# COMPARISON OF SHEAR BOND STRENGTH, ADHESIVE REMNANT INDEX AND ENAMEL DAMAGE USING DIFFERENT LIGHT SOURCE IN DEBONDING OF ORTHODONTIC BRACKETS

by

Dr. HELMI ABOBAKR QAID ALYAMANI

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## *Dedications*

*To my beloved wife and family, for their unconditional love, support and care…*

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**TABLE OF CONTENTS**

**CHAPTER 3 - MATERIALS AND METHODS**

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF ABBREVIATIONS

| | |
|---|---|
| ARI | Adhesive Remnant Index |
| Corp | Corporation |
| CQ | Camphoroquinone |
| ED | Enamel Damage |
| EF | Enamel Fracture |
| LC | Light Cure |
| LCUs | Light Cure Units |
| LED | Light Emitting Diode |
| Ltd | Limited |
| MPa | Mega Pascal |
| N | Newton |
| OSM | Olympus stereomicroscope |
| RMGIC | Resin Modified Glass Ionomer Cement |
| SBS | Shear Bond Strength |
| SEM | Scanning Electron Microscope |
| SEP | Self-Etching Primer |
| TCB | Tungsten Carbide Bur |
| TQH | Tungsten Quartz Halogen |
| USM | Universiti Sains Malaysia |
| UTM | Universal Testing Machine |
| VLC | Visible Light Cure |

**PERBANDINGAN KEKUATAN IKATAN GESEL (KIG), INDEKS REMNAN BAHAN PELEKAT (IRBP) DAN KEROSAKAN ENAMEL (KE) APABILA MENGGUNAKAN SUMBER CAHAYA YANG BERLAINAN DALAM PROSES PENYAHIKATAN BRAKET ORTODONTIK**

## ABSTRAK

Bahan pelekat braket ortodontik yang menggunakan cahaya memerlukan intensiti cahaya yang mencukupi dan ukuran gelombang tertentu untuk memulakan pempolimeran. Intensiti cahaya serta ukuran gelombang yang tidak mencukupi menyebabkan pempolimeran yang tidak sempurna, boleh mengurangkan Kekuatan Ikatan Gesel (KIG) dan membuat braket ortodontik tidak berupaya menahan daya oklusi intra-oral dan daya ortodontik. Semasa penyahikatan braket ortodontik, remnan bahan pelekat akan tertinggal pada permukaan enamel dan Kerosakan Enamel (KE) boleh terjadi. Kajian ini bertujuan membandingkan KIG braket ortodontik keluli nirkarat yang diikat dengan cahaya yang berbeza iaitu Light-Emitting Diode (LED) dan tungsten-quartz-halogen (TQH), dan membandingkan Indeks Remnan Bahan Pelekat (IRBP) dan KE selepas penyahikatan braket. Permukaan enamel 104 batang gigi pramolar dibersihkan dan difoto (T1) dengan kanta pembesar 60X mikroskopstereo Olympus dengan kamera digital untuk menilai permukaan enamel sebelum prosedur ikatan braket, menggunakan skala yang ditetapkan. Kemudian permukaan gigi tersebut dipunar dengan asid dan braket keluli nirkarat dilekatkan kepada permukaan enamel gigi dengan bahan lekat Transbond. Seterusnya ia dibahagi kepada dua kumpulan. Dalam kumpulan I, 52 braket keluli nirkarat diikat kepada enamel menggunakan cahaya LED selama 10 saat dan 52 braket keluli nirkarat diikat kepada enamel gigi dalam kumpulan II dengan cahaya TQH selama 20 saat mengikut arahan pengilang. Kesemua gigi disimpan dalam air suling selama seminggu untuk menyamai persekitaran mulut. Sebelum penyahikatan braket, setiap kumpulan dibahagi pula kepada subkumpulan A dan B. Dalam subkumpulan A, 26 braket dinyahikat dengan mesin Instron berkelajuan 1mm/minit untuk mengukur KIG. Dalam subkumpulan B, 26 braket dinyahikat dengan playar konvensional. Selepas penyahikatan, semua permukaan enamel dianalisa. Keluasan resin yang tertinggal diukur dan peratus IRBP dikira. Remnan bahan pelekat selepas penyahikatan dibersihkan dengan bur karbid tungsten dan permukaan enamel digilap dengan pumis dan cawan getah. Permukaan enamel difoto semula (T2). Skor KE sebelum ikatan braket (T1) dan selepas penyahikatan braket (T2) direkod untuk perbandingan. Ujian “Independent t-test” dan “Chi-square” diaplikasi untuk analisa. KIG braket yang diikat dengan LED tidak berbeda secara signifikan dengan braket yang diikat menggunakan TQH selepas dinyahikat dengan mesin Instron. Kedua-dua kumpulan braket menunjukkan KIG yang berpatutan sebanyak 8.64Mpa. Walau bagaimanapun, IRBP adalah lebih tinggi (54.1%) bagi kumpulan LED berbanding dengan TQH (43.17%) memberi indikasi kurang kegagalan ikatan. KE tidak berbeda secara signifikan di antara kedua-dua kumpulan. Bagi braket yang dinyahikat menggunakan playar konvensional, IRBP kedua-dua kumpulan tidak berbeda secara signifikan tetapi peratus KE adalah lebih tinggi bagi kumpulan TQH (71.4%) berbanding LED (28.6%) memberi indikasi lebih kerosakan pada permukaan enamel. Walaupun kedua-dua jenis cahaya menunjukkan KIG yang berpatutan, cahaya LED adalah lebih baik kerana masa pempolimeran lebih singkat, kurang kegagalan ikatan dan kurang KE.

**COMPARISON OF SHEAR BOND STRENGTH, ADHESIVE REMNANT INDEX AND ENAMEL DAMAGE USING DIFFERENT LIGHT SOURCE IN DEBONDING OF ORTHODONTIC BRACKETS**

## ABSTRACT

Light-curing orthodontic adhesives require light with sufficient intensity and defined wavelength to initiate polymerization. Insufficient light intensity and wavelength causes incomplete polymerization, which decreases shear bond strength (SBS) and render brackets unable to resist intra-oral forces of occlusion or orthodontic forces. During debonding of orthodontic brackets, adhesive remnants remain on the enamel surface and enamel damage (ED) may occur. This study compared the SBS of brackets when cured with two different light sources, the light-emitting diode (LED) and tungsten-quartz-halogen (TQH), and compare the adhesive remnant index (ARI) and ED after debonding. Enamel surfaces of 104 premolars were cleaned and photographed (T1) with a magnifying loupe 60X Olympus stereomicroscope with digital camera to evaluate enamel surfaces before bonding procedure according to a predetermined scale. The teeth were then etched with Self-Etching Primer and bonded with stainless steel brackets using Transbond Adhesive and divided into two groups. In group I, 52 stainless steel brackets were bonded to enamel with LED for 10 seconds and in group II, 52 stainless steel brackets were bonded to enamel with TQH for 20 seconds according to manufacturer's instruction. All teeth were then stored in distilled water for one week to simulate oral environment. Before bracket debonding, each group was divided into subgroup A and B. In subgroup A, 26 brackets were removed using Instron machine

(Instron) at a cross head speed of 1mm/min in order to measure and compare the SBS. In subgroup B, 26 brackets were removed using conventional pliers. After debonding, all enamel surfaces were re-analyzed. The area of residual resin on the enamel was measured and ARI percentages calculated. Resin remnants after debonding was cleaned with tungsten carbide bur and the enamel surfaces were polished with pumice and rubber cups. These surfaces were re-photographed (T2). The ED scores (T1) before bonding and (T2) after debonding were recorded and compared. Independent t-test and Chi-square test were applied. The SBS of brackets cured with LED were not significantly different from those cured with TQH after debonding with Instron machine. Both groups showed acceptable SBS of 8.64MPa. However, the ARI was significantly higher in the LED (54.1%) group compared with TQH (43.17%) indicating less bond failure. ED was not significantly different between the two groups. For brackets debonded with conventional pliers, ARI was not significantly different between the two groups but ED were significantly higher in TQH (71.4%) compared to LED group (28.6%) indicating more ED. Although both light sources showed acceptable SBS, LED light seems more advantageous than TQH due to shorter curing time, less bond failure and less ED.

# CHAPTER ONE

# INTRODUCTION

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# INTRODUCTION

## 1.1. Background of the study

In orthodontics, the acid-etch technique has been widely used to directly bond attachments to enamel surfaces (Bishara *et al.*, 2004). For years, the self-cured resin which begins to polymerize upon mixing, was the only type of adhesive available. One disadvantage of this resin is that the working time is limited. Studies have shown that the bond strength of the resin is weakened when air is incorporated during mixing or when the pastes are incompletely mixed (Signorelli *et al.*, 2006).

Buonocore in1970 introduced the first photosensitive light–cured resin (Signorelli *et al.*, 2006). The composition of light cure composites include organic polymer matrix, inorganic filler particles, coupling agent, and type of photoinitiators (Dunn and Bush, 2002). Camphoroquinone (CQ), a photoinitiator used in most resin composites has an absorption spectrum of 410 to 490 nm, with its peak at 468 nm (Niepraschk *et al.*, 2007). Radicals that initiate polymerization are formed when CQ is exposed to light in the presence of a reducing amine (Niepraschk *et al.*, 2007). Resin polymerization occurs when carbon double bonds in methacrylate monomers are selectively converted into single bonds, propagating polymer growth by free radicals created by light activation of diketone photoinitiators in the blue range of the visible spectrum at approximately 468 nm (Judy *et al.*, 2006).

In orthodontics, the advantages of light-cured materials are ease of manipulation, improved bracket placement (Manzo *et al.*, 2004) and longer working time before polymerization begins (Mavropoulos *et al.*, 2005).

In modern clinical practice, visible light-curing units (LCUs) play an important role by providing rapid resin-based composite polymerization on command (Judy *et al.*, 2006), thus driving an increasing number of orthodontic practices to use light-cure adhesives instead of the more traditional two-paste adhesives that require in-office mixing (Üsümez *et al.*, 2004).

At present, most sources of visible blue light used in orthodontic practice are Tungsten-Quartz- Halogen (TQH) LCUs (Oyama *et al.*, 2004). Halogen lamps have been widely used as the main curing light for composite resins (Koupis *et al.*, 2008). When light is emitted from a white halogen bulb filled with iodine or bromide gas containing a tungsten filament, the tungsten filament glows when connected to an electric current (Meyer *et al.*, 2002). Not only is a very powerful constant light produced, but also a considerable amount of heat, despite the placement of appropriate filters between the light source and the light guide of the halogen units (Althoff and Hartung, 2000).

Despite their popularity, TQH lights have several drawbacks such as the halogen bulbs have limited effective lifetime of approximately 100 hours (Dunn and Taloumis, 2002; Jandt *et al.*, 2000). The output of halogen bulbs may be reduced by degradation, reflection, cracked filters, breakage of optical fibers and tip (Rego and Romano, 2007) which may reduce the effectiveness of the halogen light unit in curing dental materials (Jandt *et al.*, 2000). Nevertheless, the relatively long curing time needed with conventional halogen curing light (HCL) still seem inconvenient (Manzo *et al.*, 2004).

In an attempt to overcome the limitations of the conventional halogen-based curing units such as the undesirable infrared and ultraviolet radiation, degradation of the bulbs, filter and photoconductive fibers over time and the limited effective lifetime (Koupis *et al.*, 2008), light-emitting diode (LED) technology has been proposed as an alternative for curing Visible Light Cure (VLC) dental materials (Jandt *et al.*, 2000). Instead of the hot filament used in halogen bulbs (Koupis *et al.*, 2008), LEDs use junctions of semiconductors (p–n junctions) to produce light by electroluminescence. The semiconductor usually consists of gallium nitride. Thus, the light produced is emitted in the blue region of the visible spectrum so that no filters are required in these curing units (Mavropoulos *et al.*, 2005). Furthermore, in contrast with TQH-based units that undergo a little degradation of light output over time, LED-based curing units have been reported to have an expected lifetime of several thousand hours (Stahl *et al.*, 2000).

LED-based curing units consume less power making them suitable for portable use. Because they are solid state devices, they can be manufactured to extremely small dimensions and withstand mechanical shock and vibration with low failure rates. LEDs are commonly used in everyday household appliances such as indicator lights and sensors and in the dashboard instrument panels of automobiles.

There are other methods for curing dental composite resins such as Xenon plasma arc lights and argon lasers which dramatically reduce the curing time for dental composite resins. But they are substantially more expensive and bulky (Judy *et al.*, 2006). The advantages of LEDs over halogen and plasma arc curing lights are that they are cordless, smaller and lighter (Dunn and Taloumis, 2002).

The reduced curing time achieved with the newer LED technology lights is an advantage for clinicians since it reduces the risk of saliva contamination and further reduces the incidence of bond failure (Sfondrini *et al.*, 2001; Thind *et al.*, 2006). Even though, at present, LEDs are nearly three times the price of conventional light sources, a busy orthodontic practice may find them a worthwhile investment for the working time it can save. The LED curing light does not have a bulb. Therefore, there is no potential for loss of intensity in light output with time nor is there a requirement for periodic replacement. Reduced running costs and improved reliability could make it cost effective even though the initial cost is greater (Thind *et al.*, 2006).

During an average orthodontic treatment of 2 year duration, the bonding interface between bracket and tooth should be strong enough to resist the applied forces and weak enough to prevent tissue damage upon bracket debonding (Bishara *et al.*, 2001; Brosh *et al.*, 2005). A successful bonding material must be dimensionally stable, flowable enough to penetrate the enamel surface, have excellent inherent strength and must be easy to use clinically (William and Henry, 2000).

The introduction of several bonding materials with improved bond strength and handling characteristics have led to the evolution of different bonding techniques. Along with bond strength and ease of application, the residual resin on the tooth surface after debonding is an important consideration (Sinha *et al.*, 1995). Recently, new self-etching primers (SEP) such as Transbond Plus SEP (3M Unitek, Monrovia, Calif) was developed especially for orthodontic bonding which include methacrylate phosphoric acid esters that will both etch and prime the enamel surface before bonding. The manufacturers claim that good results can be achieved with a more conservative etch pattern thereby reducing enamel dissolution (Bishara *et al.*, 1998; Dorminey *et al.*, 2003). Bond failure rates against the time saved in bonding and debonding is an important factor that every clinician must consider when selecting an etching and priming system (Zachrisson and Buyukyilmaz, 2005).

Reduced bonding time would have a number of advantages:

1. Increased comfort for the patient

2. Less chance of bracket drift prior to curing
3. Less time for moisture contamination
4. Less stress for the operator
5. Cost saving by reducing chairside time

(Pettemerides *et al.*, 2004).

The integrity of the enamel surface should be given utmost importance by every orthodontist. Therefore, all procedures involved in bracket bonding and debonding should be performed with extreme care e.g. prophylaxis of the enamel surface, optimal etching time, use of appliances that promote adequate bond strength and a reliable debonding technique (Kitahara-Ceia *et al.*, 2008).

Bond failure of brackets not only can be frustrating for the practitioner, but also can significantly affect treatment efficiency and have an economic impact on the practice. Often, the wire has to be removed to rectify the situation, thereby significantly delaying the progress of treatment (Northrup *et al.*, 2007).

Even though improvements in bracket engineering, debonding methods and debonding instruments have been made, yet enamel damage during the debonding of brackets is still a matter of concern for clinicians (Bishara *et al.*, 2008).

The bond strength of attachments must be sufficient to withstand functional forces but at a level to allow bracket debonding without causing damage to the enamel (Thind *et al.*, 2006). Various studies suggest that a bond strength ranging from 6 to 10 MPa is adequate (Sfondrini *et al.*, 2001, Thind *et al.*, 2006).

### 1.2. Statement of problem

With the introduction of photosensitive (light-cured) restorative materials in dentistry, various methods were suggested to enhance polymerization included layering and the use of more powerful light-curing devices. Orthodontics has benefited from LC materials and numerous LC adhesive systems to bond orthodontic brackets been developed. The advantage of LC adhesive systems is that they give ample time to accurately position the bracket on the enamel surface before polymerization. Perhaps a limitation taken to expose each bracket to the light to ensure adequate polymerization to sustain the orthodontic forces that will be immediately applied to the teeth at the time of insertion and initial ligation of the arch wires (Bishara *et al.*, 2003). Several factors including the type of bracket base retention mechanisms, the bonding system, and the type of enamel conditioner used determine bracket bond strength (Sorel *et al.*, 2002). Inadequate polymerization of adhesives and resultant unpolymerized monomers may lead to bracket failure (Abtahi and Khamverdy, 2006). The degree of cure depends on the intensity and quality of the light to which they are exposed and the curing time applied (Sfondrini *et al.*, 2006). Recently, various methods such as LED LCUs have been used to polymerize resin-based orthodontic adhesives, and preliminary studies indicate that their use to be successful (Swanson *et al.*, 2004).

In orthodontics treatment, enamel surfaces could be damaged due to cleaning with abrasives before etching, during the acid etching process, enamel fractures (EF) caused by forcibly removing brackets or mechanically removing remaining composite with rotary instruments (Hosein *et al.*, 2004). Returning the enamel surface to its original state after removal of orthodontic attachments is one of the primary concerns in orthodontics (Campbell, 1995). The ideal would be minimal loss of enamel at each stage of bonding, debonding and enamel cleanup process and the production of an enamel surface with the same degree of roughness or smoothness as the original (Hosein *et al.*, 2004). Shear/peeling, tensile or torque forces can cause bracket detachment mainly at bracket/adhesive or adhesive/tooth interface. Detachment location is also influenced by tooth preparation procedure before bonding (Brosh *et al.*, 2005). Several studies have focused on the stress distribution of an enamel/adhesive/bracket interface during different loading modes. DeHoff *et al.* (1995) showed that stress distribution across the enamel/adhesive interface was far from homogeneous and that the shear mode could cause cohesive failure. A study by Liu *et al.* (2002) on the shear bond strengths (SBS) of metal brackets bonded with adhesives revealed that failure occurred predominantly at the enamel/adhesive interface. When the bond strength of various bracket base designs was examined, it was also found that most debonding interfaces are located at the bracket/adhesive interface and at the enamel/adhesive interface and not within the adhesive itself (Wang *et al.*, 2004). In addition to shear, a twisting force is often used to debond brackets. Excessive debonding strength causes enamel cracks that are less likely to appear when lower forces are applied (Bishara *et al.*, 1995). The highest bond strength might not be the most desirable factor since brackets must eventually be removed and enamel damage (ED) during debonding could lead to clinical problems if bond strengths are excessive (Dunn and Taloumis, 2002).

### 1.3. Justification of the study

Light-cured orthodontic adhesives require a light curing source with sufficient intensity and defined wave length to initiate the polymerization reaction (Niepraschk *et al.*, 2007). Failing to achieve the sufficient light intensity and defined wave length may lead to incomplete polymerization which decreases the shear bond strength and lead to high bracket bond failure rate (Dunn and Taloumis, 2002; Krishnaswamy and Sunitha, 2007; Oesterle *et al.*, 2001). When the orthodontic bracket is debonded, not only do some adhesive remnants remain on the enamel surface, but enamel fracture or enamel damage (ED) may also occur (Sorel *et al.*, 2002). This type of ED causes staining and may lead to plaque accumulation on the rough fractured surface which in turn can cause caries. Although the traumatic effects on the enamel surface is inevitable, ED can be reduced if the appropriate light curing device (Pettemerides *et al.*, 2004; Thind *et al.*, 2006) and debonding procedure is used.

For that reason, the purpose of this study is to compare the shear bond strength (SBS) of bonded orthodontic brackets when cured with two different types of curing light, the light-emitting diode (LED) and tungsten-quartz-halogen (TQH) and to compare the adhesive remnant index (ARI) and enamel damage (ED) between the two different groups after debonding of orthodontic brackets. It is hoped that this study will help orthodontists to choose the appropriate curing light and debonding techniques, in order to maximize benefits for their patients and achieve the minimum traumatic effects to the patient's teeth.

## 1.4. Objectives

### 1.4.1. General objectives:

To compare the Shear Bond Strength (SBS), Adhesive Remnant Index (ARI) and Enamel Damage (ED) of orthodontic brackets using self-etching primer (SEP) when cured with two different types of curing devices, the light-emitting diode (LED) (Ortholux LED, 3M Unitek) and tungsten-quartz-halogen (TQH) (Ortholux XT, 3M Unitek) after debonding by Instron testing machine and conventional pliers. Instron machine was selected because it is able to measure the shear bond strength (SBS) of orthodontic brackets and conventional pliers were selected as it is widely used in all orthodontic clinics by orthodontists.

### 1.4.2. Specific Objectives:

1. To compare the SBS of orthodontic brackets using SEP cured with different light sources that are LED (Ortholux LED 3M Unitek) and TQH (Ortholux XT 3M Unitek).

2. To compare the ARI following the use of LED (Ortholux LED 3M Unitek) and TQH (Ortholux XT 3M Unitek) after bracket debonding by Instron testing machine and conventional pliers.

3. To compare the ED following the use of LED (Ortholux LED 3M Unitek) and TQH (Ortholux XT 3M Unitek) after bracket debonding by Instron testing machine and conventional pliers.

### 1.4.3. Research Hypothesis

1. There is a significant difference in SBS of orthodontic brackets using SEP cured with LED (Ortholux LED 3M Unitek) and TQH (Ortholux XT 3M Unitek).

2. There is a significant difference in ARI using LED (Ortholux LED 3M Unitek) and TQH (Ortholux XT 3M Unitek) after debonding by Instron testing machine and conventional pliers.

3. There is a significant difference in the ED following the use of LED (Ortholux LED 3M Unitek) and TQH (Ortholux XT 3M Unitek) after debonding by Instron testing machine and conventional pliers.

## 1.5. Operational definitions

**Light curing (LC)**

It is a photo-induced polymerization reaction when a liquid monomer is exposed to ultraviolet (UV) light or visible light (VL) and converted to solid monomer (Sfondrini *et al.*, 2001).

**Tungsten- Quartz- Halogen (TQH)**

It is the VL emitted from a white halogen bulb which is filled with iodine gas and contain tungsten filament that produce light of 400-500 nm (Krishnaswamy and Sunitha, 2007).

**Light Emitting Diode (LED)**

It is the VL emitted from semiconductors which consist of gallium nitride that produce light in 430-480 nm (Rego and Romano, 2007).

**Self-etching primer (SEP)**

It is a simplified adhesive system characterized by a combination of etchant + priming agent in a single application solution (Dorminey *et al.*, 2003).

**Enamel damage (ED)**

It is the amount of enamel fractures or cracks caused by forcibly removing brackets (Bishara *et al.*, 2008).

**Shear Bond Strength (SBS)**

It is a term used to describe the maximum strength of bonding when a force applied as shear stresses to dislodge the bonds (Thind *et al.*, 2006).

**Adhesive Remnant Index (ARI)**

It is an index used to measure the remaining amount of the adhesive after debonding of orthodontic brackets (Montasser and Drummond, 2009).

**Universal test machine (UTM)**

It is a united test machine used to measure the accurate tensile, compression, bending, cutting, shearing and tearing forces for any material (Northrup *et al.*, 2007).

**Image Analyzer (IA)**

It is an instrument use for surface investigation of enamel surface and adhesive remnant calculation, after orthodontic bracket debonding (Osorio *et al.*, 1999).

**Optical stereomicroscope (OSM)**

It is a tool use for surface investigation of enamel and hard tissue surfaces with different magnification loupe, after orthodontic bracket debonding (Kitahara-Ceia *et al.*, 2008).

**Scanning electron microscope (SEM)**

It is the type of electron microscope that creates various images by focusing a high energy beam of electrons onto the surface of a sample and detecting signals from the interaction of the incident electrons with the samples interface (Eminkahyagil *et al.*, 2006).

**Composite Resin (CR)**

It is the types of synthetic resins which are used in dentistry as restorative material or adhesives (Millett and McCabe, 1996).

**Tungsten carbide bur (TCB)**

It is a rotary dental bur containing equal parts of tungsten and carbon atoms, used for dental drill or composite remnant removal (Zachrisson and Buyukyilmaz, 2005).

# CHAPTER TWO

# LITERATURE REVIEW

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1. Bonding of orthodontic brackets

Since 1965, direct bonding of brackets to tooth surfaces had been a significant milestone in the practice of orthodontics (Northrup *et al.*, 2007). As stated by Owens and Miller (2000) the efforts of Buonocore, Bowen, Wilson and Tavas made the concept of direct bonding of brackets to teeth a reality.

Three types of attachments are presently available for orthodontic bracket bonding: metal-based (stainless steel, gold-coated, titanium), ceramic-based and plastic-based. Of these, most clinicians prefer metal attachments for routine applications especially in children (Zachrisson and Buyukyilmaz, 2005).

There are two techniques for bonding; direct and indirect techniques. Direct bonding does not provide as accurate a placement of brackets as indirect bonding. However, direct bonding is easier, faster (especially if only a few teeth are to be bonded) and less expensive because the laboratory fabrication steps are eliminated (William and Henry, 2000). Direct bonding of orthodontic brackets is now routinely performed for aesthetic reasons (Bishara *et al.*, 2008).

Before bonding an orthodontic attachment, it is necessary to remove the enamel pellicle and to create irregularities on the enamel surface. This is accomplished by gently cleaning and drying the enamel surface with a little pumice, then treating it with an etching agent (William and Henry, 2000). According to Zachrisson and Büyükyilmaz (2005), the standard direct bonding procedure of orthodontic brackets involves cleaning, enamel conditioning, sealing and bonding of adhesive.

## 2.2. Enamel conditioning

### 2.2.1. Acid conditioning

Acid etching or conditioning was initially introduced in 1955 by Buonocore. He demonstrated a markedly increased retention of methyl methacrylate resins to enamel when their application was preceded by enamel conditioning using 85% phosphoric acid for 30 seconds. Subsequently, the optimum concentration of acid to produce a consistent evenly distributed and optimal depth of etch pattern was reported to be in the range of 30 to 50% concentration (Vicente *et al.*, 2006).

Acid conditioning modifies the enamel surface allowing an intimate micro-mechanical bond between enamel and the composite resin (CR) component. The conditioning process increases surface roughness of the enamel and hence the surface area by removing the hydroxyapatite crystals from the enamel surface. Thus, the surface characteristics of enamel are changed due to preferential dissolution between the prism periphery and its core. Following acid conditioning, the enamel surface assumes a microscopic honeycomb lattice appearance. The surface layer of enamel lost during conditioning varies between 10-30 μm (Bishara *et al.*, 2000). The acid also has the effect of raising the surface energy of enamel from a low-energy hydrophobic surface to a high energy hydrophilic surface. This surface modification increases enamel surface tension and wettability by the cement. Thus, it facilitates the flow of the resin material over the enamel surface, allowing greater penetration of resin tags into the undercuts of the conditioned surfaces. After polymerization, the adhesive resin tags form a tightly interlocking mechanical bond with the conditioned enamel (Tang *et al.*, 2000).

Kinch *et al.* (1988) stated that an etch time of 15 seconds with 37% phosphoric acid gel has been recommended for anterior teeth and premolars. While Gardner and Hobson (2001) stated that the use of 37% phosphoric acid with a 30 second etch time has been confirmed as a sensible routine choice for routine orthodontic bonding.

Buonocore *et al.* (1968) showed that the depth of penetration of the resin tags reached up to 50 μm (Bishara et al., 2000). This resin is thought to remain on the enamel after debonding, and this could cause plaque retention, susceptibility to caries and discoloration (Waveren *et al.*, 2000). Since phosphoric acid conditioning may potentially damage enamel integrity, numerous investigations have been conducted to assess the merits of alternative treatments such as reducing acid concentration and time, the use of maleic acid (MacColl *et al.*, 1998) and polyacrylic acid (Smith and Cartz, 1973).

Investigations concerning reducing either the concentrations of the acid or the conditioning time have concluded that varying phosphoric acid concentration from 5% to 37% (Legler *et al.*, 1989; Sadowsky *et al.*, 1990; Stahl *et al.*, 2000) or reducing the conditioning time from 60 to 15 seconds (Legler *et al.*, 1989; Sadowsky *et al.*, 1990; Stahl *et al.*, 2000) and even 10 seconds (Olsen *et al.*, 1996) does not significantly affect bond strength. Thus, reducing acid concentration and conditioning time within certain limits produces less tooth damage whilst still yielding adequate bond strength. These methods can provide a SBS above the threshold of 6-8 MPa but at 30% lower than that achieved with phosphoric acid (Bishara et al., 2000). However there has been reports that reduction of conditioning time within certain limits (5 seconds) resulted in inadequate bond strength (Olsen *et al.*, 1996). According to Wang and Lu (1991) the shorter the conditioning time, the lesser is the depth of enamel loss and the fewer enamel fractures during debonding.

MacColl *et al.* (1998) compared SBS of metal brackets bonded to bovine enamel using four different conditioners: 37% Phosphoric acid (aqueous solution and gel) and 10% maleic acid (aqueous solution and gel) for 20 seconds. He demonstrated that conditioning with aqueous maleic acid (10%) was associated with the highest SBS. There was no statistically significant difference between the other three acid types used. Acid conditioning in general, may initiate enamel decalcification by removing highly mineralized fluoride rich surface enamel. However it may also promote enamel fracture during debonding due to adherent resin cement tags within the micro-porosities. The clean-up procedure of the cement after debonding may remove up to 55 microns of surface enamel (Bishara *et al.*, 2000). Therefore, using phosphoric acid for acid conditioning carries a potential risk for significant enamel loss either during conditioning or following removal of penetrated resin cement. As a result, any bonding system that can produce adequate bond strengths without any significant enamel surface alteration, subsequent decalcification, and possible enamel fracture will be a superior system (Bishara *et al.*, 2000).

### 2.2.2. Crystal Growth

Crystal growth introduced by Smith and Cartz (1973) is an alternative method of enamel surface preparation. The authors showed that polyacrylic acid containing residual sulfate ions reacted with the enamel surface to produce a deposit of white spherulitic crystalline calcium sulfate to which the adhesive resin bonds. They identified these crystals as calcium sulfate dehydrate (gypsum). The authors postulated that the carboxyl groups in the long chain polyacrylic acid molecules have the ability to chelate to calcium in the minera1 phase of tooth structure resulting in adhesion (Devanna and Keluskar, 2008). The formation of these crystals depended mainly on the sulfate ion concentration in the polyacrylic acid solution. Phosphoric acid produced only slight etching of the enamel surface whereas polyacrylic solutions that contained residual sulfate ions produced not only slight etching of the enamel but also a crystalline deposit that bonds firmly to the enamel surface (Smith and Cartz, 1973). They also demonstrated that the maximum density of the long, needle-shaped crystals growing on the enamel surface occurred after conditioning for 4 minutes with 40% polyacrylic acid. With this method of enamel conditioning, the resin penetrates the deposited crystals on the surface rather than the enamel itself (Devanna and Keluskar, 2008). The method of crystal growth for bonding has a few advantages over the etching (conditioning) technique with phosphoric acid. These advantages are: (1) minimal damage to the enamel surface, (2) easier debonding and enamel cleanup, (3) minimal loss of outer fluoride rich enamel layer, and (4) few if any resin tag remnants after debonding (Devanna and Keluskar, 2008).

Bishara *et al* (2000) compared the etch pattern of enamel surface when it was etched with 37% phosphoric acid, 10% polyacrylic acid, and 20% polyacrylic acid. When the enamel surface was examined under an electron microscope, phosphoric acid conditioning produced a much deeper etch (rougher enamel surface) than the polyacrylic acid. It has been demonstrated that the use of crystal growth enamel conditioning with polyacrylic acid, significantly increases the incidence of bond failure at the enamel-cement interface, but the bond actually fails within the crystals and not at the enamel surface. As a result, the incidence of enamel fracture is decreased (Maijer and Smith, 1979). The authors tested the value of this crystalline interface as an enhancer of the mechanical retention of orthodontic brackets. The results of their study showed that the crystalline interface produced tensile bond strength equivalent to that of a conventionally acid-conditioned enamel surface. However, other investigator (Farquhar, 1986; Maskeroni *et al.*, 1990) found that bond strengths with the use of crystal growth conditioning were significantly weaker than with the conventional acid conditioning techniques. Bishara *et al.* (1993) compared various conditioner-cement combinations and indicated that the use of polyacrylic acid as an enamel conditioner resulted in a 30% reduction in bond strength as compared with the use of phosphoric acid. However, despite this reduction, the bond strengths were acceptable for orthodontic purposes.

### 2.2.3. Adhesive Primer

Conventionally, after the enamel surface is conditioned with phosphoric acid, an intermediate unfilled low viscosity liquid resin (adhesive primer) is applied in order to thoroughly wet the enamel surface so that the bond between enamel and the resin cement is maximized. Application and curing of this adhesive primer results in resin tags that extend into the micro-porosities that are produced by acid conditioning. These resin tags bond the composite cement mechanically to enamel (Olsen *et al.*, 1996). An adhesive primer is a multifunctional monomer with a hydrophilic end that wets and bonds to tooth structure and a hydrophobic end that reacts with the double carbon bonds of the resin cement. Research has shown that the application of a layer of unfilled adhesive resin to the conditioned tooth surface prior to placement of the composite resin cement and bracket does not increase the bond strength and can, therefore, be omitted (O'Brien *et al.*, 1991; Wang and Tarng, 1991).

Tang *et al.* (2000) performed a retrospective clinical study to evaluate the retention of metal orthodontic brackets bonded without adhesive primer. In both the test and control groups the enamel was conditioned using 37% phosphoric acid. In the experimental group (n=37) Phase II resin cement (two paste auto-polymerized resin) without adhesive primer was used to bond brackets to patients' maxillary teeth. Brackets in the control group (n=37) were bonded to the teeth with Phase II and adhesive primer. The results showed that the exclusion of an adhesive primer from the auto-polymerized two paste bonding CR cement appeared to have no detrimental clinical effect.

### 2.2.4. Self-etching primers (SEP)

A recent development in the field of bonding is the use of innovative self-etching acidic primers. These materials serve simultaneously as conditioner and primer and do not have to be rinsed off. The acidic part of the primer is neutralized at some point by the calcium and phosphate ions released during demineralization. Demineralization is, therefore, self-limiting in that the high concentration of these ions tends to limit further dissolution of hydroxyapatite (Bishara *et al.*, 1998; Dorminey *et al.*, 2003). The acidic primers form a continuum between the tooth surface and the cement material by simultaneous demineralization and resin penetration of the enamel (Bishara *et al.*, 1998; Dorminey *et al.*, 2003). The advantages of acidic primers are simplified bonding procedures and improvement in both reduced working time and cross contamination to clinicians (Bishara *et al.*, 1998; Rajagopal *et al.*, 2004). As the monomers that cause etching are also responsible for bonding, the depth of the demineralization zone corresponds to the depth of penetration of the adhesive to be polymerized. This avoids problems with insufficient penetration depth and improves the quality of hybridization (Dorminey *et al.*, 2003).

The main features of the single step etch/primer bonding systems is that no separate acid etching of the enamel and subsequent rinsing with water and air spray is required. The liquid itself has a component that conditions the enamel surface. The active ingredient of SEPs is a methacrylate phosphoric acid ester that dissolves calcium from hydroxyapatite. Rather than being rinsed away, the removed calcium forms a complex and is incorporated into the network when the primer polymerizes. Etching and monomer penetration to the exposed enamel rods are simultaneous, and the depth of etch and primer penetration are identical (Zachrisson and Büyükyilmaz, 2005).

The use of acidic or self-etching acidic primers for orthodontic purposes has been evaluated in two different studies by Bishara and colleagues (Bishara *et al.*, 1998; Bishara *et al.*, 1999). The study conducted in 1998 showed that the use of an acidic primer to bond orthodontic brackets to the enamel surface provided clinically acceptable SBS (11.8± 4.1 MPa). It also decreased the amount of CR cement left on the tooth after debonding. This observation was illustrated by examining scanning electron micrographs (SEM) of the enamel surfaces. The SEM for acid conditioned enamel showed thick and uniform CR resin tags whereas the CR resin tags for the self-etching acidic primer treated enamel were thin and less uniform. The latter observation supports the finding that there is a weaker bond between the enamel and the CR cement with resulting less cement left on the tooth after debonding.