A Literature Review on the Correlation Between Shear Bond Strength and the Degree of Conversion of Orthodontic Adhesive Systems

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Abstract

Objectives: The purpose of this study is to provide a comprehensive literature review on the correlation between shear bond strength and the degree of conversion of the orthodontic adhesive systems. Thus, this is considered as a major issue for the success of the orthodontic bonding techniques. *Material and Methods:* Electronic searches were performed in Pubmed and Scopus databases using relevant keywords. Textbook searching was also applied. Following the selection, full-text English language papers were fully reviewed to ensure that they met both the inclusion and the exclusion criteria. *Results:* Recent studies suggest that when increasing the DC, the SBS will increase. Thus, this results to a stiffer and a more durable resin. *Conclusions:* There is a wide range of factors affecting the SBS, DC, and their correlation. Some of them are related to the tooth etching techniques, adhesive related factors, curing units, and bracket materials. More research is required to develop more understanding of the role of these factors in determining the bonding success. This is because there are no specific published papers which were directly linked to the correlation between the SBS and the DC of orthodontic adhesives.

Introduction

Orthodontic appliances produce controls force to create a specific tooth movement, and they are divided into two main categories: fixed and removable appliances (Foster, 1990). The success of a fixed appliance is related to the attachment systems, brackets and bands being firmly attached to the teeth, such that they cannot easily change their position during orthodontic treatment (Millett et al., 2007). In the 1980s, a fixed attachment which can be bonded to a tooth using the acid-etch bonding systems was developed, and it eliminated the need for banding (Millett et al., 2007).

The bond strength of the bracket-adhesive-enamel system in orthodontic bonding techniques depends on: the type of adhesive used; the design of the bracket base; enamel morphology; appliance force; and the clinician's technique (Proffit et al., 2007). Bracket bonding technique is based on the formation of a mechanical lock between the adhesive and the irregularities in the enamel surface of the tooth, and to the mechanical locks that is formed at the base of the orthodontic bracket (Proffit et al., 2007).

In case Bond failures occur between the tooth and the bracket, the progress of the treatment and the cost will be negatively affected. Here, it consumes more clinical time, materials, and time loss for the patient (Proffit et al., 2007). The adhesive should be ideally strong. This would make the brackets stay bonded in their position for the length of the treatment. On the other hand, the bond between the tooth and the bracket should not be over strong. Therefore, this would help to prevent the damage that may occur to the tooth surface upon removal of the bracket (Proffit et al., 2007). Subsequently, from a broad perspective, it all depends on the degree of conversion and the shear bond strength of the orthodontic adhesive system. Previous studies stated that by increasing the degree of conversion of resin composite, the mechanical properties of the material would improve (Watt, 2001; Bang et al., 2004; Dall'Igna et al., 2011).

Shear forces are unaligned forces pushing one part of the body in one direction, and another part in the opposite direction. Thus, this was commonly reported in MPa. Numerous publications have evaluated the bracket shear bond strength. This is because it is almost impossible to independently analyze all the variables that affect the bonding system in the oral environment (Bayne, 2002).

Furthermore, in-vitro studies the utilization of more standardized protocols for testing different bonding systems and materials. Thus, this is done much easier using the Universal testing machine (Bayne, 2002). It has been speculated that an adhesive-bracket system should be able to withstand a stress of at least 6-8 MPa (Reynolds, 1975; Powers, 2001). However, high values exceeding 13.5Mpa are considered to as excessive for orthodontic

use; thus, this result to a significant risk of enamel fracture on debonding (Foster, 1990).

The Degree of Conversion of resin materials is the extent to which carbon double bonds (C=C) of the monomer are converted into carbon single bonds (C-C) to form polymers during the polymerization reaction. Adhesive resin should ideally have all of its monomer converted to polymer during polymerization reaction. However, the DC% ranges from 55% to 75% under conventional light irradiation. DC can be measured by various spectroscopic methods including Fourier transform infrared (FTIR) spectroscopy and Raman microspectroscopy (Pianelli et al., 1999; Soh et al., 2004).

Raman microspectroscopy is a tool for polymers characterization, especially for the components that are present in small concentrations. When the radiation from a monochromatic source (a laser) is focused on the microregion of the sample, the radiation fraction scattered by the sample consists of a radiation component known as the Rayleigh line and other weak lines called Raman lines (Eliades & Eliades, 2001b). The frequency shifts of the Raman lines from the Rayleigh line corresponds to the molecular vibrational frequencies within the molecules of the sample. The lines of the Raman frequencies as a function of their intensities results in the formation of the Raman spectrum. This spectrum, thus, provides a detailed analysis of the structure, orientation, and the chemical structure of a sample (Eliades & Eliades, 2001b).

Raman microspectroscopy when compared to FTIR spectroscopy has several advantages. The vibrational spectrum is probed with one instrument at an increased sensitivity and at a high spatial resolution (~1 μm) (Eliades & Eliades, 2001b). Moreover, sampling procedure is easily performed and is non-destructive for most applications (Soh et al., 2004; Eliades & Eliades, 2001b).

DC affects the physical properties of composites as the polymerization of the monomer into polymer increases. The rigidity of the polymer molecule also increases, which also affect other properties such as solubility and degradation. Any totally unreacted monomer will act as a plasticizing agent and result in a polymer network with less ideal mechanical properties (Yoshida et al., 2012; Rueggeberg, 2002; Sherwood, 2010).

Correlation of the Degree of Conversion and Shear Bond Strength

In particular, it has been found that increasing the Degree of Conversion will results in increasing the Shear Bond Strength. Therefore, this would lead to a stiffer and a more durable resin (Watts, 2001; Yoshida, 2012; Sherwood, 2010).

Discussion

There are many factors which have contributed to the degree of conversion, shear bond strength, and their correlation. These factors are related to the bracket materials, etching techniques, bracket adhesives, curing units, and curing time (Sherwood, 2010).

The Bracket Material

There are several types of bracket materials: Metallic brackets such as SS, Gold, NiTi, Plastics, Ceramics, and Combination.

The ceramic brackets showed a significantly higher SBS than that of the SS type. Enamel fractures occurred in 40% of the group of ceramic brackets. The fracture of enamel is a real possibility during therapy or at the debonding of the ceramic brackets (Joseph & Rossouw, 1990).

Tooth Etching Techniques

Therefore, there are different etching techniques which include: sandblasting, acid etching, and low level laser etching.

Sandblasting was introduced by using aluminum oxide particles to produce roughness in the enamel surfaces. This was done in order to achieve proper etching that result in a better bond strength. However, several studies recorded that it may cause marked destructive effect on enamel surface which is unfavorable for rebonding procedures (Bakhadher et al., 2015).

Acid Etching relies on the micro mechanical retention obtained on the enamel surface by an acidic etchant, and subsequent penetration of the polymerized monomers into the interprismatic spaces to form enamel resin tags (Bakhadher et al., 2015).

Low level laser etching Er:YAG: By laser exposure, the enamel undergoes several physical changes, including melting and recrystallization, that lead to the formation of numerous pores, pittings, and small bubble like inclusions, the micro retention, and chemical adhesion of a restorative material to tooth structure which might be increased (Bakhadher et al., 2015).

Sagir et al. (2013), in their study, compared the effect of laser irradiation and acid etching on the SBS of orthodontic brackets. However, they found that the Er:YAG laser etching demonstrated significantly higher mean SBS compared to the acid-etched technique.

Bracket Adhesives

Consequently, there are several types of orthodontic adhesives which include the following:

GICs have been used in bracket bonding, for more than 30 years, because of no enamel etching, their ability to adhere to metal alloys, and

fluoride release which reduces the potential risk of enamel decalcification. Thus, their weak bond strength, prolonged setting reaction, late gain in strength, sensitivity to moisture contamination, and dehydration was the main drawback for further use (Toodehzaeim et al., 2012).

RMGICs: Searching for improved physical characteristics has led to the development of RMGICs. They are a hybrid of GICs with the addition of LC resin. They have the advantages of both materials, such as adhesion to tooth surface, releasing fluoride, hardening by visible light, and enhanced mechanical and physical properties. However, they are initially sensitive to moisture contamination, but later to dehydration, prolonged setting reaction, and a late gain in strength (Toodehzaeim et al., 2012).

Chemically-Cure Adhesives: They consist of two paste system. Upon mixing, the polymerization starts immediately. Thus, there is no possibility to manipulate the setting time which affects the bracket accurate position on the tooth surface (Rachala & Yelampalli, 2010; Abate et al., 2001). Also, the air bubbles might be incorporated in resins. Also, it can produce porosity which inhibit the polymerization and ultimately weakens the bond strength (Wilson, 1988; Mitchell, 1994; Nomoto, 1997; Eliades, 2006). Moreover, they consume more time due to several mixes which were often required to bond brackets to teeth in both arches (Sunna & Rock, 1999).

Light-Cure Adhesives: The composite resin polymerization starts when applying the light cure. Thus, the operator has unlimited working time and ability to remove the excess adhesive (Eliades & Eliades, 2001b; Read, 1984; Cunningham et al., 2002). The drawbacks of light-cure composite include: time required to cure under each bracket, and the possibility of insufficient exposure of the curing light that leads to incomplete polymerization of the resin under the bracket (Sunna & Rock, 1999; Smith & Shivapuja, 1993; Sagir et al., 2013).

Dually-Cured Adhesives: They are resins that were both light activated and chemically cured (Sagir et al., 2013). The term 'dual-curable luting composite' refers to an adhesive agent that contains chemical compounds behaving as accelerators and initiators for both chemical and light cure, and which can benefit from both polymerization systems (Tanoue et al., 2003; Arrais et al., 2008). The main clinical disadvantage of dual cured composites is that there is a limited working time due to their chemically cured properties. Once it has been initiated, polymerization cannot be stopped. Thus, if an operator is placed on a bracket with a half-cured adhesive or it attempted to remove access adhesive, the bond strength would be drastically affected (Sagir et al., 2013).

Light-curing Sources

Light-curing units that are available, have different light intensities, and light sources and energy levels ranging from 300 to more than 2000 Mw/cm2 (Santini, 2010). The efficacy of a light-curing unit depends on its ability to produce photo-radiation of appropriate wavelength and intensity to produce optimal number of free-radicals, which will increase possible polymerization reaction (Arrais et al., 2008). The intensity of light radiation is related to the power of the polymerization device, the surface area, and the time. Curing units that are available include: halogen curing lights, light emitting diodes, and plasma arc units (Lynch, 2008).

Quartz Tungsten Halogen: QTH curing units have been very popular because they have efficient light intensity, emit a broad spectrum light, and are relatively inexpensive (Burgess et al., 2002). The light is produced when a tungsten filament housed in a quartz bulb filled with halogen gas, emits electromagnetic radiation (Dall'Igna et al., 2011; Rueggeberg, 2002; Burgess et al., 2002; Robertson et al., 2006). However, the system's efficiency is compromised because the large part of the radiation power is wasted. Thus, this is considered as the main disadvantage of this type of light source (Santini, 2010; Lynch, 2010). The light power output is less than 1% of the consumed electrical power (Sagir et al., 2013; Althoff & Hartung, 2000; Oyama et al., 2004). Due to the possible heat generation, they also require a cooling system, a fan-generated air. Another disadvantage of halogen curing units is that the bulb, reflector, and filter can degrade over time. Thus, this reduces light output levels and compromises the photopolymerization process (Santini, 2010; Lynch, 2008; Burgress et al., 2002; Robertson et al., 2006; Sakaguchi et al., 2010; Nomoto et al., 2004; Oberholpez et al., 2005; Yazici et al., 2007).

Light Emitting Diode: A light-emitting diode (LED) uses diode technology which utilize chips containing "doped cells" (Sagir et al., 2013). Blue light is generated by a well-defined relaxation of excited electrons, and not by a thermal action (Althoff & Hartung, 2000). However, they generate a blue light of specific wavelength between 400 and 500 nm without the requirement of filters by using a semiconductor material system (Sherwood, 2010; Robertson et al., 2006; Oyama et al., 2004). When they were compared to the halogen curing units, they have much longer lifetimes and undergo few amount of degradation. Also, they are much more efficient, very shocking, and are vibration resistant in contrast to their halogen counterparts (Lynch, 2008; Burgress et al., 2002).

Advances in LED technology led to the development of high power units comparable to plasma arc curing sources (Santini, 2010; Oyama et al., 2004). LEDs have long life which is approximately 10,000 hours (Sagir et al., 2013; Oyama et al., 2004). Subsequently, the main disadvantage of LED

curing units is that they have a limited wavelength spectrum, which could only be used for camphoroquinone-based composite resins (Rueggeberg, 2002; Garg & Garg, 2004)

Plasma Arc Unit: Plasma arc curing unit was introduced as a means of rapid light curing by generating a high voltage current across two tungsten electrodes within a xenon-filled fluorescent bulb (Burgess et al., 2002; Oyama et al., 2004; Oberholpez et al., 2004; Garg & Garg, 2010). In terms of advantages, the life of PAs is much greater than that of QTH curing units. Moreover, they were intended to reduce curing times to as little as 3 sec (Lynch, 2008; Robertson et al., 2006). Through this process, they can cure composite resin more quickly compared to other curing light source (Burgess et al., 2002).

However, a concern with PA units is their low efficiency because only 1% of the energy is given light, while the remainder is converted to heat (Althoff & Hartung, 2000). Also, they have high power consumption, high operating temperatures that require a cooling system, bulky units that lack of portability, wide-spectrum light that must be filtered, and they are expensive (Santini, 2010; Burgess et al., 2002; Garg & Garg, 2010).

Polymerization Process of Light-Cured Adhesives

Light-cured adhesives contain a two-component initiator system: a ketone and an amine. The ketone is a photo-absorbing molecule which serves as an activator for polymerization (photoinitiator), while the amine is an accelerator. In most composite resins, the photoinitiator is usually camphoroquinone (Garg & Garg, 2010). It absorbs energy at the wavelength peak at approximately 465 – 470 nm within the blue region of the visible light spectrum (Lynch, 2008; Burgess et al., 2002; Althoff & Hartung, 2000).

Therefore, the greater the light intensity, the greater the number of photons that will reach the resin composite material and produce a greater number of excited camphoroquinone molecules. Inappropriate wavelength and intensities of the light from a curing unit are associated with inadequate polymerization (Garg & Garg, 2010). When the light intensity is less than optimal, a proportional increase in curing time can be applied to achieve optimal polymerization and the physical properties of the polymer. However, if the light source is inadequate to activate the polymerization reaction, no compensatory mechanisms can produce an optimally cured resin composite.

A minimum of $400mW/cm^2$ was recommended for routine polymerization of light-activated resin composites. Moreover, it was reported that other factors affecting polymerization include: composite filler type, size and loading, thickness and shade of the composite resin, effectiveness of light transmission through the light tip, light intensity, exposure time, and

distance of the light source from the composite resin (Santini, 2010; Lynch, 2008).

Curing Time and Total Energy

Inadequate curing time was associated with inadequate polymerization of composite resins including orthodontic adhesives that results in reduced orthodontic bracket bond. It is important for composite resin increment to be irradiated for an appropriate period of time, usually 20 to 30 seconds, which is the time required for the photoinitiator to be activated. If the curing time is reduced below the sufficient period, it tends to result in the early termination of polymerized chains. However, this chain increases the polymerization stresses and reduces the mechanical properties of the cured composite (Lynch, 2008).

Therefore, higher total energy delivered to composite adhesive produces greater polymerization. Also, the degree of conversion results in improved mechanical properties. However, the kinetics of polymerization has been found to be very complex without the existence of a simple reciprocal relationship between light intensity and the exposure duration (Peutzfeldt & Asmussen, 2005; Feng et al., 2009).

Conclusion

In conclusion, there is a wide range of factors affecting the SBS, DC, and their correlation. Some of them are related to the tooth etching techniques, adhesive related factors, curing units, and bracket materials. In general, as the DC increase (increase the monomer to polymer conversion), the SBS will increase. This will, however, results to a favorable bonding system without affecting the treatment progress and outcome.

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