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Evaluation of the cuspal deflection of premolars restored with different types of bulk-fill composite restorations (A comparative *in vitro* study)

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Conservative Dentistry

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Dedication

To my beloved mother and my dear father for their love,

support and prayers through all my life...

To my brothers and lovely sister

To my supervisor for her guidance, help,

encouragement, and support...

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Abstract

Cuspal deflection is a common biomechanical phenomenon that occurs in teeth restored with composite resin-based materials and represents the interaction between polymerization stress of material and the compliance of remaining tooth structure, which may cause failure during composite curing or act as a preloading, facilitating tooth fracture under occlusal loads. This study aimed to evaluate the cuspal deflection in MOD cavities of premolar teeth restored with three different types of bulk-fill resin-based materials (SonicFill™2, Beautifil Bulk Fill, and Filtek™ Bulk Fill posterior restorative) and compare to incrementally restored group with universal Tetric Evoceram® composite, and study the effect of water storage for different periods on cuspal deflection.

Forty extracted human maxillary first premolars of approximately similar size were prepared with standardized large MOD cavities. Samples were divided into four groups (n=10) according to restorative material. Group A (restored with SonicFill™2 composite), Group B (restored with Beautifil Bulk Fill restorative), Group C (restored with Filtek™ Bulk Fill posterior restorative) and Group D (restored with Universal Tetric Evoceram® composite). Groups A, B and C restored with bulk-fill technique while group D restored with oblique incremental technique. The intercuspal distance (ICD) was measured before cavity preparation, after preparation, 15 minutes after restorative procedures and after 1 and 4w incubation periods. The differences between readings were recorded as cuspal deflection. Data were analyzed statistically by using descriptive statistic, one-way ANOVA and Least significant difference LSD test.

The result of ANOVA test showed highly significant differences in cuspal deflection among all tested groups ($p<0.01$) after 15 minutes from restoration completion and at different incubation periods due to water storage.

The results of LSD showed that the bulk-fill groups A & C had less cuspal deflection than other groups with no statistically significant differences ($P> 0.05$) between them, While incrementally filled group D showed a highly significant difference ($P<0.01$) cuspal deflection than other groups after 15 min. from restoration. This may be attributed to the new bulk-fill composites produce lower polymerization shrinkage stress in comparison to a conventional composite or due to placement technique.

After 1and 4weeks incubation periods, cuspal deflection in all groups gradually decreased and compensated by hygroscopic expansion within four weeks for all groups.

In conclusion and according to the result of this study, less cuspal deflection was obtained by using the bulk-fill composite in comparison to conventional composite with layering technique. On another hand, this deflection was offset by the hygroscopic expansion of restorations within 4weeks incubation period. Therefore, our recommendation may choose bulk-fill composites for reducing unwanted polymerization shrinkage effects while simplifying the filling technique.

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List of Abbreviations

Abbreviations	Meaning
AFM	Addition-fragmentation monomers
AUDMA	Aromatic urethane dimethacrylate
Bis-EMA	Ethoxylated bisphenol-A dimethacrylate
Bis-GMA	bisphenol-A glycidyldimethacrylate
CEJ	Cemento-enamal junction
C-factor	Configuration factor
DCDT	Direct current differential transformer
DF	Degree of freedom
F-PRG	Full- prereacted glass
HS	High significant different
ICD	Intercuspal distance
LED	Light emitting diode
LEM	Low Elastic Modulus
LVDT	Liner variable displacement transducer
Mm	Millimeter
MDP	Methacryloxydecyl phosphate
Nm	Nano micrometer
NS	Non-significant different
OH	Hydroxyl group
PRG	Prereacted glass
S	Significant
SBU	Single bond universal
SD	Standard deviation
SDR	Smart dentin replacement
Sec	Second
S-PRG	Surface-prereacted glass
TEGDMA	Triethylene glycol dimethacrylate
UDMA	Urethane dimethacrylate
µm	Micrometer
UV	Ultraviolet

VOL.	Volume
WT.	Weight
X	Magnification

Introduction

Introduction

The composite resin-based materials have been widely used as a direct posterior restoration due to increase patients' demands to tooth-colored restoration and environment-friendly nature of composites. However, the polymerization shrinkage or bulk contraction of composite through the polymerization process remains a challenge and still imposes limitations in the application of direct techniques (Yap *et al.*, 2000).

Polymerization shrinkage stress is associated with two clinical problems (microleakage and cuspal deflection) depending on bond strength. When the filling material has weakly adhered to the dental tissues, a detachment of the enamel margins can occur and/or gaps can form, resulting in marginal microleakage that allows the passage of bacteria, fluids, molecules, or ions between the cavity surface and the composite resin. In contrast, if the adhesive strength exceeds the contraction stress, there is no detachment but the restoration maintains an internal tension that pulls the cavity walls together, reducing the intercuspal distance (cuspal deflection) (Gonzalez-Lopez *et al.*, 2004; Jafarpour *et al.*, 2012; Karaman and Ozgunaltay, 2013).

Incremental layering technique is recommended for placement of resin composites in large cavities due to its ability to reduce the consequences of shrinkage stress and allow an adequate degree of conversion (Park *et al.*, 2008).

The manufacturers are directed to decrease the number of increments for tooth-colored restoration and encourage the use of bulk-fill composite to avoid contamination that may incorporate between layers and decrease the time required for placement and curing each layer. Some of the bulk-fill composites can be used to restore the cavity completely, while others (usually flowable dentin replacement composites) are used as base materials. The base materials require a layer of 1.5–2 mm from a conventional composite resin to complete the restoration (Papadogiannis *et al.*, 2015).

A new sonic-activated Bulk-fill system (SonicFill™2, Kerr Corp, USA/Kavo, and Germany) was introduced to the market for direct bulk restorations. It represents a combination of flowable and universal composites by incorporating a highly-filled proprietary resin with special modifiers that react to sonic energy (Didem and Yalcin, 2014).

Beautifil-Bulk products are, multifunctional Giomer restorative material, characterized by containing bioactive filler particles. In the manufacturing process, these fillers are coated with a durable glass ionomer phase (“S-PRG”) before being embedded in the matrix. This technology allows fluoride and other ions to recharge and release (Shofu, 2014).

Filtek™ Bulk Fill Posterior Restorative contains two novel methacrylate monomers AUDMA (Aromatic urethane dimethacrylate) and AFM (Addition-fragmentation monomers) that act together to reduce polymerization stress. These methacrylate molecules react into the developing polymer by forming crosslinks between adjacent polymer chains. When stressed during polymerization, these molecules may break or fragment so providing a means for relaxation of the developing polymer network and stresses are relieved (3M ESPE, 2015).

Tetric EvoCeram is the universal nano-hybrid composite for anterior and posterior restorations that offers outstanding esthetics. The filler technology found in Tetric Evoceram is based on an optimum blend of different fillers and filler sizes (Ivoclar Vivadent, 2011).

Under clinical conditions, restored teeth are continuously bathed with oral fluids and thus water absorption and hygroscopic expansion can be expected. This expansion counterbalances polymerization contraction and thus can cancel out cuspal flexure and neutralize residual shrinkage stresses (Meriwether *et al.*, 2013).

Aims of the study

This study aimed to:

1. Evaluate the cuspal deflection in MOD cavities of premolar teeth restored with three different types of Bulk-fill resin-based materials (SonicFill™2, Beautifil Bulk Fill, and Filtek™ Bulk Fill posterior restorative).
2. Compare the cuspal deflection of MOD cavities of maxillary premolars restored with Bulk-fill resins material to those restored incrementally with universal Tetric Evoceram® composite.
3. Study the effect of water storage for different periods (one week and four weeks) on the cuspal deflection of MOD restorations.

Chapter One

Review of Literature

Review of Literature

1.1 Direct posterior dental composite

Since the introduction of resin-based composites as an alternative restoration to dental amalgam in 1950, they undergo a catastrophic development to produce restoration similar to tooth appearance with long-term performance as shown in Figure (1.1). The photointiators system, nano-particle technology, novel monomer, monomer blend, and the translucency of resin-based composite to blue light are developed for placement and curing up 4mm in thickness of restoration (Kalliecharan *et al.*, 2016).

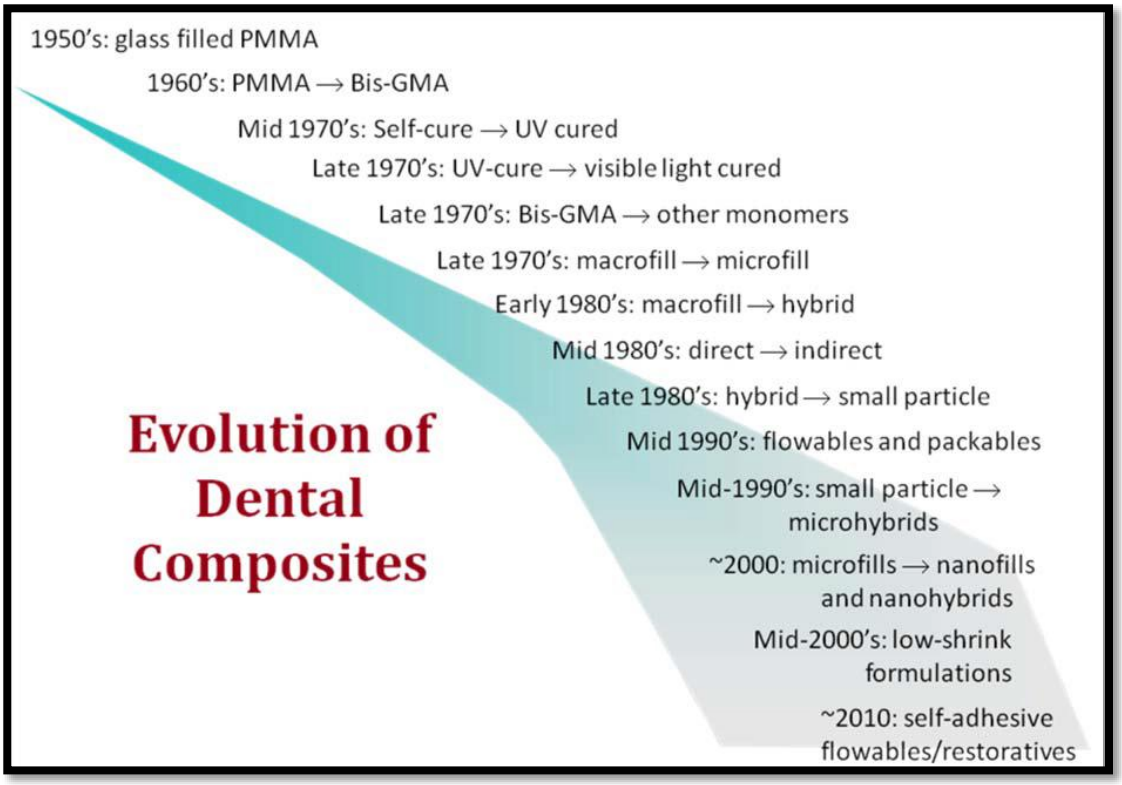

Figure (1.1): The evolution of dental composites (Ferracane, 2011).

1.1.1 Composition of dental composite

Dental resin composites are a complex mixture consists of three main phases: the polymerizable resin, filler and the filler-resin interface, each phase has its special role in determining material properties. In addition, minor components include a polymerization initiator, stabilizers, coloring pigments and inhibitors (Schneider *et al.*, 2010; Cramer *et al.*, 2011).

1.1.1.1 Organic phase (resin matrix)

Organic monomers are the chemically active component of the composite. It is converted from a fluid state into a highly cross-linked polymer through polymerization process to bring the fillers together and work as a backbone for the composite (Schneider *et al.*, 2010).

Bis-GMA (Bisphenol Aglycidyldimethacrylate) has been widely used in the formulations of dental resin composites due to its desirable features as reasonable clinical handling, minimum volatility, and low thermal expansion, but it has high viscosity nature so that it needs to dilute with other dimethacrylate monomers, such as TEGDMA (Khatri *et al.*, 2003). It has less polymerization shrinkage than other monomers and greater mechanical qualities due to its high molecular weight (Schneider *et al.*, 2010).

UDMA (Urethane Dimethacrylate) is a monomer that can be used in dental resin composite matrix as alone or in combination with other monomers. The molecular weight of UDMA is close to Bis-GMA molecular weight. It was found that the degree of conversion and flexural strength were increased if Bis-GMA partially replaced by UDMA, this due to greater flexibility and weaker intermolecular bonds promoted by UDMA (Sideridou *et al.*, 2003; Schneider *et al.*, 2010). Aliphatic urethane dimethacrylate and partially aromatic urethane dimethacrylate represent a modification on UDMA chemistry (Ilie and Hickel, 2011).

TEGDMA (Triethylene glycol dimethacrylate) is used as an efficient diluent monomer to reduce viscosity of Bis-GMA, however it has a negative drawback because it increases polymerization shrinkage and water sorption of material, so that polymerization shrinkage increases when the ratio of Bis-GMA is reduced and increased TEGDMA (Gonçalves *et al.*, 2008; Schneider *et al.*, 2010).

Bis-EMA (Ethoxylated Bis-phenol A Methacrylate), a hydrophobic monomer, is widely used as a base matrix in combination with other monomers. The absence of free OH group and low viscosity of Bis-EMA are the main differences between it and Bis-GMA (Schneider *et al.*, 2010).

Silorane matrix, a fully different chemistry of resin composite, is used a ring opening polymerization instead of free radical polymerization that represent the main alteration on the polymer matrix and essential cause for reduction in polymerization shrinkage (Ardu *et al.*, 2010; Cramer *et al.*, 2011).

1.1.1.2 Inorganic phase (fillers)

The filler particles constitute the major part of composites. They are added to the resin matrix to reduce polymerization shrinkage and stress, reinforce the resin matrix and strength of the composite, improve the optical properties of the material with a special respect to translucency, and resistance to secondary caries by incorporated fluoride containing fillers, that finally influencing on the clinical performance of restorations**.** They are composed of finely ground quartz or glass, sol-gel derived ceramics. Most of the silica glasses consist of heavy-metal oxides as zinc, barium, yttrium fluoride, or ytterbium trifluoride to get radiopacity (Schneider *et al.*, 2010; Kaisarly and El Gezawi, 2016).

1.1.1.3 Coupling agent

Coupling agents are acted as a bridge that connects filler particles with the matrix. This connection is occurred by manufacture treating filler surface with the coupling agent before incorporated into the matrix so that mechanical properties of the dental composite is improved by transferring stress from the weak matrix to more strong fillers, additionally it reduces the water sorption by providing hydrophobic media (Kaisarly and El Gezawi, 2016).

1.1.1.4 Initiators and Accelerators

Polymerization of composite is achieved by chemical or visible light activation (Craig, 1997).

I. Self-curing or chemically activated system: Chemically activated materials are supplied as two paste, one of them contains the benzoyl peroxide initiator (1%) and the other contains about 0.5% of tertiary' amine activator (Hickel *et al.*, 1998)

II. Light curing or light-activated system: The most common photosensitive or initiator system in light activation composite type is camphorquinone/amine initiation system; it is activated by absorbing visible blue light in range between 400 to 500nm. When the oligomer presents at room temperature and the composites not expose to light, camphorquinone/amine initiator remain stable (Sakaguchi and Powers, 2012). Benzoyl germanium derivatives, a new initiator system, undergo photodecomposition to form radicals without the need for a co-initiator and exhibit strong absorption up to 450 nm, which is advantageous for improved initiation efficiency in dental materials (Cramer *et al.*, 2011).

III. Dual-cured composites: To solve the problems associated with light curing combined cold-curing and visible light-curing materials were introduced. These formulations contain initiators and accelerators that allow light activation followed by self-curing alone (Sakaguchi and Powers, 2012).

1.1.1.5 Inhibitors

The inhibitors are added to resin system to react with free radicals that form accidentally when the composite exposed to light. Therefore, they reduce or prevent spontaneous polymerization of dimethacrylate monomers. butyrate hydroxyl toluene, a typical inhibitor, is used in a concentration of 0.01% wt. (Nadarajah *et al.*, 1997).

1.1.1.6 Stabilizer

UV-stabilizers decrease the risk of dental composite discoloration when they are exposed to strong ultraviolet-light and confirm a long shelf life for non-polymerized composite paste (Hickel *et al.*, 1998).

1.1.1.7 Ultraviolet Radiation Absorbers

These are added to improve color stability by absorbing electromagnetic radiation that can cause discoloration. The most commonly used absorber is 2-hydroxy-4- methoxy benzophenone (Nadarajah *et al*, 1997).

1.1.1.8 Pigments and other components

The most common pigments that added to provide shades matching to tooth shades are oxides of iron. Fluorescent agents are sometimes added to enhance the optical vitality of the composite and mimic the appearance of normal teeth (Sakaguchi and Powers, 2012).

1.1.2 New classification of resin based aesthetic materials

The new classification of the resin based aesthetic composite materials laying on the characterization of their matrix and their filler morphology with scanning electron microscope evaluation (Ardu *et al.*, 2010).

There are four different types of matrices: Methacrylate-based, Compomer-based, Ormocer-based and Silorane- based. Methacrylate resin is the most commonly used matrix in composite. A modification of this matrix represented by ormocers, where the methacrylate-based resin modified by the addition of small polysiloxane Particles (2 to 3nm). A completely different chemistry represented by the silorane matrix (Ardu *et al.*, 2010).

The other variable of resin based restorative material structure regards filler size, shape, and distribution. Fillers can be divided depending on their size as macrofillers (2µm-5µm) and microfillers (< 0.4 µm). The microfilled group is composed is composed of two subgroups, depending on the filler's homogeneity. While the homogeneous filler is rarely available due to its poor mechanical properties, the inhomogeneous filler is still in use and proposed as veneering material in anterior restorations. Whenever the filler's mean size is more than 2 um, the material is defined as a macrofilled. If a mixture of macro- and microfillers is present in the matrix, the material defined as a hybrid. Within the large family of the hybrid group, different categories found depending on their filler size. The coarse hybrid is a family of materials where the mean filler size is between 1 μm and 2 μm, the fine hybrid between 0.6 μm and 1 μm, and micro hybrid between 0.4 μm and 0.6 μm. This last group split into two sub-categories depending on the presence or absence of large particles that are composed of smaller units, i.e. aggregates of micro-fillers or prepolymerized splinters. While the homogeneous micro hybrids do not contain these particles, the inhomogeneous has them. Micro hybrid with aggregates may be at first sight confused with macro fillers, but the large particles are made of the aggregation of primary SIO2 or SIO2\ZrO2 particles of about 40 μm (Ardu *et al.,* 2010).

On the other hand, in the micro hybrid composites with splinters, the large fillers obtained not by aggregation of nano elements but crunching down large prepolymerized hybrid or microfilled composites. The more the matrix is hydrophobic, the least the material should be subjected to hydrolysis and discoloration (Ardu *et al.,* 2010).

Fillers represent the second fundamental component in adhesive material. Generally, large filler (macro fillers) tend to increase the wear rate of the material. Exposure of filler particles because of resin matrix wears results in a higher surface roughness and in a dull aspect. Therefore, this kind of material cannot be proposed as a restorative material for anterior restoration nor for posterior ones. On the other hand, because generally macro-charged materials are highly filled, they can be used as base under other restoration or as core under prosthetic restoration. Higher filler load, in fact, results in increased stiffness, harness, and compressive strength (Ardu *et al.,* 2010).

Micro-fillers give to a material a high and durable surface gloss, because they are smaller than the wavelength of visible light, thus being invisible to the human eye and used as veneering materials in anterior restorations, but are not indicated for large class IV cavities or posterior reconstructions. Micro-filled resin composite have a low filler load, thus a low Young's modulus and fracture strength, and consequently are prone to chipping and fracture (Ardu *et al.,* 2010).

A good comparison between the high mechanical properties of macro filled materials and the good esthetic properties of micro filled materials found in hybrid materials. These materials couple the necessity of being resistant to support masticatory stresses with the esthetic requirements of modern dentistry. These characteristics confer to this family of materials a large indication both in anterior and posterior areas. That is why they are currently the most commonly used and produced multi-purpose restorative materials (Ardu *et al.,* 2010).

1.2 Placement techniques of direct posterior restoration

I. The Layering Technique

The incremental technique is based on polymerizing of less than 2mm thickness layers of resin-based composites. This technique can help to improve marginal quality, prevent cavity wall distortion and ensure complete polymerization of material (Deliperi and Bardwell, 2002). Horizontal, vertical and oblique increments have been proposed as shown in Figure (1.2), all have the same goal of increasing the unbounded area in each layer of composite resin, which maximizes the relaxation of polymerization stress through external flow (Feilzer *et al.*, 1987; Liebenberg, 1996).

The following are variances related to differing stratifications:

1. Horizontal technique: This technique is an occluso-gingival layering generally used for small restorations; this technique increases the C-factor (Cavity configuration factor) (Deliperi and Bardwell, 2002).

2. Three-site technique: This is a layering technique that is associated with the use of a clear matrix and reflective wedges. It attempts to guide the polymerization vectors toward the gingival margin (Lutz *et al.*, 1991)

3. Oblique technique: In this technique, wedge shaped composite increments are placed to further prevent distortion of cavity walls and reduce the C-factor. This technique may be associated with polymerization first through the cavity walls and then from the occlusal surface to direct vectors of polymerization toward the adhesive surface (Deliperi and Bardwell, 2002).

4. Successive cusp-buildup technique: In this technique, the first composite increment is applied to a single dentin surface without contacting the opposing cavity walls, and the restoration is built up by placing a series of wedge shaped composite increments to minimize the C-factor in 3-D cavity preparations. Each cusp then is built up separately (Deliperi and Bardwell, 2002).

5. Direct shrinkage: chemically cured resin-based composite is used on the gingival floor in an attempt to direct the vectors of polymerization toward the warmer cavity walls. This should help to reduce the gap at the cervical margin (Deliperi and Bardwell, 2002).

6. Selective composite technique: This technique is use different combinations of composite materials to restore enamel and dentin. Since enamel and dentin are different substrates, they should be restored with different resin-based composite materials. Cervical and occlusal enamel are restored using a microhybrid resin-based composite that has a wear pattern and modulus of elasticity closer to that of enamel than other resin-based composites. Dentin has a modulus of elasticity lower than enamel and the use of an intermediate elastic layer may be indicated (Deliperi and Bardwell, 2002).

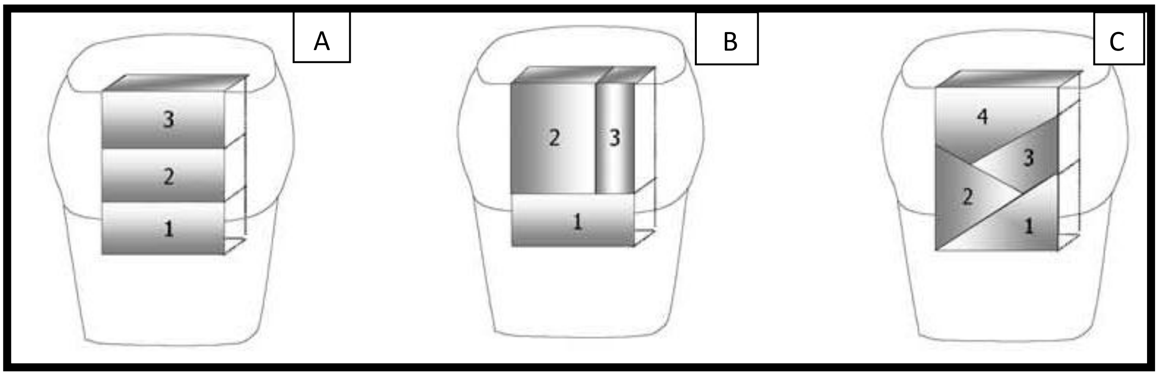

Figure (1.2): The schematic shows different incremental placement techniques (A) Horizontal technique (B) Three sided technique (C) Oblique incremental (Figueiredo Reis *et al.,* 2003).

II. Two-steps amalgam-like sculpting technique (Bulk-fill flowable and regular composite)

This technique refers to the use of two types of composites with different viscosity by building the core with a flowable Bulk-fill composite in one single layer up to 4 mm thickness, then the dentin core coated with a layer of the traditional composite as shown in Figure (1.3) (Hirata *et al.*, 2015).

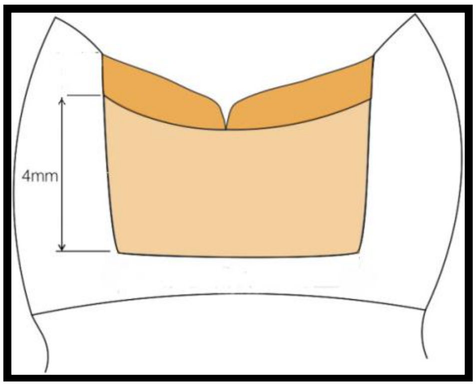

Figure (1.3): Schematic shows two-steps amalgam-like sculpting technique (Hirata *et al.,* 2015).

III. Single-step amalgam-like sculpting technique (High viscosity bulk-fill composite)

This technique refers to the use of a high viscosity bulk-fill composite in one increment up to 4-5mm without addition capping layer as shown in Figure (1.4) (Hirata *et al.*, 2015). Bulk-fill techniques have become broadly used as a direct posterior restoration after developing material that can be placed in single increment by improved curing efficiency and reduced polymerization shrinkage (Benetti *et al.*, 2015).

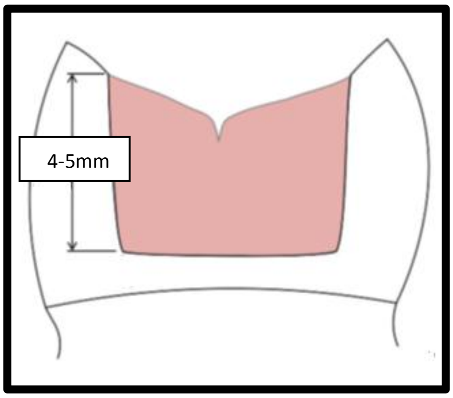

Figure (1.4): Schematic shows tooth restored with single-step amalgam-like sculpting technique (Hirata *et al.*, 2015).

1.2.1 Incremental layering technique versus bulk-fill technique

The incremental technique has been widely accepted as a standard method for resin composites placement because finite layering thickness to 2mm or less that allow enough light penetration for adequate polymerization. Adequate polymerization gives rise to a composite resin restoration with enhanced physical properties, good marginal adaptation, less cytotoxicity, and minimized polymerization shrinkage of composite restoration by reducing the volume of material and C-factor (Lazarchik *et al.*, 2007; Papadogiannis *et al.*, 2015; Costa *et al.*, 2017). Despite these benefits, the incremental technique has also disadvantages include lack bond between layers, the possibility of void incorporation or contamination, need more time for placement (El-Safty *et al.*, 2012) and difficulty in placement because limited access in conservative preparation (Sarrett, 2005).

So that the manufacturers are directed to produce an innovative class of dental resin material can be placed in a bulk layer up to 4mm with reinforced curing and controlled polymerization shrinkage that leading to time-saving for the dentist and patient and produce more comfortable restoration (Ilie *et al.*, 2013). The bulk-fill composites can be classified into two groups: flowable bulk fill and higher viscosity bulk-fill composites. The SonicFill™ (Kerr Corp, USA), which has fluctuating viscosity combining the properties of a flowable and high viscosity sculptable composite (Hickel, 2013). The depth of curing 4mm was accomplished either by incorporation of a specific photointiators system or by increasing the translucency of materials. The translucency is affected by various factors such as the refractive indices of fillers and monomers when they are matching or the difference between indices is reduced, the translucency is increased (Shortall *et al.*, 2008). The size and amount of fillers also have an influence on the translucency. The translucency of some types of composites is increased through incorporation fillers with dimension up to 20um or more as in (SureFil, SDR flow, x-tra fil, and SonicFill), which decreases, the total surface area and filler-matrix interface thus, light scattering is reduced at filler-matrix interface and allowed more light penetration to permit adequate curing at depth (Ilie *et al.*, 2013; Ilie and Stark, 2014; Karaman *et al.*, 2016). In addition, Existence nanoparticles in these types of composite and other types have maximized the translucency because the tiny nanoparticles are unable to scatter or absorb the visible light (Ilie *et al.*, 2013).

Christensen (2012) listed the following advantages and disadvantages of bulk filling Table (1.1):

Table (1.1): Advantages and disadvantages of bulk filling (Christensen, 2012).

Potential advantages of bulk filling	Potential disadvantages of bulk filling
1. Fewer voids may be present in the mass of material, since all of it is placed at one time.	1. It may be difficult to control the mass placement.
2. The technique would be faster than placing numerous increments if curing times were identical.	2. Making adequate contact areas may be challenging unless adequate matrices are used.
3. It may be easier than placing numerous increments.	3. Effects due to shrinkage stress may be more pronounced when bulk-filled than when placed in increments, since the entire mass polymerizes at one time rather than in small increments.

1.3 SonicFill™ system

SonicFill™2 (Kerr, USA) is a nanohybrid, light-cured, low-shrink, radiopaque sonic-activated bulk-fill dental restorative designed for direct placement in all cavity classes (anterior and posterior teeth). SonicFill™2 uses a new nano-scale zirconium oxide filler system, which provides excellent strength, polish, wear resistance and other important mechanical properties; also, it has a less sensitivity to ambient light to provide dentists with 35% more working time than the original version of SonicFill™ (Kerr corp., 2017). It uses refractive index matching and a more efficient curing mechanism to allow polymerization depths up to 5mm while retaining enough opacity to produce a good aesthetic result (Kerr corp., 2017).

SonicFill™ system is a novel composite system, which is introduced by the manufacturer to be used as bulk-fill posterior restoration up to 5mm. The sonic fill system is composed of specially designed handpiece manufactured by Kavo (Germany) and unidose tips of bulk-fill composite manufactured by Kerr (USA) (Tayel *et al.*, 2016).

1.3.1 Fluctuating viscosity of SonicFill composite

Special rheological modifiers in the SonicFill™2 and SonicFill™ filler system have a dramatic reaction to the sonic energy that is applied through the handpiece during placement. This reduction in the viscosity of the material reaches to 84% and gives adaptation similar to a flowable, when sonic energy is stopped, the composite returns to a viscous state that suitable for carving and shaping as in Figure (1.5) (Kerr corp., 2017).

There are numerous external handheld sonic devices for applying vibrations for modeling resins. e.g., Compothixo (Kerr, Switzerland). Whilst these are efficacious for reducing viscosity of a resin, an extra step is added to the already onerous clinical procedure. Lowering viscosity is also possible by thermal means. e.g., heating resin to around 60 °C. However, the time to transfer the composite from the heating apparatus and adapting it to the cavity may cool the material, and hence negate the potential benefit. This is because heat is rapidly dissipated when the resin is placed in a tooth that acts as a heat sink at body temperature of 37 °C, thus reverting the composite viscosity to its unheated state. The SonicFill™ system overcomes the above two difficulties by lowering the viscosity at the point of delivery by applying internal vibrations to the resin, without the need for heat or external handheld sonic devices (Jackson, 2013).

Another advantage of fluctuation viscosity is that an initial lining or a capping occlusal layer is obviated. The difference in viscosities of a material, off course, improves its handling characteristics, but it also affects the physical and mechanical properties of the resin. Unalterable, low viscosity bulk-fill resins have lower filler content to confer flow ability, which in turn makes the material weaker, requiring a capping occlusal layer with a universal composite to resist occlusal forces. Conversely, with medium viscosity materials, an initial flowable composite layer is necessary as a lining for better adaptation to the cavity walls. Similar to stratification with a universal composite, applying an initial low viscosity layer may introduce incremental voids and therefore compromise the integrity of the restoration (Ahmad, 2013).

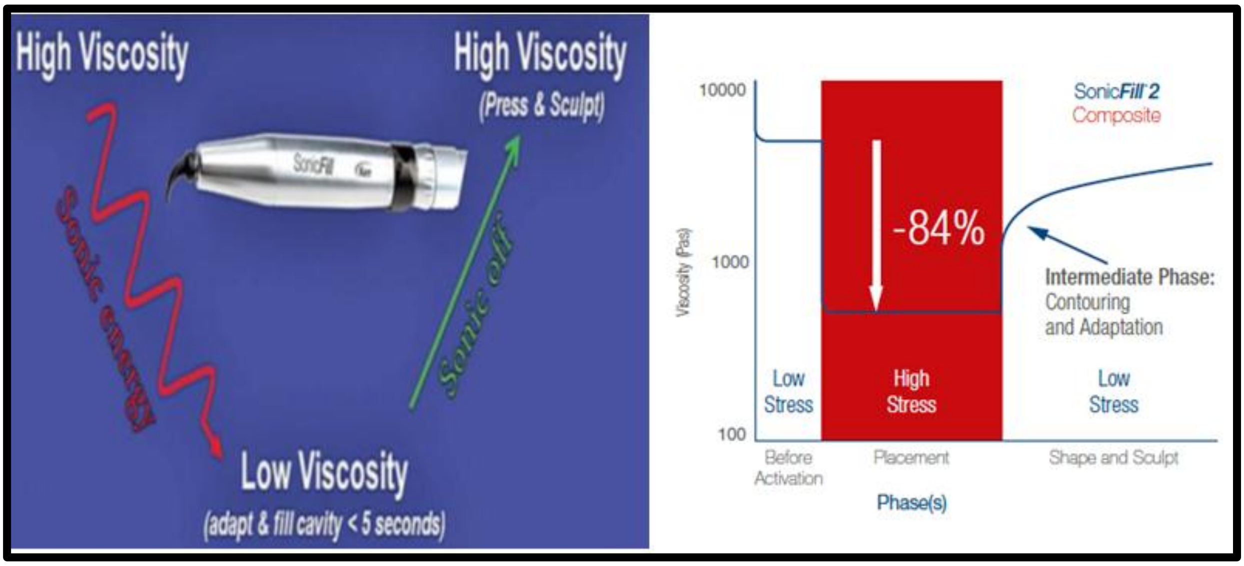

Figure (1.5): Effect of sonic energy on the viscosity of SonicFill™ composite (Kerr corp., 2017).

1.3.2 Placement of SonicFill composite

Technology for placement of SonicFill composite involves normal preparation of the cavity. Traditional total-etch or self-etch adhesives are used based upon clinician's preference. The SonicFill™ hand piece is attached to the air/water line using a coupler adaptor, and then activated by a traditional rheostat pedal. Adaptors make this easy to attach to existing systems. The dispensing rate/speed is set with the switch at the base of the hand piece. Setting 5 is the fastest speed; setting 1 is slowest. With placement of the Unidose® composite tip in the deepest part of the preparation to avoid trapping air, the SonicFill™ hand piece is activated by depressing the foot pedal and the entire cavity is filled from bottom to top until full. Once the handpiece is removed, the material is easily manipulated to conform to the tooth and then light-cured. Just one application is needed for cavities 5 mm or less. Final contours are easily achieved. The manufacturer states that an operator can go from placement to a polished restoration in less than 3 minutes on cavities up to 5mm in depth (Fahad and Majeed, 2014)

1.4 Beautifil Bulk restorative

Beautifil Bulk Fill restorative material is a visible light-cured radiopaque restorative material predominantly designed to be used for posterior restorations including occlusal surfaces and can be placed in 4 mm increments. It classified as multifunctional Giomer composites (Shofu, 2014). The high viscosity Beautifil Bulk Fill restorative material does not require capping layer of resin composite and can be used as a single step (Tsujimoto *et al.*, 2017). Beautifil Bulk resin is developed with a complex balance of four different kinds of resin monomers and fillers to minimize polymerization shrinkage and associated stress. S-PRG fillers in Beautifil Bulk have special surface treatment to increase wettability and adhesion to the resin matrix while multifunctional glass fillers exhibit refractive index close to the resin matrix to enhance light penetration into deep layers (Shofu, 2014).

Giomer (Glass ionomer+ polymer) has been introduced as the true hybridization of composite resin and glass ionomer to take the benefits of each material and simultaneously minimize the disadvantages of each one separately, which contains surface pre-reacted glass ionomer (S-PRG) filler particles within a resin matrix. PRG filler particles are prepared in present water by the acid-base reaction between polyalkenoic acid and F-B-Al-Si-glass. This technology produces a stable phase of glass ionomer described as wet siliceous hydrogel (Sunico *et al.*, 2005; Abdel-Karim *et al.*, 2014; Ilie and Stawarczyk, 2016).

Pre-reacted glass ionomer technology is classified into two categories: F-PRG (full reaction type), where the entire filler particle is attacked by polyacrylic acid, and the S-PRG (surface reaction type), where only the surface of the glass filler is attacked by polyacrylic acid and a glass core remains (Sunico *et al.*, 2005).

F-PRG fillers would release a greater amount of fluoride, as the core of the particle is totally reacted dissimilar in the S-PRG fillers, and degrade faster than S-PRG fillers. The further advantage of giomer is that it releases five ions (Al, B, Na, Si, Sr ions) in addition to fluoride, which have beneficial properties as shown in Figure (1.6). Material utilizing PRG-technology is characterized by high wear resistance and more radiopaque due to the presence of multi-functional glass fillers, shade conformity and a high sustained level of fluoride release and recharge due to the stable phase of glass ionomer formed before addition to the resin matrix (Sunico *et al.*, 2005).

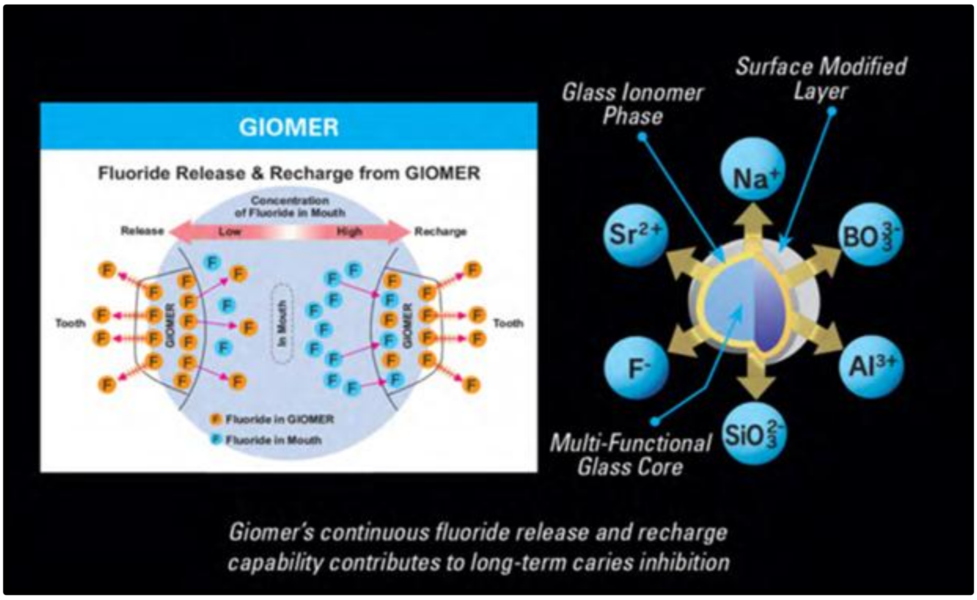

Figure (1.6): Schematic shows multifunctional Giomer composites (Shofu corp., 2014).

1.5 Filtek™ Bulk Fill Posterior Restorative material

Filtek™ Bulk Fill Posterior Restorative composite (3M ESPE, USA) is a visible, light-activated restorative composite optimized to make posterior restorations simpler and faster. The shades are semi-translucent and low-stress curing, enabling up to 5 mm depth of cure with excellent polish retention (3M ESPE, 2015).

1.5.1 Resin System

Filtek™ Bulk Fill Posterior Restorative contains two novel methacrylate monomers that, in combination, act to lower polymerization stress. One monomer, a high molecular weight aromatic dimethacrylate (AUDMA), decreases the number of reactive groups in the resin as in Figure (1.7). This helps to moderate the volumetric shrinkage and the stiffness of the developing and final polymer matrix, both of which contribute to the development of polymerization stress (3M ESPE, 2015).

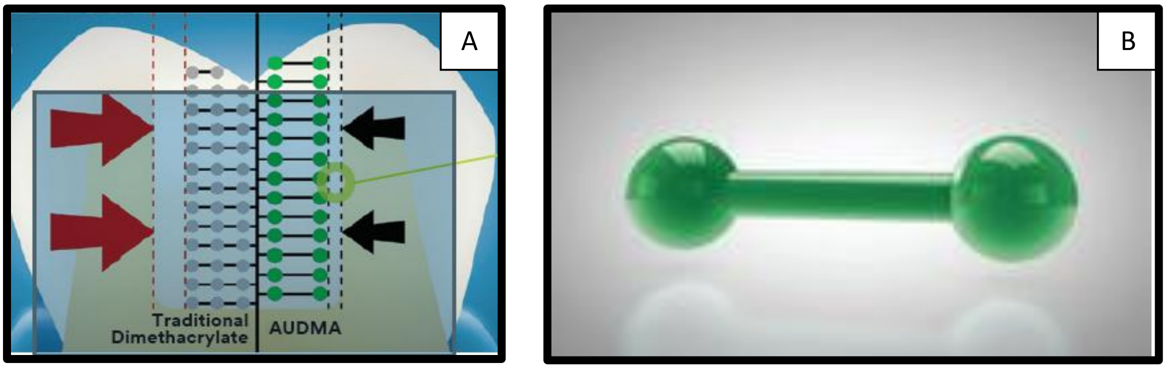

Figure (1.7): The schematic shows A. Aromatic dimethacrylate (AUDMA) in Filtek™ Bulk Fill Posterior Restorative composite, B. Aromatic dimethacrylate monomer molecule (3M ESPE, 2015).

The second unique methacrylate called addition-fragmentation monomers (AFM). During polymerization, AFM reacts into the developing polymer as with any methacrylate including the formation of cross-links between adjacent polymer chains. AFM contains a third reactive site that cleaves through a fragmentation process during polymerization. This process provides a mechanism for the relaxation of the developing network and subsequent stress relief as in Figure (1.8). The fragments, however, retain the capability to react with each other or with other reactive sites of the developing polymer (3M ESPE, 2015).

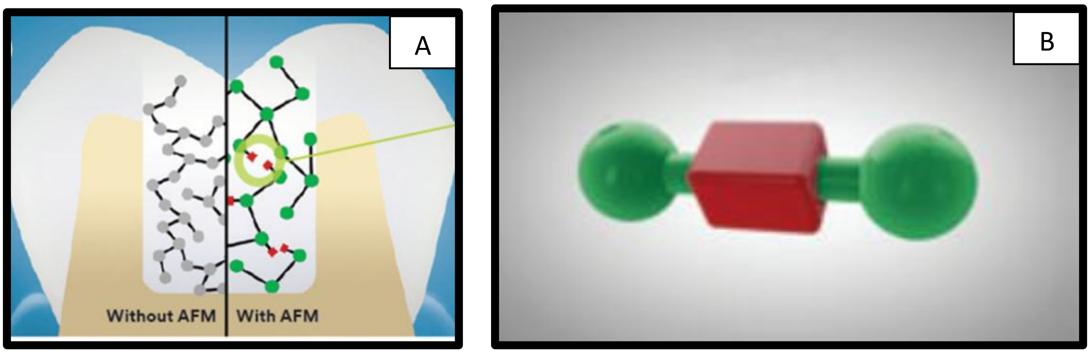

Figure (1.8): The schematic shows A. addition-fragmentation monomers in Filtek™ Bulk Fill Posterior Restorative composite, B. addition-fragmentation monomer molecule (3M ESPE, 2015)

1.5.2 Fillers technology

The filler system uses, the same nanofiller technology as Filtek Supreme Ultra restoratives, a combination of silane-treated nanoclusters and individual silane-treated nano-silica and nano-zirconia. In addition, it contains nano-scale ytterbium trifluoride to impart improved radiopacity. This technology could contribute to high strength, excellent handling, better wear resistance, and makes restoration faster and easily to polish (3M ESPE, 2015).

1.6 Universal Tetric Evoceram

Universal Tetric EvoCeram® composite (Ivoclar Vivadent) is a light-curing, radiopaque, nanohybrid composite for the direct restorative therapy (anterior and posterior teeth). The filler technology of Tetric Evoceram bases on an optimum blend of different fillers and filler sizes. It has natural shade blend with surrounding dentition to ensure outstanding restorative results (Ivoclar Vivadent, 2012).

1.6.1 Composition of Universal Tetric Evoceram® composite

The standard composition consists of the monomer matrix, which is composed of dimethacrylates. Ceramic fillers of various sizes are responsible for the material's strength, its exceptional polishing properties, high gloss and low wear. The **prepolymers** (ground composite of fillers combined with monomers and ytterbium fluoride*)* are significantly reduced shrinkage stress by the material as in Table (1.2). These properties increase the marginal integrity of restorations. The particle size of the inorganic filler with a mean particle size of 550 nm (Ivoclar Vivadent, 2012).

Table (1.2): Composition of Universal Tetric EvoCeram® composite (Ivoclar Vivadent, 2012).

Composition	Weight %
Bis-GMA, Urethane dimethacrylate, Ethoxylated Bis-EMA-EMA	16.8
Barium glass filler, ytterbiumtrifluoride, mixed oxide	48.5
Prepolymers	34.0
Additives	0.4
Catalysts and Stabilizers	0.3
Pigments	< 0.1

1.6.2 Indications of Universal Tetric Evoceram® (Ivoclar Vivadent, 2012):

- Restorations of deciduous teeth.
- Restorations in the posterior region (Classes I and II).
- Anterior restorations (Classes III, IV) and Splinting of mobile teeth.
- Class V restorations (cervical caries, root erosion).
- Extended fissure scaling in molars and premolars.
- Repair of composite and ceramic veneers.
- Build-ups for transparent, removable Invisalign® orthodontic retainers.

1.6.3 Properties of Universal Tetric Evoceram® composite

The properties of Tetric Evoceram® composite enhance by nanotechnology (Kwong, 2010):

A. The advantages of all filler sizes (containing nano-fillers) such as excellent wear resistance, easy polishing, long-lasting gloss, low shrinkage and shrinkage stress, fast, and high-level radiopacity provide by Well-balanced filler technology.

B. Nano-modifier offers excellent handling properties, raises the stability of the material and inhibits the material from sticking to instruments.

C. The shade adjustments and the chameleon effect improve by nano-color pigments.

1.7 Adhesive system

Adhesion defines as the state in which interfacial forces, which may consist of valence forces and/or interlocking force hold two surfaces together. An adhesive is a material (frequently a viscous fluid) that joins two substrates together by solidifying and transferring a load from one surface to the other (Perdigao *et al.*, 2013).

Adhesive bonding systems classify currently according to the mode of application and how they interact with smear layer into ‘etch and rinse’ or also called total-etch adhesive and ‘self-etch’ adhesives system as shown in Figure (1.9)**.** ‘Etch and rinse’ adhesives, which completely remove the smear layer by etching with phosphoric acid and subdivided into 2-steps and 3-steps depending on how the acidic primer and adhesive resin are provided by the manufacturer. While ‘Self-etch’ adhesives, which eliminate rinsing step, modify and bypass the smear layer without removing it and also classified into 2-steps and 1-step depending on how the acidic primer and adhesive resin provided by the manufacturer. A new family of adhesive, called multi-mode or universal adhesives due to their versatile manufacturer's instruction for use, can be used in the total-etch, self-etch and selective etch technique (Sultan *et al.*, 2014; Sezinando, 2014; Rosa *et al.*, 2015).

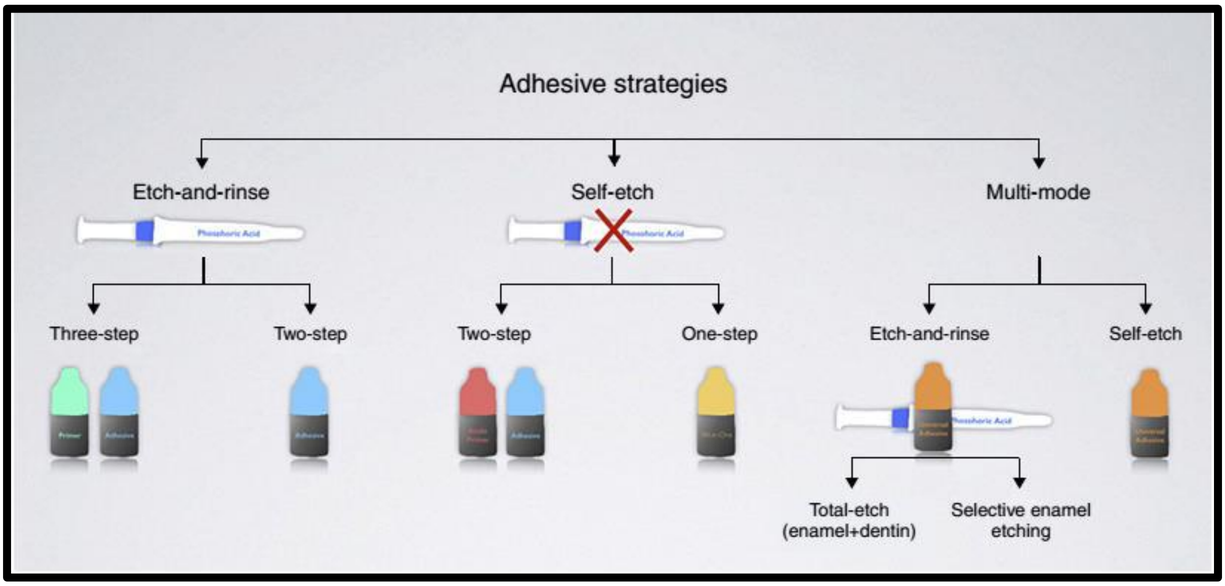

Figure (1.9): The schematic showing adhesive bonding systems (Sezinando, 2014).

1.7.1 Bonding to enamel

The near absence of organic material in enamel and its regular microscopic structure lends itself to bonding with hydrophobic resin. When etching with 37% phosphoric acid is done over an unground or ground enamel surface, the hydroxyapatite is selectively dissolved making macro and micro-porosities. These porosities are filled with the resin monomer through infiltration creating micro and macro resin tags (Pashley *et al.*, 2011).

Self-etch adhesives are less successful than etch-and-rinse adhesive system on unprepared enamel (Perdigao and Geraldeli, 2003). Composite resin restorative material is applied to the bonding resin and form a chemical bond to it during polymerization (Graham and Strange, 2012).

1.7.2 Bonding to dentine

The nature of bond to dentine is micromechanical due to interlocking of resin with microscopic irregularities in dentin. The bond is optimal superficially, where there is a relatively large surface area of intertubular dentin. Bond strength becomes compromised with deeper and caries affected dentin. The adhesive bond to dentin is optimized when the surface of dentin is slightly moist at time of bonding (Graham and Strange, 2012).

1.7.3 Hybrid layer

The infiltration of demineralized collagen fibers with resin permits formation of hybrid layer with resin tags and adhesive lateral branches, thus creating micromechanical retention of the resin to the demineralized substrate (Osorio *et al.,* 2003)

1.7.4 Single Bond Universal Adhesive

Scotchbond™ Universal Adhesive is multi-mode, ideally single-bottle, a no-mix solution that can be used reliably in the total-etch, self-etch or selective-etch mode for both direct and indirect restorations, and used on all surfaces without any extra primer according to manufacturer information (3M ESPE, 2013). SBU has methacryloxydecyl phosphate (MDP) and the polyalkenoic co-polymer within contents. 10-MDP is described as an amphiphilic functional monomer with a hydrophilic polar phosphate group on one end that capable to bond chemically to tooth tissues, metals, and zirconia, while the other end has a hydrophobic methacrylate group, that capable to bond chemically to methacrylate-based restoratives, and cement. In addition, it is in combination with polyalkenoic co-polymer, molecules have the capability to form ionic bonding with calcium in hydroxyapatite (Alex, 2015). When SBU was applied on dentin, microtensile bond strength did not vary with the variations in dentin moisture or the adhesive strategy used. However, nanoleakage was significantly lower when SBU was applied in self-etch mode. This means that SBU is not sensitive to the degree of dentin moisture. The insensitivity of single bond universal to air-dried dentin may be explained by the water content of this adhesive (10–15% by wt.) that permits the expansion of the collagen network (Sezinando, 2014).

1.7.4.1 Selective-etch mechanism

The pH of single bond Universal Adhesive is 2.7 and considered ultra-mild self-etch adhesives compared to phosphoric acid. Some dentists prefer to still utilize a phosphoric acid etch on the cut and uncut enamel surfaces. This is commonly referred to as “selective” enamel etching, which is supported and recommended with Scotchbond™ Universal Adhesive. When incorporating the “selective enamel etch” with a self-etch adhesive, the etchant is isolated to the enamel, leaving the dentin intact. Therefore, the clinician can maximize the enamel bond strength and take advantage of the low post-operative sensitivity feature that the self-etch adhesive provides and still achieve a strong bond to dentin (3M ESPE, 2013).

1.7.4.2 Total-etch mechanism

Both the enamel and dentin surfaces are directly etched with the phosphoric acid. Typically after a 15-second application, the phosphoric acid is then rinsed to remove any residual acid and the dissolved mineral from the enamel and dentin. This leaves a very well-defined etched enamel surface and also completely removes the smear layer from the dentin surface, as well as mineral within the collagen network on the dentin surface. The total-etch approach allows a thicker hybrid layer to be formed (3M ESPE, 2013). This adhesion method can be technique sensitive for the fifth generation adhesives due to the fact the dentin surface must be kept moist after etching to prevent the collapse of the unsupported collagen fiber network. If kept moist, the collagen network will remain intact and the adhesive can be applied or infiltrated to form a well-defined hybrid layer along with resin tags within the tubules. If the dentin surface is dried, the collagen network collapses and does not allow for a proper hybrid layer to be formed with the resin tags and, thus, results in a reduced and compromised bond to the dentin which can lead to decreased performance and an increase in the potential for sensitivity (3M ESPE, 2013). The primary reason for the technique sensitivity is that the formulations of the fifth generation adhesives have limited or no water available to reverse the collapse of the collagen. Water and other components can act to rehydrate the collagen and allow for the formation of a proper hybrid layer if the dentin was dried after etching. The chemistry of Scotchbond™ Copolymer allows it to provide high and consistent bond performance to etched enamel and dentin in the total-etch technique. The unique chemistry will provide consistent performance to etched dentin whether it is kept moist as recommended or dry (3M ESPE, 2013).

1.7.4.3 Self-etch mechanism

The Scotchbond™ Universal Adhesive chemistry utilizes phosphorylated monomers in an aqueous solution that provide acidity and allow the adhesive bond to dentin and cut enamel without the use of a separate phosphoric acid etching step, which therefore allows it to be considered self-etching. This is the same basic chemistry and process for Adper Easy Bond adhesive. The self-etching simplifies the technique and provides protection to the dentin surface to reduce the potential for post-operative sensitivity (3M ESPE, 2013).

1.8 Volumetric shrinkage and shrinkage stress of dental composite

During the polymerization process, the composite changes from their viscous phase to a predominantly solid substance by converting monomer molecules into a cross-linked polymer network. This conversion associated with a reduction in the volume of the composite, the reduction in the total volume of the composite is called volumetric shrinkage (Tantbirojn *et al.*, 2011; Ferracane and Hilton, 2016). Subsequently, Shrinkage stresses are generated by shrinkage and the development of elastic modulus during polymerization, but they will arise only if the composite has been bonded to the tooth structure (Boaro *et al.*, 2010; Do *et al.*, 2014; El-Damanhoury and Platt, 2014). This stress is considered undesirable and could lead to deleterious problems, such as microleakage, marginal discoloration, and secondary caries as a result of interfacial detachment when the polymerization shrinkage stress is greater than bonding strength (Braga *et al.*, 2012; Campos *et al.*, 2014). In contrast, the restoration may pull cavity walls together, reducing intercuspal distance (cuspal deflection) and it can lead to microcrack and cusp fractures as in Figure (1.10), if the bond strength is sufficient (Gonzalez-Lopez *et al.*, 2004; Jafarpour *et al.*, 2012; Nguyen *et al.*, 2016).

However, the polymerization shrinkage stress of dental composites and associated problems remain a major drawback of these materials. Numerous studies have been performed to assess and reduce the polymerization shrinkage stress. The effort has been made to produce material with minimum PSS and good mechanical properties by improving nanotechnology, progress existing dimethacrylate chemistry and novel monomer technologies introduced (Kwon *et al.*, 2012). PSS is a multi-factorial phenomenon and affected by several features of the composite such as matrix type, filler content, the degree of conversion, modulus of elasticity, water sorption of material, and configuration factor with compliance of preparation (Leprince *et al.*, 2013; El-Damanhoury and Platt, 2014). The control of the light cure intensity, improving curing techniques, using stress breaking liner under composite restoration, and incremental layering techniques are different clinical strategies that have been suggested to reduce polymerization shrinkage stress (Kwon *et al.*, 2012; El-Damanhoury and Platt, 2014; Tayel *et al.*, 2016).

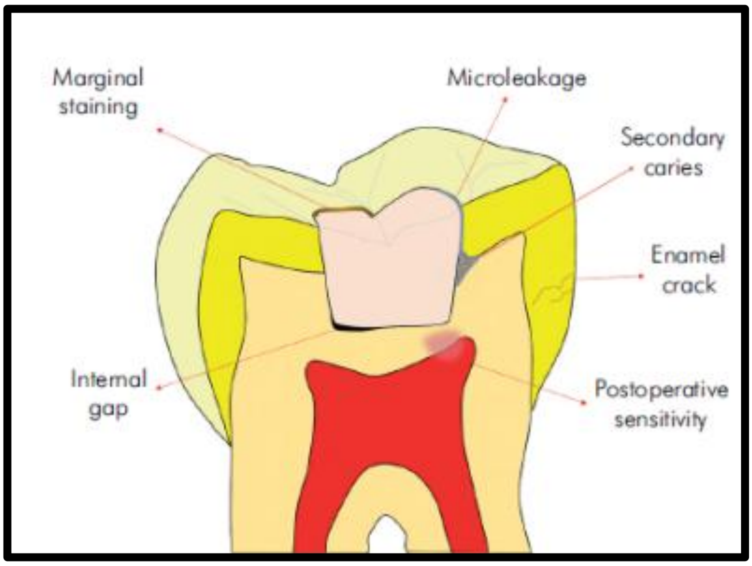

Figure (1.10): Clinical symptoms associated with residual polymerization shrinkage stress (Tantbirojn *et al.*, 2004).

1.9 Cuspal deflection

It is a common biomechanical phenomenon that occurs in teeth restored with composite resin materials and represents the interaction between polymerization stress of material and the compliance of remaining tooth structure after preparation (Lee *et al.*, 2007; Hamama *et al.*, 2011; Oskoee *et al.*, 2012). Compliance is defined as changes that occur in dimension per unit of force (Kim *et al.*, 2016). Cuspal deflection may cause changes in occlusion points, postoperative pain. The clinical importance of cuspal deflection is that the greater magnitude of this deflection leads to greater deformation in tooth and consequently, it increases the possibility of fatigue failure. This type of failure, characterized by a fracture in the presence of stress far below the maximum strength of the restored tooth, occurs in most dental fractures (Oliveira *et al.*, 2014).

1.9.1 Factors effect on the magnitude of cuspal deflection

Two main groups of biomechanical factors are affecting on amount and type of cuspal deflection. The first is geometrical factors and material properties, while the second group is clinical factors (Lee *et al.*, 2007; Oskoee *et al.*, 2012).

1.9.1.1 Geometrical factors and material properties

The geometric factor includes cavity dimension and thickness of cavity walls after preparation. The degree of cuspal deflection is directly related to the increase in cavity dimension because excessively removed tooth structure in large cavity size and losing the marginal ridge result in weakening remaining tooth structure, increasing tooth flexibility and becomes more compliance with composite restoration. Also, the greater amount of composite resin that needs to restore cavity, producing greater contraction forces (González López *et al.*, 2006). It has been reported that the deformation of the tooth is directly related to cubic of cusp length and inversely to cubic of the cantilever cusp thickness (Lee *et al.*, 2007). So the length of the cusp should be reduced to reduce cuspal deflection (Karaman *et al.*, 2016).

Material factor includes composite properties such as polymerization shrinkage, elastic modulus, flowability, hygroscopic expansion of composite material and bonding system. Polymerization shrinkage is an inherent property of resin-based composite materials generated during the polymerization process, while the elastic modulus of a material is an indicator of material stiffness. They are depended mainly on the composition of the material. The cuspal deflection has a positive correlation with these two properties because the conjugation of them leading to produce residual stresses, which represented the main cause of the cuspal deflection (Kim and Park, 2011; Tantbirojn *et al.*, 2011; Bicalho *et al.*, 2014). The effect of polymerization shrinkage and viscoelastic properties can also be variables in shrinkage stress because they depend on the compliance of the preparation (Han *et al.*, 2016). Kim et al. (2016) reported that the polymerization shrinkage was the main factor that influenced deflection when the compliance is high. While in lower compliance cavities, both the flexural modulus and the polymerization shrinkage determined the deflection.

The flow was known to be influenced by the structure of the individual molecules, cross-linking of the molecules, the filler/matrix interfacial characteristics, reaction kinetics, and cavity configuration. This factor can result in a relief of internal stresses and consequently, it reduces polymerization stress (Han *et al.*, 2016).

Hygroscopic expansion property of composites could compensate the volumetric shrinkage that occurred during the polymerization process, reduce generated stress and cuspal deflection. However, the excessive water sorption is affected on mechanical properties of the material and may be produced expansion stress that induces micro-cracks in enamel or even cracked cusps in the restored tooth (Wei *et al.*, 2013).

The adhesive system plays an important role in the determining amount of cuspal movement. If the polymerization process of resin-based composite occurs in an unrestrained condition, the internal stresses will be reduced. However, volumetric shrinkage during the polymerization process in association with effective bonding to the tooth structure results in stress transfer to cavity walls and inward deflection of the cusps of the restored tooth (Campos *et al.*, 2014).

Selective-etch technique produced less cuspal deflection than total-etch technique (Campos *et al.*, 2009). While Sultan *et al.* (2014) reported that, the single-step adhesive technique produced a lesser amount in cuspal deflection and a greater amount of microleakage in compared with 3-steps and 2-steps adhesive technique.

1.9.1.2 Clinical factors

I. Placement technique (incremental versus bulk)

In dentistry, there has been a vigorous faith that an incremental technique may reduce shrinkage stress because it reduces the ratio of bonded to free surfaces (C-factor). The reduction in contact area between resin and tooth improving the flow of material in the pre-gel state from free surfaces into the bulk and subsequently, that responsible for relieving the shrinkage of composite material toward the bonded surface (Kim *et al.*, 2015; Zorzin *et al.*, 2015). Kim *et al.* (2016) found that the incremental technique significantly reduced deflection in compare with bulk filling for both conventional and bulk-fill composites. But this concept has been attacked by other studies found that the incremental technique caused the greater amount of stress at the adhesive interface and more deformation on tooth than the bulk-fill technique (Abbas *et al.*, 2003; Moorthy *et al.*, 2012; Bicalho *et al.*, 2014; Francis *et al.*, 2015). While Campodonico *et al.* (2011) found that the incremental technique no significantly reduced deflection in compare with bulk filling.

II. Using low elastic modulus liners as stress-absorbing layers

It has been widely debated that the using of low elastic modulus liners (Glass ionomer cement, Resin-modified glass ionomer cement, and flowable composites) can reduce polymerization stress, this based on the concept of an "elastic cavity wall". According to this concept that the stress produced from polymerization of high modulus composite can be absorbed by low elastic modulus intermediary layer between restoration and the dental substrate. Thus cause less cuspal deformation from the inner compensation of polymerization shrinkage of the covering resin composite (Schneider *et al.*, 2010; Karaman and Ozgunaltay, 2013).

On the other hand, Kwon *et al*. (2012) found that the application of flowable composite as a liner under conventional composite increments shown greater cuspal deflection than teeth restored without the liner.

III. Direct or indirect restoration

Indirect restorations have better physical properties than direct composite restorations because they are fabricated under relatively ideal laboratory conditions. It has been reported that an indirect restoration could decrease the cuspal strain and cause a lesser amount of shrinkage stress because the bulk polymerization of restoration occurs extra orally and very thin space available for resin cement (Lee *et al.*, 2007; Dejak and Młotkowski, 2015).

IV. Light curing unit and protocol

Fleming *et al.* (2007a) reported that the cuspal deflection of cavities irradiated with the LED Light curing unit is significantly reduced in compared with a halogen Light curing unit (conventional and soft-start irradiation) as a result of lower temperature produced with LED in compared to halogen light cure unit. This reduction in temperature causes diminishing in the drying-out of the teeth during polymerization, which result in reduces cuspal flexure.

Abbas *et al.* (2003) found that a conventional halogen reduced cuspal deflection in compare with the turbo-boosted halogen light cure unit and deficiencies in the plasma-arc curing lights for the bulk curing of composite. While Fleming *et al.* (2007b) found no difference in cuspal deflection between the soft start and conventional protocol mode halogen light cure .

Other study found that continuous curing mode induced increased cuspal deflection compared to pulse/soft start curing modes (Alomari and Mansour, 2005; Piccioni *et al.*, 2014; Agarwal *et al.*, 2017).

1.9.2 Measurement methods of cuspal deflection

The assessment of cuspal deflection for Class II (MOD) cavities restored with resin-based composite has been widely investigated in the dental literature by using a variety of techniques (Moorthy *et al.*, 2012).

I. Photography (Segura and Donly, 1993).

II. Microscopy with cuspal indices alignment used to record cuspal deflection where two reference points determined on cusps tips. The digital image was taken and processing by special software. This method measured the intercuspal distance between cusps so that the direction of movement can be detected and more recently used in several studies to accurately measure cuspal deflection (Suliman *et al.*, 1993a; Oskoee *et al.*, 2012; Hanoudi and AL-Rawi, 2013; Shabayek *et al.*, 2013; Elsharkasi *et al.*, 2018).

The Dino-Lite AM2111 is a computerized digital microscope with high accuracy. According to manufacturer's information (AnMo Electronics Corporation, Taiwan), it offers 10x~50x and 230x zooms magnification, USB 2.0 output, and four Always-On LED lights. Dino-Lite includes software for both personal computer (DinoCapture 2.0) and Mac (DinoXcope) computers. The software is robust and reliable with some great features as follows: image capture, storage and email, live and time-lapse video, full-screen capability, auto and manual exposure control and more. Above all the color resolution is excellent due to fixed white-balance calibration, which is set at the factory by using a jeweler's color balance.

III. 3D-finite element analysis (FEA) (Boaro *et al.*, 2014).

IV. Digital-image-correlation (DIC) (Chuang *et al.*, 2011).

V. Micliehlson Interferometry apparatus (Suliman *et al.*, 1993b).

VI. Linear variable displacement transducers (LVDT) (Jantarat *et al.*, 2001; Lee *et al.*, 2007).

VII. Direct Current Differential Transformers (DCDTs) (Ilici *et al.*, 2010).

VIII. Strain gauges (Donly *et al.*, 1989; Jantarat *et al.*, 2001).

IX. Digital micrometer (González-López *et al.*, 2007; Campos *et al.*, 2009).

X. Electronic Speckle Pattern Interferometry (Gamba *et al.*, 2004).

XI. Twin channel deflection-measuring gauge (Fleming *et al.*, 2007a).

XII. Laser scanning (Miyasaka and Okamura, 2009).

XIII. Microcomputer tomography (Magne and Oganesyan, 2009).

1.9.3 Previous Studies on cuspal deflection

Al-Obaidi and Al-Rawi (2011) evaluated and compared the cuspal deflection between low-shrinkage resin composites (Filtek™ Silorane) and (Universal Tetric Evoceram), the effect of using light-cured glass ionomer cement (Viva glass Liner) and storage in the water on the cuspal deflection at different periods. The cuspal deflection was measured by using a digital micrometer, Silorane showed lower cuspal deflection and lower water uptake than Tetric Evoceram® composite. Polymerization shrinkage deformation was recompensed by hygroscopic expansion within 4 weeks.

Moorthy *et al.* (2012) evaluated the cuspal deflection and cervical microleakage of standardized Class II cavities incrementally filled with a dimethacrylate or bulk-fill flowable resin-based composite bases by using a twin channel deflection-measuring gauge. They found that the bulk-fill flowable bases significantly reduce cuspal deflection compared with conventional resin-based composite restored in an oblique incremental filling technique without change in cervical microleakage recorded.

Hanoudi and Al-Rawi (2013) evaluated and compared the cuspal deflection between four different low-shrinkage resin composites SDR (smart dentin replacement), Quixfil, Tetric EvoCeram Bulk-fill and Universal Tetric EvoCeram® composites, and effect of water storage on the cuspal deflection at different periods. The cuspal deflection was measured by using a digital microscope. They found that the SDR group showed lowest cuspal deflection, while group restored incrementally with universal Tetric Evoceram showed the highest cuspal deflection value and the polymerization shrinkage deformation was almost compensated by hygroscopic expansion within 4 weeks.

Sultan *et al*. (2014) studied the cuspal deflection and cervical microleakage of standardized MOD cavities restored with a dimethacrylate resin-based composite placed with three modes of bonding systems (three, two and one-step) and compared with the unbound condition. They found that statistically significant differences in cuspal deflection between groups. Cervical microleakage significantly increased for the negative control (unbound condition) when compared with teeth restored with a bonding system although differences between the bonding systems were evident.

Behery *et al*. (2016) compared cuspal deflection of premolars restored with three Bulk-fill composite resin materials (QuiXX, X-tra fil, Tetric Evoceram Bulk-fill) to that of incrementally restored ones with a low shrinkage silorane-based restorative material. Cuspal deflection was measured in microns as the difference between two reference points before and after restoration completion. They found that Tetric Evoceram Bulk-fill had significantly lower mean cuspal deflection compared with the two other Bulk-fill composite resins tested. Filtek low shrinkage had the lowest significant mean cuspal deflection in comparison to all tested Bulk-fill restoratives.

Nguyen *et al*. (2016) evaluated the cuspal deformation in teeth restored with different types of adhesive materials with and without a base in standard moderately large dimension MOD cavities. Teeth were divided into four groups. Each group restored with either SonicFill or a conventional Herculite Ultra. The base materials were used a flowable nano-filled resin composite (Premise Flowable) and a high-viscosity resin-modified glass ionomer cement (Riva Light-Cure HV). Cuspal deflection was measured with DCDT. Cuspal movements were recorded during and after restoration placement. Data for the buccal and palatal cusp deflections were combined to give the net cuspal deflection. All teeth experienced net inward cuspal movement. No statistically significant differences in cuspal deflection were found among the four test groups.

Chapter Two

Materials & Method

Materials and method

2.1 Materials and equipment

The materials and equipment that were used in this study include the following items (Figure 2.1):

2.1.1 Materials

1. Beautifil Bulk Fill Restorative (Universal) (Shofu, Japan) LOT: 051617, EXP. Date: 30/04/2019. **Appendix (I)**
2. Carbide small round-ended bur (Komet, Germany) REF: H1S314010, LOT: 928862.
3. Cold-curing acrylic powder and liquid (Vertex, Netherland) LOT: XR402P02, EXP. Date: 3/2021.
4. Deionized distilled water (Al–Mansur factory, Iraq) EXP. Date: 09/2018.
5. Disposable brush applicator (Dentsply, Germany) LOT: 16011.
6. Disposable plastic tubes (China).
7. Disposable gloves (Broche, Malaysia) LOT: 224030611BCZA, EXP. Date: 08/2021.
8. Enhance finishing system (Dentsply, Germany) LOT: 160916, EXP. Date: 28/06/2019.
9. Filtek™ Bulk Fill Posterior Restorative (Shade A2). (3M ESPE, USA) LOT: N840827, EXP. Date: 09/2019. **Appendix (II)**
10. Indelible pen (china).
11. Pumice (Master-Dent, USA) LOT: D150529, EXP. Date: 05/2018.
12. Rubber cup (Dentaires S.A, Switzerland).
13. Single bond™ Universal adhesive (3M ESPE, USA) LOT: 65520, EXP: 01/2019. **Appendix (V)**
14. SonicFill™2 composite (Shade A2) (Kerr Corporation, USA) LOT: 6173799, EXP. Date: 14 /12/2018. **Appendix (III)**

15. Super Etching gel (SDI, Australia) LOT: 161129, EXP. Date: 11/2019.
16. SuperMat® Adapt® SuperCap® Matrix (Kerr Hawe SA, Switzerland) LOT: 4958921, EXP. Date: 08/2018.
17. Turbine diamond fissure burs (Microdent, China) No.: 1094, LOT: 312/14.
18. Turbine diamond small rond-ended burs (Komet, Germany) REF: 6801314009, LOT: 191591.
19. Universal Tetric Evoceram® composite (Shade A2). (Ivoclar Vivadent, Liechtenstein) LOT: U56297, 11/2019. **Appendix (IV)**

2.1.2 Equipment

1. Air scaler (Victor C9000, Taiwan).
2. CompoRoller™ Assorted Kit (KerrHawe SA, Switzerland) LOT: 5517264, EXP. Date: 04/2020.
3. Composite gun (Dentsply DETREY GmbH, Germany).
4. Countdown timer (China).
5. Dental tweezers (SHAMLO CO., Pakistan) LOT: 113260A.
6. Digital Caliper (china).
7. Digital microscope (Dino-Lite capture 2.0, Taiwan).
8. Graduated periodontal probe (Pakistan).
9. High speed turbine handpiece (NSK, Japan).
10. Incubator (Germany).
11. LED Light cure device (Perfection plus, UK).
12. Magnification lens (china).
13. Modified Dental surveyor for preparation (Technic, USA). .
14. Modified Dental surveyor for teeth mounting (BIOS, Germany).
15. OPTILUX radiometer (Kerr Corporation, USA).
16. Slow speed hand piece (NSK, Japan).
17. SonicFill™ handpiece (Kavo, Germany).

Figure (2.1): Some materials and equipment used in this study.

2.2 Method

2.2.1 Teeth selection

Forty intact, non-carious human maxillary first premolar teeth were collected for this study. All teeth extracted for orthodontic causes and immediately stored in distilled water. Teeth were cleaned carefully for any calculus deposits with air scalar and polished with pumice. All selected teeth used in the study had regular occlusal anatomy and nearly similar crown size and shape, free from hypoplastic defect and cracks on visual examination by using the magnifying lens and by transilluminating fiber optic from light cure unit. The maximum bucco-palatal width and miso-distal width for each tooth was rmeasured with a digital caliper. The measured bucco-palatal width varied between 8.9 and 9.7 mm, and the measured miso-distal width varied between 6.9 and 7.6 mm with a maximum deviation of not more than 10% from the determined mean (Taha *et al.*, 2012; Bicalho *et al.*, 2014; Toz *et al.*, 2015).

2.2.2 Teeth mounting and reference point placement

A fabricated silicon mold was used to construct of 40 acrylic-teeth blocks with dimension 16 X 16X 20 mm (Hanoudi and AL-Rawi, 2013). Each tooth was marked 2±0.5 mm apical to the CEJ with an indelible pen to simulate periodontal ligament, and connected to the vertical arm of the surveyor in a way that the long axis of the tooth parallel to the arm via sticky wax as shown in Figure (2.2A). The self-cure acrylic resin mixed according to manufacturer's instructions and poured inside the mold as shown in Figure (2.2B). Surveyor was maintained in the center of the mold for 10 minutes to give time for acrylic polymerization in order to separate the surveyor arm from the tooth without distortion in the position as shown in Figure (2.2C). The same process repeated for all teeth chosen in this study and each group had specific acrylic color differ from other groups (Figure 2.2D).

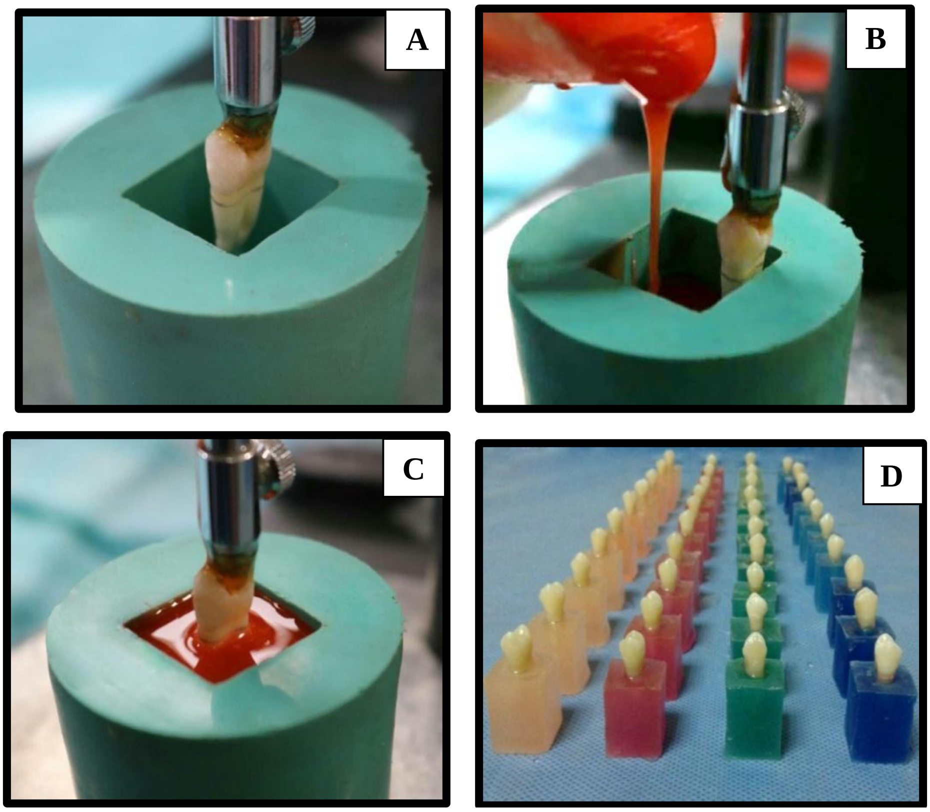

Figure (2.2): Tooth mounting by using a dental surveyor (A) Tooth centered on the mold (B) Acrylic resin was poured inside the mold (C) surveyor maintained in the center of mold for 10 minutes (D) Samples.

Two reference points were made by preparing two indentations on the tip of the buccal and palatal cusps with carbide round bar and two head of pins were bonded to indentations (Hanoudi and AL-Rawi, 2013) by using SBU adhesive system (3M ESPE, USA) to use as reference points for measurement (Alomari *et al.*, 2001) as in Figure (2.3).

Figure (2.3): The tooth with two reference points.

2.2.3 Sample grouping

The teeth were classified at random way into four main groups according to restorative material type.

Group **(A):** Ten teeth restored with SonicFill™2 Composite (shade A2) (Kerr Corp., USA).

Group **(B):** Ten teeth restored with Beautifil Bulk (universal) (SHOFU, Japan).

Group **(C):** Ten teeth restored with Filtek™ Bulk Fill shade A2 (3M ESPE, USA).

Group **(D):** Ten teeth restored with Universal Tetric Evoceram® shade A2 (Ivoclar Vivadent, Liechtenstein).

2.2.4 Sample preparation

A large class II MOD cavity with parallel walls was prepared in each tooth by using a parallel-sided, flat-ended diamond fissure bur (Microdent, China) in a high-speed handpiece (NSK, Japan) with water cooling. Before preparation of the teeth, an outline of the cavity was drawn with a super color marker (Kim and Park, 2011). Tooth preparation was carried out with aid of modified dental surveyor in order to standardize the cavity preparation. The plate of surveyor was fixed in the horizontal plane, and the specimen was then placed on surveyor's table and cavity preparation was done by moving the modified arm of surveyor, to which a high speed handpiece was attached, mesially and distally to create a mesio-occluso-distal (MOD) cavity as shown in Figure (2.4) (Fahad and Majeed, 2014). Burs were replaced every four preparations to ensure high cutting efficiency (Borges *et al.*, 2012).

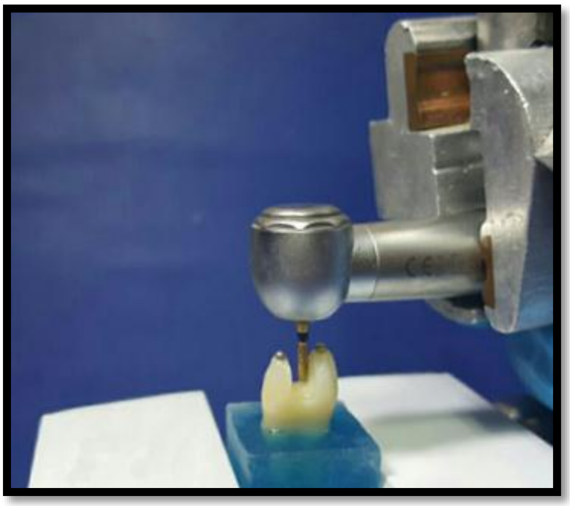

Figure (2.4): Cavity preparation by using a modified dental surveyor.

The width of the cavity was standardized 3mm.The depth of the cavity was 3mm at the pulpal floor level measured from the palatal cavo-surface margin, with 1mm depth and height of the axial wall as in Figure (2.5). The cavo-surface angle were prepared at 90°-110° like amalgam cavity preparation and rounded internal line angle with small round bur (Al-Obaidi and AL-Rawi, 2011; Fahad and Majeed, 2014).

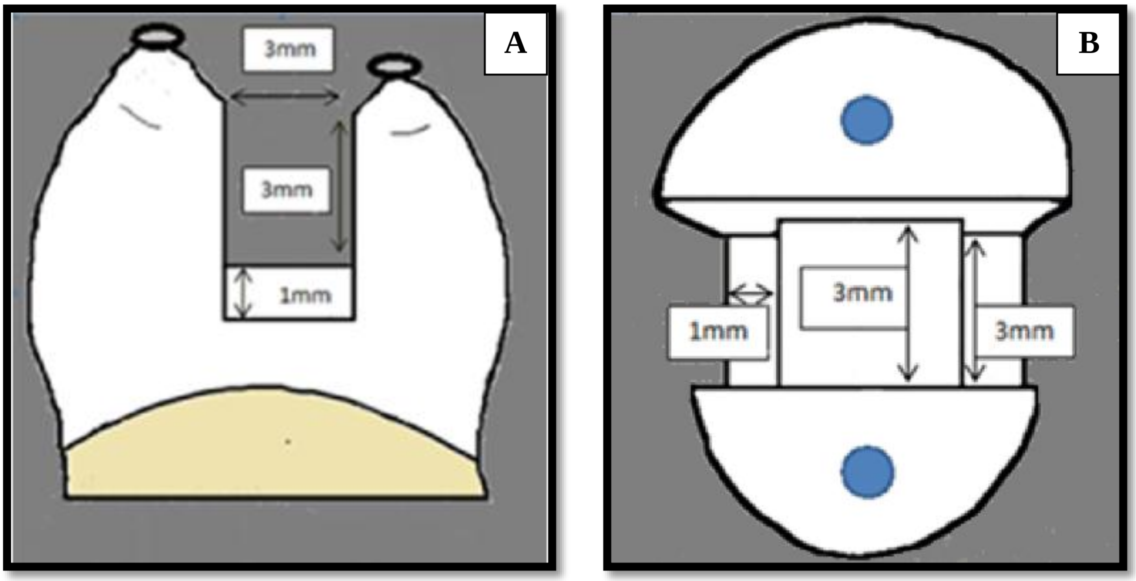

Figure (2.5): Diagram illustrating the dimensions of a prepared MOD cavity (A) proximal view shows 3mm width of the cavity, 3mm depth of the cavity at the pulpal floor level measured from the palatal cavo-surface margin, with 1mm height of the axial wall. (B) Occlusal view shows 3mm width of the cavity at the pulpal floor and gingival seat with 1mm depth of the axial wall.

The dimension of cavity was checked by using the graduated periodontal probe and digital caliper as in Figure (2.6).

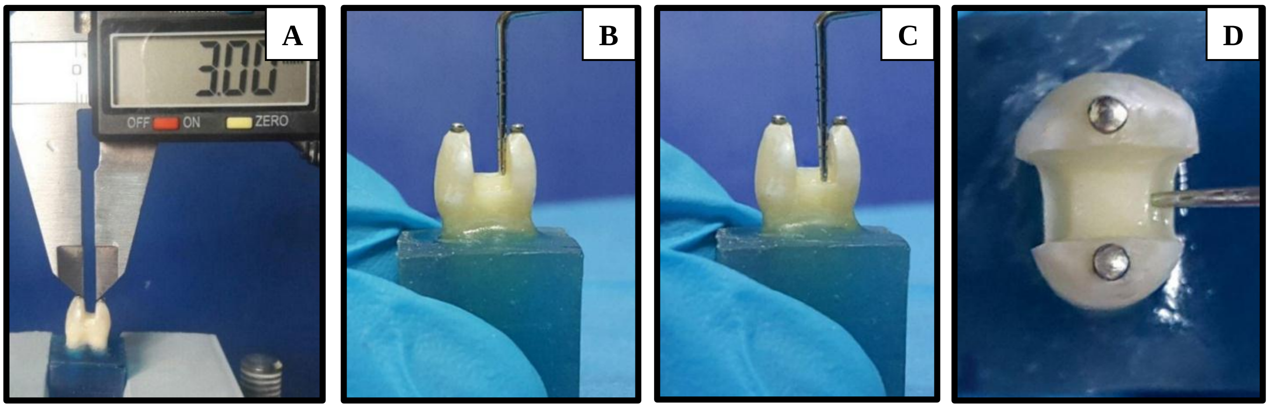

Figure (2.6): Checking of cavity dimension (A) Width of cavity measured from cavo-surface margins (B) Depth of cavity at occlusal isthmus measured from cavo-surface margin to the pulpal floor (C) Height of axial wall (D) Depth of axial wall.

2.2.5 Adhesive procedure

In all groups, etch and rinse adhesive technique was used. After completed sample preparation, the cavity was rinsed well with water and dry with air. A single bond universal adhesive (3M ESPE, USA) was used in total-etch technique followed the manufacturer instructions. The etching procedure was done by treating cavity with 37% phosphoric acid gel (super etching) for 15 seconds as in Figure (2.7A), rinsed thoroughly with water for 30 seconds to ensure removing etching material, and exposed to a gentle stream of air for 2 seconds to remove excess water and avoid dentin dryness. The placement of adhesive was done by using the disposable brush to rub the cavity with adhesive for 20 seconds as in Figure (2.7B) and thinning by gentle air stream for 5 seconds to ensure complete evaporation of the solvent. Light intensity was checked prior to curing procedure by using a radiometer (OPTILUX Radiometer, Kerr Corporation, USA) as in Figure (2.7C), the adhesive was cured with LED Light cure device (Perfection plus, UK) with power intensity equal to 800mw/cm^2 for 10 seconds according to the manufacturer's instructions as shown in Figure (2.7D).

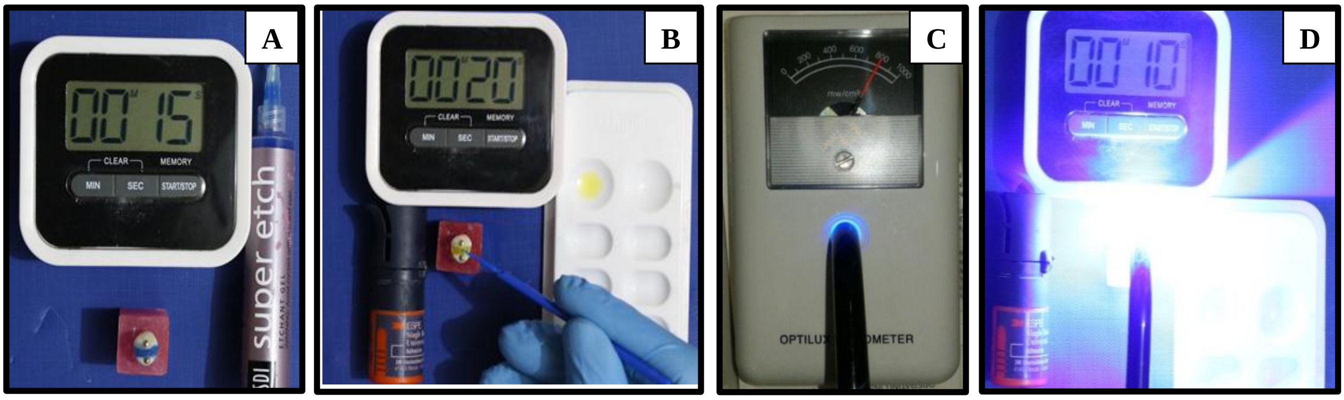

Figure (2.7): Adhesive procedure (A) etching procedure (B) bonding application (C) Checking the light intensity before used (D) curing procedure.

2.2.6 Matrix system placement

For all groups, transparent plastic SuperMat® Adapt® SuperCap® Matrix system (KerrHawe SA, Switzerland) was used as in Figure (2.8A). The system is available in two band heights: 5 mm and 6.3mm with a single shape for molars and premolars, steel or transparent Adapt® SuperCap® was used to fit band and tighten it around the tooth, the excessive tightness was avoided to prevent the effect of the band on results (Toz *et al.*, 2015) as in Figure (2.8B).

The transparent 5 mm SuperMat® was used in this study and changed for each restoration.

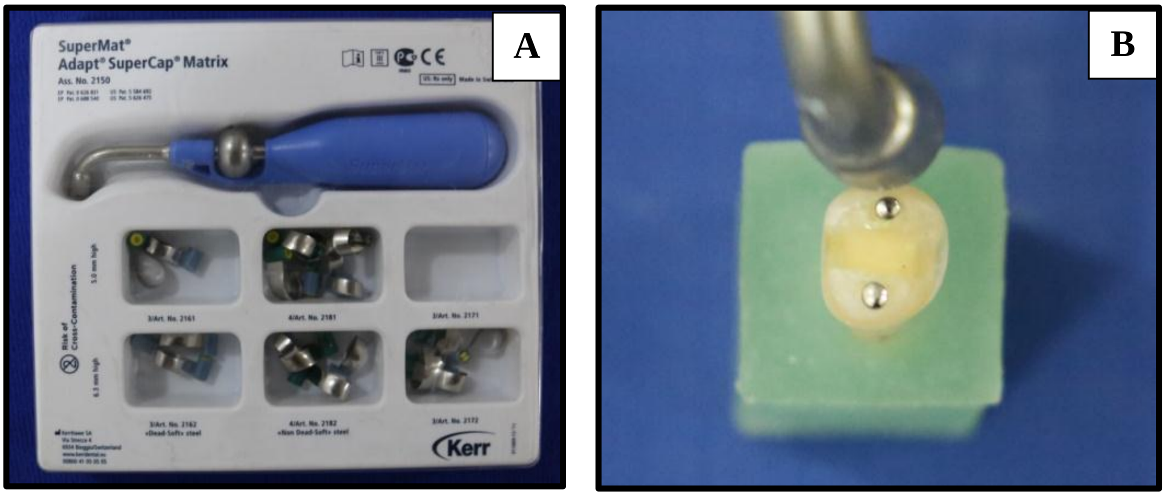

Figure (2.8): Matrix system placement (A) SuperMat® Adapt® SuperCap® Matrix system kit (B) Matrix band application.

2.2.7 Restorative procedure

2.2.7.1 Group A (SonicFill™2 group)

Teeth of this group were restored with SonicFill™2 composites (Kerr Corp., USA). According to manufacturer's, the protective cover of the unidose tip was removed by withdrawing it straight off without twisting to avoid disassembling the tip. Then an unidose tip of SonicFill™2 composite was inserted into the SonicFill™ handpiece by pushing the plunger back into the handpiece maintaining moderate pressure on the tip and the SonicFill™ handpiece was rotated in a clockwise direction until the tip was screwed into place as shown in Figure (2.9A). The SonicFill™ handpiece was turned on degree 3 to fill cavity according to manufacturer instructions and foot pedal was used to activate the sonic vibration, which changed the viscosity of the SonicFill™2 composite material from high viscosity to low viscosity. The cavity was filled in a steady, continuous stream, keeping the tip below the composite surface, and the tip is withdrawn as the cavity was completely filled as shown in Figure (2.9B). Then CompoRoller™ (Kerr Hawe SA, Switzerland) was used to compress material from the occlusal surface to ensure there are no gaps between the material and tooth, adapt margin, remove excess, and sculpting anatomy as in Figure (2.9C). The restoration was cured with LED Light cure device (Perfection plus, UK), which had a power intensity of 800mw/cm^2 for 20 seconds. The tip of light cure has touched cusp tips during curing (Figure 2.9D). Directional curing for 20 seconds from the buccal and lingual was done, according to the manufacturer's instruction, this helped to increase the ability to cure composite at the gingival margin of the proximal box in a Class II restoration (Fahad and Majeed, 2014).

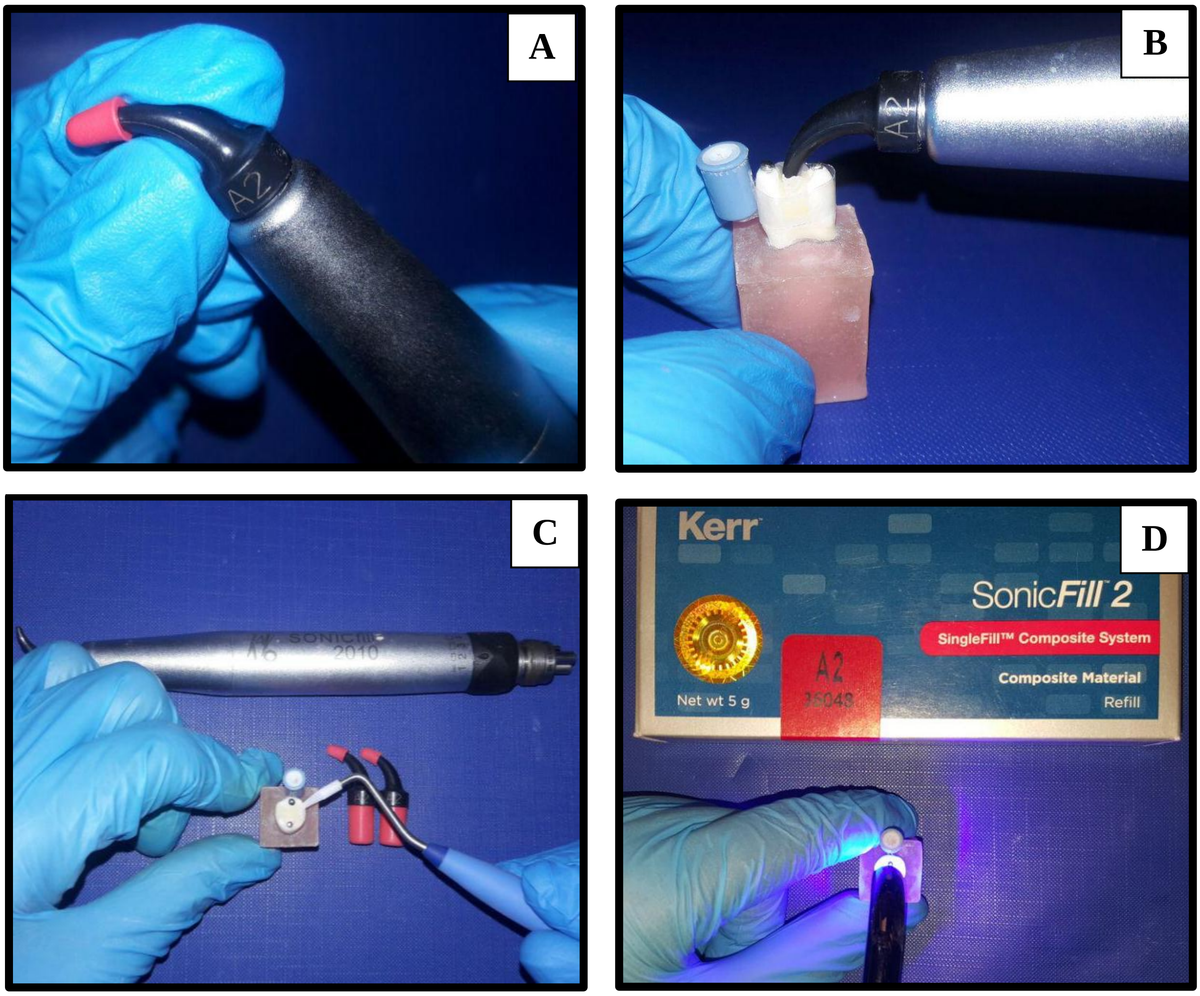

Figure (2.9): Procedure of SonicFill system application (A) Tip screwed in the SonicFill™ handpiece (B) Cavity filled with composite (C) Composite adapted with CompoRoller™ (D) curing procedure.

2.2.7.2 Group B (Beautifil Bulk)

Beautifil Bulk Fill composite (Universal Shade) was used to restore this group. It was applied to the cavity in a single layer up to 4mm according to the manufacturer’s instructions. Adaptation and final anatomy were achieved by CompoRoller™ as shown in Figure (2.10A), and cured as Group A (Figure 2.10B).

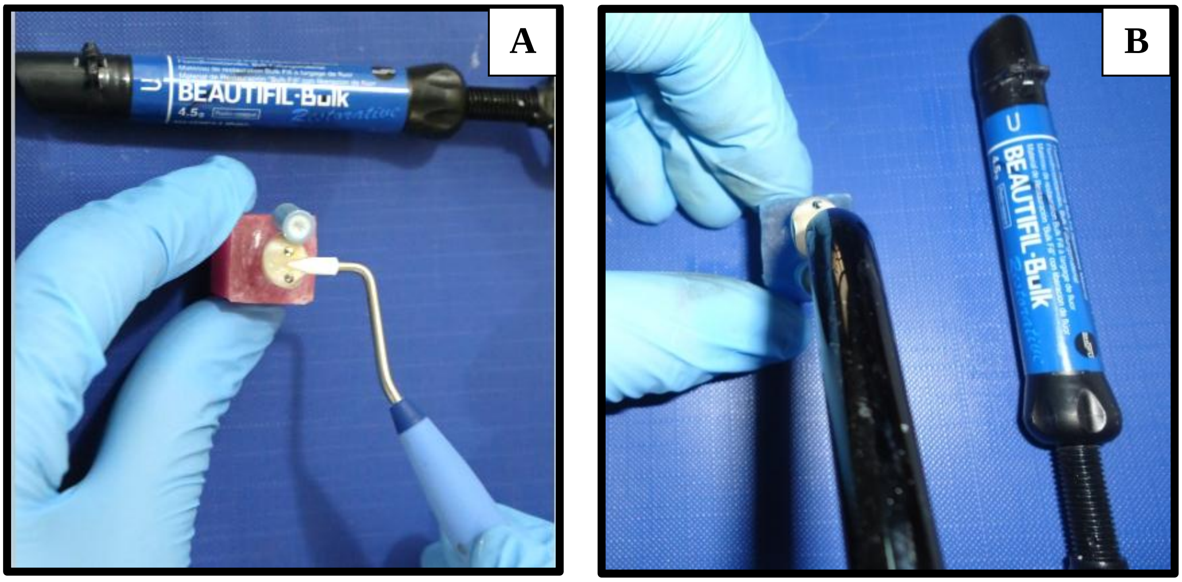

Figure (2.10): Restoration with Beautifil Bulk Fill (A) Placement restoration (B) Curing procedure.

2.2.7.3 Group C (Filtek™ Bulk Fill Posterior Restorative)

Pre-dosed capsule of Filtek™ Bulk Fill Posterior Restorative (Shade A2) was loaded in the gun and applied directly into the cavity from the capsule's tip by dispensing at the deepest portion of the cavity, and then gradually withdrawing the tip until cavity was filled up in a single increment according to the manufacturer’s instructions as in Figure (2.11A). Adaptation and final anatomy were achieved by CompoRoller™, cured as Group A (Figure 2.11B).

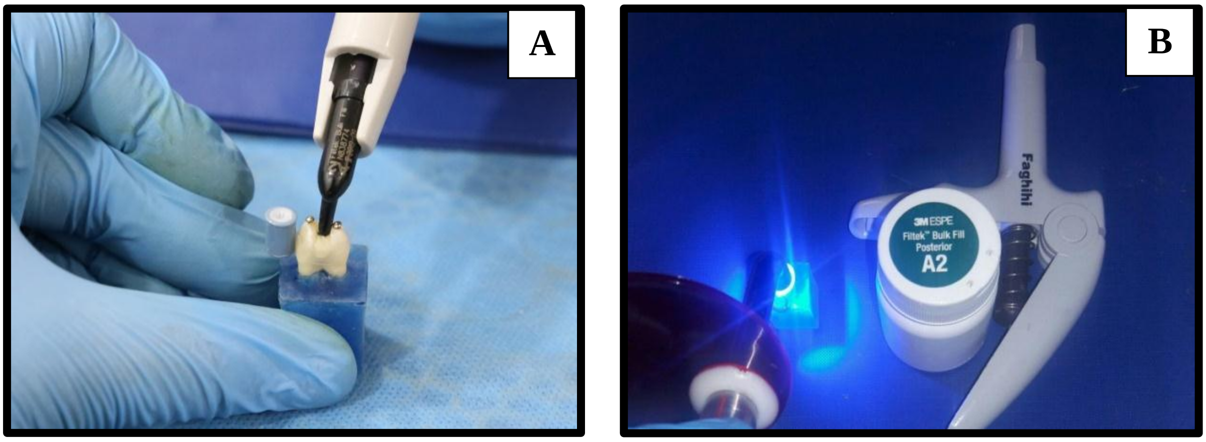

Figure (2.11): Restoration with Filtek™ Bulk Fill Posterior Restorative (A) Placement restoration (B) Curing procedure.

2.2.7.4 Group D (Universal Tetric EvoCeram®)

Universal Tetric EvoCeram® composite (shade A2) was used to restore this group in wedge-shaped layering technique. The first increment was placed against the buccal wall and gingival seat of proximal boxes and polymerized, and then another increment was placed against the palatal wall and polymerized. This procedure was repeated for the occlusal part until cavity was completely filled and a total number of increment was eight for every tooth (Fleming *et al.*, 2007a) as in Figure (2.12). Its thickness (2mm) was checked with a graduated periodontal probe. Each layer was adapted with CompoRoller™ and cured for 20 seconds according to manufacturer instructions.

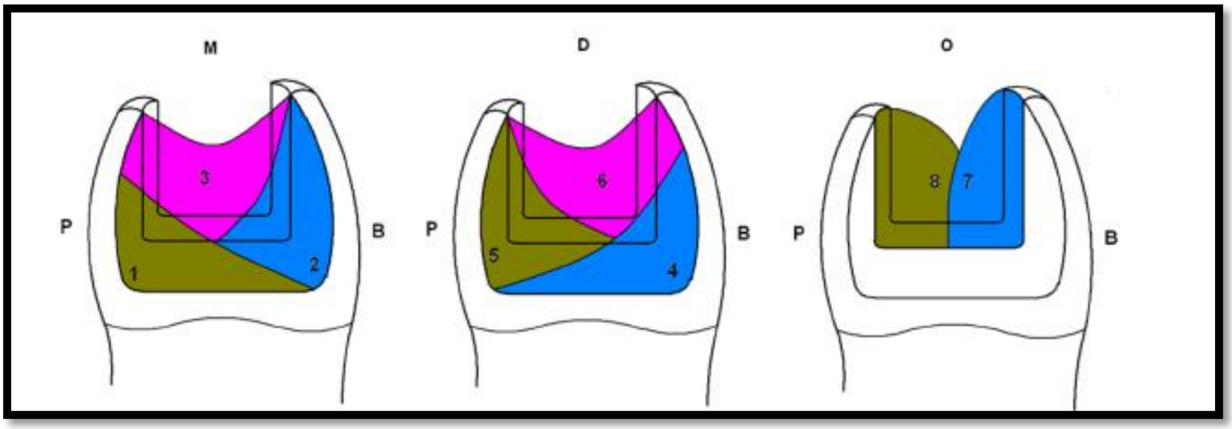

Figure (2.12): Restoration with Universal Tetric Evoceram® composite by incrementally restored each box with 3 increments and occlusal part with 2 increments.

2.2.8 Finishing and polishing procedure

The restorations were finished and polished with Enhance finishing system according to manufacturer's instruction.

1. The finishing procedure was continued with enhance finishing (cup, point, and disc) as in Figure (2.13A).

2. The final high surface luster was achieved by using PoGo polishing system and Prisma Gloss composite polishing paste as shown in Figure (2-13 B).

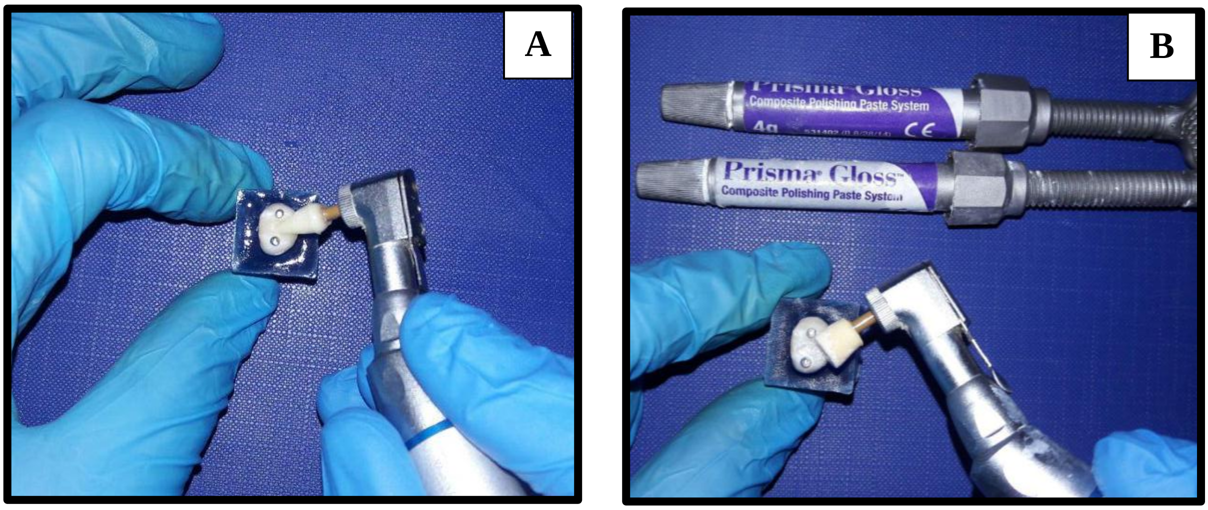

Figure (2.13): Finishing procedure (A) Restoration finishing with enhance finisher (B) Using PoGo polishing system and Prisma Gloss composite polishing paste.

2.2.9 Sample Measurement

The single operator did all measurements to minimize errors percentage. The mean value of five repeated measurements for each sample was used for the subsequent statistical analysis (Oskoee *et al.*, 2012). Measurements were performed by using a computerized digital microscope (Dino-lite) at a magnification of 75X in combination with image J software.

Before any restorative procedure, the distance between two reference points before cavity preparation (intercuspal distance) was measured by taken mean values of the five consecutive measurements.

The mean value of five consecutive measurements of the distance between two reference points for each sample after cavity preparation was documented as **initial distance**; then the cuspal deflection after preparation

(CD1) was measured by subtracting intercuspal distance after cavity preparation from intercuspal distance value before cavity preparation (Al-Obaidi and AL-Rawi, 2011) according to the following equation:

CD1 = Intercuspal distance before cavity preparation – Intercuspal distance of tooth after cavity preparation (initial distance)

CD1: Cuspal deflection value after cavity preparation.

The samples were stored in distilled water in plastic tubes for 15 minutes after restoration completion; the mean value of the five consecutive measurements of the distance between two reference points 15 minutes after tooth restoration was documented as **final distance** (Al-Obaidi and AL-Rawi, 2011).

Cuspal deflection value 15 minutes after restoration (CD2) was measured by subtracting the final distance from the initial distance (Campos *et al.*, 2009) as the following equation:

CD2 = Initial distance – Final distance

After that, teeth were stored in deionized distilled water in plastic tubes and placed in the Incubator at 37°C in Bagdad Teaching Hospital for one-week and 4weeks as in Figure (2.14). Then the cuspal deflection was measured by subtracting the final distance from ICD after each period (Al-Obaidi and AL-Rawi, 2011).

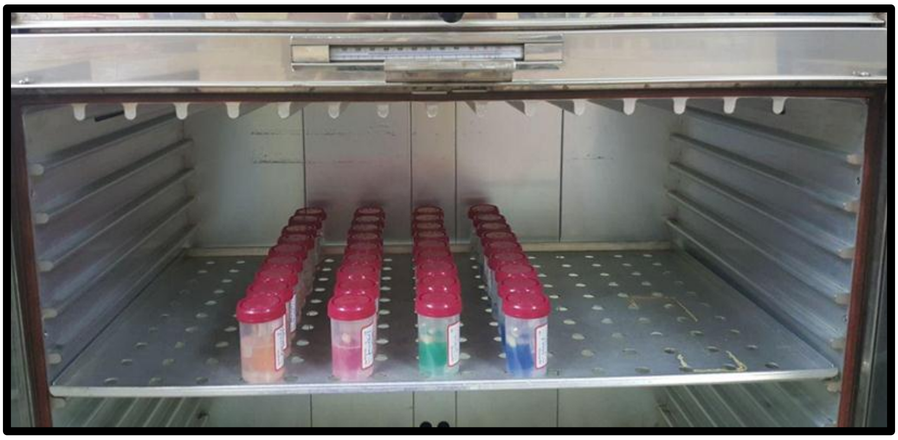

Figure (2.14): Samples storage in incubator.

The cuspal deflection after one week water storage (CD3) was measured as in the following equation:

CD3 = ICD of tooth after 1week water storage – final distance.

The cuspal deflection value (CD4) after 4weeks water storage in an incubator of MOD restoration was calculated as in the following equation:

CD4 = ICD of tooth after 4weeks water storage – final distance

The percentage of tooth recovery after 4weeks water storage in an incubator at 37^{o}C was calculated as in the following equation:

Percentage of tooth dimensional recovery = ICD of tooth after 4weeks water storage / ICD before cavity preparation X 100%.

2.2.9.1 Measurement procedure

Dino-lite digital microscope (AnMo Electronics Corporation, Taiwan) in combination with image-processing and measuring program (Image J 1.50i, U.S. National Institutes of Health, Bethesda, MA, USA) was used to precisely measure the intercuspal distance of sample. Dino-lite digital microscope composed of digital microscope sensor lens (which attached to PC via USB 2.0) and dino-capture 2.0 software.

Specially constructed modification with two rulers was fixed in the stamp of the microscope, which used to hold each sample in a fixed position under the digital microscope through all measurement periods as shown in Figure (2.15).

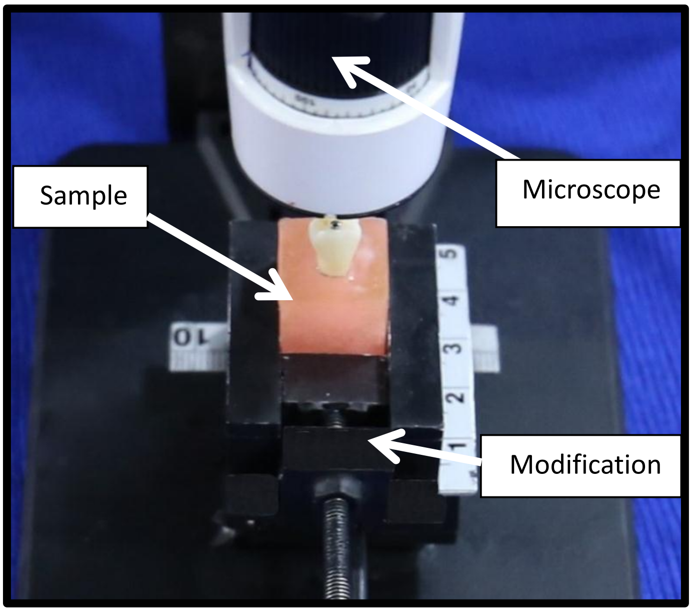

Figure (2.15): Dino-lite digital microscope with modification.

A dino-lite digital microscope was fixed in a way that the long axis of the microscope was parallel to that of the tooth, the modification was adjusted to centralize the scale crosshair with both reference points under the microscope at 75X with fixed distance during all measurement periods. The pictures were taken for all periods of measurement (before cavity preparation, after tooth preparation, 15minutes after tooth restoration, 1week water storage and finally after 4weeks water storage). Therefore, each sample had five pictures and the total number of pictures for 40 samples was 200 pictures, which can be easily saved in database and recall as in Figure (2.16).

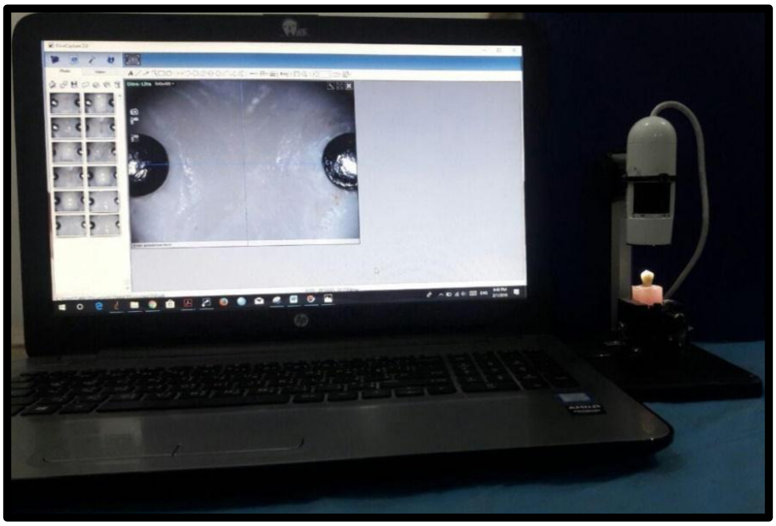

Figure (2.16): Taking images with digital microscope.

The taken pictures were opened in measurement program (image J software), which was used to measure the intercuspal distance between two reference points (head of pins) after changed the unit of the program measurement from pixel to micron. The intercuspal distance between two reference points was measured by drawing straight line between the inner borders of head of pins at zero angles as in Figure (2.17).

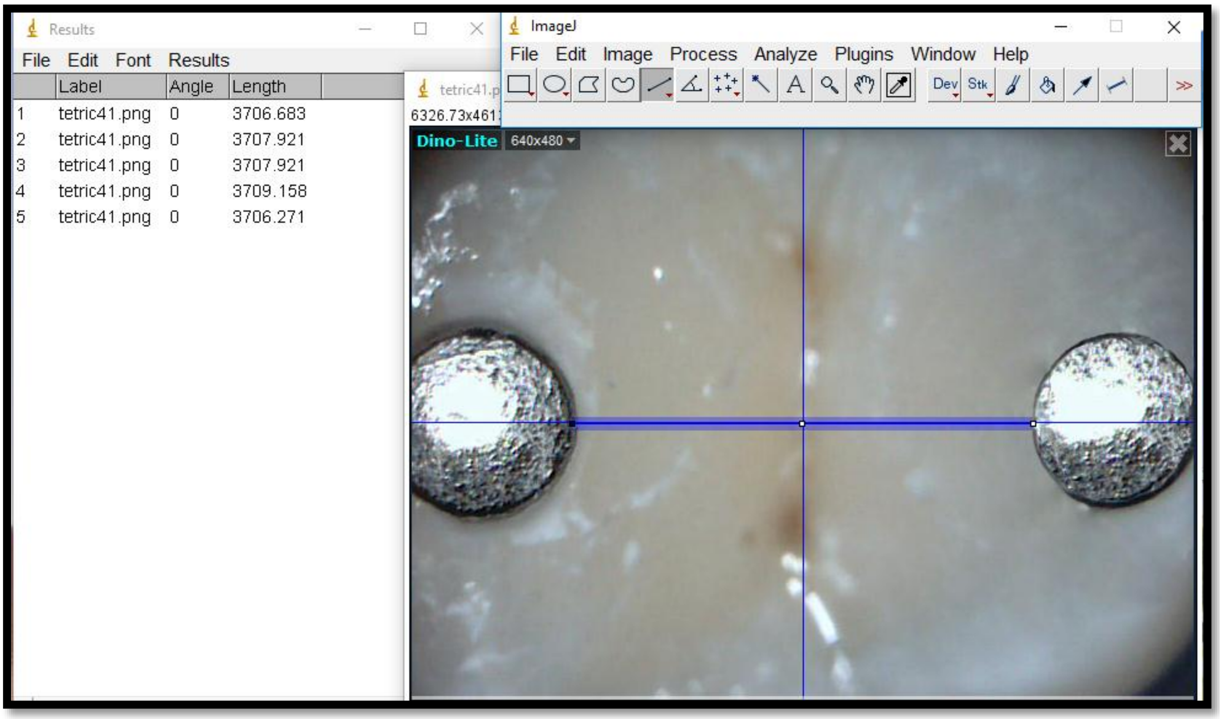

Figure (2.17): The measurement procedure.

2.2.10 Statistical analysis

The data of this study were collected and analyzed by using statistical package for social science SPSS (SPSS for Windows, IBM Corp., version: 20) for statistical analysis. The statistical methods used in order to analyze and assess the results of this study are:

A- Descriptive statistics were performed for each period:

B. Inferential statistics:

1. One-Way Analysis of Variance (ANOVA) was used to determine whether there is a statistical difference among the means of study groups for cuspal deflection at each period.

2. Least significant difference (LSD) was used to evaluate the source of significance and differences between the groups.

$P>0.05$ (Non-Significant)

$P\leq0.05$ (Significant)

$P\leq0.01$ (Highly Significant)

Chapter Three

Results

Results

Data that represented intercuspal distance and cuspal deflection for all groups at different periods of restorative procedures are listed in the appendices **VIII** and **IX** respectively.

3.1 Intercuspal distance value before cavity preparation (ICD)

The descriptive statistics, which include the minimum, maximum, mean and standard deviation values of the intercuspal distance before cavity preparation in micrometer are summarized in Table (3.1).

Table (3.1): Descriptive statistics of the intercuspal distance (ICD) in micrometers (µm) before cavity preparation for all groups (minimum, maximum, mean and SD).

Group	Minimum (µm)	Maximum (µm)	Mean (µm)	±SD (µm)
A	3897.050	4589.936	4146.901	212.342909
B	3700.120	4338.545	4074.4283	214.782769
C	3776.505	4578.062	4059.5407	234.651667
D	3695.164	4492.031	4033.4815	270.408722

It is clearly seen from (Table 3.1) that the lowest value of the intercuspal distance before cavity preparation was in Group D (4033.4815 µm), while the highest mean value was in Group A (4146.901 µm).

One-way ANOVA was used to analyze the presence of a statistically significant difference in mean values of the intercuspal distance before cavity preparation data among all groups. Result showed statistically non-significant difference ($P > 0.05$) as in Table (3.2).

Table (3.2): One- way ANOVA test of intercuspal distance before cavity preparation mean values for all groups

Source of variation		Sum of Squares	df	Mean Square	F	P-value	Sig.
Intercuspal distance in before cavity preparation	Between Groups	70813.199	3	23604.400	0.430	0.733	NS
	Within Groups	1974630.874	36	54850.858			
	Total	2045444.074	39				

P > 0.05

3.2 Cuspal deflection (CD)

3.2.1 Cuspal deflection after cavity preparation (CD1)

The descriptive statistics, which include the minimum, maximum, mean and standard deviation values of negative cuspal deflection after preparation in micrometer are summarized in Table (3.3) and Figure (3.1)

Table (3.3): Descriptive statistics of CD1in micrometer (µm) for all groups (minimum, maximum, mean and SD).

Group	Minimum (µm)	Maximum (µm)	Mean (µm)	±SD (µm)
A	3.211	6.094	-4.6482	1.170515
B	2.454	5.170	-3.8571	0.974685
C	2.356	6.426	-4.3821	1.273434
D	2.942	5.983	-4.3183	1.084197
***The negative sign added to represent the direction of the cuspal deflection to inward. It did not refer to numerical value.**				

It is clearly seen from Table (3.3) and Figure (3.1) that the lowest negative cuspal deflection after teeth preparation (CD1) was in Group B (-

3.8571 µm), while the highest negative cuspal deflection was in Group A (-4.6482µm).

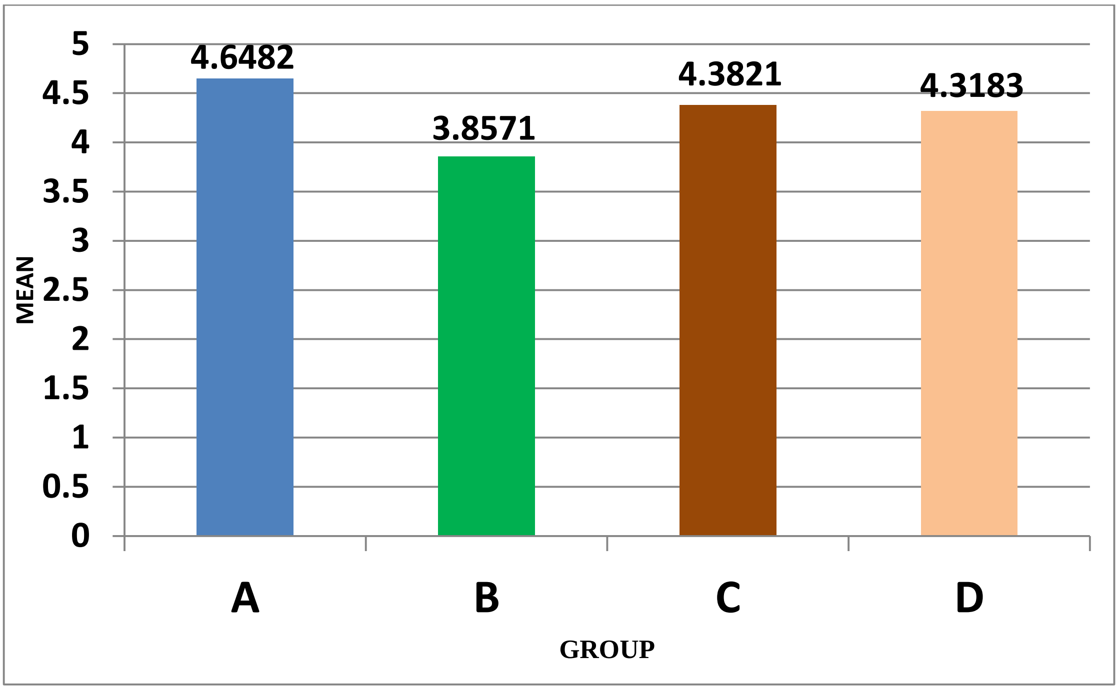

Figure (3.1): Bar chart graph showing means values of negative cuspal deflection after preparation (CD1) in all groups in micrometer.

The data were analyzed by one-way ANOVA and given a non-significant difference (P>0.05) in mean values of CD1 among all groups. As showed in Table (3.4).

Table (3.4): One-way ANOVA test of negative cuspal deflection after preparation.

Source of variation		Sum of Squares	df	Mean Square	F	p-value	Sig.
CD1	Between Groups	3.245	3	1.082	0.845	0.478	NS
	Within Groups	46.055	36	1.279			
	Total	49.300	39				

P>0.05

3.2.2 Cuspal deflection 15 minutes after tooth restoration (CD2)

The descriptive statistics, which include the minimum, maximum, mean and standard deviation values of negative cuspal deflection 15 minutes after restoration completion in micrometer are summarized in Table (3.5) and Figure (3.2).

Table (3.5): Descriptive statistics of CD2 in micrometer (µm) for all groups (minimum, maximum, mean and SD).

Group	Minimum (µm)	Maximum (µm)	Mean (µm)	±SD (µm)
A	5.219	6.951	-5.9416	0.543150
B	4.241	8.570	-7.0677	1.263111
C	3.650	7.875	-5.7807	1.198434
D	7.382	12.359	-9.4749	1.441092
*The negative sign added to represent the direction of the cuspal deflection to inward. It did not refer to numerical value.				

As shown in Table (3.5) and Figure (3.2) that the lowest cuspal deflection 15minutes after restoration was in Group C (- 5.7807µm), while the highest value was in Group D (-9.4749µm).

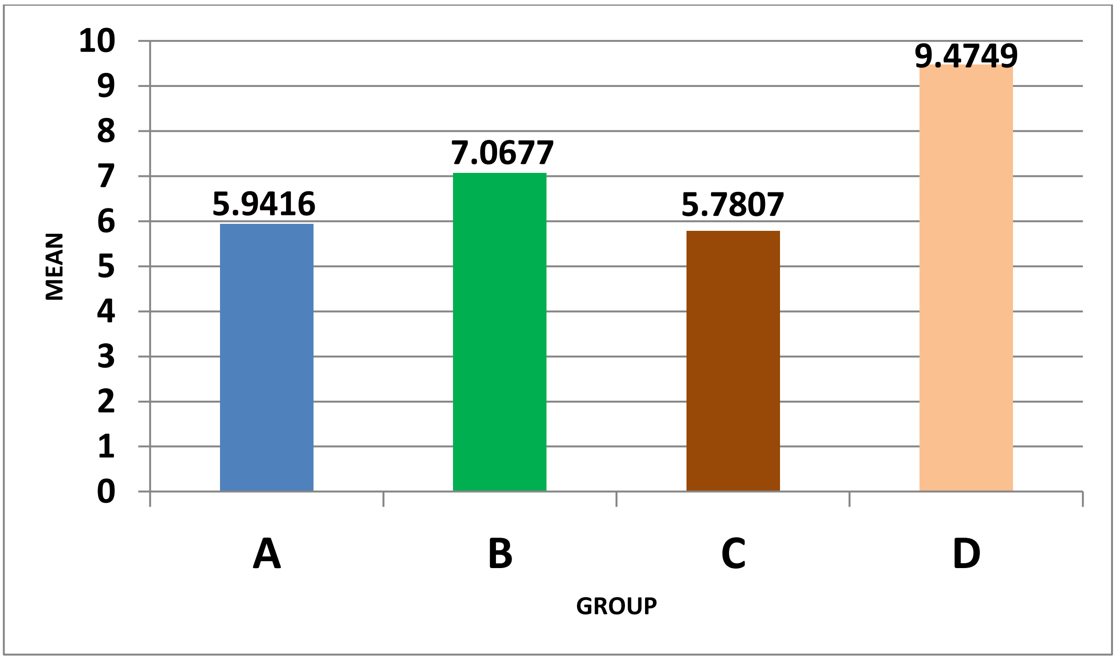

Figure (3.2): Bar chart graph showing means values of CD2 in all groups in micrometer (µm).

The data were analyzed by one-way ANOVA and given a highly significant difference (P<0.01) in mean values of CD2 among all groups. As showed in (Table 3.6).

Table (3.6): One-way ANOVA test of negative cuspal deflection 15 minutes after restoration.

Source of variation		Sum of Squares	df	Mean Square	F	p-value	Sig.
CD2	Between Groups	87.203	3	29.068	21.518	.000	HS
	Within Groups	48.631	36	1.351			
	Total	135.824	39				

P<0.01

Further comparisons among groups were needed to determine where the significant difference occurred by using the Least Significant Difference test (LSD test) as shown in Table (3.7).

Table (3.7): LSD test for comparison of significance between groups.

(I) Group	(J) Group	Mean Difference (I-J)	p-value	Sig.
A	B	-1.126	.037	S
	C	0.161	.759	NS
	D	-3.533	.000	HS
B	C	1.287	.018	S
	D	-2.407	.000	HS
C	D	-3.694	.000	HS
* The mean difference is significant at the 0.05 level.				

LSD test results showed a highly significant difference between Group D and all other groups ($P<0.01$), statistically significant differences between Groups A (restored with SonicFill™2) & B (restored with Beautifil Bulk Fill restorative) and between Groups B & C (restored with Filtek Bulk Fill) ($P<0.05$), but no-significant difference was presented between Groups (A and C) ($P>0.05$).

3.2.3 Cuspal deflection after one-week water storage (CD3)

The descriptive statistics, which include the minimum, maximum, mean and standard deviation values of positive cuspal deflection after one-week water storage are summarized in Table (3.8) and Figure (3.3).

Table (3.8): Descriptive statistics of CD3 in micrometer (µm) for all groups (minimum, maximum, mean and SD).

Group	Minimum (µm)	Maximum (µm)	Mean (µm)	±SD (µm)
A	3.744	7.807	+5.5586	1.301039
B	4.774	8.263	+6.7838	1.183082
C	2.198	5.565	+4.3717	1.075490
D	5.060	10.456	+8.9529	1.569748
***The positive sign added to represent the direction of the cuspal deflection to outward. It did not refer to numerical value.**				

As shown in Table (3.8) and Figure (3.3) that the lowest positive cuspal deflection after one-week water storage was in Group C (+ 4.3717 µm), while the highest cuspal deflection was in Group D (+8.9529 µm).

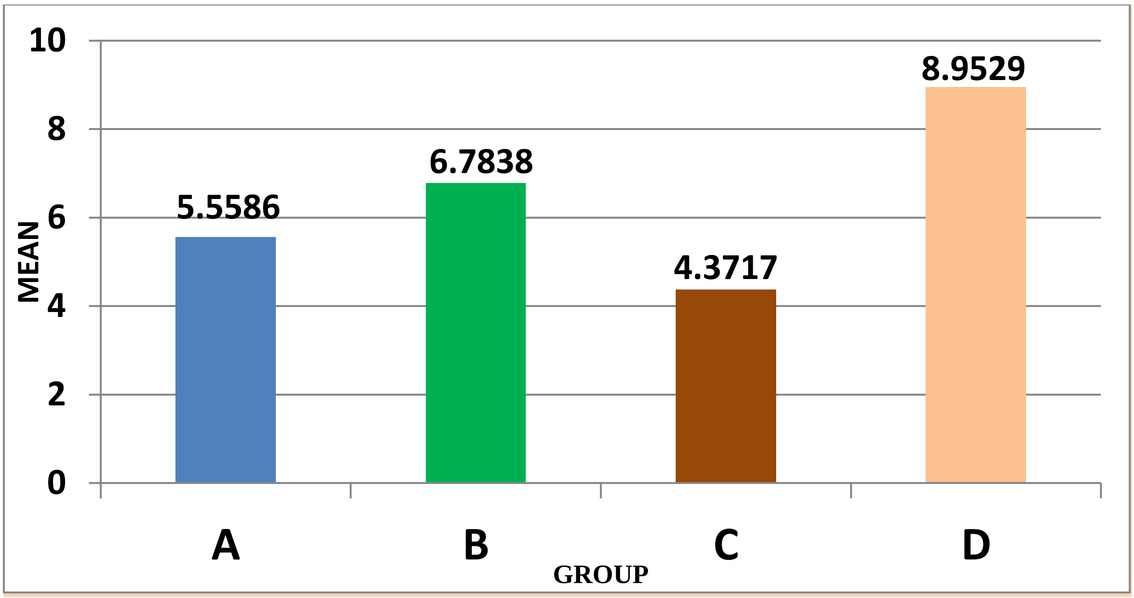

Figure (3.3): Bar chart graph showing means values of CD3 in all experimental groups in micrometer (µm).

The data was analyzed by one-way ANOVA and given a highly significant difference (P<0.01) in mean values of CD3 among all study groups. As shown in (Table 3.9).

Table (3.9): One-way ANOVA test of positive cuspal deflection after one-week water storage.

Source of variation		Sum of Squares	Df	Mean Square	F	P-value	Sig.
CD3	Between Groups	114.854	3	38.285	22.812	.000	HS
	Within Groups	60.419	36	1.678			
	Total	175.273	39				

P<0.01

Further comparisons among groups were needed to determine where the significant difference occurred by using the Least Significant Difference test (LSD test) as shown in Table (3.10).

Table (3.10): LSD test for comparison of significance between groups after one-week.

(I) Group	(J) Group	Mean Difference (I-J)	P-value	Sig.
A	B	-1.225	.041	S
	C	1.187	.048	S
	D	-3.394	.000	HS
B	C	2.412	.000	HS
	D	-2.169	.001	HS
C	D	-4.581	.000	HS
* The mean difference is significant at the 0.05 level.				

LSD test results showed statistically highly significant differences between group D and all other groups and between Groups (B and C) ($P<0.01$), but statistically significant differences between Groups (A and B) and Group (A and C) ($P<0.05$).

3.2.4 Cuspal deflection after 4weeks water storage (CD4)

The descriptive statistics, which include the minimum, maximum, mean and standard deviation values of positive cuspal deflection after 4weeks water storage are cleared in Table (3.11) and Figure (3.4).

Table (3.11): Descriptive statistics of CD4 in micrometer (μm) for all groups (minimum, maximum, mean and SD).

Group	Minimum (μm)	Maximum (μm)	Mean (μm)	±SD (μm)
A	6.618	10.939	+8.8652	1.332597
B	8.015	12.937	+10.7037	1.436495
C	6.521	11.910	+9.0072	1.661144
D	9.442	15.781	+12.7066	1.922006
***The positive sign added to represent the direction of the cuspal deflection to outward. It did not refer to numerical value.**				

As shown in Table (3.11) and Figure (3.4) that the lowest positive cuspal deflection after 4weeks water storage (CD4) was in Group A (+8.8652µm), while the highest cuspal deflection was in Group D (+12.7066µm).

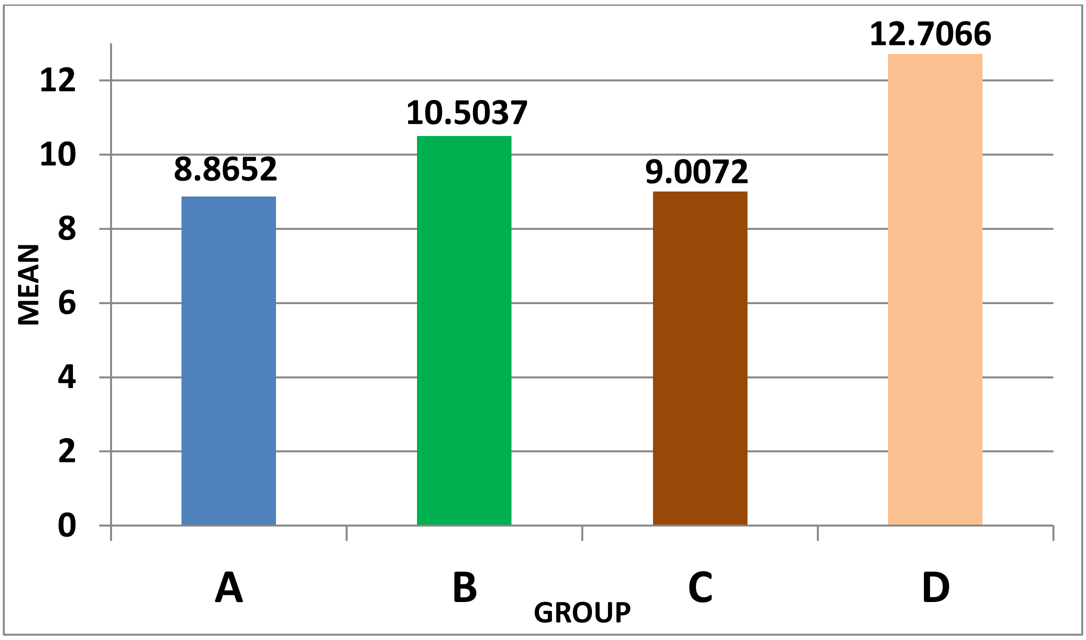

Figure (3.4): Bar chart graph showing means values of CD4 in all experimental groups in micrometer (µm).

The data were analyzed by one-way ANOVA and given a highly significant difference (P<0.01) in mean values of CD4 among all experimental groups. As shown in Table (3.12).

Table (3.12): One-way ANOVA test of positive cuspal deflection after 4weeks water storage.

Source of variation		Sum of Squares	Df	Mean Square	F	P-value	Sig.
CD4	Between Groups	96.830	3	32.277	12.543	.000	HS
	Within Groups	92.636	36	2.573			
	Total	189.465	39				

P<0.01

Further comparisons among groups were needed to determine where the significant difference occurred by using the Least Significant Difference test (LSD test) as shown in Table (3.13).

Table (3.13): LSD test for comparison of significance between groups after 4weeks.

(I) Group	(J) Group	Mean Difference (I-J)	P-value	Sig.
A	B	-1.8385	.015	S
	C	-0.1420	.844	NS
	D	-3.8414	.000	HS
B	C	1.6965	.024	S
	D	-2.0029	.008	HS
C	D	-3.6994	.000	HS
* The mean difference is significant at the 0.05 level.				

LSD test results showed statistically highly significant differences between Group D and all other groups (P<0.01) and statistically significant differences between Groups (A and B) and between Groups (B and C) P<0.05, but statically non-significant differences between Groups (A and C) P> 0.05.

Summarized mean intercuspal distance and cuspal deflection in all periods of restorative procedures represented in (**Table 3.14**).

Table (3.14): Mean intercuspal distance and cuspal deflection in micrometer in different period of restorative procedure.

Groups		Unaltered Tooth	After cavity Preparation	After tooth Restoration	1 week Water storage	4 weeks Water storage
A	ICD	4146.901	4142.2528	4136.3112	4141.8698	4145.1764
	CD		- 4.6482	-5.9416	+5.5586	+8.8652
B	ICD	4074.4283	4070.5712	4063.5035	4070.2873	4074.1072
	CD		-3.8571	-7.0677	+6.7838	+10.7037
C	ICD	4059.5407	4055.1586	4049.3779	4053.7496	4058.3851
	CD		-4.3821	-5.7807	+4.3717	+9.0072
D	ICD	4033.4815	4029.1632	4019.6883	4028.6412	4032.3949
	CD		-4.3183	-9.4749	+8.9529	+12.7066

3.3 Percentage of tooth recovery after 4weeks water storage.

The values of teeth recovery after 4weeks water storage were shown in table (3.15) and Figure (3.5).

Table (3.15): Mean of Intercuspal distance (ICD) before cavity preparation and Intercuspal distance after 4weeks values for all groups and percentage of recovery in all groups.

Groups	Mean ICD Before cavity preparation (mm)	Mean ICD after 4weeks (mm)	Percentage of Recovery%
A	4146.901	4145.1764	99.95841%
B	4074.4283	4074.1072	99.99211%
C	4059.5407	4058.3851	99.97153%
D	4033.4815	4032.3949	99.97304%

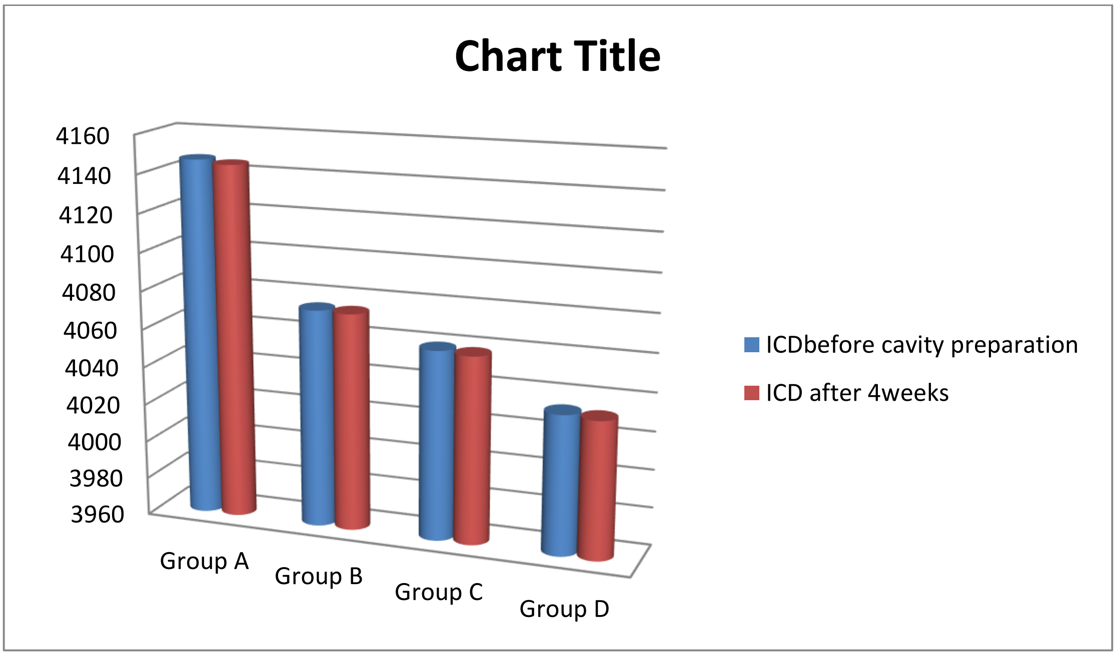

Figure (3.5): Bar chart graph showing mean value of intercuspal distance of before cavity preparation and intercuspal distance after 4weeks water storage in all groups in micrometer.

As shown in Table (3.15) and Figure (3.5), Group B has the highest percentage of tooth recovery while Group A has the lowest percentage of tooth recovery.

Chapter Four

Discussion

Discussion

Cuspal deflection is one of common complication that occurs as a result of polymerization shrinkage stress of composite on tooth structure. It also can be regarded as an indirect method to evaluate the effect of this stress on natural teeth where the stress cannot be measured in a direct way (Kwon *et al.*, 2012). The initial period of negative cusp deflection after tooth restoration is critical because normal occlusal contacts are adapted through this period. This could cause a greater tendency to tooth fracture till relaxation reaches (González-López *et al.*, 2007).

This study evaluated the cuspal deflection of three different types of newly developed bulk-fill restorative resin materials (SonicFill™2, Beautifil Bulk Fill and Filtek™ Bulk Fill) and compare that to a low polymerization shrinkage Universal Tetric Evoceram®. The selected materials share the property of thick one bulk increment (4mm in Beautifil Bulk Fill and 5mm for both SonicFill™2 and Filtek™ Bulk Fill Posterior restorative as stated by their manufacturers. However, they differ in their chemical composition and viscosity. SonicFill™2 is a high viscosity bulk-fill resin-based composite, which converts into low viscosity with the use of sonic energy (Chesterman *et al.*, 2017) and it uses a new nano-scale zirconium oxide filler system. Beautifil Bulk Fill restorative is a high viscosity Bulk-fill multifunctional giomer with high filler loading reach 87% (Shofu, 2014). Filtek™ Bulk Fill Posterior Restorative composite is a nano-filled type contains two novel methacrylate monomers that, act together to lower polymerization stress as stated by the manufacturer (3M ESPE, 2015).

On the other hand, universal Tetric Evoceram® composite was used as low-shrinkage conventional composite and placed in oblique incremental technique. This technique has been long accepted as a standard for composite placement because it delays or prevents two opposite cusps from bonding together. This leads to reduce C-factor, increase the flow of composite from the free surface toward the bonded surface, reduce stresses on the cusps and decrease cuspal deflection (Lee *et al.*, 2007; Park *et al.*, 2008).

Two reference points (heads of pins) were bonded as close as possible to cusp tips to measure intercuspal distance accurately (Hanoudi and Al-Rawi, 2013). The measurements were performed by using a digital microscope (as a non-destructive method to take images for samples). This provides more detailed and much easier procedure for measuring the deflection of the cusps with more reliability than conventional measurement methods. In addition to easily storage and recall of the data. Another advantage of this procedure was the assessment of liner deflection without any contact with the tooth, so it cannot interfere with free movement of cusps (Hanoudi and AL-Rawi, 2013; Shabayek *et al.*, 2013).

Extracted teeth have been broadly used in cuspal deflection measurement because they eliminated the problem of the compliance of the testing system and supporting structures (Sultan *et al.*, 2014). Maxillary first premolar teeth were used in this study because the uniformity in size, form, and shape (McHugh *et al.*, 2017). The size of the teeth can be further controlled through restricted the variance in bucco-palatal width of the teeth within 10% from the determined mean (Taha *et al.*, 2012; El-Helali *et al.*, 2013; Toz *et al.*, 2015).

Large MOD cavity was prepared in the present study to weaken the remaining tooth structure with high C-factor, and reduce cuspal stiffness to nearly 63%. This could increase compliance of the cusp to favour cuspal movement during restoration and provide a realistic *in vitro* simulation of the clinical situation (Abbas *et al.*, 2003; Fleming *et al.*, 2007b; El-Helali *et al.*, 2013). In addition, it was found that polymerization shrinkage of composite produced significantly greater inward cuspal displacement in three surfaces versus two surfaces restorations, because they needed a larger amount of filling

(Suliman *et al.*, 1993a; Versluis *et al.*, 2004; González-López *et al.*, 2007; Behery *et al.*, 2016).

Single bond Universal Adhesive was used in etch-and-rinse mode. This is because it has pH 2.7 which can be considered as an 'ultra mild self-etch' solutions (pH more than 2.5) with dentine interaction depth of less than 1 µm and has been shown poor perform at dentin, which could clarify its weak action in self-etch technique (Kearns *et al.*, 2014). Several studies reported that the etch-and-rinse mode resulted in significantly fewer gaps, irregularities, and microleakage than did the self-etching mode (Heintze *et al.*, 2015; Al-Qrimli and Al-Shamma, 2016).

The distances between two references points were measured after 15 minutes after complete the restoration procedure with totally hydrated specimens. This is because it has been reported that the maximum amount of inward cuspal deflection occurs through this period (McCullock and Smith, 1986; González López *et al.*, 2006; Al-Obaidi and AL-Rawi, 2011; Singhal *et al.*, 2017). This might be attributed to the remaining free radicals and double bonds in the resin-based restoration continued to react. Therefore, the deformation, which continued for several minutes after completed the curing procedure (Blažić *et al.*, 2011). Kim *et al.* (2011) reported that the cuspal deflection is much longer and slower than polymerization shrinkage.

4.1 Intercuspal distance of intact teeth

There was no-significant difference in intercuspal distance before cavity preparation among all groups as shown in Table (3.2). This could be due to that all selected teeth used in this study had nearly close crown shape and size, regular occlusal anatomy, free from cracks, and any defects on visual examination (Gonzalez-Lopez *et al.*, 2006; Shabayek *et al.*, 2013).

4.2 Cuspal deflection

4.2.1 Cuspal deflection after preparation (CD1)

All teeth exposed to cuspal deflection after preparation as shown in Table (3.3). This might be due to the preexisting residual stresses in the sound tooth. The cause for these stresses is not clear. However, they could be resulted from the extraction and water storage before using or are normal in teeth, therefore the intercuspal distance after tooth preparation was recorded as the initial distance instead of intercuspal distance before cavity preparation (Versluis *et al.*, 2011).

A negative or inward cuspal deflection occurred after cavity preparation in all samples, but this deflection was no significant among all groups as shown in Table (3.4). This is in agreement with Al-Obaidi and AL-Rawi (2011), Hanoudi and AL-Rawi (2013) Karaman and Ozgunaltay (2013), and Güler and Karaman (2014), who reported that the teeth were exposed to deflection after cavity preparation but this deflection was not statistically significant among all groups because they had performed by same operator and prepared by standardized method.

4.2.2 Cuspal deflection 15 minutes after cavity restoration (CD2)

The results of this study showed an inward deflection of the cusps for all groups after restoration. This is in agreement with Suliman *et al.* (1993a), Alomari *et al.* (2001), Abbas *et al.* (2003), Palin *et al.* (2005), González- López *et al.* (2006), Taha *et al.* (2009), Campos *et al.* (2009), Moorthy *et al.* (2012), Behery *et al.* (2016), Singhal *et al.* (2017), and Elsharkasi *et al.* (2018), who reported that the shrinkage stresses development after polymerization process results in an inward cuspal deflection in the teeth restored with resin-based composite.

The results of this study showed a highly significant difference in the cuspal deflection of MOD cavities between all groups as in Table (3.6). LSD test (Table 3.7) showed that the teeth restored with bulk-fill resin material Groups (A, B, and C) had significant lower deflection compared with Group D, which restored with conventional composite in incremental technique. This result in accordance with Moorthly *et al.* (2012), Hanoudi and Al-Rawi (2013), El-Damanhoury and Platt (2014), Francis *et al.* (2015), Rossato *et al.* (2015), Tomaszewska *et al.* (2015), McHugh *et al.* (2017), Ólafsson *et al.* (2017), Agarwal *et al.* (2017), and Elsharkasi *et al.*(2018), who found that the bulk-fill composite resin materials caused less cuspal deflection than conventional composite. This could be explained in three ways: firstly, the bulk-fill curing regimen induced an incomplete cure that resulted in decrease the cuspal deflection and increase the microleakage. While the incremental, allow full access of each increment to light and full cure, which lead to greater contraction shrinkage over the full depth of the cavity (Ólafsson *et al.*, 2017; Singhal *et al.*, 2017). Secondly, the innovative bulk-fill composites produce lower polymerization shrinkage stress in the tooth than those of a conventional composite. This may be due to change the polymerization shrinkage dynamics, increase filler loading with decrease resin matrix, the increase in the amount of inorganic filler content of composite, resulted in reduce polymerization shrinkage and cuspal deflection (Rosatto *et al.*, 2015; Ólafsson *et al.*, 2017; Elsharkasi *et al.*, 2018). Thirdly, The bulk-fill resin restoration involved the restorative material being placed in contact with both the buccal and palatal cusps prior light irradiation. this may be constrained overall mean deflection in contrast to the oblique incremental restoration technique where one cusp was only in contact with composite material and thereby stimulated cuspal deflection (Tomaszewska *et al.*, 2015; McHugh *et al.*, 2017). The polymerization shrinkage of each increment in incremental technique will cause deformity of the cavity walls and reduce cavity volume as a result; less amount of composite can be placed for the next increment. This causes higher stress at the tooth-restoration complex in a cavity, which is volumetrically filled with the less composite material than the original volume of the cavity (Agarwal *et al.*, 2017).

On the other hand, the results of this study have disagreed with Behery *et al.* (2016) reported that the incremental filling with the silorane-based composite restorative caused less cuspal deflection than bulk-fill composites. Other studies done by Do *et al.* (2014), and Güler and Karaman (2014) who reported that the new bulk-fill composites systems can be adequately cured at 4mm depths and that they do not differ from conventional composites in marginal integrity, cuspal flexure, and in the polymerization shrinkage stresses in restored teeth. While Singhal *et al.* (2017) found that bulk-fill restoration with conventional composite showed significantly highest cusp deflection. However, there were no significant differences in cuspal deflection among SonicFill™ and modified tangential incremental insertion techniques. These differences in results may be due to use other bulk-fill materials, placement technique and method of measurement.

The lowest standard deviation in the SonicFill™2 group would indicate a lower technique-sensitive method in the SonicFill system compared with the conventional resin composite that placed manually as shown in Table (3.5). Group A (restored with SonicFill ™2) showed significantly less cuspal deflection in compared with Group B (restored with Beautifil Bulk Fill) in spite of high filler loading of Beautifil Bulk Fill. This might be attributed to SonicFill™2 contains rheological modifiers that allow for increasing particle motion and dropping in viscosity upon sonic activation with a designated handpiece. This may be increased pre-gel stress-relief via internal flow and consequently, reduce cuspal strain (Ólafsson *et al.*, 2017). Additionally, the adequate adaptation of SonicFill™2 restoration to cavity walls without void formation reduces the contraction stress and the possibility of pulling the composite away from the cavity wall during polymerization, this lowering the cuspal deflection (Singhal *et al.*, 2017).

Group C (restored with Filtek™ Bulk Fill posterior restorative) showed significantly less cuspal deflection value than Group B. This might attribute to significantly lower volumetric shrinkage of Filtek Bulk Fill (2.01%) compared with Beautifil Bulk Fill (2.58%) with the same modulus of elasticity 8.3 and 8.2 respectively as reported by Tsujimoto *et al.* (2017). According to Hooke's Law, stress is determined by volumetric shrinkage and the elastic modulus of the material so that the polymerization shrinkage stress of Filtek™ Bulk Fill is significantly lower than Beautifil Bulk Fill. The reduction in volumetric shrinkage of Filtek™ Bulk Fill could be due to excluding TEGDMA monomer (286 g/mol) from its contains, which has approximately half the molecular weight of the commonly added dimethacrylates such as Bis-GMA (512 g/mol) (Kim *et al.*, 2016). Also Filtek Bulk™ Fill has two novel monomers which act to lower polymerization shrinkage stress as AUDMA and AFM. AFM has addition fragmentation chain-transfer capability. The advantage of addition fragmentation chain-transfer is that makes the covalent network capable of adapting to stress generation via bond breakage and reformation, without net loss of crosslinking via an allyl disulfide bond (Cramer *et al.*, 2011; Park *et al.*, 2012; Fugolin and Pfeifer, 2017; Mandava et al., 2017).

In this study, SonicFill™2 and Filtek™ Bulk Fill posterior restorative showed lower mean cuspal deflection with no statistically significant difference was obtained between them. This came in agreement with a study done by 3M ESPE corporation, how found a non-significant difference between these composites in the amount of cuspal deflection. According to the manufacturers, the SonicFill™2 and Filtek™ Bulk Fill Posterior composites have novel monomers and mechanism respectively, which act to lower polymerization stress.

4.3 Effect of Water storage

One of the common artificial aging methods in composite restoration is storage in water solutions. The specimens were stored for 4weeks in distilled water at 37ºC to ensure that water sorption and hygroscopic expansion were completed (Segura and Donly, 1993; Örtengren *et al.*, 2001; Rüttermann *et al.*, 2007; Versluis *et al.*, 2011).

According to this study, all experimental groups showed a reduction in cuspal deflection (represent the increase in intercuspal distance) after water storage for all storage periods (one week and four-weeks) as shown in Tables (3.8) and (3.11). This is in total agreement with Segura and Donly (1993), Suliman *et al.* (1993a), Versluis *et al.* (2011), Karaman and Ozgunaltay (2013), Meriwether *et al.* (2013) and Agarwal *et al.* (2017). Gradually decrease in cuspal deflection might be attributed to various mechanisms including stress relaxation of the resin-based materials and/or tooth tissues, which happens in viscoelastic materials that are under continuous strain (Vaidyanathan *et al.*, 2003; Meriwether *et al.*, 2013), debonding of the adhesive interface (Palin *et al.*, 2005; Taha *et al.*, 2009), and/or shrinkage can be compensated by hygroscopic expansion. The hygroscopic expansion is the swelling of a material because of water sorption. Within the oral environment, restored teeth are continuously immersed in oral fluids and consequently water absorption and hygroscopic expansion can be expected. Water sorption may increase relaxation through hydrolysis (chemical degradation of the polymers) and plasticition (water induced molecular mobility) effect. This expansion offsets the polymerization contraction, and thus cuspal flexure can be compensated and neutralized residual shrinkage stresses, and recovery to the initial situation (Meriwether *et al.*, 2013). All the restored teeth started outward deflection with approximately the same shrinkage effect within one week of water storage (CD3) but significant difference was detected. This came in accordance with Hirasawa *et* *al*. (1983) estimate that approximately 7 days is required for water sorption to offset polymerization shrinkage. On the other hands, this result has disagreed with Causton *et al.* (1985) who found no recovery in teeth kept wet and monitored for one-week.

In positive cuspal deflection (CD3), Group C showed the lowest positive cuspal deflection (+4.3717µm) compared with other groups, because Filtek™ Bulk Fill posterior restorative contains hydrophobic monomers AUDMA and UDMA that consider more hydrophobic than Bis-GMA and TEGDMA on other composite types used in this study. Monomers have the following order in hydrophilicity: TEGDMA > Bis-GMA >UDMA>Bis-EMA (Sideridou *et al.*, 2003; Bociong *et al.*, 2017).

According to LSD test, Group B showed significantly higher positive cuspal deflection than Groups (A and C) during CD3 and CD4. This might be attributed to present more hydrophilic monomers TEGDMA within resin matrix. Also, Beautifil was classified as giomer that fluoride release and recharge material, the fluoride release capacity of material determined by its ability to support water diffusion without permitting an excessively large amount of water sorption, McCabe and Rusby (2004) reported that the giomer products are tended to exhibit significantly greater water sorption than the other materials at all-time intervals tested. In addition, the presence of surface pre-reacted glass (S.PRG) within the fillers content of giomer products, which acts as discrete zones within the material structure, could generate an osmotic pressure through water storage and consequently increase water sorption (McCabe and Rusby, 2004; EL-Sharkawy *et al.*, 2012; Gonulol *et al.*, 2014).

According to the result of this study, Group D showed the highest positive cuspal deflection than other groups during all periods of storage (CD3 and CD4). This came in agreement with Hanoudi and Al-Rawi (2011), who reported that the greater positive cuspal deflection of the universal Tetric Evoceram® compared with other bulk-fill groups might be attributed to air-voids incorporated in the composite during handling the material manually and filled incrementally, which lead to form inhibition zone layer with un-polymerized material and bond failures between increments. As a result, higher water sorption occurs by filling these voids with water. In addition, the incorporation of pre-polymerized filler in the structure of universal Tetric Evoceram® composite might interfere with adequate curing of this composite, resulting in a high sorption and solubility mean value (Al-Shekhli and Al-Khfaji, 2008). Pre-polymerized filler particles are a weak link to the resin matrix because there are only a few residual double bonds on the surface of these fillers (O'Neill *et al.*, 2017). Consequently, this might result in failure at this interface, micro-cracks formation and increase degradation of the composite resin (Ferracane, 2006).

In positive cuspal deflection after 4weeks (CD4), LSD test showed a statistically non-significant difference between Groups (A and B). This might be due to the restraining forces imposed by the cavity walls that limit the extent of water sorption and swelling if the water absorption of the material is affected by the hydrophilic components of the resin matrix and this matrix is relatively flexible (McCabe and Rusby, 2004).

The gradual increase in positive cuspal deflection (CD4) of Group C might be attributed to the greater total surface area of nano-filled particles of composite, resulting from the non-agglomerated 20 nm silica filler, allowed more water to accumulate at the filler particle-polymeric matrix interfaces, thus increasing its water sorption (Silva *et al.*, 2008).

4.4 Percentage of natural tooth dimensional recovery after 4weeks water storage

As shown in Table 3.15 and Figure 3.5 of this study, the amount of negative cuspal deflection is recovered to nearly natural tooth dimension after

4weeks water storage, this result in agreement with result suggested by Versluis *et al.* (2011), who reported a non-significant difference between the control and restored teeth after 4weeks water storage. However, this result disagreed with Meriwether *et al.* (2013), who reported that remained significant difference between restored teeth and the intact teeth used as control group. While Segura and Donly (1993) reported that, the cuspal deflection of polymerization shrinkage of a resin composite restoration recovered to more than 97% of its value after 6 months immersion in water.

Thus, the amount of hygroscopic expansion and its clinical impact may vary with material characteristic.

Chapter Five

Conclusions & Suggestions

Conclusions and Suggestions

5.1 Conclusions

Within the limitations of this *in vitro* study, it can be concluded that

1. Bulk-fill restoration produced less cuspal deflection than conventional resin composite restoration (Universal Tetric Evoceram).
2. SonicFill™2 and Filtek™ Bulk Fill had significantly lower mean cuspal deflection compared with the Beautifil Bulk Fill restoratives.
3. Cuspal deformation that resulted from polymerization shrinkage stress was nearly compensated by hygroscopic expansion after 1week water storage in all restored teeth except the Filtek™ Bulk Fill group.
4. Beautifil Bulk Fill restorative group reported highest total recovery percentage among other bulk-fill composites resin materials.
5. All restored teeth returned to nearly natural tooth dimension after 4weeks incubation period.

5.2 Suggestions

1. Measurement the cuspal deflection and bond integrity of the same Bulk-fill Composites.
2. Measurement the cuspal deflection and fracture resistance of endodontically treated teeth restored with different types of Bulk-fill resin materials.
3. Using finite element analysis method to measure three-dimensional effect of polymerization shrinkage stress of these types of restoration on the cuspal deflection.
4. Study cuspal deflection of premolars restored with direct bulk-fill restoration and indirect restoration.
5. Study effect of different adhesive mode on the cuspal deflection and cervical microleakage.

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Appendices

Appendix (I)

Manufactures scientific documentation for Beautifil Bulk Fill restorative material used in this study.

Product	Beautifil Bulk (universal)
Manufacture	SHOFU, Japan
Type	Giomer nano-hybrid bulk-fill restorative material
Resin Components	Bis-GMA (bisphenol-Aglycidyldimethacrylate), UDMA (urethane dimethacrylate), Bis-MPEPP (Bisphenol A polyethoxy methacrylate), TEGDMA (triethyleneglycol dimethacrylate).
Filler type	S-PRG filler based on F–Br–Al–Si-glass
Filler loading(Wt/Vol)	(87% wt., 74.5% vol.)
Method of activation	Visible light cure.
.Curing time mW/cm2.	20 sec for light intensity 520-800 mW/cm2 10 sec for light intensity 800-1000 mW/cm2

Appendix (II)

Manufactures scientific documentation for Filtek Bulk Fill composite restorative material used in this study.

Product	**Filtek Bulk-fill (A2)**
Manufacture	3M ESPE, St. Paul, USA
Composite type	Nano-filled bulk-fill composite
Resin Components	Aromatic UDMA, UDMA, addition-fragmentation monomers (AFM), 1,12 dodecanedimethacrylate
Filler type	non-agglomerated/non-aggregated silica filler, non-agglomerated/nonaggregated zirconia filler, aggregated zirconia/silica cluster filler, ytterbium trifluoride filler
Filler loading(Wt/Vol)	(76.5 %wt., 58.5% vol.)
Method of activation	Visible light cure.
Curing time.	20 sec for light intensity 520-800 mW/cm2 10 sec for light intensity 800-1000 mW/cm2.

Appendix (III)

Manufactures scientific documentation for SonicFill™2 composite restorative material used in this study.

Product	**SonicFill™(A2)**
Manufacture	Kerr Corporation, USA.
Composite type	Sonically activated nano-hybrid Bulk-fill composite
Resin Components	Bis-GMA (bisphenol-Aglycidyldimethacrylate), Bis-EMA (Ethoxylated bisphenol A dimethacrylate).
Filler type	new filler system containing nano-scale zirconium oxide and silica oxide particles
Filler loading(Wt/Vol)	81.3% wt. filler load, unreported%vol.
Method of activation	Visible light cure.
Curing time	20sec for light intensity 520-800 mW/cm2. 10 sec for light intensity 800-1000 mW/cm2.

Appendix (IV)

Manufactures scientific documentation for the Tetric Evoceram® composite restorative material used in this study:

Product	**Universal Tetric EvoCeram® (A2)**
Manufacture	ivoclar vivadent (Liechtenstein)
Composite type	nano-hybrid composite
Resin Components	Bis-GMA (Bisphenol A-diglycidyl dimethacrylate), Bis-EMA (Ethoxylated bisphenol A dimethacrylate) and UDMA (Urethane dimethacrylate).
Filler Type	Barium glass, ytterbium- trifluride,mixed oxide and Prepolymer
Filler Loading (Wt/Vol)	75-76 wt. % 53-55 Vol.%
Method of activation	Visible Light cure
Curing Time	20 sec.

Appendix (V)

Manufactures scientific documentation for the adhesive material used in this study.

Product	**Single Bond Universal**
Manufacture	3M ESPE, St. Paul, USA
Adhesive type	Single-component universal
Composition	Bis-GMA, HEMA, Vitrebond™ copolymer, filler, ethanol, water, initiators, silane Filler loading: 10% by weight
Application protocol	Total-etch / Self-etch
Method and time of curing	Visible light curing for 10s

Appendix (VI)

Buccopalatal, mesiodistal and occlusogingival dimensions of teeth of each group.

Group A				Group B			
Sample no	**B-P**	**M-D**	**O-G**	**Sample no**	**BP**	**MD**	**O-G**
1	9.50	7.00	8.93	1	9.10	7.52	9.00
2	9.70	7.60	9.19	2	9.03	7.00	8.87
3	9.70	7.50	9.14	3	9.70	7.45	9.10
4	9.60	7.40	9.17	4	9.60	7.30	9.21
5	9.64	7.59	9.05	5	9.05	7.00	8.93
6	9.19	7.27	9.00	6	9.21	6.90	8.75
7	9.10	7.50	8.99	7	9.50	7.20	8.97
8	8.90	6.90	8.85	8	9.50	7.51	9.15
9	9.00	7.50	8.87	9	9.70	7.67	9.11
10	9.40	7.60	9.12	10	9.70	7.40	9.15
Mean	**9.373**	**7.386**	**9.031**	**Mean**	**9.409**	**7.295**	**9.004**
±SD	**0.30266**	**0.25189**	**0.12306**	**±SD**	**0.281798**	**0.260694**	**0.1301**
Group C				**Group D**			
Sample no	**B-P**	**M-D**	**O-G**	**Sample no**	**B-P**	**M-D**	**O-G**
1	8.90	6.91	8.79	1	9.39	7.38	9.13
2	9.23	7.21	8.90	2	9.25	6.90	9.16
3	9.66	7.36	9.18	3	9.40	7.30	9.05
4	9.49	7.48	9.15	4	8.90	7.54	8.92
5	8.96	6.90	8.93	5	9.00	7.60	8.97
6	9.55	7.01	8.86	6	9.50	7.60	9.26
7	9.47	7.01	9.00	7	9.20	7.00	9.08
8	9.47	7.30	9.17	8	9.40	7.27	8.91
9	9.70	7.53	9.09	9	9.16	7.20	8.93
10	9.42	7.10	8.92	10	9.50	7.40	9.15
Mean	**9.385**	**7.181**	**8.999**	**Mean**	**9.270**	**7.3190**	**9.056**
±SD	**0.27257**	**0.22990**	**0.14019**	**±SD**	**0.205805**	**0.3283**	**0.1203**

Appendix (VII): One-way ANOVA for samples dimensions with no significant difference.

ANOVA		Sum of Squares	Df	Mean Square	F	P-value
Bucco-palatal dimension	Between Groups	0.113	3	0.038	0.523	0.669 (NS)
	Within Groups	2.589	36	0.072		
	Total	2.702	39			
Mesio-distal dimension	Between Groups	0.219	3	0.073	1.209	0.321 (NS)
	Within Groups	2.170	36	0.060		
	Total	2.388	39			
Occluso-gingival dimensions	Between Groups	0.010	3	0.003	0.229	0.876 (NS)
	Within Groups	0.550	36	0.015		
	Total	0.561	39			

Appendix VIII: Intercuspal distance for all groups in different periods of restorative procedures in micrometer.

Groups	ICD Before cavity preparation	ICD after preparation	IVD After 15 minutes	ICD After one-week	ICD After four-weeks
A1	4333.339	4327.588	4321.932	4327.451	4331.129
A2	4078.174	4074.324	4068.144	4074.459	4076.258
A3	3897.05	3892.62	3885.669	3893.476	3896.608
A4	3967.077	3963.866	3957.701	3962.225	3965.121
A5	4235.981	4229.99	4224.756	4229.682	4234.754
A6	3952.806	3948.63	3943.13	3949.607	3952.176
A7	4169.708	4165.843	4159.757	4163.693	4166.375
A8	4004.235	3998.141	3992.922	3998.534	4002.63
A9	4589.936	4586.724	4580.332	4587.058	4588.18
A10	4240.704	4234.802	4228.769	4232.513	4238.533
Means	4146.901	4142.2528	4136.3112	4141.8698	4145.1764
B1	4084.669	4079.765	4072.134	4080.237	4083.289
B2	4098.823	4095.224	4088.02	4095.552	4098.986
B3	3736.288	3731.561	3722.991	3731.254	3735.52
B4	4322.017	4316.847	4309.424	4315.793	4322.361
B5	4200.89	4196.989	4189.79	4196.415	4200.805
B6	3997.551	3994.578	3988.283	3994.47	3997.804
B7	4144.729	4142.275	4134.165	4139.339	4145.162
B8	4338.545	4334.258	4330.017	4334.791	4338.032
B9	3700.12	3697.648	3689.661	3696.791	3699.478
B10	4120.651	4116.567	4110.55	4118.231	4120.635
Means	4074.4283	4070.5712	4063.5035	4070.2873	4074.1072
C1	3933.628	3928.259	3923.415	3928.2	3932.289
C2	4215.926	4209.5	4204.11	4207.957	4213.375
C3	4010.329	4007.973	4002.102	4005.553	4008.805
C4	3815.73	3810.932	3805.68	3811.092	3816.554
C5	4148.085	4144.839	4136.964	4141.869	4146.756
C6	4172.492	4168.57	4161.918	4166.18	4170.888
C7	3906.781	3902.361	3896.941	3902.435	3905.952
C8	4578.062	4574.227	4568.493	4570.691	4576.645
C9	3776.505	3770.53	3763.411	3768.976	3775.321
C10	4037.869	4034.395	4030.745	4034.543	4037.266
Means	4059.5407	4055.1586	4049.3779	4053.7496	4058.3851
D1	4311.211	4305.999	4296.25	4304.771	4308.127
D2	4073.743	4070.745	4060.944	4071.306	4072.919
D3	4013.278	4009.73	3999.41	4009.247	4013.065
D4	3707.591	3702.839	3693.285	3702.01	3707.12
D5	3740.795	3734.812	3725.74	3735.854	3741.521
D6	4492.031	4489.089	4480.134	4485.194	4489.576
D7	4258.114	4252.92	4240.561	4251.017	4255.545
D8	3695.164	3690.129	3679.991	3688.971	3693.034
D9	3945.357	3942.184	3934.802	3943.142	3946.286
D10	4097.536	4093.187	4085.766	4094.9	4096.756
Means	4033.4815	4029.1632	4019.6883	4028.6412	4032.3949

Appendix IX: Cuspal deflection measurements for all groups in different periods of restorative procedures in micrometer.

Groups	CD1	CD2	CD3	CD4
A1	-5.751	-5.656	+5.519	+9.197
A2	-3.85	-6.18	+6.315	+8.114
A3	-4.43	-6.951	+7.807	+10.939
A4	-3.211	-6.165	+4.524	+7.42
A5	-5.991	-5.234	+4.926	+9.998
A6	-4.176	-5.5	+6.477	+9.046
A7	-3.865	-6.086	+3.936	+6.618
A8	-6.094	-5.219	+5.612	+9.708
A9	-3.212	-6.392	+6.726	+7.848
A10	-5.902	-6.033	+3.744	+9.764
Means	- 4.6482	-5.9416	+5.5586	+8.8652
B1	-4.904	-7.631	+8.103	+11.155
B2	-3.599	-7.204	+7.532	+10.966
B3	-4.727	-8.57	+8.263	+12.529
B4	-5.17	-7.423	+6.369	+12.937
B5	-3.901	-7.199	+6.625	+11.015
B6	-2.973	-6.295	+6.187	+9.521
B7	-2.454	-8.11	+5.174	+10.997
B8	-4.287	-4.241	+4.774	+8.015
B9	-2.472	-7.987	+7.13	+9.817
B10	-4.084	-6.017	+7.681	+10.085
Means	-3.8571	-7.0677	+6.7838	+10.7037
C1	-5.369	-4.844	+4.785	+8.874
C2	-6.426	-5.39	+3.847	+9.265
C3	-2.356	-5.871	+3.451	+6.703
C4	-4.798	-5.252	+5.412	+10.874
C5	-3.246	-7.875	+4.905	+9.792
C6	-3.922	-6.652	+4.262	+8.970
C7	-4.42	-5.42	+5.494	+9.011
C8	-3.835	-5.734	+2.198	+8.152
C9	-5.975	-7.119	+5.565	+11.910
C10	-3.474	-3.65	+3.798	+6.521
Means	-4.3821	-5.7807	+4.3717	+9.0072
D1	-5.212	-9.749	+8.521	+11.877
D2	-2.998	-9.801	+10.362	+11.975
D3	-3.548	-10.32	+9.837	+13.655
D4	-4.752	-9.554	+8.725	+13.835
D5	-5.983	-9.072	+10.114	+15.781
D6	-2.942	-8.955	+5.06	+9.442
D7	-5.194	-12.359	+10.456	+14.984
D8	-5.035	-10.138	+8.98	+13.043
D9	-3.173	-7.382	+8.34	+11.484
D10	-4.349	-7.421	+9.134	+10.99
Means	-4.3183	-9.4749	+8.9529	+12.7066

الخلاصة

انحراف الاحداب هو ظاهرة بايوميكانيكية شائعة تحدث في الأسنان المرممة بمواد الراتنج، والذي يمثل التفاعل بين اجهاد البلمرة من المواد والامتثال لبنية الأسنان المتبقية. مما قد يسبب الفشل الحشوة عند تعرضها للتصلب الضوئي ، مما يسهل كسر الأسنان تحت تأثير الأحمال الاطباقيه. تهدف هذه الدراسة لتقييم انحراف الاحداب في الاسنان الضواحك العليا المرممة بثلاثة انواع من كومبزت الراتنج بتقنية الطبقة الواحدة (SonicFill™2, Beautifil Bulk Fill, and Filtek™ Bulk Fill) ومقارنته بالمجموعة المرممة براتنج الكومبزت (Universal Tetric Evoceram®) بطريقة الطبقات المتعددة ، ودراسة تأثير تخزين المياه لفترات مختلفة على انحراف الاحداب.

تم اعداد أربعين عينة من الاسنان الضواحك العلوية المتشابهة من حيث الحجم بحفر تجاويف ثنائية كبيرة، وتم تقسيمها إلى أربع مجموعات (10 عينات لكل منها) وفقا لمادة راتنج الكومبزت المستخدمة:

المجموعة أ : مرممة براتنج الكومبوزت المفعل صوتيا(SonicFill™2).

المجموعة ب: مرممة براتنج الكومبوزت (Beautifil Bulk Fill).

المجموعة ج : مرممة براتنج الكومبوزت (Filtek™ Bulk Fill).

المجموعة د: مرممة براتنج الكومبوزت (Univeral Tetric Evoceram®).

تمت استعادة المجموعة A و B و C بتقنية بتقنية الطبقة الواحدة، بينما تمت استعادة المجموعة D بطريقة الطبقات المتعددة المائلة.

تم قياس المسافة بين الاحداب باستخدام المجهر الرقمي قبل وبعد الانتهاء من الإجراءات الترميمية ب15 دقيقة، بعد أسبوع واحد وبعد أربعة أسابيع من فترات الحضانة في ماء مقطر منزوع الأيونات. وتم تسجيل انحراف الاحداب بقياس الاختلافات بين القراءات وتحليل البيانات إحصائيا باستخدام اختبار تحليل التباين ANOVA واختبار الفرق المعنوي الاصغر. وأظهرت نتائج اختبار أنوفا وجود فروقات ذات دلالة إحصائية عالية بين جميع المجموعات بعد 15 دقيقة من اكمال الحشوة وخلال فترات الحضانة المختلفة بسبب تخزين المياه ($p<0.01$) .كما أظهرت نتائج المقارنات المتعددة أن المجموعتين (أ) و (ج) كانت أقل انحرافًا من المجموعات الأخرى ولكن لا توجد فروق ذات دلالة إحصائية ($P> 0.05$) بينهما ، بينما أظهرت المجموعة (د) المرممة بطريقة الطبقات المتعدة اختلافًا كبيرًا ($P <0.01$) في انحراف الاحداب عن المجموعات الأخرى بعد 15 دقيقة من الترميم. ويمكن أن

يعزى ذلك إلى مركبات الراتنج ذو الطبقة الواحدة تنتج إجهاد انكماش للبلمرة أقل مقارنةً بالمركب التقليدي أو بسبب تقنية وضع المادة.

بعد فترة حضانة لمدة اسبوع و 4 أسابيع ، انخفض انحراف الاحداب في جميع المجموعات بشكل تدريجي وتم تعويضه عن طريق التوسع الاسترطابي في غضون أربعة أسابيع.

ومن النتأئج اعلاه ، فان استخدام راتنج الكومبزت ذو الطبقة الواحدة ادى الى تقليل قيمة انحراف الاحداب مقارنة بمركبات راتنج الكومبوزت المرممة بتقنية الطبقات المائلة، ومن ناحية أخرى، تم تعويض هذا الانحراف عن طريق التوسع الاسترطابي في الترميمات خلال فترة حضانة لمدة 4 أسابيع. لذلك ، قد تقوم توصيتنا باختيار مركّبات راتنج الكومبزت ذو الطبقة الواحدة لتقليل تأثيرات انكماش البلمرة غير المرغوب فيها مع تبسيط تقنية التعبئة.

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بغداد
كلية طب الأسنان

تقييم انحراف الاحداب للضواحك المرممة بأنواع مختلفة من راتنج الكومبوزت ذو الطبقة الواحدة (دراسة مختبرية مقارنة)

رسالة مقدمة الى مجلس كلية طب الأسنان / جامعة بغداد
كجزء من متطلبات نيل شهادة الماجستير
في معالجة الاسنان

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