composite resins and other restorative materials. Generally, dental composite resins, when compared to porcelain and amalgam restorations, have the same flexure strength, fracture toughness and tensile strength and are higher than that of glass ionomers. Furthermore, the composite resin has a lower elastic modulus when compared to the amalgam restoration, which may lead to more dimensional changes on the occlusal surface when subjected to high stress forces (56).

2.1.5.2. Future Enhancement:

Continuous enhancement in the dental composite resins properties are constantly necessary to provide new advances in strength and toughness, as well as polymerization stress and subsequent shrinkage (56, 57). The main goal for shrinkage level is to be a little bit more than zero. This well permits a room for the expansion caused by water sorption, as a recent composite resin is not totally hydrophobic, the level of water uptake is mainly related to the monomer formulation, and a current research has revealed lower water absorption for silorane-based composite (57). However, as recent formulations are prepared to be self-adhesive, they will be more hydrophilic than the nowadays composite resins. Thus, a polymerization shrinkage level of 0.5% until 1.0% by the volume might be a more appropriate goal, and some of the current materials are at or close to this level.

When concerning strength and toughness, recent composite resins are approximately as strong as dental porcelain and amalgam, but lower than that of ceramic system and casting alloy (58). It is likely that flexure strength of several hundred Mpa, which is equal to that of the high-strength ceramics, might be more ideal. This is not an easy task, as the flexure strength of heat-cured dental composite might be increased to a little bit over 200 Mpa by the addition of high-strength whiskers (59). Furthermore, fracture toughness is an essential property, and might be related to the chipping of margins and surfaces of the restoration (60). The fracture toughness of the best current dental composite resin has been below 2.0 Mpa, which is like that of amalgam and higher than porcelain. However, the addition of reinforcement fiber or whisker has provided adequate improvements in toughness, but not to the level of ceramic toughness or casting alloys, and this may be what is needed to make the materials more resistant to fracture under all stress conditions (59).

2.1.6. The Most Important Clinical Problem of Composite Restorations:

2.1.6.1. Polymerization Shrinkage:

The process of dimethacrylate-based composite polymerization is usually associated with subsequent volumetric shrinkage which is about 2% to 6% (61, 62). Throughout the polymerization process, transition of monomer molecules into a polymer network leads to a closer packing of the molecules resulting in a bulk reduction (63, 64).

Clinically, composite resin strain is interfered by the restriction of the composite bonded to the teeth, and as a result: shrinkage showed itself as stress within the restoration, which might have an adverse effect, such as:

- Tooth deformation, such as enamel fracture, or cracked cusps, which results from transferring the polymerization shrinkage stress to tooth structure (65, 66).
- Polymerization shrinkage stress has a capability to initiate the adhesive failure at the composite-tooth interface, if the polymerization contraction force exceeds dentin bond strength (67). Resulting in a gap formation between the cavity walls and the composite restoration, which subsequently, leads to microleakage, secondary caries, and postoperative sensitivity (65, 68).
- If the bond strength of the adhesive interface between the composite restoration and the cavity walls was sufficient to prevent gap initiation during hardening, the stress concentration within the composite restoration might lead to micro-cracks before setting completion (69). On other hands, this never happens since the compliance of the surrounding tooth structures relatively decreases the setting stress to a level below the cohesive or adhesive strength.
- The restoration size has an effect on the shrinkage stress, as the tooth structure's resistance to polymerization shrinkage decreases with more loss of hard dental structure. Larger restorations lead to a decrease in stress levels within the restoration and tooth-restoration junction, but it increases stress within the tooth (70).

2.1.6.1.1. Factor effecting the Polymerization Shrinkage Stress:

2.1.6.1.1.1. Inorganic Filler:

The polymerization shrinkage is directly correlated to the volume fraction of the polymer matrix in the dental composites. The composite contraction increases when more monomer is united and changed into polymer chains, forming networks. Furthermore, the portion filled with filler particle does not take part in the curing contraction. So, the presence of high filler percentage within the composite formulation is essential to diminish the rate of polymerization shrinkage (71). Filler particle content greatly impacts the mechanical properties of composite resins (72). Due to it is influence on elastic modulus and volumetric shrinkage, the filler loading in dental composites has an essential role in the development of polymerization contraction stress (73).

2.1.6.1.1.2. Degree of Conversion DC:

In some types of composite, the decrease in the final DC will result in lower contraction stress and lower shrinkage. From another point of view, the reduction of DC might have an adverse effect on the mechanical properties of materials (20). In contrast, a little bit increase in DC will lead to a significant increase in stress, but it will improve the material's mechanical properties (74).

2.1.6.1.1.3. Elastic Modulus

Laboratory studies have revealed that the interfacial stress during the setting shrinkage of a dental composite resin is completely related to the stiffness rate of the setting materials which can be identified as the elastic modulus or young's modulus (75). So, at a certain shrinkage rate, the most rigid material, the material that exhibits the greatest elastic modulus, will lead to the highest stress. Clearly, as the polymerization reaction proceeds, the young's modulus also increases. The higher the elastic modulus and polymerization shrinkage rate, the higher the contraction stress (76).

2.1.6.1.1.4. Water Absorption

The water absorption of dental composite resins and their subsequent hygroscopic expansion might have a direct relationship to the resin composite shrinkage (77). Although the hygroscopic expansion might result in a subsequent relaxation of polymerization contraction stress, this hygroscopic expansion develops gradually and might need days, while the polymerization shrinkage stress grows rapidly (75).

On the other hand, the water sorption leads to a number of adverse effect on the dental composite such as diminishing in mechanical properties with reduction in color stability (78).

2.1.6.1.1.5. C-Factor:

There is a correlation between stress development and cavity shape. Smooth surfaces and shallow cavities reproduce the most satisfactory situations for the creation of a stable composite-dentin bond (79). In these cavity forms, polymerization contraction is limited to one side, thus permitting the composite to flow freely in the early rigid phase (80). This situation inhibits the contraction forces from generating stress and providing stable bond to the cavity (67). When the contraction is obstructed in three dimensions, the stress will be less recompensated with the flow (67). Feilzer et al. (78), introduce the C-factor idea, which is the connection between the ratio of the restrained and the free composite surface area of dental restoration.

2.1.6.1.2. Reduction of Shrinkage Stress:

Two general approaches have been used to overcome the problem of stress concentration and marginal failure of light-activated resins:

- Alteration of the chemistry and the composition of the resin system in order to decrease volume contraction.
- Some practical techniques are designed to compensate the effect of polymerization shrinkage.

In the meantime, different techniques have been investigated, and can immediately be put into practice by the clinician. These techniques are related to the incremental buildup and to the control of the curing rate (81).

2.1.6.1.2.1. Incremental Build-Up and Cavity Configuration:

Placing the composite resin layer by layer within the cavity, and curing one layer at a time, effectively, decreases polymerization stress by minimizing the C-factor. Thus, an incremental technique overcomes both limited depth of cure and residual stress concentration, but adds to the time and difficulty of placing a restoration (81).

2.1.6.1.2.2. Different Light Curing Techniques:

There are two light curing techniques that might be used to reduce curing stress. The soft start curing technique, which begins at low light intensity and ending with high intensity. This technique gives a chance for the polymerization process to be initiated gradually, as it elevates the initial level of stress relaxation throughout the early phases, and it completes with the greatest intensity once the gel point has been reached (17).

Variations of this technique include ramping and delayed cure. In delayed curing technique, the composite at the first stage is incompletely cured at low intensity, after that, the clinician then shapes and finishes the restoration, and finally applies a second exposure of light for the final cure. In ramping technique, the light intensity is slowly elevated or "ramped-up" during the time of light exposure. Both of delayed and ramped techniques seem to offer the greater decline in curing stress, but might require more time (17).

2.1.6.2. Fracture and Wear Behavior:

Fractures that occur at the margins, or within the body of restorations have been considered as a main reason of posterior composite's failure (82). The material properties, which have a direct relation to fracture, such as: elasticity, fracture resistance, and marginal degradation under stress have generally been assessed by the establishment of material's parameters; fracture toughness, flexural strength and flexural modulus (83). Fracture toughness explains the resistance of brittle materials to the catastrophic spread of flows under an applied force. It is relative to the energy utilized in plastic deformation and it provides a comparative level of material's capacity to resist crack propagation. The increase of filler loading in the dental composite resins increases the fracture toughness, and the toughness mechanisms are supposed to be crack trapping, crack deflection, and filler-matrix interactions (84).

There are two main behaviors of composite wear, the first one is two-body wear with direct interaction between the restoration and opposing teeth. The second mode is three-body wear, with presence of a foreign body between the restoration and the teeth (17).

The wear behavior of dental composite, mainly, influenced by filler particles size and their loading capacity (46). Composite resins with smaller filler particles size, and high filler fraction capacities were supposed to wear less, on the other hand, composite with larger filler size is likely to exhibit the higher wear rate (85).

2.2. Adhesive Technology

It is unthinkable to talk about dental composite resins without mentioning resin bonding agents. Definitively, one of the most important developments in dentistry is the capability to bond materials to tooth structure. Bonded restorations have numerous advantages over old non-adhesive restorations. Adhesive technology has extended the variety of options for esthetic dentistry (86).

Adhesion includes molecular inter-relations at the interface between materials. Any situation termed as adhesion is essentially an association that includes an adherent (or substrate) with an applied adhesive, which generates a conjunction (interface). This arrangement is named as the adhesive junction. In dentistry, adherents might be relatively different (enamel, dentin, composite, amalgam, glass ionomer, ceramic, cast alloy, and others). On the other hand, the adhesives may include a single interface, such as: sealants, ceramics bonded to metal, or it may include more than one interface, for example: ceramic restorations bonded to tooth tissue (87).

2.2.1. Evaluation and History

In 1955, Buonocore was the first to discover that the enamel surface may be changed by an acid action, which makes it more acceptable for an adhesion process. He reported that the natural teeth might be bonded to acrylic resin materials after the application of a phosphoric acid of 85% concentration. Buonocore conclude numerous utilizations of this technique, including: class III and V with pit and fissure sealants. Over the past 45 years, there has been a variation in chemistry, application, and mechanism of action for dental bonding systems. This goes together with the enhancement development of dental composite resins and dental ceramics with the increase in the patients demands for esthetics. The advancement in bonding agents has been enhanced as the need for bonded esthetic restorations has continuously increased (88).

2.2.2. Generations of Dentine Adhesive System

Dental adhesives have been developed from no-etch to total-etch system (fourth and fifth generations) to self-etch system (sixth, seventh and eight generations) (89). Each of these generation has attempted to diminish the number of steps needed in the bonding procedure, so it would allow a more rapid application technique and it provides a better chemistry to facilitate more durable bonding (90).

2.2.2.1. The First Generation

This generation of adhesive agents was developed in 1960s. The first generation passed over the smear layer, and dentin etching did not advocate with this generation. Monomers such as N-pherylglycine glcidyl methacrylate (NPG-GMA), polyurethanes, and cyanoacrylates were incorporated in the composition of the first generation (90). The bond strength of this generation have reported to be 2 to 3 Mpa. A six month study reported a failure rate of about 50% in the clinical cases (91).

2.2.2.2. The Second Generation

This generation was used in the end of 1970s. In this generation, to promote bonding to the calcium in hard tooth structure, polymerizable phosphate has been added to Bis-GMA resins. The smear layer was still not eliminated and this might give a relatively weak and unpredictable bond strength (4-6 Mpa) (92).

2.2.2.3. The Third Generation

Third generation of bonding agents were offered in the end of 1970s and early 1980s. A very significant alteration was introduced in the third generation: dentin acid-etching in an attempt to change or partially remove the smear layer. This method provided a greater bond strength (16-26 Mpa) and it consisted of three components: etching, primer and adhesive (92).

2.2.2.4. The Fourth Generation

The fourth generation was considered as the golden standard in bonding agent systems. This generation has three main components (etchant, primer and bond) which were usually packaged in distinct bottles and applied in a sequence. The acid dissolves the hydroxyapatite crystals among collagenous fiber networks, after washing and drying, the primer is applied to cavity walls. The primer permits itntercollagenous water removing which remains after acid washing and drying. Finally, the application of bonding agent. The shear bond strength values reported to be high and might reach 25 Mpa for both enamel and dentin. Fusayama and Nakabayashi also explained the penetration of resins into dentin and providing dentinal seal with the elevation in bond strength values. Furthermore, Kanca described the wet bonding theory with this generation (93).

This generation is still the golden standard by which all the new systems are assessed. However, due to the complexity of its various steps, dentists started to ask for a simpler adhesive systems (92).

2.2.2.5. The Fifth Generation

This generation of adhesive systems are basically provides an adjustment for the fourth generation, providing faster and simpler application technique, as it is a self-priming (one-bottle) system. In this generation the primer and bonding agent were incorporated into one bottle and applied to enamel and dentin surface after application of 35 to 37 % of phosphoric acid for about 15-20 seconds (94).

In addition, the fifth generation is more susceptible to water deterioration than the fourth generation. Where the classical bond strength to dentin is about 3 to 25 Mpa (95).

2.2.2.6. The Sixth Generation

This generation was introduced in late 1990s and early 2000s and was accepted as a (self-etching primer), which made a significant jump forward. Directly, after the tooth preparation, an acidic primer was applied instead of acid-etching with phosphoric acid. When compared to the previous generations, the occurrence of post-operative sensitivity was declined with this generation. However, its bond strength to enamel and dentin is lower than that of the fourth and the fifth generations (88).

The major benefit of this generation is its adequacy, as it appears to be less dependent on the dentin hydration state than the total-etch systems. These new systems exhibit adequate bond to dentin surface, while it was less effective in enamel bonding. In demand to eliminate this problem, it is suggested to etch enamel with phosphoric acid etching before the application of this generation (94).

2.2.2.7. The Seventh Generation

It was discovered in late 2002s, this generation blend materials for etching, primer and bonding in a single solution and it is named as the all-in-one system. Researches demonstrated that this generation shows a bond strength and a marginal seal similar to that in the sixth generation (96).

2.2.2.8. The Eight Generation

In 2010, the eight generation was introduced as a self-cured, light-cured and dual-cured, nano-reinforced one-step, self-etch adhesive and delivered in a single dose systems. The bond strength to both enamel and dentin was exhibited to be more than 30 Mpa with light-cured dental composite resins (97).

2.2.3. Problems in Bonding to Dentin

Enamel bonding has been broadly and effectively used in dentistry for more than 20 years, on the other hand, reliable bonding to dentin has only been possible during the last decade. The bonding process of resins to dentin is more problematic than the bonding to enamel. There are some difficulties, which might influence the effectiveness of the bonding to dentin, and these include the histological structure of dentin and smear layer formation after cavity preparation (98).

2.2.3.1. Histological Structure of Dentin

In general, the histological structure of dentin is more different and more complex than the enamel structure and also different according to the location. Normally, enamel by volume consists of 92% of inorganic hydroxyapatite, while dentin consists of only 45% inorganic hydroxyapatite. Dentinal hydroxyapatite are inconstantly organized within an organic matrix, which involves principally collagen, and are not regularly organized as they are in enamel structure. Furthermore, dentin contains a high number of fluid-filled tubules that are directed from the pulp to the detino-enamel junction (99).

There are also regional variations in dentin structure and composition, as the dentin composition changes according to its depth and region of the tooth. The permeability properties of dentin, noticeably, explain these regional changes. For example, the occlusal dentin permeability is lower at the center of the occlusal surface than that over the pulp horn, proximal dentin permeability is higher than that of occlusal dentin and coronal dentin is more permeable than root dentin (100).

In caries-effected and sclerotic dentin there are alterations in the composition and the structure, which might cause more difficulties in the dentin bonding process (12). Resin penetration into sclerotic dentin is lower than that of sound dentin and this might has an adverse effect on the bonding procedure (101).

2.2.3.2. Smear Layer Formation

The smear layer is an adherent layer of debris that covers the tooth surface after being abraded with hand or rotary instruments (102). After the cavity preparation, the cavity walls are covered with a smear layer. When this layer is examined under scanning electron microscope (SEM) it is shown as a 1 to 2 µm layer of debris with a mostly granular fragment that totally covers the dentin surface. The opening of dentinal tubules are also blocked by debris tags, which are known as smear plugs, and might extend until the depth of about 1 to 10µm (103), these smear plugs are continuous with the smear layer.

The smear layer is assumed to contain crushed hydroxyapatite, as well as fragmented and degenerated collagen. Also in some clinical cases a smear layer might be contaminated with saliva and microorganisms (104). Although the smear layer acts as a diffusion barrier that declines dentin permeability, it also can be regarded as a block that restricts the penetration of resin in the underlying dentin substrate. Also, it is intrinsically a weak bond to the underlying dentin (105).

Basically, there are two choices to deal with the low bond strength, resulting from the restricted strength of the smear layer these choices are smear layer elimination before the bonding procedure, or the integration of the smear layer within the bonding interface (106).

2.2.4. Mechanism of Adhesion

The essential step in the adhesion process to tooth structure is an exchange of inorganic part of tooth structure (hydroxyapatite) with a synthetic resins (bonding agent). This process comprises two steps; firstly, dissolution of hydroxyapatite to generate micropores, secondly, the infiltration of resin monomers into the micropores with subsequent polymerization. In consequence, resin tags form micromechanical interlock with the hard tissue (17). A fundamental part of dentin bonding is the generation of hybrid layer. The characteristic of hybrid layer formed has a greater impact on the bond strength of resin dentin interface. The better bond strength is obtained from the thicker and more uniform hybrid layer. In addition to the thickness importance of hybrid layer, the uniformity in the formation of the hybrid layer is also essential. The total-etch technique produces a more uniform hybrid layer, while self-etch technique produces a less uniform and irregular layer with high amount of debris (107).

In general, resin bonding to tooth structure is an outcome of four possible techniques which are:

- Mechanical penetration with the formation of resin tags within the tooth structure.
- Chemical bonding (adsorption) to the inorganic part or organic part of the hard tooth structure.
- Diffusion precipitation of substance over the tooth structure to which resin monomers can either bond mechanically or chemically.

- A combination of the earlier three mechanisms, that are generally responsible for bonding with current adhesives (108).

2.2.5. Main Components of Bonding Systems

2.2.5.1. Acid Etchant

Preparation of enamel and dentin to receive the primer using 35-37% orthophosphoric acid. It creates microporosities for up to 7.5 µm, which helps to create the resin tag and therefore creates a micromechanical bonding. The acidic monomer in self-etch systems serves as an etchant and a primer at the same time (17, 109).

2.2.5.2. Primer

The main function of the primer is to maintain an opened collagen network, while eliminating the remaining water to permit infiltration of the hydrophobic adhesive monomer. The primer is composed of hydrophilic monomers mainly carried in a water-soluble solvent (water, acetone, and ethanol) to permit a good flow and infiltration into hydrophilic dentin, which can affect the resulting bond strength. 2-hydroxyethyl methacrylate (2-HEMA) is generally used as a primer monomer, because of its hydrophilicity and solvent like nature (17, 109).

2.2.5.3. Bonding Agent

The adhesive promotes bonding between resin composite restorative materials and tooth structure (enamel and dentin)**.** Adhesive provides a joint between the restoration (hydrophobic resin composite) and hydrophilic resin primer. Proper curing is needed to permit adequate sealing and retention. The seventh generation agent used a primer-adhesive that is an acidic monomers.

Generally, adhesive resins are composed mainly of hydrophobic dimethacrylates such as Bis-GMA, TEGDMA and UDMA, and a small amount of a hydrophilic monomer such as HEMA (17). In recent times, nanofillers have been added with range of 0.5% to 40% by the weight in the eighth generation of adhesive systems. Fillers modified the handling properties, and might improve bond strength with the increase in the adhesive film thickness (110).

The hydrophilic characteristic of dentin permits an adequate wetting, when a hydrophilic bonding is used. Thus, the main role of the solvent used in adhesive agent is to permit good infiltration of monomer within the collagen network of the demineralized dentinal structure, thus enhancing the penetration capability of resin. The most used solvent in adhesive agents are water, ethanol, and acetone (17).

To initiate the curing process, similar systems are used in both adhesive and composite restorations, which include a photoinitiator system as camphoruinone and an initiator as tertiary amine, through a self-cure system that includes a chemical initiator (benzoyl peroxide) or through a dual-cure initiator system (17).

2.2.6. Requirement to Create Good Adhesion

2.2.6.1. Clean Surface

One of the important necessities for a strong adhesive bonding is the clean surface with a high energy state. Acid etching has a cleaning action which eliminates most of the debris, generating a surface roughness for micromechanical interaction (111). Etched enamel is simply wet by monomers, permitting adequate infiltration for bonding agent and producing micromechanical bonding more easily.

2.2.6.2. Surface Roughness

For a good adhesion, the adhesive should wet the underlying substrate. The main way to assess wetting ability is by measuring the contact angle. Wettability is improved in most dental situations by the creation of microsurface roughness (112).

2.2.6.3. Proper Contact Angle and Good Wetting

The contact angle is the internal angle between a drop of liquid and a solid surface when coming into contact. Wetting is characterized from liquid contact angle as non-wetting when the contact angle is more than 90º, and spreading when it is equal to zero.

Although all liquids can wet all solid surface to some range; the degree of wetting is equal to the degree of adhesion (112).

2.2.6.4. Low Viscosity Adhesive and Sufficient Flow

The viscosity of adhesive agent should be low enough to be able to flow adequatly within the accessible working time to spread and adapt to the details of the adherent substance. Most of adhesive systems require adequate infiltration within small surface irregularities. The ability to flow within holes might be assessed in terms of a penetration coefficient (113).

2.2.6.5. Resistance to Phase Separation

Dental adhesive formulations are essentially depended on volatile diluents that lead to adhesive phase separation during the latest phases of flow as solvent elimination is occurring rapidly.

2.2.6.6. Adhesive Solidification

All enamel and dentin adhesive systems need polymerization of bonding agent in the latest step of the application procedure. Several dental circumstances that necessitate the use of adhesives are challenged by poor access for visible light curing. So, the susceptible degree of conversion is needed for adequate adhesion (114).

2.2.7. Classification of Adhesive System According to Etching Pattern

2.2.7.1. Etch- and –Rinse Adhesive (Total-Etch System)

This adhesion strategy might be of three steps or two steps; the three steps consists of etch and rinse, priming and bonding application steps, and the two steps combine priming and bonding steps in a single application (one-bottle). This etch and rinse method is still the most effective method, which provides sufficient bonding to enamel. The first initial step includes etching of tooth structure with phosphoric acid gel that results in dissolution of hydroxyapatite crystals. This is followed by photopolymerization of bonding resin that is readily absorbed by capillary attraction within etch generated pits.

There are two kinds of resin tags interlock within the etch-pits; the first one is a macro-tags, when the resin fills the space that surrounds the enamel prisms. The second type is numerous micro-tags generation when the resin infiltrates within minute etch-pits at the core of etched prism (115).

In dentin, acid-etching followed by water rinsing eliminates the smear layer, decalcifies the intertubular and peritubular dentin with opening of obstructed dentinal tubules. Hydroxyapatite crystals are dissolved, leaving a collagen meshwork unsupported, which subsequently can lead to shrinkage and collapse in this meshwork. After the etchant is rinsed off, a primer is applied. The primer application enhance dentin wettability as it wets and infiltrates within the collagen meshwork.

Subsequently, the bonding agent is applied to the primed dentin. The bonding agent mainly have a hydrophobic monomer like Bis-GMA, as well as a more hydrophilic monomer, such as HEMA to modify wetting. The bonding agent co-polymerizes with the primer to generate an intermixed layer of collagen fibers and resin, which is named the hybrid layer (resin-reinforced zone), this layer, has been assessed as the most significant factor for providing an adequate adhesion between resin and dentin (116).

Even though total-etch adhesive systems are still the gold standard for all of dental adhesions, it seemed to be incapable of preventing nanoleakage formation regardless of their acceptable long-term clinical performance. Nanoleakeges are known to have an adverse effect on the bonding durability. Because of that, the current tendency is to develop simplified self-etching adhesive system (117).

2.2.7.2. Self-Etch Adhesive System (SE)

This system is considered as a simplified bonding system, and this system alters the smear layer instead of removing it, generating a thin HL of 0.5-1.2 µm thickness (67). The generated resin tags for this system are short and narrow. However, because of their low acidity, the existence of smear layer or smear plugs is common after the bonding procedure. In spite of forming a thin HL, this system shows a chemical bond to the dentin structure. The main drawback of this system is insufficient etching to enamel, which result in low bond strength than total-etch system (117). And these system can be categorized into two-step self-etch system and one-step self-etch system.

2.2.7.2.1. Two-Steps Self-Etch System

This system has two components: one bottle that contains primer and acid together, while the other bottle contain hydrophobic bond resin. The self-etch primers are aqueous acidic solutions having numerous vinyl monomers, which can all together etch and penetrate into dentinal tissues, then photopolymerize with the resin (118).

2.2.7.2.2. One-Step Self-Etch System

This adhesive system may be accessible as two separated bottles, which need mixing before application, or as a single bottle. These systems can be considered as the only real one-bottle or all-in-one adhesives, as they are an association of conditioning, priming and application of bonding resin in one step. The main drawback of this system is correlated to their high hydrophilicity. That makes the adhesive layer more susceptible to water sorption, which may affect the bonding performance (118).

2.2.7.3. Universal Adhesive System (UA)

Recently, a universal adhesive system have been developed with the aim that the same bottle with or without the earlier application of phosphoric acid etching, without compromising the efficiency of bonding when applied to enamel or dentin. This type of adhesion can take the place of the pervious basic adhesive systems (two-step total-etch and two-step self-etch). The universal adhesive system composed of monomers that permit chemical bonding to dentin and enamel. So they can be utilized as self-etch adhesives or as a selective etching for enamel (119).

Although there are similarities between different adhesive systems, the chemical composition of the universal system varies from the recent SE adhesives by the addition of monomers that have the ability to produce a chemical and a micromechanical bond to the dental structure. For example, (MDP) Methacryloyloxydecyl Dihydrogen phosphate monomer, as these monomers allow a universal system to be utilized with any etching protocol and also have biphenyl dimethacrylate (BPDM), dipentaerythritol pentaacrylate phosphoric acid ester and polyalkenoic acid copolymer, which might improve the bonding to tooth structure and have been part of the composition of various materials for decades. The matrix of a universal adhesive is generally based on the mixture of hydrophilic and hydrophobic monomers with intermediate nature monomers (Bis-GMA). This mixture of properties permits universal systems to generate a connection over the gap between the hydrophobic resin restorative materials and hydrophilic tooth substance, under different surface conditions. Furthermore, some of the universal adhesive systems may contain saline in their composition, potentially eliminating the silanization step during bonding procedures to glass ceramic or dental resin composites (117).

2.3. Longevity of Composite Restorations

Composite resin has been the first option for direct restoration in anterior and posterior region. The high popularity is linked to their esthetic properties and it declines the need of sound tissue destruction as compared with previous restorative materials.

For a long time, numerous researches have assessed the clinical durability of composite restorations in different mouth regions. Systemic reviews have concluded that, dental composite restorations might have adequate clinical performance, with annual failure rates (AFRs) changing from 1% to 4%. Nevertheless, replacement of restorations is still very common in general and private clinics, taking a significant part of clinical time with high financial costs for health systems (120).

2.3.1. Factor Influencing Longevity of Composite Restorations

2.3.1.1. Patient Related Factor

Patient related factors have an important impact on the durability of restorations. There are many patient-variables, which include the following:

2.3.1.1.1. Caries-Risk Index

Patients with high-caries index have a high restoration failure rate more than the patient with low-caries index (121).

2.3.1.1.2. Bruxism and Parafunctional Habits

Extreme habits of clenching and grinding by bruxism patients has an adverse effect on both sound tooth structure as well as existing restorations, and subsequently increase the failure risk (especially fracture) (122).

2.3.1.1.3. Patient Age

Although patient age might have an important effect, especially for old patients and very young patients, the evaluation of the influence of patient age on longevity of restoration should not be measured as an isolated factor (122).

2.3.1.1.4. Socioeconomic Status

Authors recognized that patient who had always lived in the poorest environments, had high rate of restoration failure than those who lived in the richest environments (122).

2.3.1.1.5. Esthetic Demand

High demand for esthetic appearance of teeth, especially in the anterior region is possible to lead to more restorations being replaced for esthetic causes (123).

2.3.1.2. Operator Related Factor

It is highly recognized that the operator is possibly the most vital factor of dental restorations failure. The operator has a considerable impact on the restoration longevity with the mention of significant factors, such as: country of qualification, age and occupation status. Furthermore, it is the dentist who takes a decision whether a restoration requires to be replaced or not (122).

2.3.1.3. Restorative Material and Clinical Technique

In a systemic review considering the durability of posterior composite resins, the type of composite resin was not assessed as a significant risk factor for survival when compared to other factors (patient's caries index and the size of restoration). Position of restored teeth in the mouth, large cavity size, teeth with endodontic treatment or presence of thick layer of glass ionomer cavity liner. All of these factors might have an adverse effect on the longevity of composite restorations (124).

2.3.2. Main Causes of Failure:

2.3.2.1. Secondary Caries

One of the main causes of restoration failure is secondary caries (recurrent caries) which mainly occurred at the margin of the existing restoration and this caries has similar features as primary caries lesions (125).

2.3.2.2. Fracture

Fracture is the second main cause of restoration failure. It may be a bulk fracture, which include the fracture of the isthmus in class II, or any fracture within the body of the restoration, or at the marginal ridge, but the restoration is still in place, or it may be a degraded, or a ditched margin, especially in composite veneers (125).

2.3.2.3. Esthetic

Failure due to esthetic reasons is more common in the anterior teeth than the posterior teeth. Esthetic defect can be mainly in the form of marginal or surface staining, or it might be a mismatch of color during treatment steps (124).

2.3.3. Treatment Option of Defected Restoration

A failed restoration with little defects is regularly treated by most clinicians with replacement of the whole restoration. For that reason, for a long time, the replacement of failed restorations has been established as the most public management in dental clinics (122).

During recent years, the literature has included abundant information on treatment options to increase longevity of lifespan of restorations through alternative methods to replacement such as repairing, sealing, or refurbishing (126). These can be explained as follows:

- **Repair:** is described as removing of only a defected part of a restoration together with any surrounding caries tissue, followed by the restoration with proper materials

- **Sealing:** is the sealant application over the non-caries marginal gap (opened margin).

- **Refurbishing:** in this method no material or tooth substance will be eliminated, and no new material will be added to the old one. Re-polishing or refinishing are used to recover the surface anatomy and texture (127).

2.3.3.1. Repair as an Alternative to Replacement

During a replacement procedure, a considerable amount of sound tooth structure is destructed and the cavity becomes larger. Furthermore, the replacement might be more expensive than the other alternative options, such as resurfacing or repair of defected restorations (122). Gordan et al. (128) concluded that repaired restorations have the highest survival rate when compared with the restorations that were replaced.

There are many benefits for repair rather than replacement of the failed restoration which can be summarized as the following:

- There is no need for local anesthesia during simple repair procedures.
- Sound tooth structure preservation.
- Limitation of damaging effect to dental pulp.
- Decrease the risk of iatrogenic damaging effect to neighboring teeth.
- Treatment time and cost reduction.
- Increased lifespan of restoration.
- Adequate patient acceptance (129).

2.3.3.1.1. Clinical Indication of Repair

2.3.3.1.1.1. Secondary Caries

When the lesion is in a limited situation without clinical or radiographic sign of failure within the rest of the restoration, but if there is a large caries lesion near or under the restoration with heavy stains, total restoration replacement might be necessary (130, 131).

2.3.3.1.1.2. Wear

Repair of a restoration is indicated when the wear is of restricted nature, such as wear of occlusal surface and space exists to effect a repair (130, 131).

2.3.3.1.1.3. Fracture

When the bulk fracture is restricted to a small portion of the restoration, repair might be possible. In the case of fracture of surrounding tooth structure, a repair might be suggested if the reason of the facture can be correctly diagnosed (130, 131).

2.3.3.1.2. Contraindication of Repair

In some cases, the repair is contraindicated and the restoration should be totally replaced, and the examples of these cases are:

- Patient refuses a repair of old restoration and require a new restoration.
- Patient's irregular attendance to follow-up visits.
- Patient with high caries index.
- Presence of radiographic evidence for caries lesion underneath a large part of restoration.
- History of failure of an earlier repair (132).

2.3.3.1.3. Repair Procedure and Factor Enhance the Success of Repair Procedure

According to a data collected from in-vivo and in-vitro studies, the following recommendations for repair can be made:

- Local anesthesia if necessary.
- Removing the defective portion of the old restoration and any secondary caries present in the surrounding tooth structure.
- Adequate moisture control with rubber dam if possible, and pulpal protection in deep cavity.
- Preparation of old composite substrate by different surface treatment techniques.
- Application of corresponding adhesive systems.
- Apply dental composite resin using 2mm incremental technique and then light cured.
- Finishing, polishing of composite and checking occlusion with removing of any interference (132, 133).

In repair of old dental composite, it should be well-known that alterations that take place in composite resins over time occur as a result of aging including: chemical degradation, water sorption and losing of some eliminates. These alterations might decline the reactivity of old composite and complicate the repair procedure, resulting in adverse effect on the success of repaired restoration in some conditions (134).

So, the duration and conditions of aging of an old dental resin have an essential role in the repair procedure. These situations should be considered into account by laboratory studies to simulate the clinical situations by synthetic aging (133).

In in-vitro researches, composite resins aging has been established by numerous approaches, which include storage in water (135), immersion in citric acid (1, 133), and thermocycling (1, 133, 136). Thermocycling is a commonly used method for composite resins aging during repair procedures. This process includes exposing samples to high temperatures. It is clear that the high temperature during aging procedures have the weakening effect on physicochemical properties of composite resins, temperature variations can also reduce the number of unreacted C=C double bond within the composite surface, which has an adverse effect on the composite repair bond strength (133).

Among a numerous number of studies, the number of utilized thermal cycles is changed. There is no agreement on which number of thermal cycles exhibit the most horrible case or most clinically significant scenario (1, 133, 134, 135).

To improve repair bond strength between old and fresh composite resins a variety of surface pretreatment and adhesive systems application has been utilized in different studies to enhance bonding interface (133, 137).

2.3.3.1.3.1. Role of Surface Treatment in Repair Procedure

Achieving an appropriate bond between the aged and fresh composite resin is challengeable due to absence of oxygen inhibited layer (unpolymerized superficial layer). So, the effective repair procedure necessitates a strong bond between the old and fresh composite resin. Bonding to aged composite can be so difficult, because of water sorption over time and the reduction in the number of accessible C=C double bond, which is very important to react with a new composite (138). The surface of the old composite resins acts as a bonding substrate that must be adjusted with suitable treatment approaches before starting the repair procedure (139).

Successful repair procedures require the adequate union between the remaining part of old restoration and the new added composite. The surface treatment is one of important factors in the success of a repair process. Furthermore, surface treatments may include mechanical, chemical treatment or combination of both (140).

There are several methods that have been tested in many researches and it include the following:

- Surface abrasion or grinding with diamond burs of different grids (141, 142).
- Acid conditioning with 8-9% hydrofluoric acid or 35-37% phosphoric acid (140, 141).

- Air abrasion with 50 µm aluminum oxide particles.
- Sandblasting with silica coated particles instead of pure aluminum oxide.
- Saline coupling agent application (alone or in combination with other methods) (137).
- A recently suggested method for surface treatment is the use of Erbium Laser (143).

Surface treatment permits macro- and micro-mechanical retention and provides a bond between substrates with the same type of material. Rodrigues et al. (11) reported that, the repair procedure can be accomplished with three mechanisms; micromechanical interaction through surface irregularities, chemical union between two resin materials, and chemical linkage between the restorative material. Although several studies tested different surface treatment methods, none of these treatments can be suggested as a universal technique for successful repair.

Melo, et al. (144) reported similar bond strength for composite resin repair following a surface preparation with a diamond bur, phosphoric acid, saline, adhesive and air abrasion when compared to the control group. Moreover, they suggested that, the surface preparation with 37% phosphoric acid along with bonding application should not be used alone for repair of composite resin.

D’Arcangelo and Vaninib (145), in 2007 stated that, composite surface preparation with adhesive, sandblasting or a combination of sandblasting and salinization produced a higher bond strength than hydrofluoric acid etching followed by salinization.

Bonstein et al. (146) evaluated different repair protocols for aged composite restorations, using five surface preparation protocols, and concluded that the surface preparation with bur and air abrasion created the highest bond strength.

Ikeda et al. (147) in their study, attributed the highest shear bond strength to sandblasting, and reported that the acid-etching provided lower value of bond strength.

In another in-vitro study, Trajtenberg and Power (148) evaluated the role of three surface preparation methods, and it was concluded that 8% hydrofluoric acid used with (Art Glass) composite resin and saline primer provided the highest strength.

2.3.3.1.3.2. Influence of Intermediate Agent on Repair Procedure

Using an intermediate adhesive agent in the repair process has also a significant effect on the durability of old restorations repairs. Bond strength of the repaired restoration is greatly enhanced after the adhesive agent are applied following surface treatments (149).

In some studies, the application of adhesive agents provides the highest tensile bond strength values, and even reaching the cohesive strength of the material. The favorable effect of adhesive agents on the repair bond strength is essentially correlated to the diminished infiltration capability of the fresh composite resin into the surface of old composite resin, and this is related to their high viscosity (135). Furthermore, a diminished potential of chemical bond in the substrate is likely after the aging procedure (150). Intermediate unfilled resins improve chemical bonding to the matrix of old resin materials and to the uncovered fillers (151). In addition, they enhance micromechanical retention by penetrating into the micro-roughness formed by the surface treatment methods (149).

With the total-etch adhesives system, the application of phosphoric acid is an essential step. As the acid-etching provides the cleaning effect for the surface of an old composite when used in the repair procedure, and also might expose the underlying surface and filler particles (152). This might enhance the surface area (135), and wettability of the old composite surface (153).

For the self-etch bonding agents, the same influence of phosphoric acid can be attained by the acidic primer of this system (154). On the other hand, one-step self-etch adhesive system is mostly more hydrophilic when compared to the two-steps system, which consists high acidic monomers (155) with the absence of separated bonding agent application, it might adversely affect their bonding capacity to composite resin (156).

Moreover, with universal adhesive system, which contain MDP monomer, might enhance the micromechanical interlocking to the prepared surface of old composite like the conventional adhesive systems, rather than permitting an additional chemical bonding (4).

Some researchers investigated the influence of numerous adhesive systems on the repair bond strength of aged composite resin (2, 157). Cavalcanti et al. (154) concluded that, self-etch Clearfil SE bond system presented higher bond strength than three-step total-etch system (Single Bond). They demonstrated that, the positive affect of Clearfil SE Bond on the bond strength was due to the presence of proprietary acid phosphate monomer 10-methacryloyloxydecyl dihydrogen phosphate in their composition, which might increase the wettability of composite surface.

Teixeria et al. (157) examined the influence of various self-etch adhesives systems on the shear bond strength of repaired composite, and they found that Optibond Plus SE exhibited a higher bond strength than that of the other adhesive systems.

Shahdad et al. (149) supposed that, long-established bonding agent depend on chlorphosphate esters of Bis-GMA that have been established to be a suitable option as an intermediate material for use in repair procedures.

Lucena et al. (158) explained that, the low-viscosity filled bonding agents have been established to have a high wetting ability of composite resin surface, and infiltrate within the organic phase.

Coma L et al (159) in their studies showed that, the influence of adhesive systems was not clear, but significant, suggesting stable and high values of bond strength when the Optibond FL (three-step total-etch) was tested in composite repair.

Irmak O, et al (160) in their study concluded that, the use of two-steps self-etch or two-steps total etch adhesive system provides repair bond strength than the one-step self-etch adhesive. Generally, there is a large number of studies that demonstrated the effect of adhesive systems on the repair procedures, some of it found the difference in bond strength values with the use of adhesive agents (157, 158, 161), while others did not find any difference between them (6, 149, 154, 162, 163).

3. MATHERIALS AND METHODS

This study was an in-vitro experimental research and it was conducted in the Hard Tissue Laboratory in the Faculty of Dentistry at Yeditepe University. The materials used in this study with their types, manufacturer and compositions are illustrated in (Table 3.1).

3.1. Specimen Preparation:

Ninety composite resin cylindrical specimens of 8mm in diameter and 4.5mm in height were prepared using Estelite Sigma Quick composite resin with A2 shade (Figure 3.1). It was incrementally prepared using a condenser and a plastic instrument within a transparent mold which has been made especially for this test.

Figure 3.1: Estelite Sigma Quick Composite shade A2.

Before placement of composite, the mold was held firmly over a glass slab covered with a mylar strip to provide uniform, smooth glazed surface. Subsequently, the composite was placed within the mold by 2mm incremental technique and then light cured for 20 seconds with a LED curing device (Demetron II, Kerr, Orange, CA, USA) with output intensity of a 750 mw/cm². After the placement and polymerization was completed, the specimens were removed from the mold and the bottom surface were furthermore cured for additional 20 seconds to complete the polymerization process (Figure 3.2).

Table 3.1: The material utilized in the study according to the compositions, type and manufactures.

Material and their punch number	Type and manufacture	Composition
Estelite Sigma Quick TKY004	Super nanofilled universal composite by Tokuyama.	82% by weight (71% by volume) of silica-zirconia filler and composite filler. Inorganic filler is a spherical submicron filler (mean particle size of 0.2µm). organic matrix contains Bis-GMA and TEGDMA with radical-Amplified photopolymerization initiators technology (RAP).
Clearfil SE bond 1972KA	Self-Etch two-step adhesive system by (Kuraray Co.,Ltd, Osaka, Japan).	Primer: HEMA, MDP, hydrophilic dimethacrylate, photo-initiator and water. Bonding: Bis-GMA, HEMA, MDP, hydrophobic dimethacrylate, photo-initiator and silanated colloidal silica.
Adper single bond 2 51202	Total-Etch two-step adhesive system by (3M ESPE).	HEMA, Bis-GMA, dimethacrylate, ethanol, water, photoinitiator and a methacrylate functional copolymer of polyalkenoic acid and polyitaconic acids and silica nanofiller.
G-primo bond 009277	Universal adhesive system by (GC Corporation Tokyo Japan).	4-MET, MDP and MDTP monomers (HEMA-free formulation) fillers.
Royale Etch Jumbo Refill: 2-25 ml Syringes. ER50R	Total-etching gel by (Pulpdent)	Contains 37% phosphoric acid

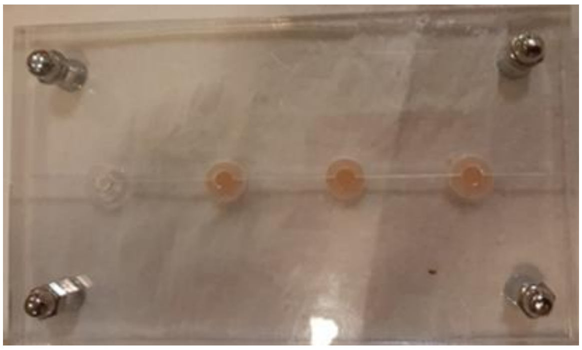

Figure 3.2: Transparent mold with the composite specimen.

After that, to permit a whole polymerization of composite, the specimens were kept in distilled water for 24 hours. Then to provide a constant smear layer, the uppermost surface of the specimens were grinded by (2500 grit silicon carbide paper) with water cooling for 20 seconds using a polishing device (phoenix Beta, Buehler, USA) (Figure 3.3).

Figure 3.3: A polishing device (phoenix Beta, Buehler, USA).

The bottom surface of each specimen was identified by minute mark made by a small round diamond bur with high speed hand-pice to facilitate differentiation between the specimen surfaces. After that the specimens were kept in distilled water for another 24 hours.

Subsequently, the specimens were exposed to 10.000 thermal cycles with thermocycling machine (Salibrus Technica) (figure 3.4) and all of the thermal cycles were completed between 5-55Cº with dwell time of 30 seconds. These procedures took about 300 hours to be completed. After the thermocycling, specimens were separated according to surface treatment techniques into two groups of 45 specimens each.

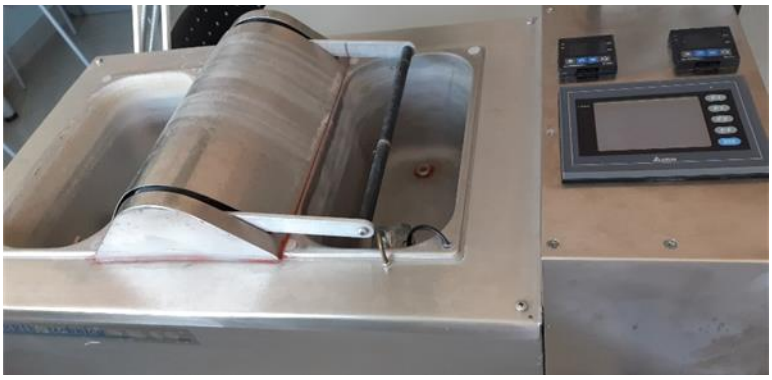

Figure 3.4: Thermocycling Machine (Salibrus Technica).

3.2. Mechanical Surface Grinding with Diamond Bur (Group A):

In this group, the specimens were abraded with a diamond bur in five movements (REF 806 314 111 534 012 / Germany) (Figure 3.5) using high speed handpice with water-cooling, and for every four specimens a new bur was used.

Figure 3.5: Diamond Bur (REF 806 314 111 534 012 / Germany).

3.3. Surface treatment with Air Abrasion (Group B):

The specimen surfaces were abraded using an abrasion machine (Renfert Basic Master, Germany) (Figure 3.6) at a pressure level of 70 PSI for 7 seconds with 50μm aluminum oxide particles size. The device tip was located 5mm away from the specimen surface. After that, the specimens were cleaned with an ultrasonic device before repair procedures.

Figure 3.6: Air abrasion machine (Renfert Basic Master, Germany).

3.4. Adhesive System Application:

After the surface treatment procedures were completed, both of the two main groups were further subdivided into five sub-groups of nine specimen each according to the adhesive system used for repair procedure. Before the application of the adhesives, the specimens were cleaned with water and then air-dried. In all of the sub-groups, adhesive systems were applied according to manufacturer's instructions (Table 3.2). Subsequently, the adhesives were light cured.

The First Sub-Group: in this sub-group, a Single Adper Bond 2, two-steps total-etch adhesive system (3M ESPE St Paul, USA) was applied after surface preparation procedures according to manufacturing instructions (Table 3.2).

The Second Sub-Group: SE Clearfil Bond, two-steps self-etch adhesive system (Clearfil SE Kuraray Tokyo, Japan). For this sub-group the selective etch technique was used. After the surface treatment was completed, 37% phosphoric acid was applied for 20 seconds, then rinsed for 20 seconds and then air-dried gently, after that, without using the primer, only the bonding agent was applied, dried gently and then polymerized for 10 seconds (Table 3.2).

The Third Sub-Group: In this group, SE Clearfil Bond, two-steps self-etch adhesive (Clearfil SE Kuraray Tokyo, Japan) was used with a self-etching technique according to manufacturing instructions (without the acid etching application step). First, the primer was applied actively with a brush to the surface and then there was a waiting period for 20 seconds, then air-dried for 5 seconds. Second, the bonding agent was applied to the surface, air-dried gently and finally cured for 10 seconds.

The Fourth Sub-Group: In this sub-group, G-perimo Bond (one-step universal adhesive system) (GC Cooperation, Tokyo Japan) was applied and a selective etch technique was used (37% phosphoric acid was applied for 20 seconds, rinsed for 20 seconds and dried gently). After that, the bonding agent was applied according to the manufacturing instructions (Table 3.2).

The Fifth Sub-Group: In this sub-group, G-perimo Bond (one-step universal adhesive system) (GC Cooperation, Tokyo Japan) was applied to the surface according to the manufacturer's instructions (Table 3.2).

After the adhesive applications, the upper part of the mold was used which was designed for the repair procedure with 2mm in diameter and 4mm in height. This mold was firmly fixed over the aged composite discs. For repairing the same brand of the old composite; the same shade was used (Estelite Sigma Quick Tokuyama shade A2). The Composite was incrementally placed into the mold and finally light cured with a LED curing light unit for 40 seconds.

Table 3.2: Adhesive systems application protocols according to the manufacturing instructions.

Adhesive system	Application protocol
Single Adper Bond 2 (total-etch adhesive)	Firstly application of 37% phosphoric acid for 20 seconds. Rinsed with water for 15 seconds, air dried gently. Application of bonding agent in two coats, air dried and light cured for 20 seconds.
Clearfil SE Bond (self-etch two-step adhesive)	Primer application: apply the primer actively with a brush to the surface, wait for 20 seconds, then air-dry for 5 seconds Application of bond with brush, gentile air-dried with oil-free compressed air, and finally light cured for 10 seconds.
G-Perimo Bond (universal adhesive)	Application of bonding agent to the surface leave undisturbed for 10 second and light cured for 10 seconds.

3.5. Shear Bond Strength Test (SBS):

After the repair procedure was completed, the specimens were stored in 37Cº water for 24 hours. After that, the specimens were embedded into the chemically cured acrylic resin with a metal blocks (Figure 3.7).

Figure 3.7: Specimen embedded in acrylic resin within a metal blocks.

Subsequently, the shear bond strength test was completed by Universal Testing Machine (Material Testing System model 3345, Instron Limited / England) (Figure 3.8). A knife-edge blade apparatus was applied to a direction parallel to shearing force as near as possible to the bonding interface between the old and the new composite (Figure 3.8).

Figure 3.8: Material Testing System Model 3345, Instron Limted / England.

Shear de-bonding forces were registered in Newton (N). The failure loads (N) were divided by the bonding area (mm²), then the shear bonding forces were changed into Mpa units.

After the test was completed, the specimens' surfaces were analyzed to determine the type of adhesive failure that happened. The specimens were tested under a surgical microscope (73446 Oberkochen, Carl Zess Surgical / Germany) (Figure 3.9) with 12× magnification to determine the type of failure, which can be categorized as following:

- Adhesive failure, which occur at the interface.
- Cohesive failure, which occur in the base or repair composite.
- Mixed or combined failure of the above two types.

Figure 3.9: Surgical Microscope (73446 Oberkochen, Carl Zess Surgical / Germany).

3.6. Data Statistical Analysis:

In this study, the obtained data was evaluated and statistically analyzed using statistical package for social science (` IBM SPSS Inc., version 22.0, Chicago, Illinois, USA). The normal distribution fitness of the parameters was evaluated by Shapiro Wilks test and the parameters were found to be normally distributed. (two-way ANOVA) test was used to compare the descriptive statistical methods (Mean, Standard Deviation) as well as the common effect of the main group and sub-groups on shear bond strength in the comparison of the quantitative data. The (One-way ANOVA test) and the (Tukey HDS test) Tamhane's T2 test were utilized to detect the groups that caused the difference. (Student test) was used to compare the two groups of parameters. Significance was assessed at $p<0.05$ level.

4. RESULTS

Results of the shear bond strength values in Mpa of all groups in this study were presented in (Table 4.1).

Table 4.1: The shear bond strength values in Mpa parameters among all groups with minimal (Min) and maximum (Max) values and Mean with Standard Deviation (SD).

Sub-groups	Number	Min-Max of shear bond strength values Mpa	Mean ± SD (Mpa)
A1: surface grinding with diamond bur + two-step total etch adhesive	9	9,57-11,61	10,28±0,64
A2: surface grinding with Diamond bur + two-step self-etch adhesive with selective etch	9	13,26-15,46	14,28±0,71
A3: surface grinding with Diamond bur + two-step self-etch adhesive system	9	14,6-17,6	15,91±1,15
A4: surface grinding with Diamond bur+ universal adhesive with selective etch	9	14,28-15,89	14,94±0,52
A5: surface grinding with Diamond bur + universal adhesive	9	15,46-17,8	16,5±0,79
B1: Air-abrasion + two-step total etch adhesive system	9	11,88-13,53	12,99±0,61
B2: Air-abrasion + two-step self-etch adhesive system with selective etch	9	14,16-15,34	14,74±0,49
B3: Air-abrasion + two-step self-etch adhesive system	9	7,98-11,61	9,57±0,99
B4: Air-abrasion + universal adhesive system with selective etch	9	10,74-12,7	11,86±0,82
B5: Air-abrasion+ universal adhesive system	9	11,2-13,27	12,31±0,7

There was a statistical significant difference between the shear bond strength values in Mpa among all sub-groups (p: 0.000; p<0.05). The shear bond strength values of diamond bur treatment plus universal adhesive sub-group (A5) were found to be statistically higher than the other sub-groups (except sub-group A3) (p: 0.00, p: 0.002, p<0.05) and there was no statistical significant difference between this sub-group (A5) and diamond bur treatment plus self-etch adhesive sub-group (A3). On the other hand, the shear bond strength values of diamond bur plus total etch adhesive sub-group (A1) and air abrasion plus self-etch sub-group (B3) were found to be statistically lower than that the other sub-groups with a significant difference (p: 0.00, p<0.05) (Table 4.2) (Figure 4.1).

Table 4.2: Evaluation of shear bond strength values in Mpa between all sub-groups

Sub-groups	Shear bond strength Mpa mean± SD
Sub-group A1	10,28±0,64
Sub-group A2	14,28±0,71
Sub-group A3	15,91±1,15
Sub-group A4	14,94±0,52
Sub-group A5	16,5±0,79
Sub-group B1	12,99±0,61
Sub-group B2	14,74±0,49
Sub-group B3	9,57±0,99
Sub-group B4	11,86±0,82
Sub-group B5	12,31±0,7
p	0,000*

Oneway Anova Test *p<0.05

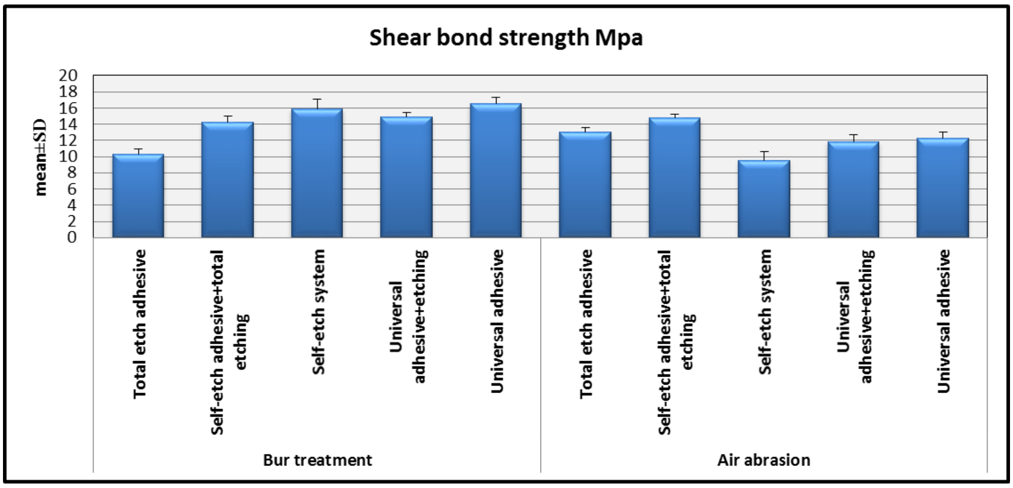

Figure 4.1: A bar chart representing the mean ± SD of shear bond strength Mpa values among all sub-groups.

4.1. Evaluation of Shear Bond Strength Mpa Values of surface treatment Groups.

When evaluating the results of two groups (surface grinding with diamond bur and air abrasion treatments), regardless the adhesive systems used in sub-groups, they demonstrated that the mean shear bond strength (Mpa) values of the bur treatment group was found to be significantly higher (p: 0.00, p<0.05) than that of the air abrasion treatment group. (Table 4.3) (Figure 4.2).

Table 4.3: Evaluation of shear bond strength (SBS) Mpa values within surface treatment groups using Student t-test.

Surface treatment groups	SBS Mpa Mean±SD
Bur treatment A	14,38±2,34
Air abrasion B	12,29±1,84
p^1	0,000

Student t test p^1: 0.00

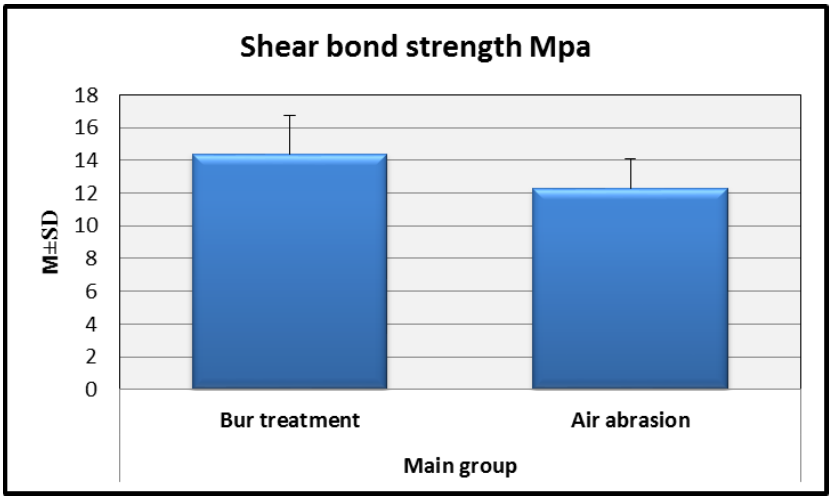

Figure 4.2: A bar chart showing the mean ± Standard Deviation (M± SD) of shear bond strength of main groups (bur treatment and air abrasion).

4.2. Evaluation of Shear Bond Strength Mpa Values within Sub-Groups:

There was a statistically significant difference in shear bond strength Mpa values along the sub-groups (p: 0.00, $p<0.05$), regardless of the surface treatment in the main groups (Table 4.4) and (Figure4.3). The shear bond strength of the total etch adhesive sub-group was found to be statistically lower in the Mpa averages than the self-etch adhesive with selective etch technqiue, universal adhesive with selective etch technqiue and universal adhesive sub-groups, and there was no statistically significant difference in shear bond strength Mpa between other sub-groups ($p>0.05$).

Table 4.4: Evaluation of shear bond strength SBS Mpa valuse in mean ± SD within sub-groups (using Oneway ANOVA Test).

Sub-groups	SBS Mpa Mean±SD
Total etch adhesive	11,63±1,52
Self-etch adhesive+selective etch	14,51±0,64
Self-etch system	12,74±3,43
Universal adhesive+selective etch	13,4±1,72
Universal adhesive	14,41±2,28
p	0,000*

Oneway Anova Test *$p<0.05$

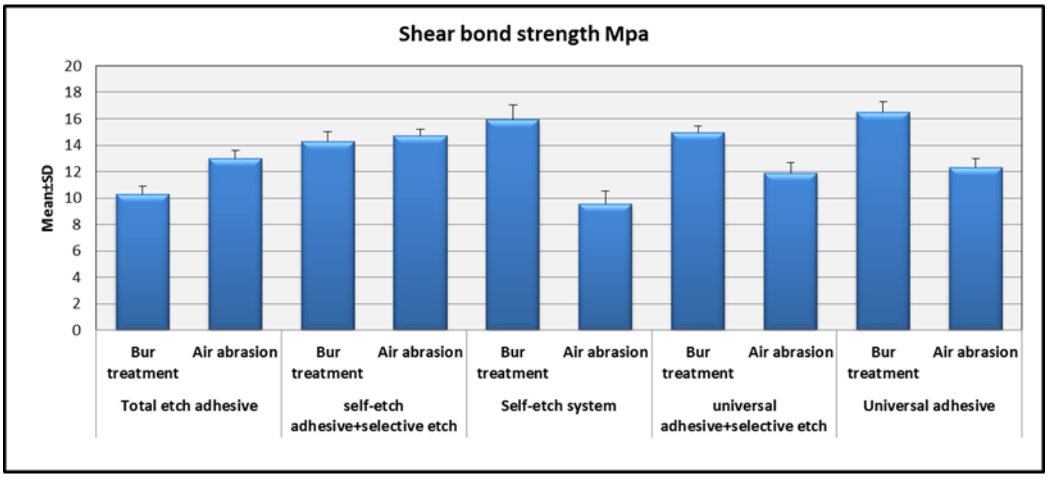

Figure 4.3: A bar chart showing mean± SD of shear bond strength Mpa for sub-groups.

4.3. Evaluation of Shear Bond Strength Mpa Values in Sub-Groups in Relation to the Surface Treatment.

Two-steps total etch adhesive sub-groups: the mean shear bond strength of the bur treatment sub-group was observed to be statistically significant lower than that of the air abrasion sub-group (p: 0.00, $p<0.05$) (Table 4.5).

Two-steps self-etch adhesive with selective etch tech technique sub-groups: between the bur treatment sub-group and air abrasion sub-group there was no statistical significant difference in shear bond strength Mpa values ($p>0.05$) (Table 4.5).

Two-steps self-etch adhesive sub-groups: the mean shear bond strength of the bur treatment sub-group was found to be significantly higher than that of air abrasion sub-group (p: 0.00, $p<0.05$) (Table 4.5).

Universal adhesive with selective etch technique sub-groups: the bur treatment sub-group Mpa values were observed to be statistically higher than that of air abrasion sub-group (p: 0.00, $p<0.05$) (Table 4.5).

Universal adhesive sub-groups: the mean shear bond strength Mpa values of bur treatment sub-group was found to be significant higher than that of the air abrasion sub-group (p: 0.00, $p<0.05$) (Table 4.5)

Table 4.5: Assessment of the shear bond strength Mpa values in sub-groups in relative to surface treatment.

Adhesive systems	Surface treatments	SBS Mpa (mean±SD)
Two-step Total etch adhesive system	Bur treatment	10,28±0,64
	Air abrasion	12,99±0,61
	p	0,000*
Selective etch + two-step Self-etch adhesive system	Bur treatment	14,28±0,71
	Air abrasion	14,74±0,49
	p	0,128
Two-step Self-etch system	Bur treatment	15,91±1,15
	Air abrasion	9,57±0,99
	p	0,000*
Selective etching + Universal adhesive system	Bur treatment	14,94±0,52
	Air abrasion	11,86±0,82
	p	0,000*
Universal adhesive system	Bur treatment	16,5±0,79
	Air abrasion	12,31±0,7
	p	0,000*

Student t Test *$p<0.05$

4.4. For the Diamond Bur grinding Group:

There was statistically significant difference in shear bond strength Mpa values between the sub-groups (p: 0.00, $p<0.05$). The values of two-steps total-etch sub-group were found to be statistically significantly lower than that of self-etch adhesive with selective etch technique sub-group, self-etch adhesive sub-group, universal adhesive with selective etch technique and universal adhesive sub-group (p: 0.00, $p<0.05$). The shear bond strength Mpa of the two-steps self-etch adhesive sub-groups with selective etch sub-group was found to be statistically significantly (p1:0.001, p2: 0.00, $p<0.05$) than that of the self-etch system and universal adhesive sub-groups. The shear bond strength Mpa of the self-etch system sub-group was statistically lower than that of the universal adhesive sub-group (p: 0.001, $p<0.05$). There was no statistically significant difference in shear bond strength Mpa between the other sub-groups ($p>0.05$) (Table 4.6).

4.5. For the Air Abrasion Treatment Group:

There was a significant difference in Mpa values of shear bond strength between the sub-groups(p: 0.00, p<0.05). The shear bond strength of the self-etch system sub-group was found to be statistically significant lower (p: 0.00, p<0.05) than the total etch adhesive, self-etch adhesive plus total etching, universal adhesive plus total etching and universal sub-groups. The shear bond strength of self-etch adhesive with selective etch technique was established to be statistically significantly higher (p: 0.000, p <0.05) than total-etch adhesives, universal adhesive with selective etch technique and universal adhesive sub-groups. The shear bond strength MPa of total-etch adhesive group was found to be significantly higher than Universal adhesive plus total etching sub-group (p: 0.021, p <0.05). There was no significant difference in the Mpa values of shear bond strength between the other sub-groups (p>0.05) (Table 4.6).

Table.4.6: Evaluation of shear bond strength Mpa parameters in surface treatment groups according to the adhesive systems.

Groups	Sub-groups	SBS Mpa (mean±SD)
Grinding with diamond bur	Two-steps Total-etch adhesive	10,28±0,64
	Self-etch adhesive with selective etch	14,28±0,71
	Self-etch system	15,91±1,15
	Universal adhesive with selective etch	14,94±0,52
	Universal adhesive	16,5±0,79
	p	0,000*
Air abrasion	Two-steps Total-etch adhesive	12,99±0,61
	Self-etch adhesive with selective etch	14,74±0,49
	Self-etch system	9,57±0,99
	Universal adhesive with selective etch	11,86±0,82
	Universal adhesive	12,31±0,7
	p	0,000*

Oneway Anova Test *p<0.05

After the evaluation of shear bond strength test, the results of assessment of the failure mode showed that there was a high percentage for cohesive failure type among all groups about 72% of all groups. (Table 4.7) (Figure 4.4).

Table 4.7: Evaluation of failure types (cohesive, adhesive or mixed) among all groups.

Groups	Cohesive (%)	Adhesive (%)	Mixed (%)
A 1	8 (89%)	0	1(11%)
A 2	7 (78%)	0	2 (22%)
A 3	7 (78%)	0	2 (22%)
A 4	7 (78%)	0	2 (22%)
A 5	5 (55.5%)	1 (11%)	3 (33%)
B 1	6 (67%)	0	3 (33%)
B 2	7 (78%)	0	2 (22%)
B 3	6 (67%)	0	3 (33%)
B 4	6 (67%)	1 (11%)	2 (22%)
B 5	6 (67%)	1 (11%)	2 (22%)
Total of all groups	65 (72%)	3 (3%)	22 (24%)

Figure 4.4: Cohesive failures among a number of the specimens.

5. DISSCUSION

This research examined the influence of two surface treatment techniques and three adhesive systems with different application protocols on the shear bond strength of composite resins repair. According to the results in this study, the surface treatments and the adhesive systems significantly influence shear bond strength of the aged composite resins. For that reason, the null hypothesis suggesting that the surface treatment and the different bonding agents would not have any consequence on the repair bond strength of composite resins, was excluded.

Different bond strength tests were used to assess the repair bond strength of aged composite resins (2, 164). The shear test is the most frequently utilized method for the evaluation of repair bond strength. An easy preparation of samples and a simple testing protocol are the most important advantages of this method (165). It permits a common measurement of the highest stress potential at the interface between the bonded materials. This test might be the most suitable test in assessing the success of repair procedures in the anterior region, where the restorative materials are generally exposed to shear force during functional movements (149). Furthermore, the shear bond strength test reproduce the oral clinical situations more professionally than any other test in the evaluation of composite repair (166). So, in this study the shear bond strength test was used to assess the bond strength of repaired composite resins.

The entire restoration replacement is the main choice by most clinicians to treat the failed restorations even with minor defects. For this reason, for a long time the replacement of failed restorations has been considered as the most common management option in the overall dental clinics, and it represents a main part of dental care between adult patients (2).

Replacement of restorations may provide superior clinical results and higher esthetics, however, it may also cause additional destruction of tooth structure and pulpal injury, while being time-consuming and costly (167). Therefore, repair of composite restorations might be a more suitable choice, since it saves time, cost and the remaining tooth structure, when compared to complete replacement (168). Gordan et al. (128)

defined the published studies concerning the repair equality of composite resin restorations as followed: the repaired restorations when compared to the restorations that have been replaced have the highest survival rate.

During the daily routines, such as drinking, eating and smoking, dental restorations are exposed to intraoral thermal variations. All of these influences have an impact on the restoration's durability (169). The composite failure might develop a couple of months or years after it is placed in the prepared cavity. So, there are some alterations that might have been happened in the composite restoration over the time, like water absorption, chemical deterioration and leaching of some compounds. These changes can adversely affect the repair procedure (170). So, the purpose of an artificial aging process is to duplicate these variations which occurred during the clinical service, and it plays an essential role in the assessment of repair bond strength in in-vitro studies (171).

No consensus has been reached on the best effective method for the aging procedure. Several techniques have been used in previous studies for aging, such as thermocycling, boiling and storage in different solutions (citric acid, sodium chloride or distilled water); water is the most commonly used medium for storage (148, 172, 173).

Thermocycling and various periods of water storage are among the most common techniques utilized to replicate the aging process of restorative materials in the laboratory researches. These techniques aimed to initiate the hydrolytic degradation that take place in dental composite restorations during service (173). The water storage at 37ºC has been stated in the studies for period lasting for: nine days (11), twenty days (146, 174), two months (139, 175), and six months (176). Storage in the water produces a growth in surface roughness (1), which did not influence the bond strength (135), it also leads to swelling rather than matrix deterioration (1). The saturation of composite with water diminishs the amount of free radicals available as well as the capacity of chemical reactions with fresh composite (11). Moreover, thermal changes can lead to resin matrix degradation, resulting in the exposure of the underlying filler particles and the increased level of surface roughness. Enhancement in surface roughness might result in micro-crack development and failure of the filler-matrix interaction (1). So the thermocycling is a combination of thermal and hydrolytic degradation (175).

The aim of a thermocycling procedure is to initiate thermal strains at the bonding interface with thermal variations in water baths in a range of 5-55ºC. The recurrence of thermal changes in this process weakens the bond between the filler and the organic matrix of composite material (1).

Numerous variations in the thermocycling procedure can influence the bond strength test results, such as number of cycles, temperature setting and dwell time. The first one is an essential factor in this process (177).

Although there has been no consensus has been reached on the most effective number of cycles and dwell time, the range of cycles has been reported to be from one to 1,000,000 with a mean value of 10,000 cycles. Nonetheless, Gale et al. (178) performed 10,000 cycles (with average of 20 to 25 thermal cycles every day) corresponding to one year of (clinical service) in the oral situation (178).

Özcan et al. (133) concluded that, the thermocycling aging technique is more effective when compared to the other aging techniques that provide worse situations for composite restorations.

Kiomarsi N et al. (179) were performed thermocycling with 5.000 and 10.000 cycles for the composite aging process in their study and their results revealed that, 10.000 thermal cycles have significantly diminished the bond strength of composite resin, while 5.000 cycles did not provide any effect on the repair bond strength, and these results were corresponding with the study of Magni et al (136).

In this study, for aging process 10.000 thermal cycles were performed within the range of 5 to 55 ºC with dwell time of 30 seconds. In this study there was no aim to assess the influence of aging on composite resin repair, but it was performed this process only for the purpose of standardization of composite samples.

During repair of aged restorations, a commonly asked request is whether the repair materials bond sufficiently to the old restorative materials. A repair procedure of composite resins often shows several difficulties, such as: the absence of oxygen-inhibited layer or any unreacted C=C double bond on the surface of the old composite, which is essential to permit the chemical bonding between fresh and old composite resins (180). The surface treatment procedure of aged composite resin has two main functions; firstly, elimination of the superficial layer that is changed by the action of oral environment to expose a clean higher-energy composite surface, secondly, formation of surface microporosities which lead to the surface area enhancement (11). So, the bonding between old and new composites might occur with three different mechanisms:

- Chemical bond to the organic matrix.
- Or chemical bond to the exposed filler particles.
- Micromechanical interlocking to the roughened surface (151).

However, placement of fresh composite directly over the abraded surface will not obtain the close adaptation required for a successful bonding, since the composite resin is a viscous material (150). Therefore, it is essential to place a low viscosity resin bonding agent over the treated surface before the placement of new composite materials. This might also simulate any probable chemical bonding of fresh composite to the old one (141). Although the chemical bonding cannot be disregarded, there is some agreement that the bonding between a fresh to an aged composite is a micromechanical bonding. (161). Therefore the rough composite surface must be attained (150).

Pervious researchers (151, 171) reported that, the most essential factor contributing to repair bond strength is the mechanical interlocking. Enhancement in surface roughness will give superior mechanical interlocking and will improve the chance to find residual free carbon bonds within the surface area (181). Studies using SEM, for newly abraded composite surfaces prior to the bonding process, revealed an irregular surface with pits, grooves, porosities, and exposed filler particles that enhance the micromechanical retention (6, 11, 182).

There is a number of mechanical and / or chemical surface pretreatment methods to roughen the composite surface, which includes: roughening with diamond bur, carbide bur, silicon carbide paper, green carborundum stone, air abrasion with aluminum oxide particles (50µm in size), or with silica coating particles, etching with 37% phosphoric acid gel, or etching with 8-9% hydrofluoric acid (5).

Among the different types of surface treatment techniques available, the use of phosphoric acid and /or diamond tips is the simplest, and most accessible method with good clinical practice. Moreover, many studies indicated that the acid-etching did not alter the morphology of the resin composite surface, and it seemed to provide only a cleaning influence, without any enhancement in micromechanical bonding of composite association (153, 162).

Roughening the surface with a diamond bur has a significant role in promoting macro- and micro-retention in the substrate. However, a difference in grits of diamond bur did not affect repair enhancement, which is in consistency with the finding in a study by Da Costa et al. who establish that there were no notable differences in tensile bond strength (TBS) values between surfaces abraded with different diamond bur grits, founding that even if roughness contours were different, micro-retention profiles were in the same manner (183).

Micro-retention provided by the bur is almost certainly a common cause of bonding to the underlying composite surface (184). Some authors found that, the surface conditioning using a combination of diamond bur treatment with a suitable bonding agent is a simple, cost-effective method and does not need the use of any other materials or equipment.

Another most common surface treatment used for surface conditioning is the sandblasting (air abrasion) with aluminum oxide particles or with silica coated particles, which has been established and utilized by many practitioners. This has been demonstrated to have a possibly good influence on the micromechanical bond strength (6, 182). Air abrasion is capable to create surface irregularities on the aged composite by mechanical shocking of alumina particles, irregularly eliminating parts of the polymer matrix and filler particles. Then, the mechanical adhesion happens by the interaction between new and old composite resins to initiate a bonded interface. Besides the mechanical interlocking and the air abrasion are capable of leaving a silica particles over the composite surface when silica-coated alumina particles are used in air abrasion. Following silanization, these silica particles might provide a chemical coupling at the interface (185).

The surface modifications caused by air abrasion depends on some variables, like air abrasion pressure, particle size and exposure time and also the distance between the tip of machine and abraded surfaces (185).

However, this process needs the application of rubber dam to provide protection from the destruction and erosive effects of abrasive silica particles to the oral soft tissue and the airway of the patient. Also, these particles will lead to the contamination of a wide area of the operatory area, and it would be dangerous for both patient and operator as well. So, this point may considered as the main disadvantage for air abrasion technique (11).

When comparing the roughness configuration of air abrasion and surface grinding with diamond bur treatment; the grinding with diamond bur is the surface treatment that provide macro-and micro- retention features, while air abrasion initiate just micro-retention features (151). Without application of bonding agents, higher bond strength is might obtained from method causing macro-retentive features. Furthermore, with bonding agents a good surface wettability might obtained, as the adhesive resin penetrate onto the composite surface micro-porosity (149, 151, 182).

In this study, the effect of both diamond bur grinding and air abrasion surface treatment on the SBS of old composite repair was evaluated. The result of this study concluded that, the SBS of the diamond bur grinding group was found to be significantly higher than that of air abrasion group (p: 0.00, $p<0.05$) regardless of the effect of different adhesive protocols and this result might be contributed to that, the diamond bur grinding provides both micro- and macro retentive features.

The results of this study were in agreement with the results of a study by Tabatabaei et al (186), who concluded that, the grinding with a diamond bur is the most operative surface treatment technique for repair procedures in composite resins.

Furthermore, Brosh et al. (151) in their study suggested that, the grinding with diamond bur treatment has a significant effect on the bond strength of repaired composite resins than that of the sandblasting technique.

Like-wise, Bonstein et al. (146) establish that, in the repair process of composite resins, the diamond bur surface treatment provided a higher bond strength values than that of the air abrasion treatment.

Rosatto et al. (187) made a comparison between the effect of grinding with diamond bur, lasing and air abrasion on the repair bond strength, and they concluded that there was no statistical difference between laser and bur treatment groups.

As mentioned before, in this study, the shear bond strength values of air abrasion group was found to be significantly lower than that of grinding with diamond bur group. Some investigators have confirmed a diminishing in repair bond strength after air abrasion and they have mostly attributed this decrease to the exposure of the filler particles after abrasion, and therefore diminishing the opportunity of primary bonding to the resin (186). Other causes for low bond strength with air abrasion might be the interference of the surface contaminant with the repair procedure and the enclosure of air at the bonding interface, which could decrease the surface area accessible for adhesion.

In contrast, Covalcanti et al. (154) established that, the surface pretreatment of composite resins with the air abrasion technique provides a higher repair bond strength values in comparison to diamond burs.

Bouschlicher et al. (167) did not find any significant differences in the repair bond strength values while using diamond burs or air abrasion.

Furthermore, Andreas Rathke et al. (6) found that, grinding with a diamond bur followed by etching with phosphoric acid was supposed to provide lower bond strength than sandblasting with aluminum oxide.

Moreover, these differences in findings between the studies might be correlated to the type of composite used, concluding that compositions of resin composites might influence the effectiveness of different mechanical surface treatments, and the degree of surface roughness produced (158).

The composite used in this study was a super nanofilled type and the microstructural character and their influence on the wear manner of the nanofill composite were earlier explained by Mitra et al (48) who concluded that, the way through which the nanofillers responded when mechanically abraded is through the breakdown of the clusters. This describes the occurrence of round holes in the surface of the sandblasted nanofilled composite. As stated before, the loss of fillers might diminish the collaboration with the saline, decreasing the bond strength values when compared to microhybrid composite.

In the end of matter, the results of this study suggests that there is no need to purchase any additional armamentaria in dental clinic, such as chair-side air abrasion device and making repair procedures more simple, efficient, and cost-effective with the use of diamond bur surface treatment.

Another significant influence on the composite repair process is the use of bonding agents. Repair bond strength of composite resins is greatly increased when the bonding agents are applied subsequently after surface treatment procedures (149, 167).

The capability of monomers and solvents to infiltrate within the surface of composite resin is related to the degree of composite hydration and chemical attraction of materials. Most of composite resins have a hydrophobic character, but might have some amount of absorbed water, which can increase surface infiltration with hydrophilic bonding agent (157). The bonding agent effectiveness is enhanced by its low degree of viscosity, which creates a small contact angle and provides a better wettability for substrate (149).

A recent research presented that, the composite surface which is aged in a laboratory demonstrated superficial dissolution with an increase in surface roughness, which might provide mechanical entanglement of the bonding agents. On the other hand, the new composite material is likely to be thicker to infiltrate within the surface irregularities. These results might be considered as valued for clinicians, since the use of just a bonding agent is simpler than the combination of silane coupling agent with adhesive. Furthermore, during repair procedures it is common that dentists will apply the adhesive system to all of the cavity preparation (both tooth structure and remaining composite) prior to composites application (188).

In this study the effect of three different adhesive systems was evaluated with different application protocols within five sub-groups; first sub-group with two-steps total-etch system (Adper Single Bond), second sub-group with two-steps self-etch system (Clearfil SE Bond) with selective etching technique, third sub-group with Clearfil SE Bond with self-etch technique, fourth sub-group with universal system (G-perimo Bond) with selective etch technique and fifth sub-group with G-perimo Bond with self-etch technique.

Teixeria et al. (157) established that, the bond strength of composite resin repair must be in a range of 15 to 25 Mpa. Within the results of this study, the values of universal adhesive with self-etch protocol in combination with bur surface treatment sub-groups were found to be the highest values within all sub-group (16.5±0.79 Mpa).

When comparing the sub-groups within each other, regardless of the type of surface treatments, the SBS values of the total etch adhesive group was found to be statistically significantly lower than other sub-groups.

Most of the recent bonding agents have hydrophilic primer in their construction with somewhat high percentage (2-HEMA) monomer, which have low molecular weight. This molecule provides a good wettability for old composite resin surface through the alteration of surface tension, and permits deep infiltration into the surface irregularities. Beside the wetting ability of adhesive systems, some of them have water chasing or dehydrating abilities if the acetone or alcohol is present in their formulation. The minor size with amphiphilic nature of 2-HEMA monomer allows it to infiltrate within the wetted part of old composite (with their hydrophilic property) and this monomer might also provide a chemical bond to the resin materials when light cured (with their hydrophobic property). Hydrophobic monomers present within the dental restorative materials have a high capacity to bond simply to the same monomers found in the bonding resin, and this process occurs also between bonding agent and tooth structure (enamel and dentin) (155, 187).

The total-etch adhesive system is utilized with etch- and -rinse protocol, the phosphoric acid etching permits elimination of the surface debris, that cover the surface of old composite and might expose the underlying filler particles. This action might arise the surface area available for a bonding process (135) with an increase in composite surface wettability (152). So, acid etching might increase the wetting capacity of total-etch system, as this system is more hydrophobic with high viscosity when compared to self-etch adhesive and universal adhesive (152). This might be attributed to low values of shear bond strength among the total-etch sub-groups in the current study.

The self-etch adhesive system (Clearfil SE Bond) incorporates 10-methacryloyloxydecyl dihydrogen phosphate (proprietary acid phosphate monomer) in their formulation, therefore the hydrophilic self-etching primers of this system might provide a good adhesion to the surface of aged composite through the reaction between the phosphate group of self-etch system and composite resin (152, 154).

Yoshida Y et al. (189). Found that, the particular nature of functional monomer molecules of self-etch adhesive system (Clearfil SE Bond) provide a probable and strong bond to tooth structure.

Furthermore, the active application technique used with self-etch adhesive system could have a positive effect on the re-bonding process, and the light brushing motions might permit an easier precipitation of the monomer and solvent into the repaired surface. In this study, the Clearfil SE Bond was used with an active application technique which might increase the surface wettability and subsequently provide an enhancement in repair bond strength (154, 189).

Teiexeira et al. (157) in their study found high repair bond strength values when the old composite was repaired with a self-etch adhesive agents.

Cavalcanti et al. (154) concluded that, the use of self-etch Clearfil SE Bond, which has a functional monomer (10-MDP) in their formulation for repair of aged composite resins provided the highest bond strength values and they attributed that to the high wettability of 10-MDP monomer. However, more research is required to evaluate this hypothesis.

Universal adhesive systems have been introduced in field of restorative dentistry to be used in different fields, such as bonding to composite resins, dental ceramic and other alloys. It has been established that, adequate and firm bond strength to tooth structure might be accomplished with selective etch or self-etch protocols. This property might permit bonding to different surfaces without the requirement of separated step of primer, such as: salines, or any other primers. In that regard, failed restorations might also involve enamel, dentin and composite borders, and these types of bonding agents might be more useful to be used in this situation (4).

Fornazari IA et al. (190) concluded that the use of universal bonding agent that have a saline in their composition was as effective as other combination of saline and any type of adhesive agent on the bond strength of repaired nanofilled composite.

In the study of Kiomarsi N et al. (191) they found that, the diamond bur surface treatment with subsequent application of the universal adhesive agent might enhance the repair bond strength of aged composite resin.

In this study G-perimo universal adhesive agent provides the highest value of shear bond strength, which was near that of self-etch system, and this might contributed to the presence of functional monomer like MDP and MDTP monomers, which might attribute to the good wettability of these adhesive systems. On the other hand, MDP monomer might permit a chemical bond to zirconia particle surface, and the type of composite used in this study contained about 82% by weight of silica-zirconia filler and it could be concluded that the MDP monomers within universal adhesive might provide additional chemical bond which can improve repair bond strength (4, 192).

However, when concerning the surface treatments while comparing the results of sub-groups, all sub-groups except the first group (total-etch adhesive) showed low values of SBS with air abrasion surface treatment than the diamond bur treatment with statistical significant difference (although there was no statistical significant difference within the second sub-group) and as mentioned before within the results of the present study, the diamond bur treatment provided an enhancement in the values of SBS. But for the first sub-groups (total-etch adhesive) the SBS values with air abrasion surface treatment was statistically significantly higher than that of diamond bur treatment, and this study contributed that to the application of phosphoric acid etching before the application of adhesive system. Generally, phosphoric acid etching is used during the repair process of composite resin materials, mainly when the defect part involve both composite and tooth structure (enamel and / or dentin).

Fawzy et al. (135), Papacchini et al (162), and Hannig et al. (193) established that acid etching is likely to provide a superficial cleaning result, which eliminates contamination and any grinding debris from the surface of composite resin.

Andreas Rathke et al. (6) found that, the use of diamond bur surface treatment for repair procedures followed by acid etching with phosphoric acid might provide lower bond strength than with air abrasion technique.

In their study, Jafarzadeh et al. (174) concluded that not only the application of phosphoric acid etching was ineffective in their study, it also had a negative influence on the SBS and they attributed these differences to the manufacturer and chemical composition details, and the equality of different brands used in their study.

According to the results in this study, the application of 35% phosphoric acid after grinding the composite surface with diamond bur gives negative effects on SBS values for all adhesive systems (total-etch, self-etch and universal adhesive) just with a number without a statistical difference, and it was found that the use of acid-etching within total-etch groups could remove surface debris or include air that reduced the surface area available for bonding after air-abrasion, giving a positive effect on SBS. While with bur treatment, the acid-etching remove smear layer that was formed after grinding with a bur, which might be more effectively penetrated or wetted with adhesive agents especially if silane is applied (186).

The results of the assessment of the fracture type in the repaired specimens showed that, there was a high percentage of cohesive failure within all groups followed by mixed type and few numbers of adhesive failure. The predominance of failure type might be related to the fact that the composite may contain numerous air inclusions, and these air inclusions can acts as stress points, thus giving rise to the increased likelihood of cohesive failure within the specimen (194). On the other hand, these cohesive failures might be correlated to the decrease in the cohesive strength of composite resin materials as a result of aging processes rather than the increase in the bond strength of adhesive junctions (4)

Finally, it is still not reasonable to suggest a universal protocol for all situations of composite repair, since many studies have established different results (146, 156, 157, 195). However, one might select a protocol, which is safer to be used in the oral cavity and to be simpler. Surface preparation methods, such as acid etching with hydrofluoric acid or air abrasion might have an adverse influence (140). Therefore, the use of an appropriate bonding agent, subsequently, after a diamond bur surface treatment might be a more suitable and safer method for composite resin restorations repair.

6. CONCLUSION

1. The aging process is performed in order to duplicate the variations, which occur during clinical service, as it has an essential role in the assessment of repair bond strength in in-vitro studies.
2. For successful repair procedures there is a need for adequate mechanical surface treatment and the application of a corresponding bonding agent.
3. The shear bond strength obtained by the mechanical surface grinding with diamond bur is statistically significantly, and higher than that obtained with air abrasion surface treatment.
4. Two-step total-etch adhesive regimen produces lower bond strength when compared to other groups regardless of the surface treatment used.
5. The combination of a universal adhesive system, or a two-step self-etch adhesive system and the grinding with a diamond bur for repair procedures provides the highest values of SBS.
6. The application of 37% phosphoric acid after grinding the composite surface with a diamond bur provides an adverse effect on the shear bond strength values with all adhesive systems, while with air abrasion surface treatment, it gives a positive influence on the shear bond strength values.

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