Accuracy of Orthodontic bracket adaptation

A Master's full thesis submitted in fulfilment of the requirements for the degree of Magister Scientiae in the faculty of Dentistry, University of the Western Cape.

DR. NAEEMAH NOORDIEN

Student ID: 2132402

Supervisor: Dr. Athol Hudson

Co-supervisor: Dr. Riaan Mulder

April 2019

Accuracy of Orthodontic bracket adaptation

Naeemah Noordien

KEYWORDS

Orthodontic Brackets

Orthodontic Bracket base

Curvature

Marginal adaptation

Premolars

ABSTRACT

Background: A close marginal adaptation between the tooth and the bracket base is important since it provides the space for the adhesive. In order to withstand and resist the orthodontic forces exerted as well as everyday forces like mastication and oral hygiene practices, the adhesive material to the bracket must have sufficient sheer bond strength. This means that no deformations, cracks, or fractures should occur within the bracket material and adhesive (Keizer et al., 1976).

Aim: The aim of this study was to determine the accuracy of the marginal adaptation of the bracket bases of seven different brands of orthodontic brackets to the tooth surface of a right upper first premolar (ie. Abzil, Forestadent, GAC, Gemini, IMD, Ormco and Victory LP).

Method: This research was an *in vitro*, descriptive comparison study. Fifteen caries and crack free intact human first premolars were used. The teeth were obtained from patients requiring extractions for orthodontic purposes and collected from Tygerberg Oral Health Centre. A convenience sample method was used, where whenever an upper caries free premolar was extracted, the parent was asked if the tooth could be used for this study and consent was obtained. The crowns of the 15 teeth were cleaned and polished with pumice and rubber cups for 10 seconds (as the clinician would do prior to bracket cementation). The same 15 teeth were used with the seven different brands of brackets in order to establish a comparison of the adaptability of the brackets. The brackets were placed at a set orthodontic prescription of 4mm (measured from the slot area of the bracket to the tip of the buccal cusp of the tooth) on the upper first premolars. After bracket placement, the dontrix gauge was applied to the bracket to engage the slot area. The brackets were held in place with a constant force of 0.70 Newton (N) by the dontrix gauge. This allowed for reproducibility for the seven brackets with all fifteen teeth. In order to assess the space between the brackets and the teeth no adhesive was used. The space between the margins of the bracket and tooth interface was viewed under the Stereomicroscope (Carl Zeiss microscope, Zeiss Stemi508) at 50 times magnification. A two way mixed measures ANOVA was run to determine whether there were differences between the seven brackets placed at six points on the tooth surface.

Results: GAC had the smallest overall mean measurement between bracket base and tooth surface followed by Ormco and Gemini respectively. Abzil had the largest overall mean measurement for the six points around the bracket

Conclusion: The results of this study showed that there was no correlation in the space between bracket base and tooth surface between the seven brackets. Furthermore, the space was not uniform at all six points of reading for the same bracket between the various teeth.

DECLARATION

I, the undersigned, Naeemah Noordien, hereby declare that the work contained in this dissertation titled, "Accuracy of Orthodontic bracket adaptation" is my original work and has not been previously in its entirety or in any part submitted at any university for any degree or examination.

Naeemah Noordien

April 2019

Signature:

ACKNOWLEDGEMETS

I wish to express my heartfelt gratitude to Doctors Athol Hudson and Riaan Mulder for supervising this project. Thank you for your motivation, guidance and continuous support.

Thank you to Dr. Faheema Kimmie Dhansay for performing and explaining the statistical analysis to me several times with patience and a smile.

I am grateful to Prof. Nadia Mohamed for giving me the much needed time to complete my thesis, her kindness is appreciated.

And last but certainly not least, thank you to Aneeq for holding the fort through tantrums and heartache. And to my kids Nihaal, Ibrahim and Zakariya for allowing me to complete this goal.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BL: Bottom left

BM: Bottom middle

BR: Bottom right

MPa: Mega pascal

µm: Micrometer

mm: Millimetre

N: Newton

sd: Standard deviation

TL: Top left

TM: Top middle

TR: Top right

WSL: White spot lesions

CHAPTER 1: INTRODUCTION

Dr. Angle developed the edgewise system in 1928. It served as a template for future bracket systems. The initial appliance included attachment of the orthodontic brackets to the tooth with stainless steel bands. The bracket was welded to the band before cementation of bracket around each tooth. The disadvantages of this system was that it was time consuming, bands were unaesthetic, bands were unhygienic and it created interdental spaces. These interdental spaces were created at the start of treatment to accommodate the bands. At the end of treatment these spaces needed to be closed when the bands were removed (Moyers, 1988).

The use of acid etch bonding techniques have led to many changes in orthodontic treatment. The etching of enamel is clinically acceptable even though there may be enamel decalcification and loss (Hosein et al., 2004). Pre-adjusted appliances are frequently used and its success is dependent on good marginal adaptation with proper bracket positioning to allow for adequate tip and torque ensuring optimal alignment of teeth (Balut et al., 1992). Fixed orthodontic appliances are routinely bonded from second molar to second molar and is considered successful (Tsibel and Kuftinec, 2004). However, there are several disadvantages to bonding. Bonded brackets have a weak attachment to the buccal surface of teeth when compared to cemented bands used previously (Graber and Swain, 1990). Bond failures continue to be a problem in clinical practice despite the advancements of bonding materials (Northrup et al., 2007).

Good sheer bond strength is dependent on a dry etched enamel surface, undisturbed polymerisation of adhesive and adhesive with sufficient strength (Sfondrini et al., 2004).

A bond strength of 5.9MPa to 7.8 MPa has been recommended as adequate for clinical orthodontic requirements (Reynolds, 1975). Bracket de-bonding takes place at the adhesive enamel interface, in the enamel, the adhesive bracket interface or in the adhesive material (Sperber et al., 1999; James et al., 2003). Irregular adaptation of a bracket base to the tooth surface may result in an uneven thickness of bonding adhesive (Andrews, 1990).

This study will assess various aspects of bracket base adaptation to the surface of the tooth and provide some insight to the closeness of marginal adaptation between bracket base and tooth surface in relation to de-bonding.

Hypothesis of this study:

- All seven brackets will have a uniform space between the margins of the bracket base and tooth surface with all fifteen premolars (ie. Abzil, Forestadent, GAC, Gemini, IMD, Ormco and Victory LP).

The aim of this study was:

- To determine the accuracy of the marginal adaptation of seven different brands of orthodontic brackets to the tooth surface of a right upper first premolar (ie. Abzil, Forestadent, GAC, Gemini, IMD, Ormco and Victory LP).

The objectives of this study were:

- To assess the space between the tooth and bracket at the margin of the brackets at six predetermined areas around each of the brackets.
- To compare the accuracy of the marginal fit of the seven brackets.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Various studies in the literature look at several aspects of orthodontic brackets and adhesive materials and the impact that fixed orthodontic treatment may have on the oral environment (Jarabak, 1960; Mestriner et al., 2006; Carlson and Johnson, 2001; Miethke and Melsen, 1999; Angle, 1928). About 20% of all orthodontic research involved adhesive material science (O'Brien, 2005). As early as 1988 Matasa published "Adhesion and its ten commandments". He quoted these as "The adhesive", "The substrate/ interface" and "The System":

"A. The adhesive

1. Shall resist ambient environment, at the same time protecting the interfaces.
2. Shall be fluid enough.
3. Shall set hard and tough.
4. Shall tolerate/ dissolve tiny amounts of impurities.
5. Shall not cure slowly, unduly shrink or allow discontinuities.

B. The substrate/ interfaces

6. Shall be clean.
7. Shall be firm.
8. Shall allow air to escape.

C. The System

9. The adhesive has to 'love' both substrates.
10. Have a thin 'glue line'."

This study set out to look at the closeness of the fit between bracket base to the tooth surface as no research into this aspect could be found by the researcher.

Fixed orthodontic treatment must provide patients with both function and aesthetics while keeping a balance between facial, skeletal and dental structures (Jarabak, 1960). Bracket position is important to allow effective and correct torque delivery on the crown and root to obtain tooth movement, therefore bracket placement is important (Mestriner et al., 2006). The inclination of the bracket slot area relative to the occlusal plane determines the amount of torque required (Mestriner et al., 2006). Therefore, poorly placed brackets may result in an alteration in torque and incorrect alignment of teeth (Carlson and Johnson, 2001). The buccal surface of the premolar is convex and not flat and the curvature differs between premolars. It is important therefore, that the curvature of the bracket base adapts to this (Viana et al., 2005). A discrepancy in the vertical height of the bracket will influence the horizontal position (Miethke and Melsen, 1999). Meyer and Nelson (1978) claimed that a 3mm difference in bracket placement height could lead to a 15º alteration in torque.

Angle (1928) suggested that the best position for the bracket was in the centre of the buccal surface of the tooth. This should give the best possible fit from base to tooth. The brackets should be placed by measuring a distance from incisal edge or cuspal tip of the tooth (Balut et al., 1992).

Successful orthodontic treatment depends on the interaction between the arch wires and the positioned brackets (Erduran et al., 2016). However, literature shows that there are discrepancies in the dimensions of brackets provided by manufacturers (Brown et al., 2015). The slot is considered to be the most important part of the bracket but when the size is altered it could change the orthodontic mechanics (Jones et al., 2002). Although positioning devices were made to determine the ideal height to place attachments to the tooth, often it is still not achieved due to clinician preferences and the curvature of the teeth (Armstrong et al., 2007). Hence it would be important for the bracket base curvature to follow the curvature of the tooth (Dellinger, 1978).

2.2 The curvature of the bracket base

A study by Gontijo et al. (2004) echoed this and concluded that the closer the curvature of the bracket base to the tooth buccal surface, the closer the adaptation. This will result in better adhesion, retention and efficiency (Gontijo et al., 2004).

Carlson and Johnson (2001) describes four criteria needed for the successful placement of brackets. These include base adaptation, rotational position, vertical position and slot angulation. They suggested that if the curvature of the bracket base does not follow the curvature of the tooth, the bracket base should be adjusted. The bracket base could be flattened or increased in concavity. They further concluded that an ideal fitting base to tooth surface would help to ensure a uniform amount of adhesive between tooth surface and bracket base. This will ensure an even flow of adhesive for adequate bracket seating.

Matasa (1988) emphasized this too, referring to the adhesive layer as a 'thin glue line' in his ten commandments of adhesion.

2.3 The curvature of the buccal surfaces of teeth

Andrews (1976) suggested that the curvature of buccal surfaces amongst teeth does not vary enough to affect the correct positioning of brackets on the tooth surface. This theory differed with the findings of Dellinger (1978), Meyer and Nelson (1978) and Germane et al. (1989). The latter found there to be a great variation in crown morphology that could lead to incorrect placement of brackets. There is a strong relationship between the curvature of the bracket base adapting to the curvature of the buccal surface of teeth and the application of forces to the teeth (Viana et al., 2005).

2.4 The size of the bracket base

There are many variations in the bracket base sizes between different brands of orthodontic brackets. Matasa (2003) claimed that the size of the base has decreased by 75% in recent years. The average base size of a metal bracket is 9 to 12mm² (Bishara et al., 1999; Sorel et al., 2002). The size of the bracket base is essential for considerations with regards to oral hygiene, bond strength and aesthetics (Matasa, 2003). The metal bracket base relies on the mechanical retention for the bond strength to the bracket. A large retentive base improves adhesion but also increases the risk of fracture at the bracket adhesive interface (Cozza et al., 2006).

Hudson et al. (2011) assessed three different bracket bases and its effect on sheer bond strength. The study concluded that size and design of the bracket bases influences the sheer bond strength (Hudson et al., 2011). Brackets with larger mesh apertures showed greater sheer bond strengths when compared to smaller mesh apertures (Hudson et al., 2011).

Manufacturers claim that the adhesive systems have improved allowing a smaller bracket base to maintain adequate sheer bond strength (Cozza et al., 2006). However, manufacturers are known to supply incorrect bracket dimensions (Erduran et al., 2016).

2.5 Design of the bracket base

There are several bracket base designs available on the market for clinical use. Sheer bond strength may be influenced by the retentive area of the bracket, conditioning procedure, treatment of the bracket base and bracket base design. The bracket base/ adhesive interface has been the weak link in orthodontic bonding. (Sharma-Sayal et al., 2003).

A study by Sorel et al. (2002) found that 75% of brackets with a simple foil mesh base experienced bond failure at the bracket adhesive interface. A large retentive base improves adhesion but also increases the risk of fracture at the bracket adhesive interface (Cozza et al., 2006).

Sharma-Sayal et al. (2003) demonstrated that bracket bases with a 60 gauge foil-mesh or an integral undercut machined base achieved higher bond strengths.

Wang et al. (2004) found that the Tomy bracket with its circular base produced a higher sheer bond strength than foil based brackets.

Hudson et al. (2011) found that brackets with larger mesh apertures showed greater sheer bond strengths when compared to smaller mesh apertures (Hudson et al., 2011). The number of openings per unit of area of the bracket base is determined by the wire diameter and the spacing. For the adhesive to penetrate the base effectively, air needs to be able to escape. This is determined by the free volume between the mesh and the bracket base (Wang et al., 2004).

2.6 Microleakage

Demineralization (decalcification) occurs when the pH of the oral environment favours diffusion of calcium and phosphate ions out of enamel around the bracket (Gorelick et al, 1982). This occurs frequently with orthodontic patients affecting the buccal surfaces of teeth and creating a clinical problem after de-banding. The orthodontic appliance creates a site for plaque retention (Gorelick et al., 1982). Stainless steel brackets showed the highest potential for micro-organism adhesion (Eliades et al., 1995).

Previous studies (Gorelick et al, 1982; Eliades et al., 1995) focused mostly on decalcifications and white spot lesions around the brackets and not beneath the brackets. Although the area around the brackets are critical, the area beneath the brackets also needs attention. This potential space between the bracket base and the tooth surface is essential to the volume of adhesive present between the bracket and the tooth. This space is essentially filled with the adhesive between bracket base and tooth surface.

James et al. (2003) were the first to point out increased risk of demineralisation caused by microleakage beneath orthodontic brackets between the adhesive and the tooth. The polymerisation shrinkage of the adhesive material may cause gaps between the adhesive material and enamel surface and lead to microleakage, thus facilitating the formation of white spot lesions under the bracket surface area. Microleakage results in the formation of white spot lesions on the enamel at the adhesive enamel interface (James et al, 2003).

A study by Boersma et al. (2004) looked at the prevalence of white spots lesions after de-banding. They found that 97% of the 64 patients presented with white spot lesions after de-banding.

Polymerisation shrinkage in conservative dentistry is a great concern as composite is placed in volume of the cavity preparation (Chikawa et al., 2006). However, in orthodontic applications, it is less of a concern because the adhesive layers are relatively thin. (James et al., 2003). According to Matasa (1988), having a 'thin glue line' (adhesive layer) is one of the ten commandments of Adhesion. It is believed that the adhesive at the edge of the brackets absorb some of the shrinkage. And because the bracket sits freely, the shrinkage will pull the bracket closer to the enamel (Oesterle et al., 2001). This theory would be dependent on the adhesive being a thin layer but does not consider an adhesive layer of varying thickness due to an uneven marginal adaptation between bracket base and tooth surface. Conventional glass ionomers adheres chemically to the tooth therefore less risk of any polymerisation shrinkage (Ewoldsen and Demke, 2001). The added benefit would also be the release of fluoride over time.

Fluoride is used as a cariostatic agent to remineralise these white spot lesions (Chin et al., 2009). For successful remineralisation, the fluoride must constantly be available in the oral cavity (Dijkman et al., 1993). The use of fluoride releasing adhesives between bracket and tooth allows for the reservoir of fluoride which may help to avoid white spot lesions (Wiegand et al., 2007).

A study by Sudjalim et al. (2007), looked at different adhesives and the effect it had on demineralisation around the brackets. The study concluded that the use of resin modified glass ionomers decreased the enamel demineralisation when compared to composite adhesives.

The orthodontic patient should also play a role in the prevention of white spot lesions. This would depend on the oral hygiene and cooperation of the patient. A good oral hygiene routine should be in place before the placement of fixed orthodontic treatment (Gavrilovic, 2014).

Arhun et al. (2006) looked at microleakage at the adhesive bracket interface between ceramic and metal brackets. Although both groups showed microleakage, the study concluded that metal brackets cause more leakage than the ceramic brackets between the adhesive bracket interface. This may lead to lower clinical sheer bond strength and white spot lesion formation (Arhun et al., 2006).

A study by Moolya et al. (2014) concluded that bracket base design can have a large impact on bacterial load and on periodontal parameters. Plaque formation is mainly attributed to the complexity of the bracket design and ligating methods. The outcome of this study showed an increase in plaque and gingival index around brackets over a period of one week (Moolya et al., 2014).

Similarly, Lee et al. (2005) found differences in the periodontal pathogens in subgingival dental changes associated with plaque in orthodontic patients compared to patients who did not have orthodontic treatment. The study concluded that the changes associated with orthodontic brackets increases periodontal pathogens in dental plaque and therefore these patients would be more susceptible to periodontal disease (Lee et al., 2005).

Bond strength is also dependent on a dry enamel surface, using an adhesive with sufficient strength and a tooth surface free of blood and saliva contamination (Sfondrini et al., 2004). Bishara et al. (1999) suggested that there are other variables influencing sheer bond strength clinically between the enamel and bracket base. These include polymerisation of the adhesive accelerated by a curing light, type of enamel conditioner, acid etchant, etching time, type of adhesive material, design of bracket base and bracket material, the oral environment and the clinician's skill (Bishara et al., 1999).

An adhesive system should have an *in vitro* sheer bond strength of between 6 to 8 mega pascals to perform well clinically (Clarke et al., 2003). With clinical de-bonding, the metal bracket bases become distorted resulting in the separation between bracket base and tooth surface. This separation can occur in the adhesive material, at the adhesive enamel interface, at the bracket adhesive interface and in the enamel (Sperber et al., 2003; James et al., 2003).

An irregular enamel surface also has an influence on sheer bond strength. It is thought that this may allow an adhesive layer that is not uniform between bracket base and tooth surface (Swanson et al., 2004). According to Swanson et al. (2004) the thickness of the adhesive layer is determined by the clinician's bracket placement technique, the amount of filler particles in the adhesive and its viscosity. However, there is no mention of the impact on sheer bond strength of the space between bracket base and tooth surface, adaptation or how closely the bracket fits to the tooth surface.

Motivation for this study

With the current literature in mind, this study will focus on the marginal adaptation looking at the space between the margins of the bracket base and buccal surface of the tooth without the use of adhesive. In doing so, an incidental finding of the irregularities in the bracket bases will be discussed with regard to the influence on the clinical aspects of fixed orthodontic treatment.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Aim

The aim of this study was to determine the accuracy of the marginal adaptation of seven different brands of orthodontic brackets to the tooth surface of a right upper first premolar (ie. Abzil, Forestadent, GAC, Gemini, IMD, Ormco and Victory LP).

3.2 Objectives

- To assess the marginal adaptation between the tooth and bracket at the margin of the brackets at six predetermined areas around each of the brackets.
- To compare the overall accuracy of the marginal fit of the seven brackets.

3.3 Research design

This research was an *in vitro*, descriptive comparison study. The researcher was blinded during data collection.

3.4 Study population

Fifteen caries and crack free intact human first premolars were used. The teeth were obtained from patients requiring extractions for orthodontic purposes and was collected from Tygerberg Oral Health Centre. The teeth were stored in 1% Thymol.

3.5 Ethical considerations

Approval to conduct the study was received from the University of the Western Cape Research Ethics Committee (Project Registration Number: BM 16514). Informed consent was obtained from the patient/parent for the use of the teeth in this study

3.6 Sampling criteria

A convenience sample method was used, where whenever an upper caries free premolar was extracted, the parent was asked if the tooth could be used for this study and consent was obtained. The teeth were numbered one to fifteen (Figure 3.6).

Figure 3.6: Fifteen premolars used for this study

3.7 Sample size

A statistician was consulted to assist with the determination of the sample size. After doing a power calculation, it was established that 15 teeth should be used with 7 different brackets, assessing the marginal adaptation of the bracket at six predetermined areas.

3.8 Bracket positioning

The brackets were placed at a set orthodontic prescription of 4mm (measured from the slot area of the bracket to the cusp tip of the tooth) on the upper first premolars. All 15 teeth were numbered and a marker was used to mark the area, in the centre of the buccal surface and 4mm from the buccal cusp tip. After bracket placement, the dontrix gauge was applied to the bracket to engage the slot area. The brackets were held in place with a constant force of 0.70 Newton (N) by the dontrix gauge. This allowed for reproducibility for the seven brackets with all fifteen teeth. Note: In the device, the dontrix gauge engaged the slot area of the bracket and was perpendicular to the horizontal plane. The central fissure of the tooth was parallel to the horizontal plane.

3.9 Different brands of brackets used

Table 3.9: Bracket types, description and lot numbers

Bracket Name	Lot number	Bracket description
Abzil (ABZ272-133)	LOT: 160900193	Bracket Agile ULR 1BIC + 2BIC MBT 022
Forestadent (FOR/733-0401)	LOT: A342	BioQuick MBT .022 U4R
GAC (89-142-00)	LOT: A532	INOV R ROT 022/UR4&5- 7T0A2D
Gemini (UTK119-779)	LOT: DP3PM	Gemini TWN ULR BIC – 07T/00A 022
IMD (IMD/13-221-14)	LOT: 5316210	Copolla Roth. 022 U4R
Ormco (OR4540410)	LOT: 13E621E	Ortho Mtwn Upr 1st Bic Rt G/Off – 6T OA
Victory LP (UTK024-890)	LOT:013761802	VS LP MBT ULTRT BIC – 7T/OA 022

3.10 Pilot study

As follows: A Forestadent bracket was bonded to an upper first premolar with Transbond XT (3M ESPE). Enamel was etched and Scotchbond single bond universal was used as the primer, the bracket was positioned onto the buccal surface of the tooth 4mm from the incisal cusp tip, and the excess Transbond XT removed and then light cured with a 3M Deep Cure-S curing light.

In order to assess the adhesive space between the bracket base and buccal surface of the tooth, the tooth was embedded in cold cure acrylic covering the bracket. Three parallel longitudinal sections were made through the occlusal surface with a diamond blade (Isomet, 11-1180 Low speed saw) in the bucco-lingual direction (Arhun et al., 2006). The three sectioned areas were viewed under the stereomicroscope to look at the volume of adhesive, measuring the space occupied by the adhesive (Figure 3.10). It became evident that the curvature of the premolar and the curvature of the bracket base displayed differences. This would directly impact the space available for adhesive and result in varying thickness of adhesive.

In order to evaluate space between brackets on various premolars the brackets should not be bonded. In clinical practice a Dontrix gauge is used to apply a constant force to the bracket prior to curing of adhesive. This allows for similar conditions between brackets. This concept then brought about the idea for this study whereby the space was measured without the adhesive. This principle was followed with the idea to construct a custom made device to hold the bracket in place with a constant force by the dontrix gauge. The device was designed so that different premolars could be inserted, and exposed to a constant force (Figure 3.11.1a). The device could also ensure the constant positioning of the brackets as the dontrix gauge would line up with the slot area of the bracket.

The device consisted of a central base that remained stationery and a movable component housing the tooth and dontrix gauge. This movable component could be swivelled at 180 degrees around the central base. In so doing, the occlusal and cervical margins of the tooth and bracket could be viewed without moving the position of bracket and tooth (Figure 3.11.1b and Figure 3.11.1c).

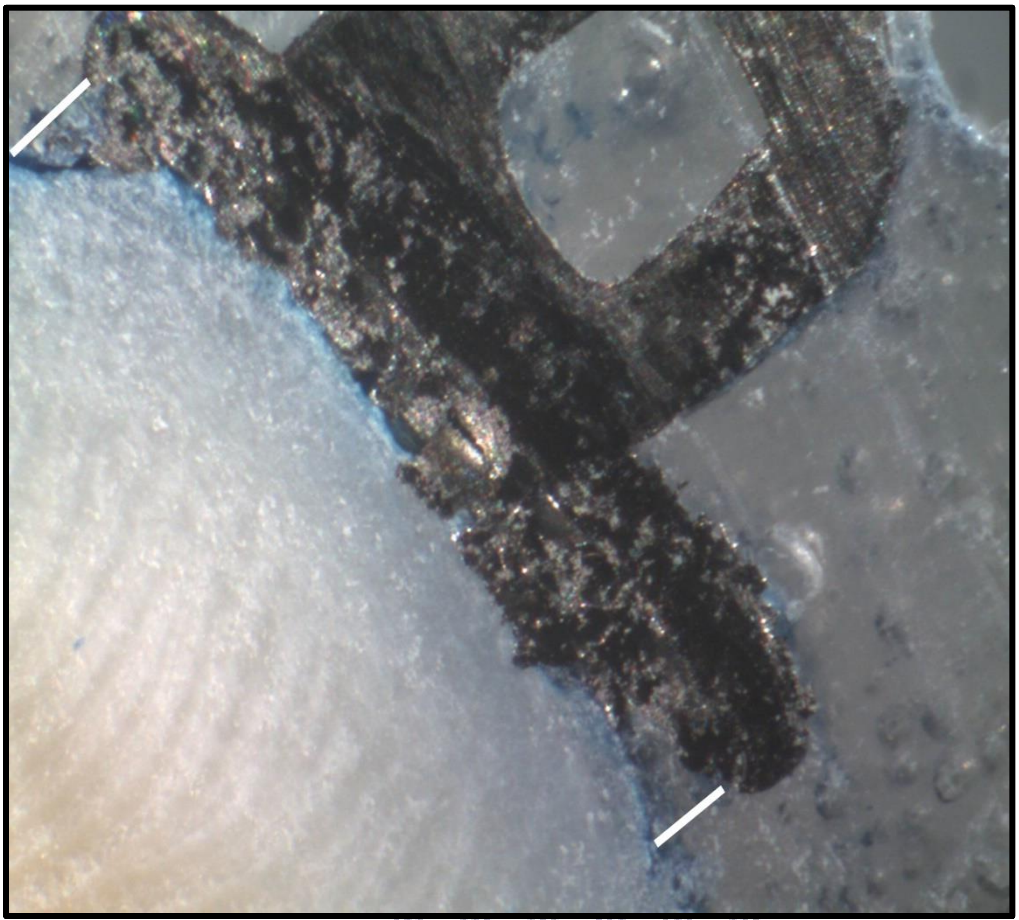


Figure 3.10: Cemented bracket, invested and sectioned

3.11 Data collection technique

3.11.1 Viewing of brackets with a Stereomicroscope

The crowns of the 15 teeth were cleaned and polished with pumice and rubber cups for 10 seconds (as the clinician would do prior to bracket cementation). The same 15 teeth were used with the seven different brands of brackets in order to establish a comparison of the adaptability of the brackets. The brackets were placed at a set orthodontic prescription of 4mm (measured from the slot area of the bracket to the cusp tip of the tooth) on the upper first premolars. All 15 teeth were numbered and a marker was used to mark the area, in the centre of the buccal surface and 4mm from the buccal cusp tip. After bracket placement, the dontrix gauge was applied to the bracket to engage the slot area. This allowed for reproducibility for the seven brackets with all fifteen teeth (Figure 3.11.1a).

The Dontrix gauge was essential, since under clinical circumstances the clinician would use it to establish a constant force against the tooth during clinical cementation of an orthodontic bracket. The force used in this study was 0.70 Newton (N).

In order to assess the space between the margins of the bracket bases and the teeth no adhesive was used. The space between the bracket and tooth interface was viewed under the Stereomicroscope (Carl Zeiss microscope, Zeiss Stemi508) at 50 times magnification (3.11.1b).

3.11.2 Readings on each bracket

Six readings at predetermined locations on the margins of the brackets were compared on the 15 teeth on which the seven different brands of brackets were attached. Figure 3.11.2(a-g), shows the areas that were assessed. The ideal design would be a bracket well adapted to the tooth surface with minimal distance between the tooth and bracket. For this to be possible, the contour of the fitting surface of the bracket base should be the same as that of the premolar.

The Stereomicroscope was used to view the corners and the middle of each bracket on both the occlusal and cervical margin of the tooth (Modified method from Arhun et al., 2006). The space between the tooth and the bracket of each bracket was measured in micro-meter (µm) from both occlusal and cervcal margins (space between the tooth and the bracket, at each corner and in the middle). The cervical readings were possible without moving the tooth and bracket as the movable component of the device could be swivelled at 180 degrees around the stationery base, showing the cervical margin of the bracket to tooth surface (Figure 3.11.1c). This maintained accuracy for all six readings taken on the seven brackets.

Figure 3.11.1a: Photograph of the custom made device with Dontrix gauge (side view)

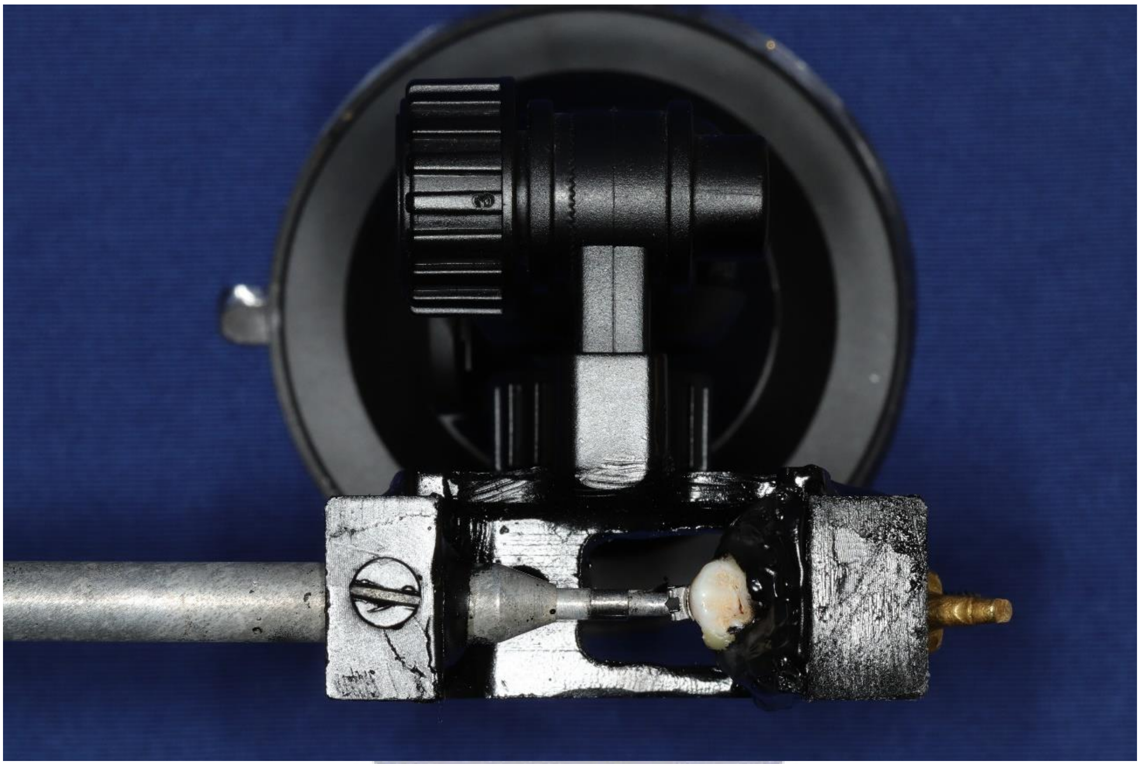


Figure 3.11.1b: Photograph showing the occlusal margin of the bracket

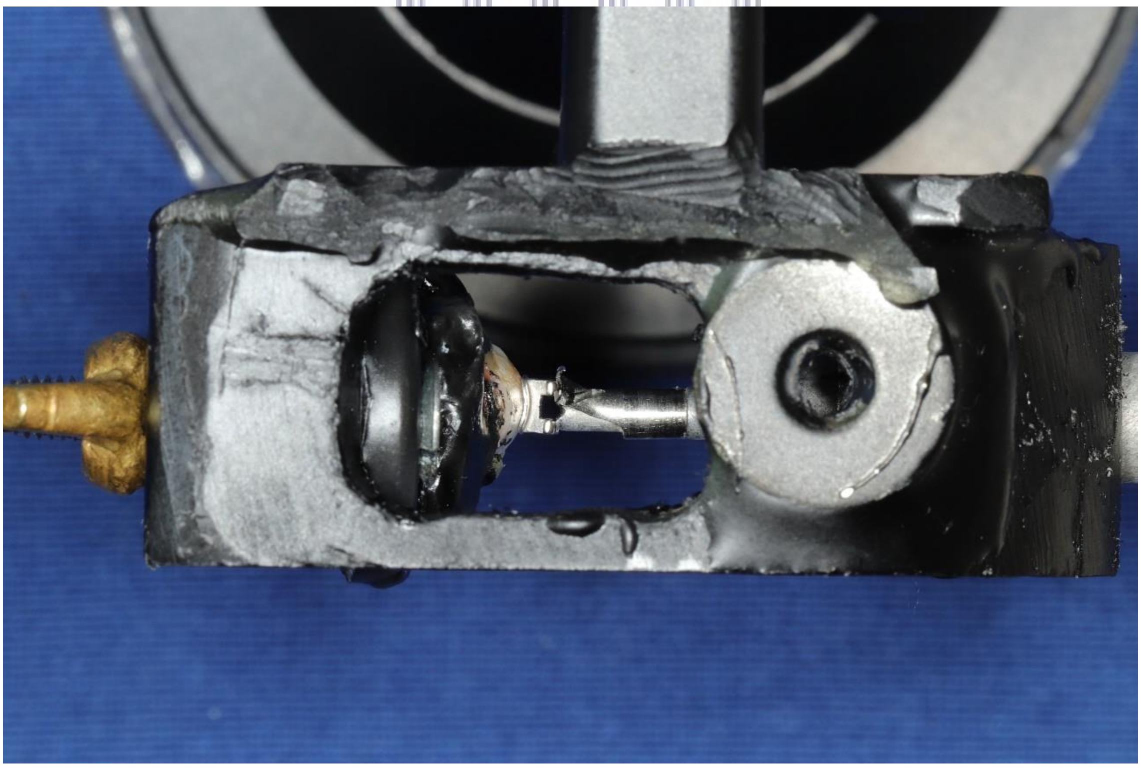


Figure 3.11.1c: Photograph of the custom made device showing the cervical margin of the bracket

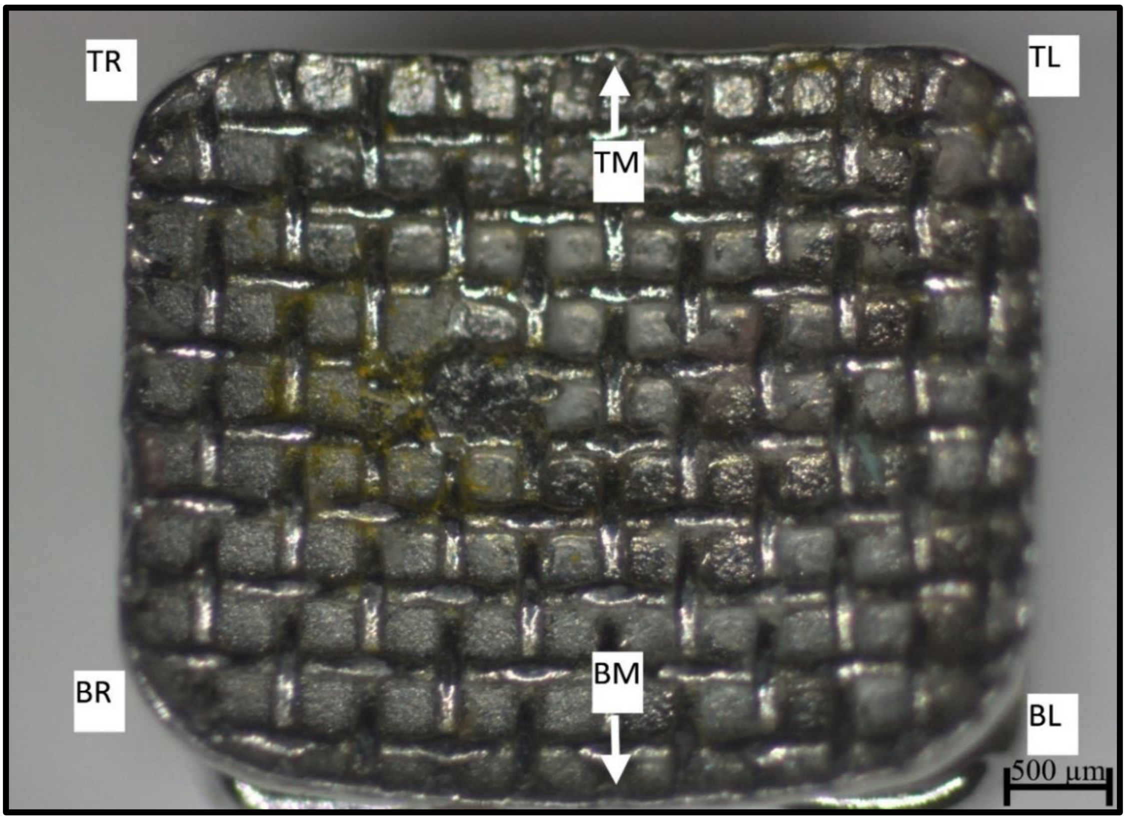


Figure 3.11.2a: Abzil fitting surface (showing 6 points on bracket at 50x magnification)

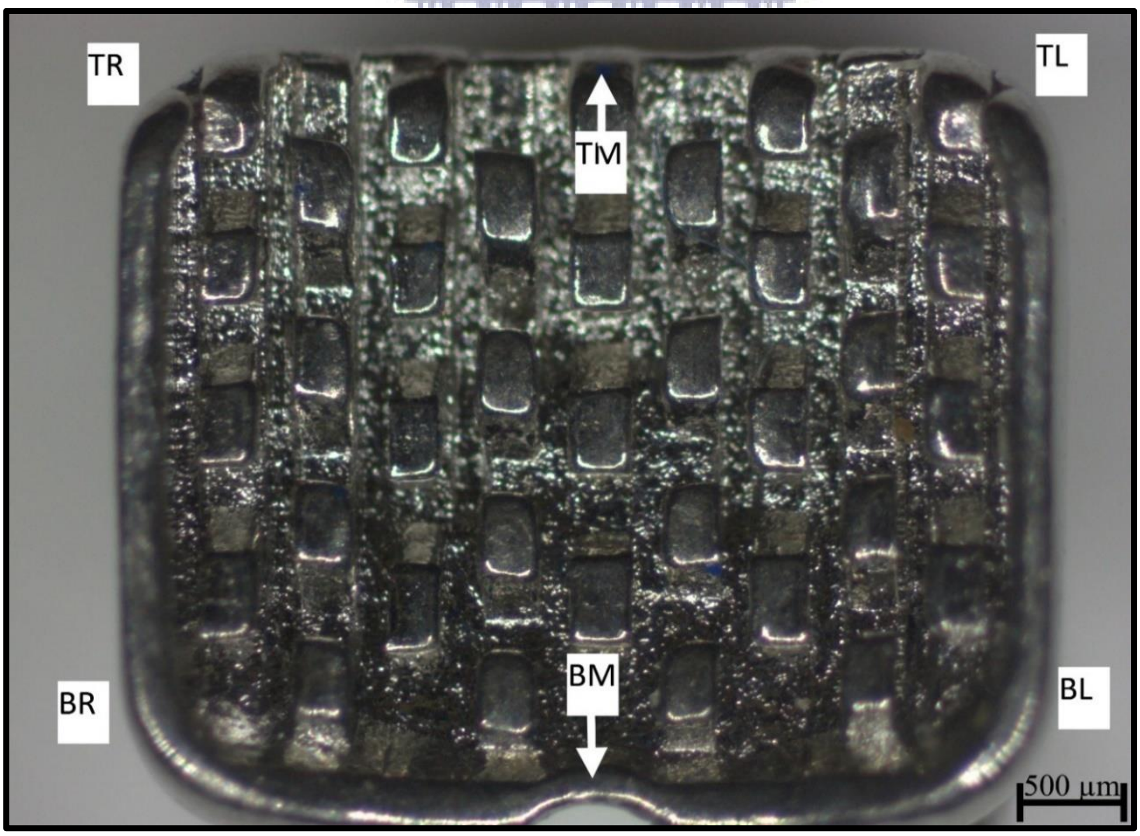


Figure 3.11.2b: Forestadent fitting surface (showing 6 points on bracket at 50x magnification)

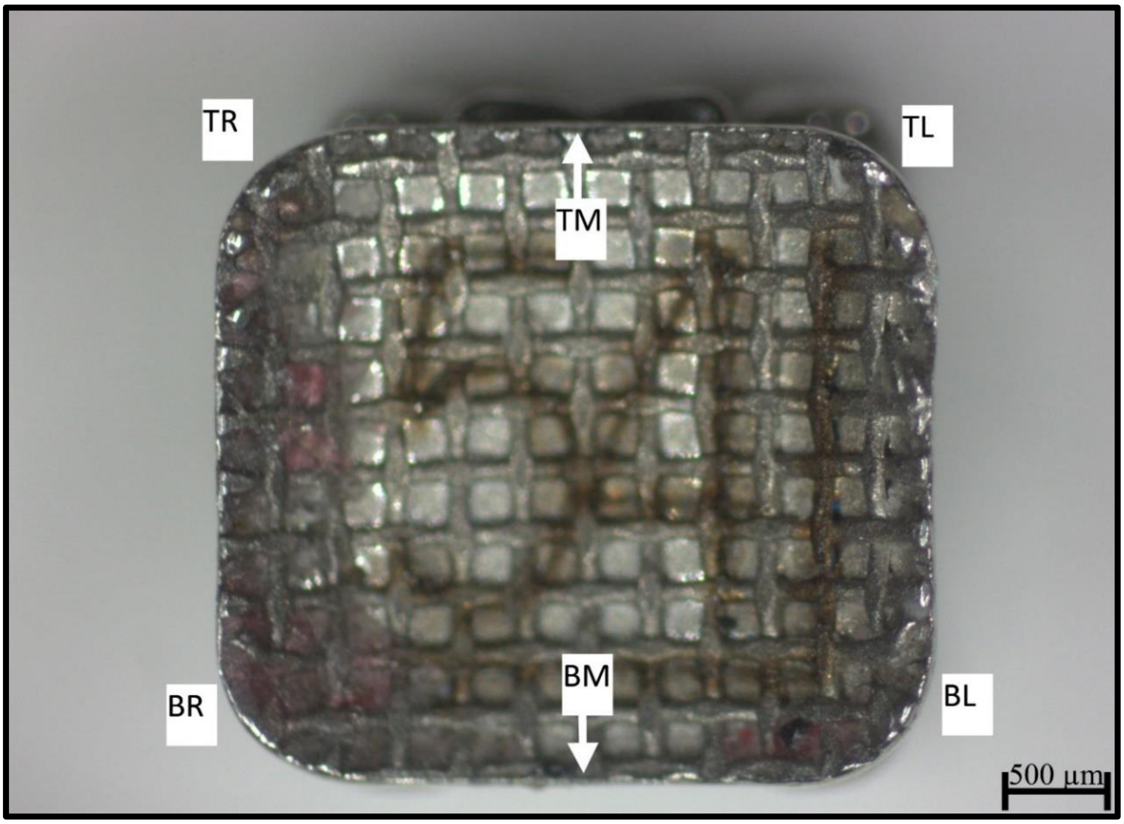


Figure 3.11.2c: GAC fitting surface (showing 6 points on bracket at 50x magnification)

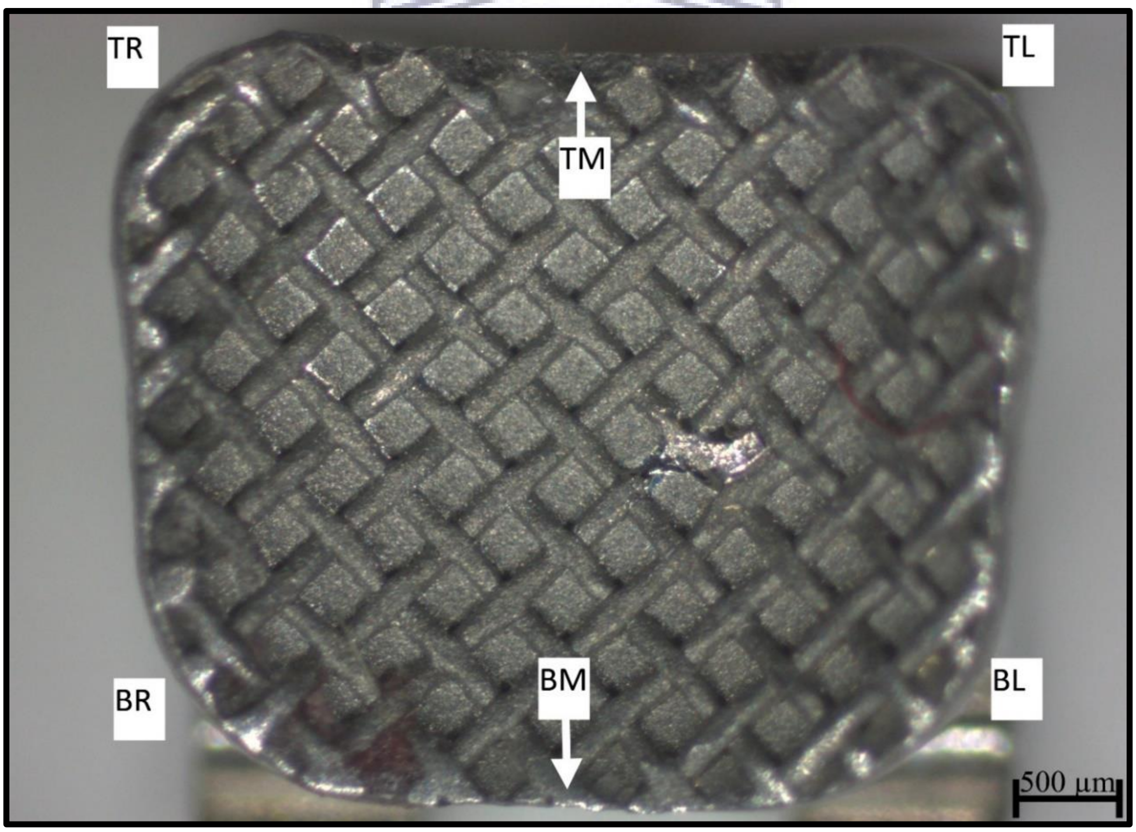


Figure 3.11.2d: Gemini fitting surface (showing 6 points on bracket at 50x magnification)

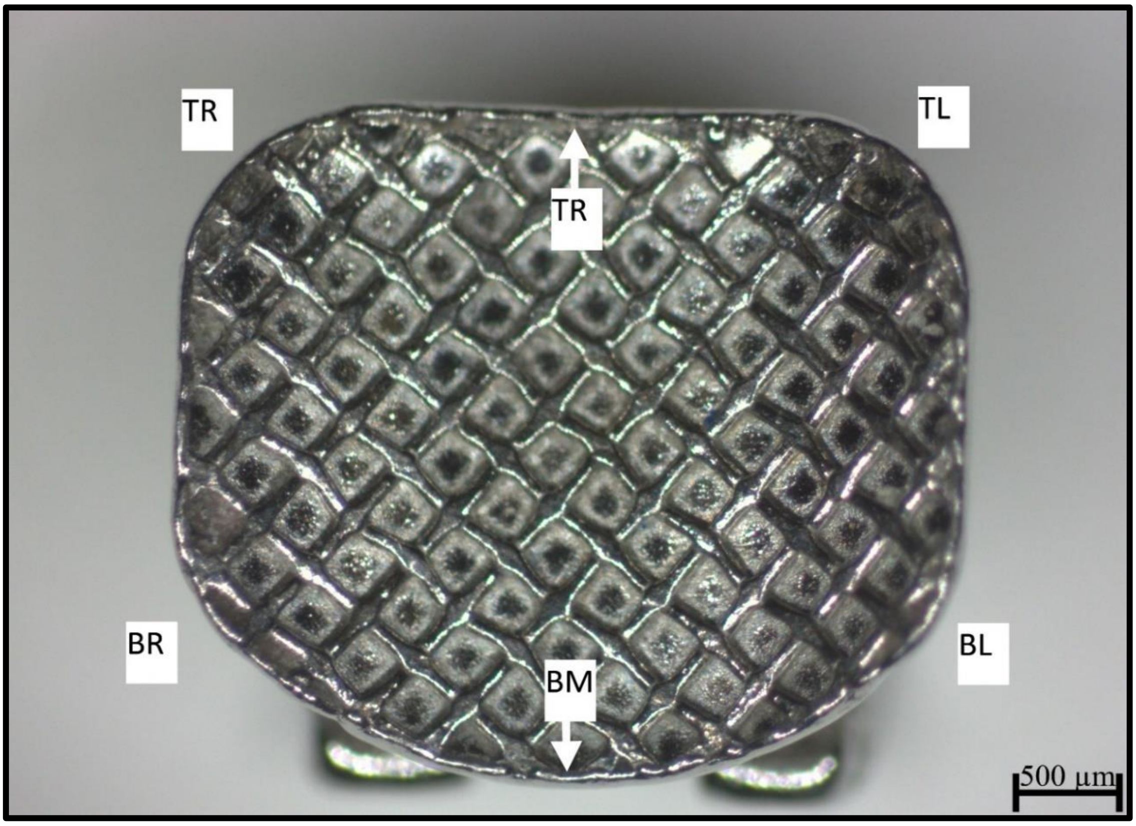


Figure 3.11.2e: IMD fitting surface (showing 6 points on bracket at 50x magnification)

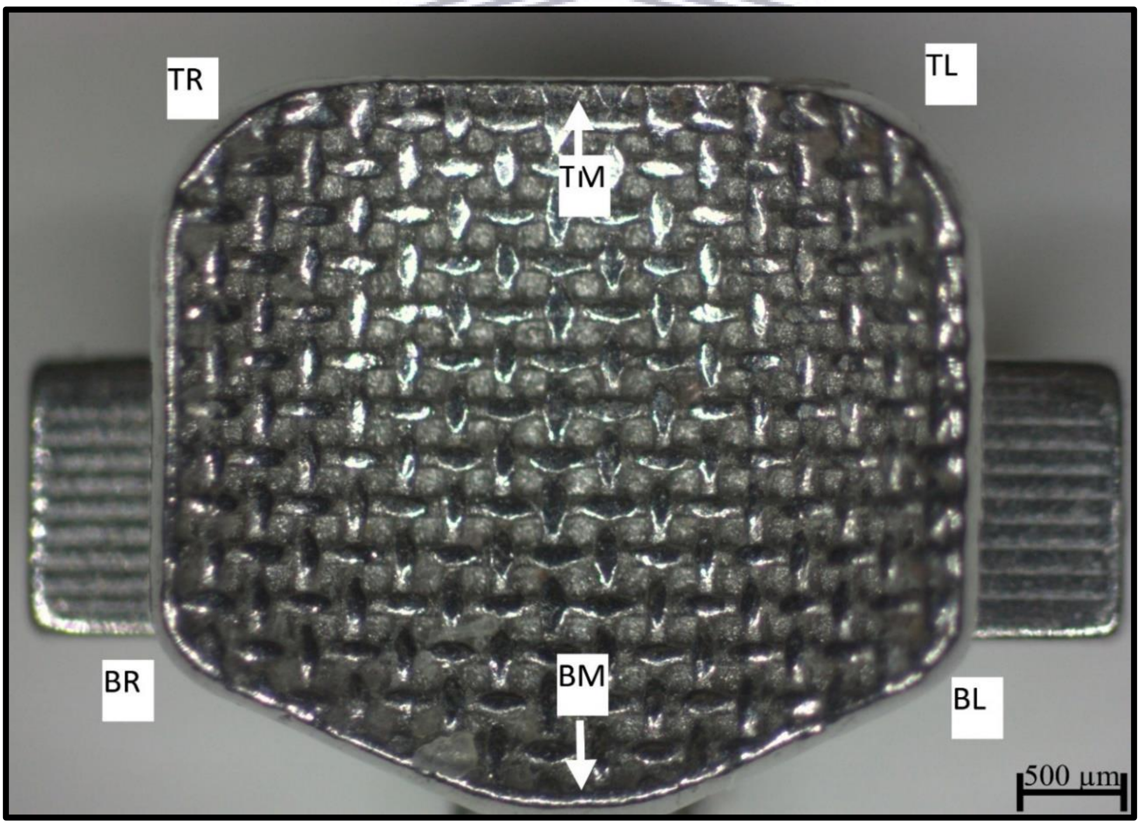


Figure 3.11.2f: Ormco fitting surface (showing 6 points on bracket at 50x magnification)

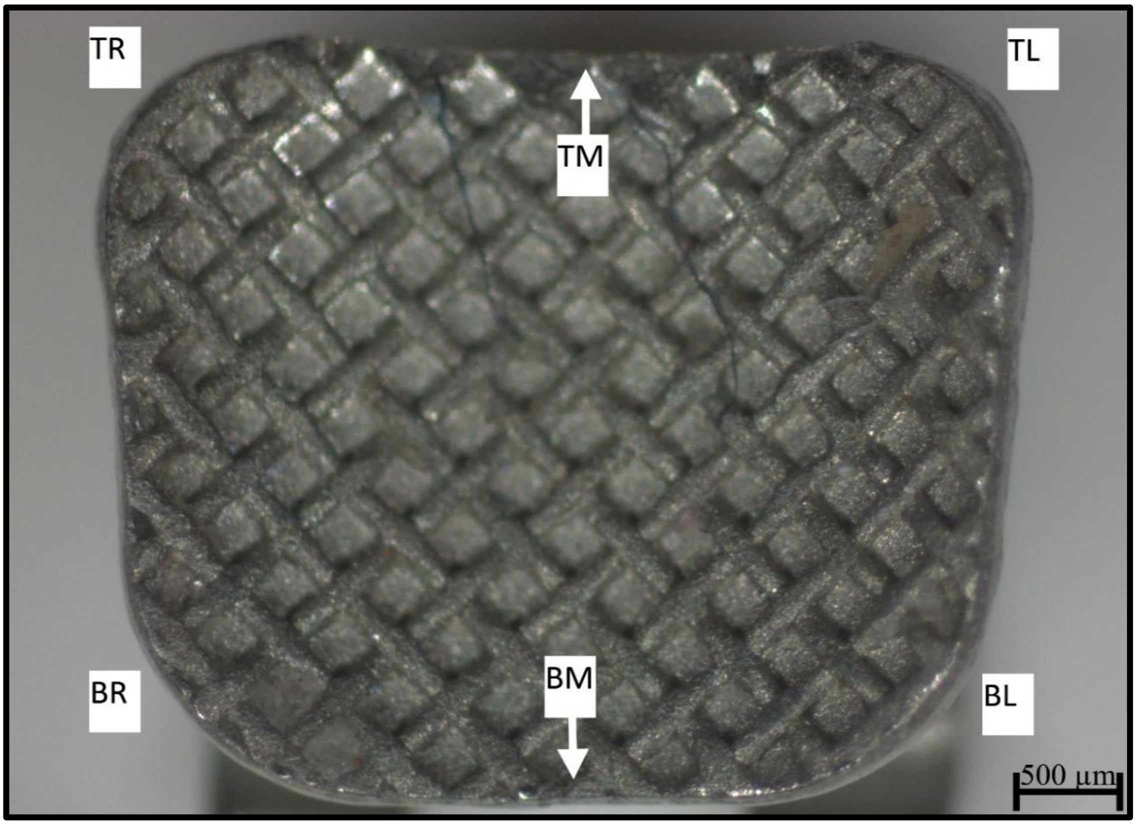


Figure 3.11.2g: Victory fitting surface (showing 6 points on bracket at 50x magnification)

Table 3.11.2: Bracket width in µm

Bracket type	Occlusal width (TR-TL)	Cervical width (BR-BL)
Abzil	4104.51	3882.65
Forestadent	4077.25	3944.56
GAC	3077.92	3042.48
Gemini	4041.87	3396.38
IMD	3272.43	2848.08
Ormco	3308.05	2892.20
Victory	3962.27	3431.62

3.11.3 Assessment of the space between the bracket and the tooth

The investigator/researcher was blinded to what brand of bracket was being assessed. The corner was marked with a super fine permanent marker, in order to ensure repeatability of the six predetermined positions (olive green arrows). The gaps were viewed by using the Steriomicroscope at 50x magnification and a camera (Zeiss camera, Axiocam ERc5s) attached to the microscope photographed the images for later use. Six images were taken for every bracket with all fifteen teeth. The distances were then measured using the software programme of the microscope (Zen 2.3 blue edition, Carl Zeiss Microscope 2011 GmbH) (Figure 3.11.3).

Each photograph was prepared for measurement by drawing an ellipse to follow the curvature of the tooth (red ellipse). A line parallel to the bracket was drawn (royal blue), crossing the ellipse. The crossing point between the ellipse and the parallel line (depicted with a sky blue line for demonstration), is where the measurement was taken towards the bracket (white line perpendicular to bracket). This was done for each of the 15 teeth.

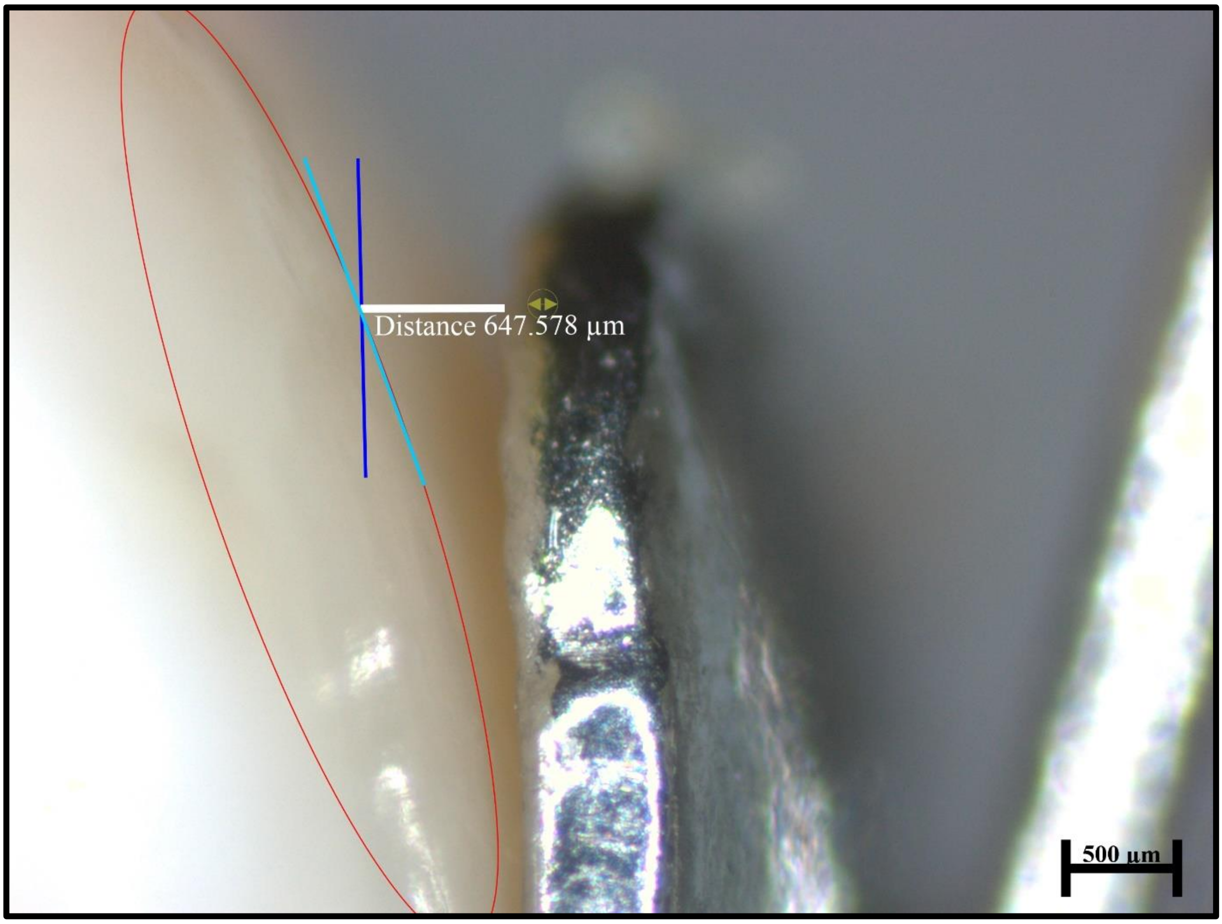


Figure 3.11.3: An example of how the marginal adaptation was measured (µm)

3.12 Validity and reliability

The sample was examined by the researcher who was blinded while viewing the brackets. 10% of the sample was re-examined for intra-observer reliability. 2% percent of the sample was examined by another researcher for inter-observer reliability. Calibration of the researcher was done with the supervisors of the project.

To test the reliability of the results, the two-way mixed-effects model was chosen because the selected investigators were the only investigators of interest. With this model, results for reliability apply to the specific investigators involved in the reliability experiment. The results cannot be generalized to other investigators even if those raters have similar characteristics. Values less than 0.5 are indicative of poor reliability. Values between 0.5 and 0.75 indicate moderate reliability. Values between 0.75 and 0.9 indicate good reliability and values greater than 0.90 indicate excellent reliability.

3.13 Statistical analysis

A two way mixed measures ANOVA was run to determine whether there were differences between the seven brackets placed at six points on the tooth surface. All outliers assessed by boxplot were included. Shapiro-Wilk's test showed that the data was not normally distributed. Levene's test of homogeneity of variances showed that for the most part there was homogeneity of variances.

The results of the two way mixed measures ANOVA showed that there was a significant difference ($p < 0.05$) in bracket types between the bracket and the tooth surface. The statistics are displayed as mean (Standard deviation).

The analysis revealed significant difference between the distances and the bracket with the tooth surface ($p = 0.0001$).

CHAPTER 4: RESULTS

4.1 Validity and Reliability

Table 4.1a: Intra Examiner reliability (two-way mixed-effects model, > 0.9 indicates excellent reliability)

	ICC	95% Conf. Interval	
Individual	0.9996296	0.9994288	0.9997598
Average	0.9998148	0.9997143	0.9998799
ICC: Intraclass correlation coefficient 95% Conf Interval: 95% confidence interval			

Table 4.1b: Inter Examiner reliability (two-way mixed-effects model, > 0.9 indicates excellent reliability)

	ICC	95% Conf. Interval	
Individual	0.9995403	0.9984041	0.9998676
Average	0.9997701	0.9992014	0.9999338
ICC: Intraclass correlation coefficient 95% Conf Interval: 95% confidence interval			

The obtained ICC value for the average score for distance between the bracket and the tooth for the test/retest and the inter-examiner reliability was 0.99. This indicates excellent reliability.

4.2 Individual points around the bracket

Table 4.2a: Statistical information for space measured between the bracket base and tooth surface for each bracket tested (µm)

Bracket no	Statistics	Top Right	Top Middle	Top Left	Bottom Left	Bottom Middle	Bottom Right
Abzil	**N**	15	15	15	15	15	15
	mean	348.48	376.45	323.23	369.32	461.28	349.35
	sd	325.47	199.045	170.48	314.57	294.51	205.24
Forestadent	**N**	15	15	15	15	15	15
	mean	249.57	338.09	312.08	280.50	450.63	261.11
	sd	209.73	184.30	207.13	246.26	214.62	130.23
GAC	**N**	15	15	15	15	15	15
	mean	205.98	325.38	260.44	352.43	308.51	187.05
	sd	106.78	127.67	81.378	247.67	181.33	110.95
Gemini	**N**	15	15	15	15	15	15
	mean	198.99	331.74	360.89	260.88	318.80	258.12
	sd	125.11	121.49	143.62	162.39	181.66	135.33
IMD	**N**	15	15	15	15	15	15
	mean	288.58	327.98	318.73	320.98	583.25	329.15
	sd	167.64	116.78	170.14	173.70	314.87	193.11
Ormco	**N**	15	15	15	15	15	15
	mean	234.80	214.97	314.33	315.64	268.85	356.41
	sd	198.82	107.71	161.44	126.19	100.32	313.91
Victory LP	**N**	15	15	15	15	15	15
	mean	269.65	333.72	336.66	239.90	350.92	332.24
	sd	221.43	140.35	134.45	143.67	399.02	188.16
Total	**N**	105	105	105	105	105	105
		256.58	321.19	318.05	305.67	391.75	296.21
		204.56	149.29	154.92	210.31	271.20	196.23

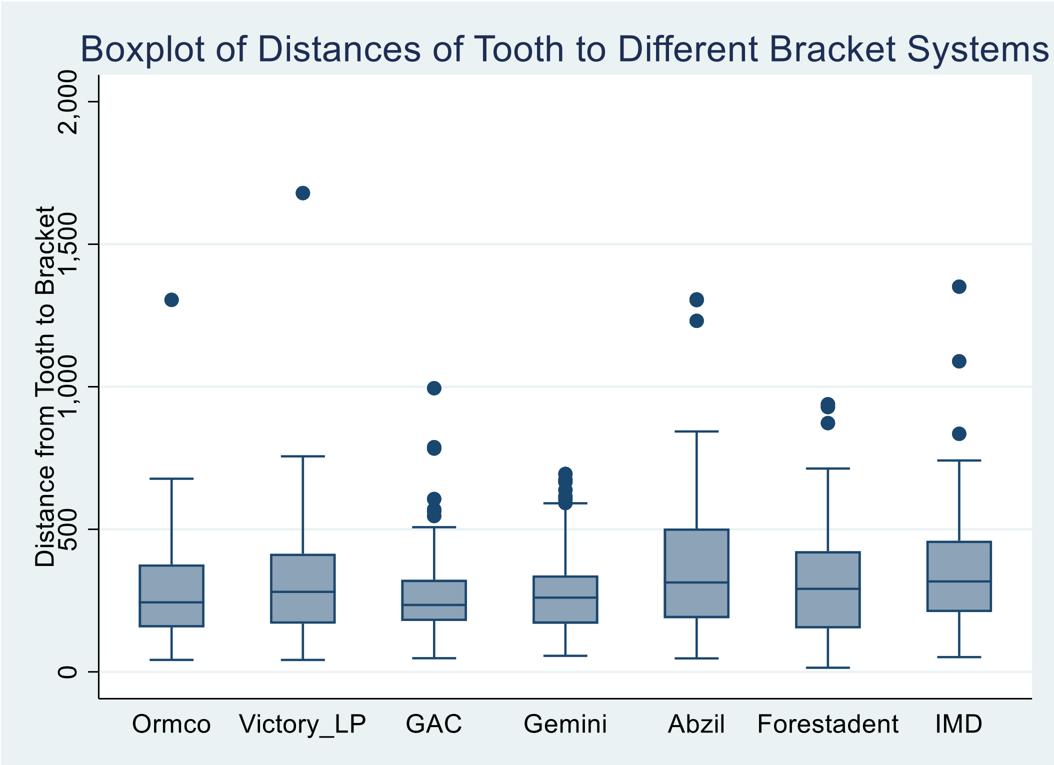


Figure 4.2a: Boxplot of distances of tooth to different bracket systems

The Boxplot shows the distances (µm) of tooth surface to the different bracket bases at all six predetermined areas of each bracket for all fifteen teeth. The box represents 50% of the readings, divided by a horizontal line representing the median of each bracket type. The boxplot plus the whisker represents the full spread of the data, excluding the outliers. The dots are representative of extreme values obtained known as outliers. Most of these outliers were seen at the cervical margin of the brackets represented in Table 4.2b.

Table 4.2b: Location and space between bracket base and tooth surface (μm) of all outliers for the seven brackets

Bracket type	**Outliers** (μm)	**Surface area**	**Tooth**
Abzil	1306.42	Occlusal mesial (TR)	1
	1304.09	Cervical centre (BM)	8
Forestadent	713.26	Cervical distal (BL)	2
	707.21	Occlusal mesial (TR)	4
GAC	994.85	Cervical distal (BL)	1
	788.06	Cervical centre (BM)	8
	783.24	Cervical distal (BL)	12
	606.34	Occlusal centre TM)	1
	569.73	Cervical mesial (BR)	11
Gemini	694.31	Cervical centre (BM)	11
	673.71	Cervical mesial (BR)	15
	615.56	Occlusal distal (TL)	3
	605.25	Occlusal mesial (TR)	15
IMD	1351.09	Cervical centre (BM)	8
	1089.29	Cervical centre (BM)	10
	835.02	Cervical centre (BM)	9
Ormco	1304.81	Cervical mesial (BR)	2
Victory LP	1679.35	Cervical centre (BM)	9

Table 4.2c: Mean values of individual brackets at the six predetermined points (µm)

Bracket name	Top Right	Top Middle	Top Left	Bottom Left	Bottom Middle	Bottom Right
Abzil	348.48	376.45	323.23	369.32	461.28	349.35
Forestadent	249.57	338.09	312.08	280.50	450.63	261.12
GAC	205.98	325.38	260.44	352.43	308.51	187.05
Gemini	198.99	331.74	360.89	260.88	318.81	258.12
IMD	288.58	327.98	318.74	320.98	583.25	329.15
Ormco	234.80	214.97	314.33	315.64	268.85	356.41
Victory LP	269.65	333.72	336.66	239.90	350.92	332.24

The smallest space between tooth surface and the bracket base was seen in GAC, Bottom Right (cervical mesial margin) with a mean value of 187.05µm. The largest space was seen in IMD, Bottom Middle (cervical centre) with a mean value of 583µm.

Table 4.2d: Numerical grading of the distance (gap) between bracket and tooth

Bracket name	Top Right	Top Middle	Top Left	Bottom Left	Bottom Middle	Bottom Right
Abzil	7	7	5	7	6	6
Forestadent	4	6	2	3	5	3
GAC	2	2	1	6	2	1
Gemini	1	4	7	2	3	2
IMD	6	3	4	5	7	4
Ormco	3	1	3	4	1	7
Victory LP	5	5	6	1	4	5

*1= shortest distance (gap) from bracket to tooth

*7= largest distance (gap) from bracket to tooth

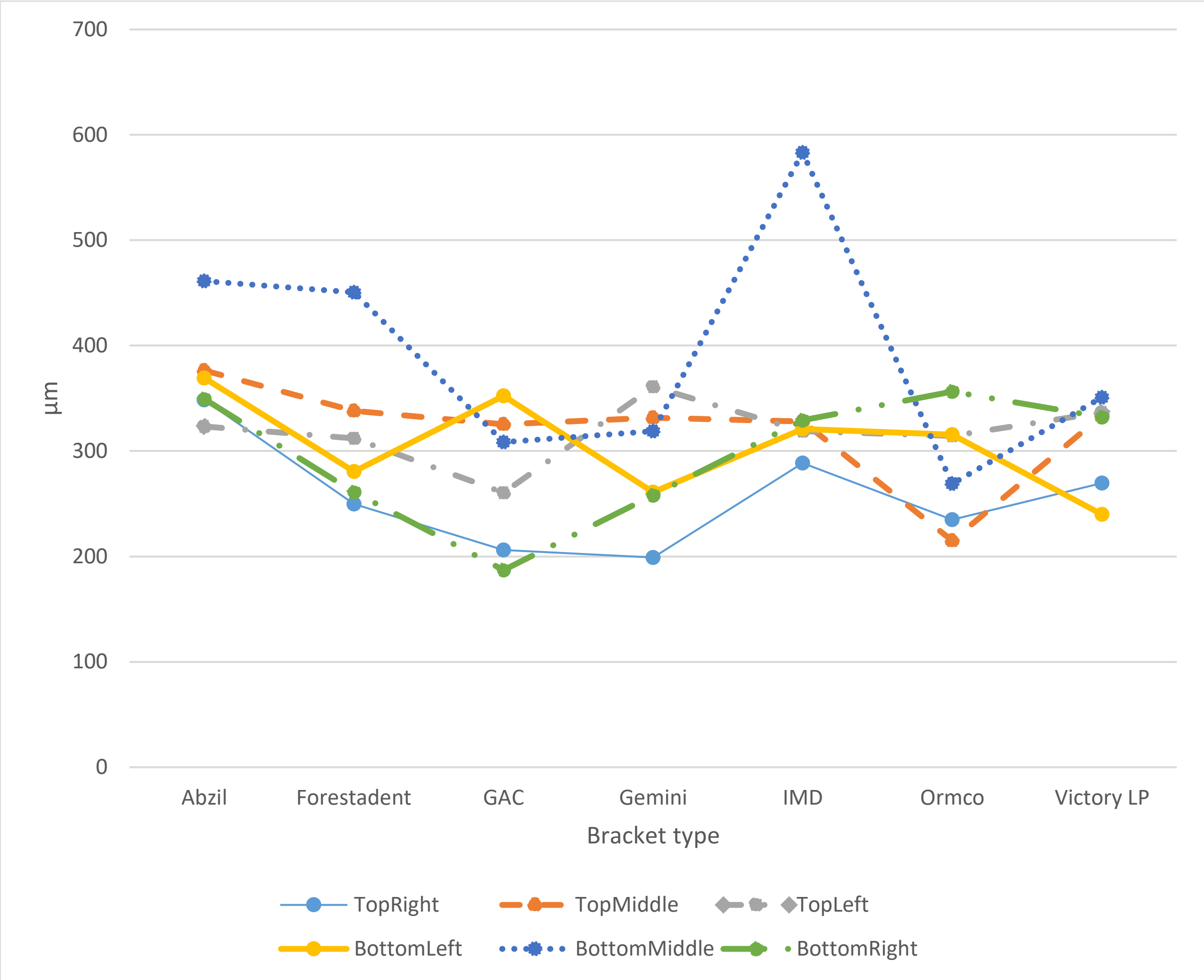


Figure 4.2b: Representation of Mean values of all brackets at the six points

Figure 4.2b demonstrates the mean values (µm) obtained for each bracket at the six pre-determined areas of all fifteen teeth. GAC showed the best marginal adaptation followed by Ormco, Gemini, Victory LP, Forestadent, IMD and Abzil showed the worst adaptation.

4.3 Points around sections of the brackets

Table 4.3a: The combined sum of the mean values for the distal, mesial, occlusal and cervical sections of the bracket (µm)

Bracket name	Distal section of bracket	Mesial section of bracket	Occlusal section of bracket	Cervical section of bracket
Abzil	692.55	697.84	1048.16	1179.96
Forestadent	592.59	510.68	899.74	992.26
GAC	612.87	393.04	791.80	847.99
Gemini	621.77	457.12	891.64	837.81
IMD	639.71	617.73	935.29	1233.39
Ormco	629.98	591.22	764.10	940.90
Victory LP	576.57	601.89	940.03	923.07

Table 4.3a demostrates that GAC showed the best marginal adaptation in the mesial section of the bracket.

Table 4.3b: Comparison test with Bonferroni correction between brackets when comparing the p-value of the brackets relative to Abzil on the mesial side of the brackets

Brackets	Bonferroni p-value
Abzil vs Forestadent	0.56
Abzil vs GAC	**0.04**
Abzil vs Gemini	0.19
Abzil vs IMD	2.83
Abzil vs Ormco	2.03
Abzil vs Victory	2.33
(^) indicates significance of **$p < 0.05$**	

GAC showed a significant difference in adaptation when compared to Abzil on the mesial side of the bracket.

Table 4.3c: Comparison test with Bonferroni correction between brackets when comparing the p-value of the brackets relative to Abzil on the distal side of the brackets

Brackets	Bonferroni p-value
Abzil vs Forestadent	1.90
Abzil vs GAC	2.55
Abzil vs Gemini	2.87
Abzil vs IMD	3.58
Abzil vs Ormco	3.18
Abzil vs Victory	1.48
(^) indicates significance of **$p < 0.05$**	

There were no significant differences seen in adaptation when comparing Abzil to the other brackets on the distal side of the brackets.

Table 4.3d: Comparison test with Bonferroni correction between brackets when comparing the p-value of the brackets relative to Forestadent on the mesial side of the brackets

Brackets	Bonferroni p-value
Forestadent vs GAC	1.74
Forestadent vs Gemini	3.78
Forestadent vs IMD	2.01
Forestadent vs Ormco	2.81
Forestadent vs Victory LP	2.47
Forestadent vs Abzil	0.56
(^) indicates significance of **$p < 0.05$**	

There were no significant differences seen in adaptation when comparing Forestadent to the other brackets on the mesial side of the brackets.

Table 4.3e: Comparison test with Bonferroni correction between brackets when comparing the p-value of the brackets relative to Forestadent on the distal side of the brackets

Brackets	Bonferroni p-value
Forestadent vs GAC	5.03
Forestadent vs Gemini	4.62
Forestadent vs IMD	3.82
Forestadent vs Ormco	4.24
Forestadent vs Victory LP	5.23
Forestadent vs Abzil	1.90
(^) indicates significance of **$p < 0.05$**	

There were no significant differences seen in adaptation when comparing Forestadent to the other brackets on the distal side of the brackets.

Table 4.3f: Comparison test with Bonferroni correction between brackets when comparing the p-value of the brackets relative to GAC on the mesial side of the brackets

Brackets	Bonferroni p-value
GAC vs Gemini	3.38
GAC vs IMD	0.27
GAC vs Ormco	0.46
GAC vs Victory LP	0.37
GAC vs Abzil	**0.04**
GAC vs Forestadent	1.74
(^) indicates significance of **$p < 0.05$**	

GAC showed a significant difference in adaptation when compared to Abzil on the mesial side of the bracket.

Table 4.3g: Comparison test with Bonferroni correction between brackets when comparing the p-value of the brackets relative to GAC on the distal side of the brackets

Brackets	Bonferroni p-value
GAC vs Gemini	5.57
GAC vs IMD	4.73
GAC vs Ormco	5.18
GAC vsVictory LP	4.29
GAC vs Abzil	2.55
GAC vs Forestadent	5.03
(^) indicates significance of **$p < 0.05$**	

There were no significant differences seen in adaptation when comparing GAC to the other brackets on the distal side of the brackets.

Table 4.3h: Comparison test with Bonferroni correction between brackets when comparing the p-value of the brackets relative to Gemini on the mesial side of the brackets

Brackets	Bonferroni p-value
Gemini vs IMD	0.90
Gemini vs Ormco	1.37
Gemini vs Victory LP	1.63
Gemini vs Abzil	0.19
Gemini vs Forestadent	3.78
Gemini vs GAC	3.38
(^) indicates significance of **$p < 0.05$**	

There were no significant differences seen in adaptation when comparing Gemini to the other brackets on the mesial side of the brackets.

Table 4.3i: Comparison test with Bonferroni correction between brackets when comparing the p-value of the brackets relative to Gemini on the distal side of the brackets

Brackets	Bonferroni p-value
Gemini vs IMD	5.14
Gemini vs Ormco	5.61
Gemini vs Victory LP	3.90
Gemini vs Abzil	2.87
Gemini vs Forestadent	4.62
Gemini vs GAC	5.57
(^) indicates significance of **$p < 0.05$**	

There were no significant differences seen in adaptation when comparing Gemini to the other brackets on the distal side of the brackets.

Table 4.3j: Comparison test with Bonferroni correction between brackets when comparing the p-value of the brackets relative to IMD on the mesial side of the brackets

Brackets	Bonferroni p-value
IMD vs Ormco	0.90
IMD vs Victory LP	1.37
IMD vs Abzil	1.63
IMD vs Forestadent	0.19
IMD vs GAC	3.78
IMD vs Gemini	3.38
(^) indicates significance of **$p < 0.05$**	

There were no significant differences seen in adaptation when comparing IMD to the other brackets on the mesial side of the brackets.

Table 4.3k: Comparison test with Bonferroni correction between brackets when comparing the p-value of the brackets relative to IMD on the distal side of the brackets

Brackets	Bonferroni p-value
IMD vs Ormco	5.53
IMD vs Victory LP	3.16
IMD vs Abzil	3.58
IMD vs Forestadent	3.82
IMD vs GAC	4.73
IMD vs Gemini	5.14
(^) indicates significance of **$p < 0.05$**	

There were no significant differences seen in adaptation when comparing IMD to the other brackets on the distal side of the brackets.

Table 4.3l: Comparison test with Bonferroni correction between brackets when comparing the p-value of the brackets relative to Ormco on the mesial side of the brackets

Brackets	Bonferroni p-value
Ormco vs Victory LP	5.54
Ormco vs Abzil	2.03
Ormco vs Forestadent	2.81
Ormco vs GAC	0.46
Ormco vs Gemini	1.37
Ormco vs IMD	4.87
(^) indicates significance of **$p < 0.05$**	

There were no significant differences seen in adaptation when comparing Ormco to the other brackets on the mesial side of the brackets.

Table 4.3m: Comparison test with Bonferroni correction between brackets when comparing the p-value of the brackets relative to Ormco on the distal side of the brackets

Brackets	Bonferroni p-value
Ormco vs Victory LP	3.55
Ormco vs Abzil	3.18
Ormco vs Forestadent	4.24
Ormco vs GAC	5.18
Ormco vs Gemini	5.60
Ormco vs IMD	5.53
(^) indicates significance of **$p < 0.05$**	

There were no significant differences seen in adaptation when comparing Ormco to the other brackets on the distal side of the brackets.

Table 4.3n: Comparison test with Bonferroni correction between brackets when comparing the p-value of the brackets relative to Victory LP on the mesial side of the brackets

Brackets	Bonferroni p-value
Victory LP vs Abzil	2.33
Victory LP vs Forestadent	2.47
Victory LP vs GAC	0.37
Victory LP vs Gemini	1.16
Victory LP vs IMD	5.32
Victory LP vs Ormco	5.54
(^) indicates significance of **$p < 0.05$**	

There were no significant differences seen in adaptation when comparing Victory LP to the other brackets on the mesial side of the brackets.

Table 4.3o: Comparison test with Bonferroni correction between brackets when comparing the p-value of the brackets relative to Victory LP on the distal side of the brackets

Brackets	**Bonferroni p-value**
Victory LP vs Abzil	1.48
Victory LP vs Forestadent	5.23
Victory LP vs GAC	4.29
Victory LP vs Gemini	3.90
Victory LP vs IMD	3.16
Victory LP vs Ormco	3.55
(^) indicates significance of **$p < 0.05$**	

There were no significant differences seen in adaptation when comparing Victory LP to the other brackets on the distall side of the brackets.

4.4 Mean values of all measurements around the brackets

Table 4.4a: Overall mean values for each bracket (µm)

Bracket	N	Mean (sd)
Abzil	90	371.35 (±255.40)
Forestadent	90	315.33 (±207.52)
GAC	90	273.29 (±160.99)
Gemini	90	288.24 (±152.43)
IMD	90	361.45 (±217.85)
Ormco	90	284.17 (±184.90)
Victory LP	90	310.52 (±221.80)
Total	630	314.91 (±205.05)

From Table 4.4a the overall mean values for each bracket showed that Abzil had the largest space between bracket base and tooth surface at a mean value of 371.35µm (sd±255.40). The smallest space was seen by GAC with a mean value of 273.29µm (sd±160.99).

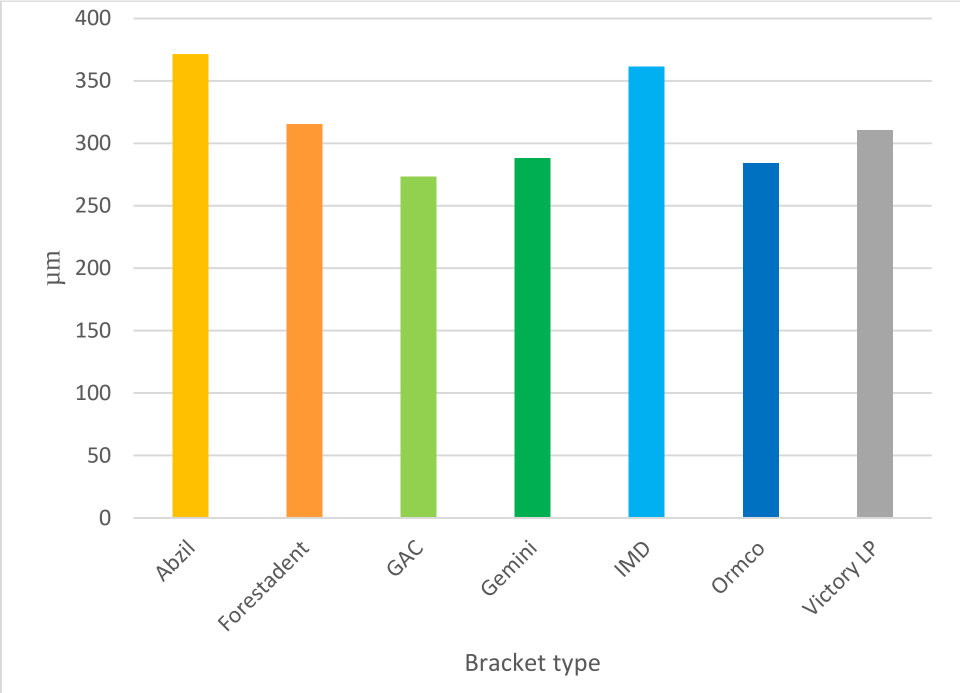


Figure 4.4: Representation of the Overall Mean values for each bracket

Figure 4.4 illustrates the overall mean values for each bracket. Abzil had the largest space between bracket base and tooth surface at a mean value of 371.35µm (sd±255.40). The smallest space was seen by GAC with a mean value of 273.29µm (sd±160.99).

Table 4.4b: Multiple comparison between brackets to indicate significance ($p < 0.05$)

Bracket	Contrast	Delta-method Std. Err.	Unadjusted T	P>t	Unadjusted (95% Conf. Interval)	
Victory vs Ormco	26.35	29.76	0.89	0.04	-32.09	84.79
GAC vs Ormco	-10.87	29.76	-0.37	0.72	-69.31	47.58
Gemini vs Ormco	4.07	29.76	0.14	0.89	-54.37	62.52
Abzil vs Ormco	87.19	29.76	2.93	**0.004**	28.74	145.63
Forestadent vs Ormco	31.16	29.76	1.05	0.29	-27.28	89.61
IMD vs Ormco	77.28	29.76	2.60	**0.010**	18.83	135.72
GAC vs Victory LP	-37.22	29.76	-1.25	0.212	-95.66	21.23
Gemini vs Victory LP	-22.28	29.76	-0.75	0.454	-80.72	36.17
Abzil vs Victory LP	60.84	29.76	2.04	0.041	2.39	119.28
Forestadent vs Victory LP	4.82	29.76	0.16	0.871	-53.63	63.26
IMD vs Victory LP	50.93	29.76	1.71	0.088	-7.51	109.37
Gemini vs GAC	14.94	29.76	0.50	0.616	-43.50	73.39
Abzil vs GAC	98.05	29.76	3.29	**0.001**	39.60	156.49

Forestadent vs GAC	42.03	29.76	1.41	0.158	-16.41	100.48
IMD vs GAC	88.15	29.76	2.96	**0.003**	29.70	146.59
Abzil vs Gemini	83.11	29.76	2.79	**0.005**	24.67	141.56
Forestadent vs Gemini	27.09	29.76	0.91	0.363	-31.35	85.54
IMD vs Gemini	73.21	29.76	2.46	**0.014**	14.46	131.65
Forestadent vs Abzil	-56.02	29.76	-1.88	0.060	-114.46	2.42
IMD vs Abzil	-9.91	29.76	-0.33	0.739	-68.35	48.54
IMD vs Forestadent	46.11	29.76	1.55	0.122	-12.33	104.56
(^) indicates significance of **$p < 0.05$**						

Significant differences were seen when comparing the mean values of all the brackets at the six pre-determined points. Significant differences ($p < 0.05$) were seen between Abzil and Ormco ($p = 0.004$), Abzil and GAC ($p = 0.001$) and Abzil and Gemini ($p = 0.005$).

Significant differences ($p < 0.05$) were seen between IMD and Ormco ($p = 0.010$), IMD and GAC ($p = 0.003$) and IMD and Gemini ($p = 0.014$).

CHAPTER 5: DISCUSSION

Introduction

A close marginal adaptation between the tooth and the bracket base is important since it provides the space for the adhesive. In order to withstand and resist the orthodontic forces exerted as well as everyday forces like mastication and oral hygiene practices, the adhesive material to the bracket must have sufficient sheer bond strength. This means that no deformations, cracks, or fractures should occur within the bracket material and adhesive (Keizer et al., 1976).

In this study, the hypothesis that all the brackets have a uniform space between bracket base and tooth surface between the fifteen premolars was rejected. Great variability was seen between the different brands of brackets with the same set prescription and the buccal curvature of the teeth used.

The base of the bracket should ideally follow the curvature of the tooth for close adaptation. The closer the adaptation of bracket base and the tooth, will result in better adhesion, longer retention before the bracket de-bonds and the tooth movement will be more efficient (Gontijo et al., 2004). The closer the adaptation of the bracket to the tooth, the better the adhesion will be and the longer the retention of the bracket to the tooth resulting in more effective tooth movement. When adaptation is poor, more adhesive is required to fill the space between tooth surface and bracket base. When compared to restorative techniques, an incremental uniform filling technique of composites demonstrates more effective adhesion to a cavity floor (Chikawa et al., 2006). Likewise this may help to avoid polymerisation shrinkage creating undue forces between the tooth and the bracket. The poor adaptation could also create a gap at the adhesive enamel interface resulting in microleakage with a lower sheer bond strength (Arhun et al., 2006). This could lead to white spot lesions developing below and around the bracket base (James et al., 2003).

This dissertation will highlight that the bracket adaptation and fitting surface therefore has an influence on the potential for white spot lesions forming at the bracket margin and an influence on sheer bond strength. To the knowledge of the researcher, there are no other studies in the literature looking at specifically the measurement of space between the margin of the bracket base and tooth surface without the use of an adhesive on a random sample of teeth.

5.1 Discussion of raw findings

5.1.1 *Validity and reliability*

The sample was examined by the researcher who was blinded while viewing the brackets. 10% of the sample was re-examined three months later for intra-observer reliability. 2% percent of the sample was examined by another researcher for inter-observer reliability. Calibration of the researcher was done with the supervisors of the project.

To test the reliability of the results, the two-way mixed-effects model was chosen because the selected investigators were the only investigators of interest. With this model, results for reliability apply to the specific investigators involved in the reliability experiment. The results cannot be generalized to other investigators even if those raters have similar characteristics. Values less than 0.5 are indicative of poor reliability. Values between 0.5 and 0.75 indicate moderate reliability. Values between 0.75 and 0.9 indicate good reliability and values greater than 0.90 indicate excellent reliability. Both inter-reliability and intra-reliability scores were greater than 0.9 indicating excellent reliability (Table 4.1a, Table 4.1b). This is due to the accuracy of the software programme of the microscope (Zen 2.3 blue edition, Carl Zeiss Microscope2011 GmbH)(Figure 3.10.3).

5.1.2 *Individual points around the bracket*

The brackets studied showed considerable differences in base size and shape (Figure 3.11.2a-g and Table 3.11.2). These figures also show where the marginal adaptation measurements were taken on the bracket base.

Table 4.2a represents the mean value with its standard deviation for the brackets assessed at the individual points of the 15 teeth. Although the standard deviation is large between the individual observations when particular readings were compared, the Pearson correlation indicated that there were no significant difference ($p>0.05$) between the standard deviation values for any of the brackets at their correlated points. Because the

15 teeth were randomly selected, it is representative of an appropriate sample and one would expect that the bracket adaptation would be more consistent.

Based on this premise figure 4.2a represents a Boxplot of all observations for all the brackets and will illustrate how the outliers contribute to the seemingly large standard deviation. The Boxplot shows the distances (µm) of tooth surface to the different bracket bases at all six predetermined areas of each bracket for all fifteen teeth (Figure 3.11.2a-g). There were many outliers that were all included in the statistical analysis of this study (Figure 4.2a). The box represents 50% of the readings, divided by a horizontal line representing the median of each bracket type. The boxplot plus the whisker represents the full spread of the data, excluding the outliers. The dots are representative of extreme values obtained known as outliers. Most of these outliers were seen at the cervical margin of the brackets and that does not conform to the premise of the bracket having an equal space between the tooth and bracket base (Table 4.2a).

From Table 4.2a and Figure 4.2a, the individual teeth and their outlier surfaces were assessed in more detail. It was found that the bracket surface at tooth numbers 1, 2, 8, 9, 10, 11, 12 and 15 had large spaces between bracket base margin and the tooth surface at the cervical area (13 surface areas between the 8 teeth). Abzil, Gemini and GAC were the only brackets that had outliers on the occlusal surface with tooth numbers 1, 3, 4 and 15. Therefore most of the outliers were located at the cervical area. This clearly indicates that all of the brackets with outliers have a poorer adaptation to the cervical area. The significance of this is discussed in paragraph 5.2.3. When the brackets were considered as a whole (all outliers) it became apparent that he distribution of the outliers were the most for GAC with 11 outliers, Abzil (6), Gemini (6), IMD (6), Forestadent (3), Ormco (2) and Victory (2). The significance of this is discussed in paragraph 5.1.4.

Table 4.2b and 4.2c demonstrates the mean values (µm) obtained for each bracket at the six pre-determined areas of all fifteen teeth. All six values of each bracket vary and there is no standardisation between the six readings of each bracket. Likewise there is no standardisation between the seven brackets. This shows that there is not a uniform space between the margin of the bracket base and the tooth surface.

A numerical grading of the distance (space) between bracket and tooth is seen in Table 4.2d. Numerical value 1 refers to the closest adaptation between bracket and tooth and numerical value 7 referring to the poorest adaptation. Based on numerical grading in Table 4.2d, GAC had the best adaptation overall except for cervical distal. When referring to Figure 4.2b, the marginal adaptation of GAC as well as Ormco are better when compared to the other brackets. Figure 4.2b illustrates the brackets comparing the best adaptation to the worst. GAC showed the best adaptation followed by Ormco, Gemini, Victory LP, Forestadent, IMD and Abzil showed the worst adaptation. Upon detailed investigation of the data represented in table 4.2b, Table 4.2c and Figure 4.2b, further trends toward the size of the space with its specific location can be explored in paragraph 5.1.2a – 5.1.2g.

5.1.2a GAC bracket

The closest adaptation between bracket base and tooth surface in the entire study can be seen in GAC, at the cervical mesial point (BR), at a mean value of 187.05µm (sd±110.95). At Occlusal distal (TL), the smallest space was also seen with GAC at a mean value of 260.43µm (sd±81.38) (Table 4.2a, 4.2c, Figure 4.2b).

5.1.2b Ormco bracket

The Ormco bracket showed the smallest space at two different measuring points. At occlusal centre (TM), the smallest space was seen with Ormco at a mean value of 214.97µm (sd±107.71) and at cervical centre (BM), at a mean value of 268.85µm (sd±100.32).

However, the largest space was seen at cervical mesial (BR), at a mean value of 356.4µm (sd±313.90) (Table 4.2a, 4.2c, Figure 4.2b).

5.1.2c Gemini bracket

At the point occlusal mesial (TR), the smallest space was seen with Gemini at a mean value of 198.99µm (sd±125.11). At occlusal distal (TL), the largest space was seen with Gemini at a mean value of 360.89µm (sd±143.62) (Table 4.2a, 4.2c, Figure 4.2b).

5.1.2d Victory series bracket

At the cervical distal point (BL), the smallest space was seen with Victory series at a mean value of 239.90µm (sd±143.67) (Table 4.2a, 4.2c, Figure 4.2b).

5.1.2e Forestadent bracket

Forestadent brackets did not have the largest nor smallest distances between bracket base and tooth surface amongst the six measuring points (Table 4.2a, 4.2c, Figure 4.2b).

5.1.2f IMD bracket

The largest space between bracket base and tooth surface of the study was seen by IMD, cervical centre (BM), with a mean value of 583µm (sd±314.87) across the 15 teeth (Table 4.2a, 4.2c, Figure 4.2b).

5.1.2g Abzil bracket

The Abzil bracket showed the largest space at three different measuring points. At the occlusal mesial point (TR), the largest space was seen with the Abzil bracket at a mean value of 348.48µm (sd±325.47), also at the occlusal centre (TM), at a mean value of 376.45µm (sd±199.05) and at the cervical distal point (BL), at a mean value of 369.32µm (sd±314.57) (Table 4.2a, 4.2c, Figure 4.2b).

5.1.3 *Points around sections of the bracket*

Table 4.3a looked at various sections of the brackets (Mesial section, distal section, occlusal section and cervical section). This was calculated from the combined sum of mean values for the different sections. For the mesial section, the average was taken when combining the mesial occlusal and mesial cervical values. For the distal section, the average was taken when combining the distal occlusal and distal cervical values. For the occlusal section, the average was taken when combining the mesial occlusal, distal occlusal and occlusal centre values. For the cervical section, the average was taken when combining the mesial cervical, distal cervical and cervical centre values. From Table 4.3a, there is a bigger space between the bracket and the tooth on the distal section when compared to the mesial section. Similarly, there is a bigger space on the cervical section of brackets when compared to the occlusal section of the brackets (Table 4.3a).

Kruskal Wallis multiple comparison test with Bonferroni correction showed significance when comparing the mesial side of the brackets. From Table 4.3b, there was a significant difference when looking at the mesial side of brackets between Abzil and GAC ($p = 0.04$)

(Table 4.3b, Table 4.3f). The spread of the data for the mesial side of Abzil and GAC when considering the standard deviation, was determined to be ±108.86 for GAC compared to ±428.09 for Abzil. This trend was additionally confirmed by Abzil presenting with a much greater mean space between bracket base and tooth surface (697.84µm) when compared to GAC (393.04µm) on the mesial side. This suggests that the Abzil bracket is not adapting well to the curvature of the tooth on that side. There were no other significant differences when comparing the mesial and distal sides nor their standard deviations of all other brackets (Figure 4.3c-o).

5.1.4 *Mean values of all measurements around the brackets*

The overall mean values for each bracket showed that Abzil had the largest space between bracket base and tooth surface at a mean value of 371.35µm (sd±255.40). The smallest space was seen by GAC with a mean value of 273.29µm (sd±160.99) (Figure 4.4, Table 4.4a). The measurement range for Abzil was between 115.95µm and 626.75µm and for GAC it was between 112.3 µm and 434.28 µm. This spread of data was visually confirmed by the size of the Boxplot in Figure 4.2a. This small spread of the GAC data including the outliers resulted in GAC having the smallest measurement across the brackets investigated. According to the Pearsons correlation for paired data for Abzil vs GAC, there was no significant difference ($p=0.13$) for the standard deviations of the average space between bracket base and tooth surface.

The space between bracket base margin and the tooth surface is vital as it dictates the amount of adhesive cement required between bracket base and tooth surface. Therefore the measurement of the space must have some clinical relevance influencing bracket position, adaptation, bacterial colonisation, white spot lesions and sheer bond strength. This dissertation will now look at whether this space could have an impact on these factors. These aforementioned clinical parameters and their impact based on the bracket and the tooth were explored in Table 4.4b and Figure 4.4. Significant differences were seen when comparing the mean values of all the brackets at the six pre-determined points. Significant differences ($p < 0.05$) were seen between Abzil and Ormco ($p = 0.004$), Abzil and GAC ($p = 0.001$) and Abzil and Gemini ($p = 0.005$). There are no studies in the literature looking at the adaptation of IMD brackets. Therefore it is difficult to make comparisons. However, from this present study IMD showed a large overall mean gap size of 361.45µm (sd±217.85) (Table 4.4a, Figure 4.4). Significant differences ($p < 0.05$) were seen between IMD and Ormco ($p = 0.010$), IMD and GAC ($p = 0.003$) and IMD and Gemini ($p = 0.014$) (Table 4.4b). Figure 4.4 illustrates the overall mean value of the gap between the bracket and the tooth and clearly shows that GAC followed by Ormco and Gemini provided the best fit to the teeth.

5.2 Possible practical relevance of space between bracket base and tooth surface

5.2.1 *Bracket position*

The prescription used for the placement of the bracket in this dissertation was justified based on various aspects of bracket placement studies in the literature (Mestriner et al., 2006; Armstrong et al., 2007; Mota Junior et al., 2018). Bracket position has been cited to be important as it allows for effective and correct torque delivery to the crown and root. Therefore, bracket placement is essential to the efficient and accurate movement of teeth (Mestriner et al., 2006). In the aforementioned study the bracket was set at a prescription of 4mm from the buccal cusp tip to the slot area on the bracket. This indicates that a prescription of 4mm is adequate for premolars and clinically reproducible.

Armstrong et al. (2007), concluded that placement of brackets in the position determined by measuring the distance from the incisal edge appears to be more accurate in the vertical dimension for the upper and lower anterior teeth and therefore the recommendation for bracket positioning of premolars (Armstroong et al., 2007).

A study by Mota Junior et al. (2018) looked at the correct bracket positioning by using a prototype bracket positioning gauge and also placed the bracket at 4mm from the incisal cusp tip. The study included clinicians of different experience levels and brackets were bonded to incisors, canines and premolars. But the important conclusion was that the clinical experience of the clinician interfered with the vertical accuracy of bracket positioning. They found that the closest means to the standard measurement were those from the premolars when compared to that of the canines and incisors.

Therefore the prescription of 4mm was used for the present in vitro analysis of the space between bracket base and buccal surface of the premolar. This allowed for the most accurate representation of the prescription and the ideal sample size to test the hypothesis that all brackets will have the same marginal adaptation between bracket base and tooth surface between the fifteen premolars.

However, the fitting surface of the bracket base should also be considered when placing the brackets. Vianna et al. (2005), looked at the influence of the bracket base curvature in relation to the curvature of the buccal surface of the lower canine. Torsion load and stress distribution using finite element analysis was assessed. The study concluded that there was no standardisation between the curvatures of the four brackets tested. It was also found that the curvature of the bracket bases were very different to the dental anatomy of the buccal surface of the lower canine. This variation compromises the optimal position of bracket placement and based on the finite element analysis will adversely influence the intended function of the bracket (Vianna et al., 2005).

Similarly in the present study, the seven brackets tested all showed different marginal adaptation of bracket base and tooth surface to each other, with no standardised fit of where the space formed between bracket base and tooth surface (Table 4.2a). This highlights the differences in adaptation to the same fifteen teeth with the same set prescription for the seven brackets. There were many outliers as shown by a Boxplot, they were all included in the statistical analysis of this study (Figure 4.2a), because the investigator reliability with the measurements was high. The Boxplot shows the cumulative distances (µm) of the tooth surface to the different bracket bases at all six predetermined areas of each bracket for all fifteen teeth. The box represents 50% of the readings, divided by a horizontal line representing the median of each bracket type. The dots are representative of "extreme values" that do not conform to the median obtained and are known as outliers. 78% of these outliers were seen at the bottom of the bracket bases suggesting it is more ill-fitting in these areas (Table 4.2a) which further supports the findings of Vianna et al. (2005).

5.2.2 *Adaptation*

5.2.2a Surface area

The size and shape of the bracket bases used in this study varied between the different brands (Figure 3.11.2a-g). The occlusal and cervical widths also differed between brackets (Table 3.11.2). The occlusal width was measured from the occlusal mesial to occlusal distal points (TR-TL). Likewise the cervical width was measured from the cervical mesial to cervical distal points (BR-BL). There is a correlation between bracket base size and sheer bond strength which is discussed later in paragraph 5.2.5.

A study by Shintcovsk et al. (2015), compared the surface area of four conventional brackets. The study concluded that the surface area of the Abzil bracket was more homogenous than the other three brackets. However, the Abzil brackets showed a larger area of imperfections for upper bracket bases. The gingival blades showed greater irregularities when compared to the other brackets. This resulted in more corrosion related alterations when submitted to biodegradation. These imperfections were also seen in the present study (Figure 5.2.2a).

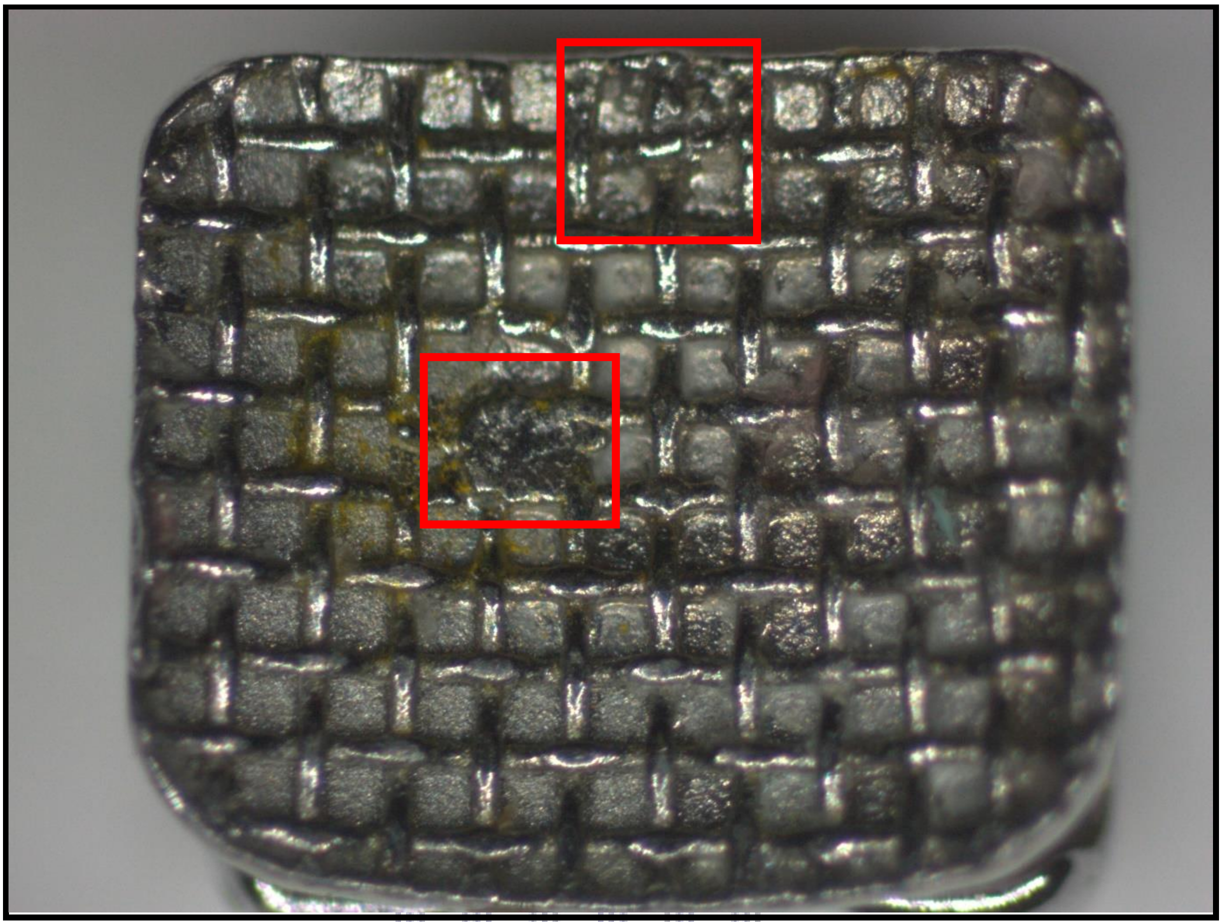


Figure 5.2.2a: Abzil fitting surface (showing imperfections)

5.2.2b Slot size

The slot of the bracket can be seen as the most important part as it plays a role in the force distribution and tooth movement. A change in size can therefore influence the orthodontic mechanics of tooth movement. This may compromise frictional resistance and application of angles and torques (Jones et al., 2002). The slot is used clinically to position the bracket as discussed in paragraph 5.2.1 (Mota Junior et al., 2018). The literature stated that there were variations in the brackets manufactured and supplied to the clinician (Erduran et al., 2016). This became apparent upon investigation of the bracket slot sizes, although this was not the initial hypothesis of this thesis. This incidental finding re-affirmed that variation in brackets is present. Slot height can be defined as the distance between the slot base and slot top. Measurements of these slot heights may be difficult due to the shape of the slot walls. Some may be rounded or bevelled and this complicates the evaluation of the exact end point of the bracket slot (Cash et al., 2004). Table 5.2.2 shows the mean values of different authors in relation to the brackets used in this dissertation. Figure 5.2.2b-e shows the slot heights of four of the brackets in this study. There were differences identified and this lead to the conclusion that the tolerance of accuracy during bracket manufacture are not consistent. This would mean that with another batch of brackets the adaptation and contour of the brackets could also have a variation if this variation in Table 5.2.2 is carried through to other aspects of the orthodontic brackets. The numerical rating however, indicates that the sequence 1-4 for this dissertation matches up perfectly with that of the slot sizes from the literature.

Table 5.2.2: Comparison of slot heights between studies (µm)

Bracket Type	**Erduran et al., 2016 Height (µm)**	**Present study Height (µm)**	**Numerical rating**
Abzil	588	1457.16	4
Forestadent	565	1088.24	2
GAC	560	955.84	1
Ormco	573	1327.85	3
Victory LP	not assessed	1641.56	excluded
Gemini	not assessed	1763.99	excluded
IMD	not assessed	1585.72	excluded

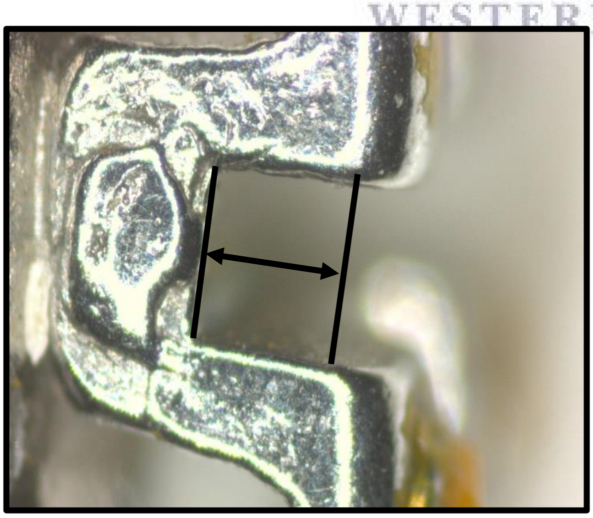


Figure 5.2.2b: Abzil bracket slot height

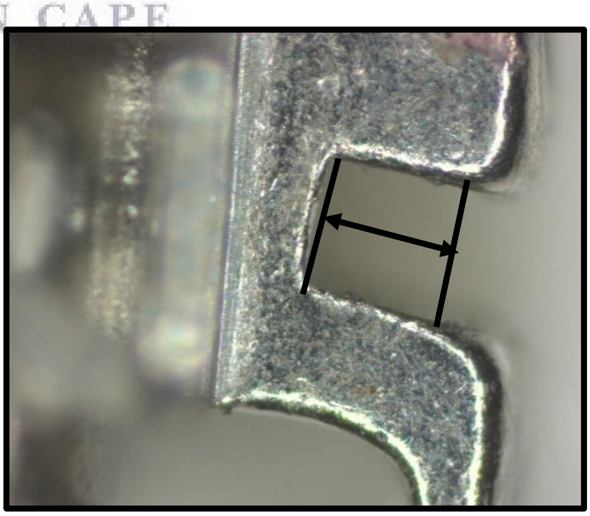
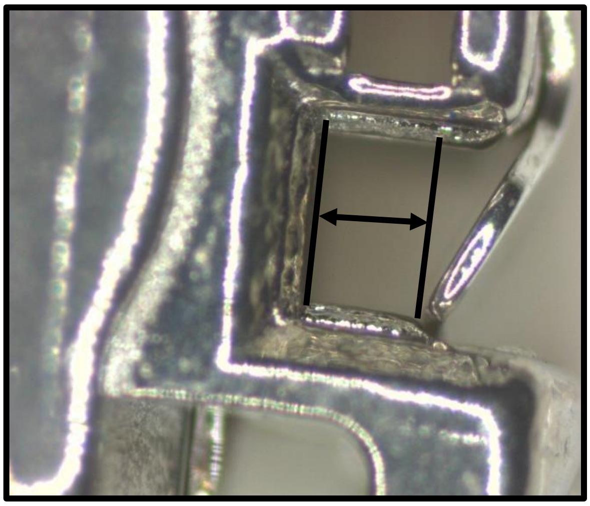


Figure 5.2.2c: Ormco bracket slot



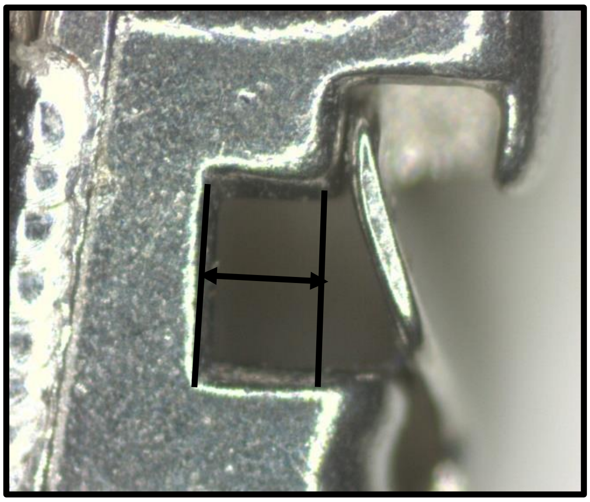


Figure 5.2.2d: Forestadent bracket slot height **Figure 5.2.2e:** GAC bracket

Erduran et al. (2016), did an analysis on the precision of torque and slot dimensions of eight different orthodontic bracket brands. The results were compared to the ISO standard (ISO 027020). The study found that the Forestadent and GAC bracket was amongst three brackets that did not differ with regards to the ISO 027020 standard. The other five brackets tested did not comply with the ISO standard. Four common brackets were used in the present study and Erduran et al. (2016). These brackets were Abzil, Forestadent, GAC and Ormco. Although measurements differ between the two studies, the rating of slot size are the same (Table 5.2.2). In decending order of slot size: Abzil, Ormco, Forestadent and GAC (Figure 5.2.2 b-e).

Slot tolerance refers to the dimensions of the slot that should allow for the application of angles and torques (Jones et al., 2002). A study by Martinez Perez et al. (2014), looked at slot tolerance from three different orthodontic brackets. The results confirmed that the slot sizes of all the brackets were larger than the manufacturer claimed. Ormco bracket was found to be significantly different and did not comply with measurements provided by the manufacturer. A similar study looking at slot tolerance found the GAC bracket to be significantly larger than manufacturers claim (Diaz et al., 2014).

Cash et al. (2004), also evaluated slot size in orthodontic brackets. The results showed that orthodontic bracket slots are larger than manufacturers claim (Cash et al., 2004; Pogulwar et al., 2018). Cash et al. (2004), found the Victory series bracket slot to be divergent and oversized by 6%. The study further concluded that clinicians should consider that there may be a loss in tooth positioning due to the use of orthodontic brackets with large slots. The present study also found Victory series bracket to be divergent (Figure 5.2.2e).

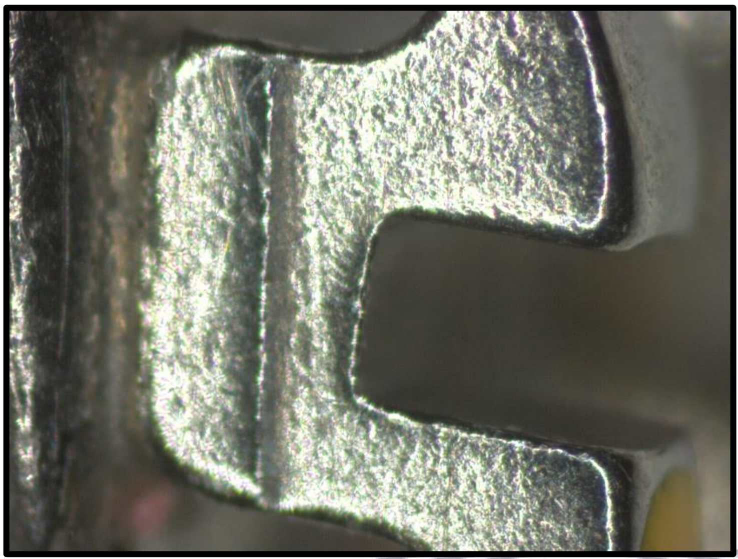


Figure 5.2.2f: Victory bracket divergent slot

Gemini bracket slots were also found to be larger than manufacturers claim but had the least difference in their torque value compared to the standard values (Pogulwar et al., 2018). In this dissertation, the Gemini bracket had the largest slot size when compared to the other six brackets (Table 5.2.2, Figure 5.2.2g).

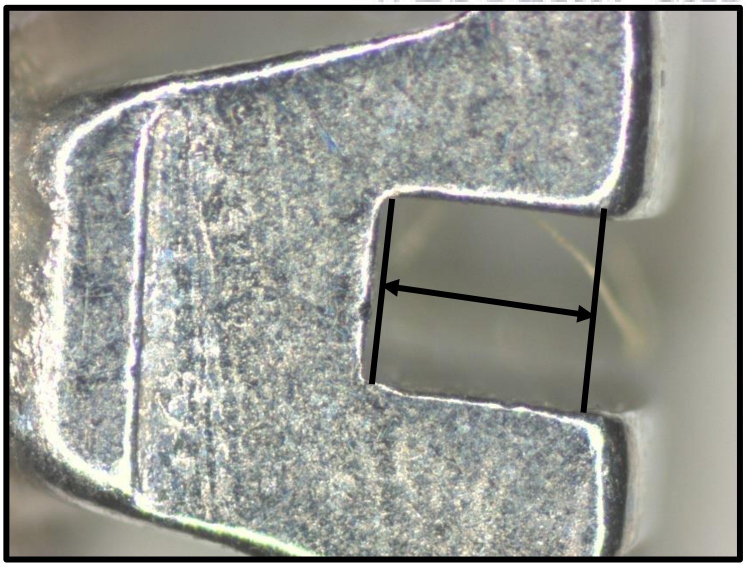


Figure 5.2.2g: Gemini bracket with largest slot size

5.2.3 Bacterial colonisation

The orthodontic brackets have been found to be contaminated by bacteria in the original packaging supplied by the manufacturer (Barker et al., 2013, Dos Santos Gerzson et al., 2015). In a study by Dos Santos Gerzson et al. (2015), bacteria was found on Abzil and Morelli brackets. This data suggested that the manufacturers of these materials should improve the quality of packaging to secure patient oral health. Brackets are removed from packaging and placed directly onto the tooth surface by most clinicians. Diseases can be transmitted through direct contact with contaminated instruments when used directly from the manufacturer's packaging (Morrison & Conrad, 2009).

A study by Gwinnet and Ceen (1979), showed plaque deposits at the junction between the bracket and its base of mesh-back brackets. The deposits covered the mesial and distal surfaces of the base next to the bracket. Poor adaptation of the bracket base to tooth surface would therefore aid these plaque deposits. Table 4.3a demonstrates the comparison between mean values for various sections of the bracket (µm) for each of the seven brackets. Table 4.3b is the comparison test with Bonferroni correction between brackets when comparing the readings on the right hand side of the brackets (Kruskal Wallis). A significant difference was found between Abzil and GAC (p=0.04) on the Right surface (mesial surface) (Figure 5.2.3). This aligns with the overall mean results of the brackets where GAC had the smallest space and Abzil had the largest space between bracket base and tooth surface (Table 4.4a, Figure 4.4).

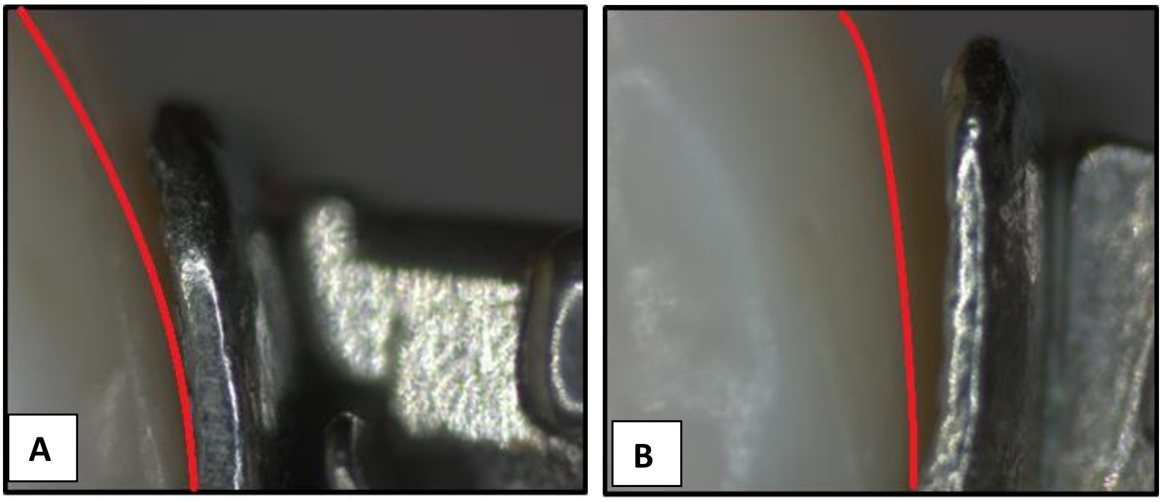


Figure 5.2.3: Comparison of gap sizes on the mesial surface between GAC (A) and Abzil (B).

Clinically, plaque formation is most commonly found on the cervical surface of brackets, gingival the leveling arch, and its accumulation is exacerbated by patient's difficulty cleaning these sites (Cardoso et al., 2015). Results from this study shows that the gap between bracket base and tooth surface is greater at the cervical surface (bottom section in this dissertation) of bracket when compared to the occlusal section. From Table 4.3a, there is a larger space between the bracket and the tooth on the distal section when compared to the mesial section. Similarly, there is a larger space on the cervical section of brackets when compared to the occlusal section of the brackets. (Table 4.3a).

Bracket design also has an impact on bacterial load. It is believed that plaque formation could be attributed to the complexity of the bracket design. The most popular site for bacterial adhesion to the brackets is at the bracket adhesive-enamel junction. This area was cited as being most difficult to clean (Moolya et al., 2014). The most common site for demineralisation appears to be in the area between the bonding resin and enamel. Therefore an increase in the measurement of the space between bracket base and tooth surface would therefore exacerbate the bacterial load in this area. This combined with the bacteria already present on new brackets would further put the patient at risk. Excess composite/adhesive around the bracket base is a critical site for plaque accumulation due to its surface roughness and the presence of a distinct gap at the adhesive-enamel interface (Sukontapatipark et al., 2001).

5.2.4 *White spot lesions*

White spot lesions (WSL) can be defined as demineralisation of enamel (Gavrilovic, 2014). Demineralised white spot lesions occur often after orthodontic treatment (Willmot, 2008; Mizrahi, 1983).

The prevalence of WSL can be reduced by the use of a fluoridated toothpaste, a mouth rinse containing fluoride and professionally applied fluoride gel or varnish at regular intervals during orthodontic treatment (Dabas et. al, 2016).

Clinically, white spot lesions (WSL) can be seen around orthodontic brackets after only 4 weeks of orthodontic treatment. The presence of brackets and other orthodontic attachments with their uneven surfaces increases the accumulation of plaque on the buccal surfaces of crowns (O'Reilly & Featherstone, 1987). Few studies have been done on the precise location of WSL and the literature shows no clear measurement of the precise surface areas of affected teeth (Willmot, 2008). However, Mizrahi (1983) found the WSL to be largely situated in the cervical area of the tooth. White spot lesions have various contributing factors that may influence the severity. This includes the microbial factors and its adherence to the orthodontic brackets, stagnation areas around brackets and difficulty for patients to clean areas around the brackets (Srivastava, 2013). This is due to the irregular surfaces of brackets, bands, wires and other attachments. It creates stagnation areas for plaque accumulation (Rosenbloom & Tinanoff, 1991). Teeth most often affected are molars, upper lateral incisors, lower canines and premolars (Ogaard et al., 1988).

Richter et al. (2011) did a study looking at the patient orthodontic records at the University of Michigan school of Dentistry. They looked at 350 cases treated over a period of 7 years from 1997 to 2004. They found that the incidence of new WSL during treatment was 72.9% of the patients and 2.3% of the patients developed cavitated lesions.

Savariz et al. (2012) did a study with Abzil premolar brackets and found that demineralisation and WSL were reduced when using a fluoride releasing adhesive compared to a non-fluoride releasing adhesive. This dissertation found the Abzil brackets to have the poorest marginal fit when compared to all other brackets tested (Table 4.4a, Figure 4.4). Significant differences were seen when comparing the overall mean values for the space between bracket base and tooth surface. Significant difference regarded as $p < 0.05$. Abzil showed a significant difference with Ormco ($p = 0.004$), GAC ($p = 0.001$) and Gemini ($p = 0.005$) (Table 4.4b).

It could then be assumed that the larger the space between the bracket base and tooth surface, more adhesive would be required to fill the space between tooth and bracket. This may then lead to microleakage and WSL formation due to greater polymerisation shrinkage.

5.2.5 Sheer Bond Strength

Bond failures continue to be a problem in clinical practice despite the advancements of bonding materials (Northrup et al., 2007). Irregular adaptation of a bracket base to the tooth surface may result in an uneven thickness of bonding adhesive (Andrews, 1990).

An in vitro study by Jain et al. (2013), aimed to determine the optimum adhesive thickness by varying the force applied and then observed the effect on sheer bond strength. The study showed that adhesive thickness is inversely proportional to applied force. The adhesive thickness between bracket base and tooth surface decreased with an increase in force applied from 0.28N-0.83N. Mean sheer bond strength decreased when adhesive thickness decreased from 0.99mm to 0.83mm. And also decreased when adhesive thickness reached 0.72mm. The study concluded that optimum adhesive thickness should be considered at 0.83mm. Therefore for the ideal bracket placement, the bracket base should be flush against the tooth surface and follow the curvature of the tooth when no adhesive is used (as close to zero µm as possible). This will place the responsibility on the clinician to use a dontrix gauge with an equal applied force of 0.28N-0.83N. The goal would be for the final clinical result to have the ideal amount of adhesive to achieve a uniform adhesive thickness of 0.83mm.

A study by Hudson et al. (2011), concluded that the size and design of the orthodontic bracket surface also plays a role in sheer bond strength. A thicker mesh wire combined with a smaller mesh aperture lead to a lower sheer bond strength (Matasa, 2003).

It has been shown that bond strength differs with the different types of teeth. It plays a role in sheer bond strength which is lower with premolars when compared to molars (Hobson et al., 2001).

There have been various studies in the literature comparing sheer bond strengths between different brackets from several manufacturers (Cozza et al., 2006; Lugato et al., 2009; Sfondrini et al., 2010; Hudson et al., 2011; Chavez et al., 2013; Goyal et al., 2013). Clinically, sheer bond strengths of 5.88 to 7.85 MPa are adequate for orthodontic brackets (Reynolds, 1975). In order to see if there is a correlation between sheer bond strength and the space between bracket base and tooth surface, the researcher looked at sheer bond strengths of brackets used in this dissertation to see if any conclusions could be drawn.

From Table 5.2.5, Cozza et al. (2006) compared the sheer bond strength of different metal orthodontic brackets. Amongst these were Forestadent and Victory series brackets common to the present study. Victory series brackets had a higher sheer bond strength when compared to Forestadent. Lugato et al. (2009) looked at a comparison of sheer bond strength between Abzil metal brackets in its conventional form and Abzil brackets sandblasted. There was no significant differences in sheer bond strength. Sfondrini et al. (2010) tested the sheer bond strength of four stainless steel brackets including Forestadent and Ormco brackets. Ormco was found to have a higher sheer bond strength when compared to Forestadent. Hudson et al. (2011) compared the sheer bond strengths of Victory series, Ormco and GAC brackets with three different adhesives. Victory series was found to have the highest sheer bond strength, closely followed by GAC and Ormco having the lowest sheer bond strength. Chavez et al. (2013) looked at Gemini premolar brackets and compared the sheer bond strength between two different adhesives. The study concluded that there was no significant difference between the two adhesives with regards to sheer bond strength. Looking at sheer bond strengths of six different premolar brackets, Gemini was found to have the second lowest sheer bond strength (Goyal et al., 2013).

Even though these studies did not test the same brackets on all the same teeth, deductions can be made on the brackets that were tested. When comparing these studies in Table 5.2.5, the highest sheer bond strength was seen with Victory series brackets, followed by GAC, Ormco and lastly Forestadent. Abzil could not be compared because Lugato et al. (2009) only looked at the Abzil bracket and did not compare it to another bracket. IMD could not be compared because there is not sufficient literature on IMD brackets. It is evident that marginal adaptation alone does not influence sheer bond strength as various factors contribute to the success of sheer bond strength. However, the marginal adaptation may have an influence on sheer bond strength as it dictates the amount of adhesive present in the space between bracket base and tooth surface. Other factors to consider include different types of adhesives as covered by Hudson et al., 2011, effects of curing devices on sheer bond strength, mechanical removal of adhesive material and the effects of fluoride pre-treatment solutions on sheer bond strength (Ewoldsen and Demke, 2001; Di Nicolo et al., 2010; Chen et al., 2013; Leodido et al., 2012).

Table 5.2.5: Sheer bond strength vs space measurement (overall mean values µm)

Bracket Types	Cozza et al., 2006 (N)	Lugato et al., 2009 (MPa)	Sfondrini et al., 2010 (MPa)	Hudson et al., 2011 (MPa)	Chavez et al., 2013 (MPa)	Goyal et al., 2013 (MPa)	Present study overall mean values (µm)
Abzil		10.84-13.51					371.35
Forestadent	200.60N		11.8				315.33
GAC				9.2-11.7			273.29
Gemini					6.01-7.35	19.58	288.24
IMD							361.45
Ormco			19.75	5.8-7.6			284.17
Victory	273.40N			9.8-11.8			310.52
Teeth used	Incisors (bovine)	Incisors (bovine)	Incisors (bovine)	Molars (human)	Premolar (human)	Premolar (human)	
Testing machine	Instron universal	DL 3000 universal	Instron universal	Zwick universal	Instron universal	Lloyd universal	

5.2.5a Types of adhesive

Fixed orthodontic brackets should not interfere with the patient's oral hygiene and should not promote demineralisation of the tooth around or beneath the brackets. This could be avoided by choosing an adhesive suitable to each individual case. There are five broad material groups to choose from ie. Zinc phosphate, glass ionomer, resin modified glass ionomer, resin and polyacid-modified composite resins (Ewoldsen and Demke, 2001). Several bond failures have been reported between the resin and brackets because of stress areas at the interface and defects in the resin material (Wang et al, 2004). However it remains one of the most used types of adhesive. Composite resins and polyacid-modified composite resins adhere to the tooth surface micro-mechanically only, requires a dry tooth surface and requires the enamel to be etched and adhesive placed before placing the bracket and resin adhesive. Resin adhesive releases little to no fluoride. Conventional glass ionomers adheres chemically to the tooth and releases optimum amounts of fluoride over time. Resin-modified glass ionomers adhere to the tooth both mechanically and chemically and releases fluoride (Ewoldsen and Demke, 2001).

Santin et al. (2018) compared sheer bond strengths between three different types (composite resin, resin modified glass ionomer and conventional glass ionomer) of adhesives on human premolar teeth. They found the composite resin cement and resin modified glass ionomer to be very close in sheer bond strengths and the conventional glass ionomer to be significantly lower in sheer bond strength.

It can then be assumed that if there is a large space between bracket base and tooth surface, it may be best to use a resin-modified glass ionomer with comparable sheer bond strengths and the ability to release fluoride and therefore limit demineralisation.

5.2.5b Effects of curing devices on sheer bond strength

James et al. (2003) evaluated the sheer bond strength of three curing devices (plasma arc light, argon laser and conventional halogen light) and two different bracket adhesives (Transbond XT and Adhesive Precoated). This study concluded that the plasma arc light produced mean bond strengths greater than the halogen light depending on which adhesive was used. With Transbond XT, the plasma arc light showed greater sheer bond strengths than the conventional halogen light and the argon laser. With Adhesive Precoated, the plasma arc light showed similar sheer bond strengths to the conventional halogen light and greater sheer bond strengths to the argon laser. The argon laser therefore produced the lowest sheer bond strengths with both adhesives.

Di Nicolo et al. (2010) did an in vitro study comparing the effect of curing with a halogen light (Quartz-Tungsten-Halogen) and a light emitting diode (LED) on the sheer bond strengths of orthodontic brackets. Adhesive Precoated was used as the adhesive cement. This study concluded that there was no significant differences between the sheer bond strength using either the halogen or LED light. It further suggested that bonding orthodontic brackets for 10 seconds using the LED light should be used as it reduces clinical chair time.

Therefore both halogen and LED lights would be suitable to attain adequate sheer bond strengths.

5.2.5c Mechanical removal of adhesive cements

Patients find it difficult to maintain good oral hygiene with fixed orthodontic brackets (Chen et al., 2013). This is imperative to avoid white spot lesions. But it should also be acknowledged that vigorous cleaning around the brackets could result in de-bonding and lowered sheer bond strength. It has been suggested that ultrasonic instrumentation around brackets lowers sheer bond strength (Scribante et al., 2017).

Sheer bond strengths of brackets are potentially influenced by the friction during tooth brushing (Hansen et al., 1999). Toothbrush bristles have been associated with abrasions at the cement-enamel junction (Radentz et al., 1976). It could then be concluded that the bigger the gap at this junction, the more adhesive would be indicated and therefore a greater chance of these abrasion lesions.

Studies looking at the effect of different manual toothbrushes on sheer bond strength found no significant differences between the different brushes. However, sheer bond strength decreases over time with continual brushing (Oliveira et al., 2010).

5.2.5d Effects of Fluoride pre-treatment solutions on sheer bond strength

Leodido et al. (2012) did an in vitro study to evaluate sheer bond strength of orthodontic brackets after pre-treatment with three different types of fluoride (neutral fluoride, acidulated phosphate fluoride and sodium fluoride varnish) solutions. After pre-treating the teeth, the same adhesive was used to cement the brackets. When testing the sheer bond strength, the control group (without pre-treatment) had the highest sheer bond strength. Teeth pre-treated with acidulated phosphate fluoride and sodium fluoride varnish had significantly lower sheer bond strengths. These findings were confirmed by Cossellu et al. (2017) who did a similar study. The control group (without pre-treatment) in this study also yielded significantly higher sheer bond strengths. This could be as a result of the fluoride pre-treatment forming a layer which could hinder the depth of the acid etch.

CHAPTER 6: CONCLUSION

The results of this study showed that there was no correlation in the space between bracket base and tooth surface between the seven brackets. Furthermore, the space was not uniform at all six points of reading for the same bracket between the various teeth. Therefore, it can be said that none of the brackets had a uniform measurement of 830µm which would be needed for the ideal adhesive thickness of 0.83mm as recommended by Jain et al. (2013). GAC had the smallest overall mean gap size followed by Ormco and Gemini respectively. Abzil had the largest overall mean measurement for the six points around the bracket. Most of the large readings presented at the cervical area meaning that the brackets fit poorly along the curvature of the cervical area of the premolars. This was true for all the brackets. Sheer bond strength *in vitro* studies showed that GAC and Gemini both de-bond at the tooth interface with less than half the adhesive left on the tooth. This could be due to how well these brackets are adapted to the tooth surface. Ormco bracket performed well in this study but sheer bond strength *in vitro* studies showed that the bracket de-bonds at the bracket interface with more than half to all of the adhesive left on the tooth. This means that although the bracket is adapting well to the curvature of the tooth, the base design of the bracket also plays a role in de-bonding (Hudson et al., 2011). Therefore, a relationship between the space between bracket base and tooth surface, bond strength and the bracket base design became evident. This study also had an incidental finding of the inaccuracy of slot heights when compared to information given by manufacturers. This paper agrees with literature stating that there were variations in the brackets manufactured and supplied to the clinician (Erduran et al., 2016).

6.1 Limitations of this study

A possible limitation of this study was the number of teeth used, based on the variation established between the individual six points and the average measurements of teeth in this study. A solution would be to assess the curvature of hundreds of teeth (a representative sample taking into account racial differences and first and second premolars) and develop an average curvature that would serve to guide the design of the bracket base. This would allow a smaller space between the tooth and the bracket for a larger buccal curvature range.

6.2 Recommendations

This study highlights the need for further investigation into marginal adaptation of brackets as the literature is lacking in this regard. The space between the bracket base and tooth surface needs to be further investigated in order to draw more definite clinical relevance. A recommendation would be to redo the study using more than one bracket per brand. Also different bracket bases if the average tooth curvature could be mapped, a tool could be developed to determine which bracket has the best adaptation. By doing this, the consistency could be assessed between brackets of the same brand. Another recommendation would be to further investigate the marginal adaptation and focus on the relationship between poor marginal adaptation, amount of adhesive required and the incidence of polymerisation shrinkage.

REFERENCES

Andrews, L. (1976). The straight-wire appliance, origin, controversy, commentary. *Journal of Clinical Orthodontics*, 10(2), pp.99-114.

Andrews, L. (1990). Interviews on the straight wire appliance. *J Clin Orthod*, 24, pp.493 - 508.

Angle, E. (1928). The latest and best in orthodontic mechanism. *Dent Cosmos*, 70, pp.1143 - 1158.

Arhun, N., Arman, A., Cehreli, S., Arıkan, S., Karabulut, E. and Gulsahı, K. (2006). Microleakage beneath Ceramic and Metal Brackets Bonded with a Conventional and an Antibacterial Adhesive System. *Angle Orthodontist*, 76(6), pp.1028 - 1034.

Armstrong, D., Shen, G., Petocz, P. and Darendeliler, M. (2007). A comparison of accuracy in bracket positioning between two techniques--localizing the centre of the clinical crown and measuring the distance from the incisal edge. *The European Journal of Orthodontics*, 29(5), pp.430-436.

Balut, N., Klapper, L., Sandrik, J. and Bowman, D. (1992). Variations in bracket placement in the preadjusted orthodontic appliance. *American Journal of Orthodontics and Dentofacial Orthopedics*, 102(1), pp.62-67.

Barker, C., Soro, V., Dymock, D., Sandy, J. and Ireland, A. (2013). Microbial contamination of “as received” and “clinic exposed” orthodontic materials. *American Journal of Orthodontics and Dentofacial Orthopedics*, 143(3), pp.317-323.

Bishara, S., VonWald, L., Olsen, M. and Laffoon, J. (1999). Effect of time on the shear bond strength of glass ionomer and composite orthodontic adhesives. *American Journal of Orthodontics and Dentofacial Orthopedics*, 116(6), pp.616-620.

Brown, P., Wagner, W. and Choi, H. (2015). Orthodontic bracket slot dimensions as measured from entire bracket series. *The Angle Orthodontist*, 85(4), pp.678-682.

Boersma, J., van der Veen, M., Lagerweij, M., Bokhout, B. and Prahl-Andersen, B. (2004). Caries Prevalence Measured with QLF after Treatment with Fixed Orthodontic Appliances: Influencing Factors. *Caries Research*, 39(1), pp.41-47.

Cardoso, M., Saraiva, P., Maltagliati, L., Rhoden, F., Costa, C., Normando, D. and Capelozza Filho, L. (2015). Alterations in plaque accumulation and gingival inflammation promoted by treatment with self-ligating and conventional orthodontic brackets. *Dental Press Journal of Orthodontics*, 20(2), pp.35-41.

Carlson, S. and Johnson, E. (2001). Bracket positioning and resets: Five steps to align crowns and roots consistently. *American Journal of Orthodontics and Dentofacial Orthopedics*, 119(1), pp.76-80.

Cash, A., Good, S., Curtis, R. and McDonald, F. (2004). An Evaluation of Slot Size in Orthodontic Brackets— Are Standards as Expected?. *Angle Orthodontist*, 74(4), pp.450 - 453.

Chávez, J., Santana, F., Yáñez, S. and Alatorre, J. (2013). Comparison of the shear bond strength of brackets between two adhesive systems (SEP and MIP Transbond) at 60 minutes and 24 hours. *Revista Mexicana de Ortodoncia*, 1(1), pp.e38-e43.

Chen, Y., Wong, R., Seneviratne, C., Hagg, U., McGrath, C. and Samaranayake, L. (2013). The effects of natural compounds-containing mouthrinses on patients with fixed orthodontic appliance treatment: clinical and microbiological outcomes. *International Journal of Paediatric Dentistry*, 23(6), pp.452-459.

Chikawa, H., Inai, N., Cho, E., Kishikawa, R., Otsuki, M., M Foxton, R. and Tagami, J. (2006). Effect of Incremental Filling Technique on Adhesion of Light-cured Resin Composite to Cavity Floor. *Dental Materials Journal*, 25(3), pp.503-508.

Chin, M., Sandham, A., Rumachik, E., Ruben, J. and Huysmans, M. (2009). Fluoride release and cariostatic potential of orthodontic adhesives with and without daily fluoride rinsing. *American Journal of Orthodontics and Dentofacial Orthopedics*, 136(4), pp.547-553.

Clark, S., Gordon, P. and McCabe, J. (2003). Anex vivoinvestigation to compare orthodontic bonding using a 4-META-based adhesive or a composite adhesive to acid-etched and sandblasted enamel. *Journal of Orthodontics*, 30(1), pp.51-58.

Cossellu, G., Lanteri, V., Butera, A., Laffi, N., Merlini, A. and Farronato, G. (2017). Timing considerations on the shear bond strength of orthodontic brackets after topical fluoride varnish applications. *Journal of Orthodontic Science*, 6(1), p.11.

Cozza, P., Martucci, L., De Toffol, L. and Penco, S. (2006). Shear Bond Strength of Metal Brackets on Enamel. *Angle Orthodontist*, 76(5), pp.851-856.

Dabas, A., Dabas, N., Sidhu, M., Prabhakar, M., Grover, S. and Kumar, S. (2016). White Spot Lesions: Fixed Orthodontic Treatment Scars - A Review. *Indian Journal of Health Sciences and Care*, 3(2), pp.85 - 95.

Dellinger, E. (1978). A scientific assessment of the straight-wire appliance. *American Journal of Orthodontics*, 73(3), pp.290-299.

Diaz, R., Díaz, R., Botello, G. and Olvera, S. (2014). Tolerance in a 0.022" x 0.025" bracket slot from three commercial brands used in the Department of Orthodontics of the National Autonomous University of Mexico. *Revista Mexicana de Ortodoncia*, 2(3), pp.e188-e191.

Dijkman, G., de Vries, J., Lodding, A. and Arends, J. (1993). Long-Term Fluoride Release of Visible Light-Activated Composites in vitro: A Correlation with in situ Demineralisation Data. *Caries Research*, 27(2), pp.117-123.

Di Nicoló, R., Araujo, M., Alves, L., Souza, R. and Rocha, D. (2010). Shear bond strength of orthodontic brackets bonded using halogen light and light-emitting diode at different debond times. *Brazilian Oral Research*, 24(1), pp.64-69.

Dos Santos Gerzson, D., Simon, D., dos Anjos, A. and Freitas, M. (2015). In vitro evaluation of microbial contamination of orthodontic brackets as received from the manufacturer using microbiological and molecular tests. *The Angle Orthodontist*, 85(6), pp.992-996.

Eliades, T., Eliades, G. and Brantley, W. (1995). Microbial attachment on orthodontic appliances: I. Wettability and early pellicle formation on bracket materials. *American Journal of Orthodontics and Dentofacial Orthopedics*, 108(4), pp.351-360.

Erduran, R., Maeda, F., Ortiz, S., Trivino, T., Fuziy, A. and Carvalho, P. (2016). Analysis on the precision of the dimensions of self-ligating brackets. *Microsc. Res. Tech.*, 79, pp.1188–1192.

Ewoldsen, N. and Demke, R. (2001). A review of orthodontic cements and adhesives. *American Journal of Orthodontics and Dentofacial Orthopedics*, 120(1), pp.45-48.

Gavrilovic, I. (2014). White Spot Lesions in Orthodontic Patients: Formation, Prevention and Treatment. *Journal of Oral Hygiene & Health*, 02(05).

Germane, N., Bentley, B. and Isaacson, R. (1989). Three biologic variables modifying faciolingual tooth angulation by straight-wire appliances. *American Journal of Orthodontics and Dentofacial Orthopedics*, 96(4), pp.312-319.

Gontijo, L., Mazziero, E. and Junior, J. (2004). Straight-Wire Bracket base curvature variation: A comparative study of four trademarks. *Dental Press Journal Of Orthodontics and Facial Orthopedics*, 9, pp.38 - 46.

Gorelick, L., Geiger, A. and Gwinnett, A. (1982). Incidence of white spot formation after bonding and banding. *American Journal of Orthodontics*, 81(2), pp.93-98.

Goyal, A., Kumar Chandna, A., Sehgal, V., Kannan, S., Gupta, A., Rajain, A. and Gupta, G. (2013). Retentive Shear Strengths of Various Bonding Attachment Bases: An in vitro Study. *The Journal of Indian Orthodontic Society*, 47, pp.121-127.

Graber TM, Swain BF. (1990). *Orthodontics Current Principles and Techniques*. The C.V. Mosby Company. 3rd Edition. 485-563.

Gwinnett, A. and Ceen, R. (1979). Plaque distribution on bonded brackets: A scanning microscope study. *American Journal of Orthodontics*, 75(6), pp.667-677.

Hansen, P., Killoy, W. and Masterson c, K. (1999). Effect of brushing with sonic and counterrotational toothbrushes on the bond strength of orthodontic brackets. *American Journal of Orthodontics and Dentofacial Orthopedics*, 115(1), pp.55-60.

Hobson, R., Ledvinka, J. and Meechan, J. (2001). The effect of moisture and blood contamination on bond strength of a new orthodontic bonding material. *American Journal of Orthodontics and Dentofacial Orthopedics*, 120(1), pp.54-57.

Hosein, I., Sherriff, M. and Ireland, A. (2004). Enamel loss during bonding, debonding, and cleanup with use of a self-etching primer. *American Journal of Orthodontics and Dentofacial Orthopedics*, 126(6), pp.717-724.

Hudson, A., Grobler, S. and Harris, A. (2011). Orthodontic Molar Brackets: The Effect of Three Different Base Designs on Shear Bond Strength. *International journal of Biomedical science*, 7(1), pp.27-34.

Jain, M., Shetty, S., Mogra, S., Shetty, V. and Dhakar, N. (2013). Determination of optimum adhesive thickness using varying degrees of force application with light-cured adhesive and its effect on the shear bond strength of orthodontic brackets: An in vitro study. *Orthodontics The Art and Practice of Dentofacial Enhancement*, 14(1), pp.e40-e49.

Jarabak, J. (1960). Development of a treatment plan in the light of one's concept of treatment objectives. *American Journal of Orthodontics*, 46(7), pp.481-514.

James, J., Miller, B., English, J., Tadlock, L. and Buschang, P. (2003). Effects of high-speed curing devices on shear bond strength and microleakage of orthodontic brackets. *American Journal of Orthodontics and Dentofacial Orthopedics*, 123(5), pp.555-561.

Jones, S., Tan, C. and Davies, E. (2002). The effects of reconditioning on the slot dimensions and static frictional resistance of stainless steel brackets. *The European Journal of Orthodontics*, 24(2), pp.183-190.

Keizer, S., ten Cate, J. and Arends, J. (1976). Direct bonding of orthodontic brackets. *American Journal of Orthodontics*, 69(3), pp.318-327.

Lee, S., Yoo, S., Kim, H., Kim, K., Yoon, Y. and Lim, S. (2005). Prevalence of putative periodontopathogens in subgingival dental plaques from gingivitis lesions in Korean orthodontic patients. *Microbiol*, 43, pp.260 - 265.

Leódido, G., Fernandes, H., Tonetto, M., Presoto, C., Bandéca, M. and Firoozmand, L. (2012). Effect of fluoride solutions on the shear bond strength of orthodontic brackets. *Brazilian Dental Journal*, 23(6), pp.698-702.

Lugato, I., Pignatta, L., Arantes, F. and Santos, E. (2009). Comparison of the shear bond strengths of conventional mesh bases and sandblasted orthodontic bracket bases. *Brazilian Oral Research*, 23(4), pp.407-414.

Matasa CG. 1988. Adhesion and its ten commandments. *Phoenix Without Ashes* (Quarterly newsletter of the Ortho-Cycle Company June 1988).

Matasa CG. (2003). In Search of a Better Bond: State of the Art. *The Orthodontic Materials Insider*, 15(1).

Martínez Pérez, L., Ruíz Díaz, R., Ruiz Botello, G. and Padilla Olvera, S. (2014). Slot tolerance from three different commercial brands of brackets. *Revista Mexicana de Ortodoncia*, 2(1), pp.e38-e41.

Mestriner, M., Enoki, C. and Mucha, J. (2006). Normal torque of the buccal surface of mandibular teeth and its relationship with bracket positioning: a study in normal occlusion. *Brazilian Dental Journal*, 17(2), pp.155-160.

Meyer, M. and Nelson, G. (1978). Preadjusted edgewise appliances: Theory and practice. *American Journal of Orthodontics*, 73(5), pp.485-498.

Miethke, R. and Melsen, B. (1999). Effect of variation in tooth morphology and bracket position on first and third order correction with preadjusted appliances. *American Journal of Orthodontics and Dentofacial Orthopedics*, 116(3), pp.329-335.

Mizrahi, E. (1983). Surface distribution of enamel opacities following orthodontic treatment. *American Journal of Orthodontics*, 84(4), pp.323-331.

Moolya, N., Sharma, R., Shetty, A., Gupta, N., Gupta, A. and Jalan, V. (2014). Orthodontic bracket designs and their impact on microbial profile and periodontal disease: A clinical trial. *Journal of Orthodontic Science*, 3(4), p.125.

Morrison, A. and Conrod, S. (2009). Dental burs and endodontic files: are routine sterilization procedures effective ?. *J Can Dent Assoc*, 75, p.39.

Mota Júnior, S., Campos, M., Schmitberger, C., Vitral, J., Fraga, M. and Vitral, R. (2018). Evaluation of the prototype of a new bracket-positioning gauge. *Dental Press Journal of Orthodontics*, 23(2), pp.68-74.

Moyers, R. (1988). *Handbook of orthodontics*. 4th ed. Chicago: Year Book Medical Publishers, pp. 518-524.

Northrup, R., Berzins, D., Bradley, T. and Schuckit, W. (2007). Shear Bond Strength Comparison between Two Orthodontic Adhesives and Self-Ligating and Conventional Brackets. *The Angle Orthodontist*, 77(4), pp.701-706.

O'Brien K. (2005). Quality assurance in orthodontic research. A keynote lecture. *World Journal of Orthodontics,* 6, supplement, 154.

Oesterle, L., Newman, S. and Shellhart, W. (2001). Rapid curing of bonding composite with a xenon plasma arc light. *American Journal of Orthodontics and Dentofacial Orthopedics*, 119(6), pp.610-616.

Oliveira, G., Pavone, C., Costa, M. and Marcantonio, R. (2010). Effect of toothbrushing with different manual toothbrushes on the shear bond strength of orthodontic brackets. *Brazilian Oral Research*, 24(3), pp.316-322.

Øgaard, B., Rølla, G. and Arends, J. (1988). Orthodontic appliances and enamel demineralization. *American Journal of Orthodontics and Dentofacial Orthopedics*, 94(1), pp.68-73.

O'Reilly, M. and Featherstone, J. (1987). Demineralization and remineralization around orthodontic appliances: An in vivo study. *American Journal of Orthodontics and Dentofacial Orthopedics*, 92(1), pp.33-40.

Pogulwar, S., Hegde, A., Kalia, A., Khandekar, S. and Punmiya, S. (2018). Evaluation and Comparison of Slot Characteristics and Mechanical Properties of Various Orthodontic Metallic Brackets Available in the Indian Market – An In-Vitro Study. *Oral Health and Dentistry*, 3(3), pp.660 - 672.

Radentz, W., Barnes, G. and Cutright, D. (1976). A Survey of Factors Possibly Associated With Cervical Abrasion of Tooth Surfaces. *Journal of Periodontology*, 47(3), pp.148-154.

Reynolds, I. (1975). A Review of Direct Orthodontic Bonding. *British Journal of Orthodontics*, 2(3), pp.171-178.

Richter, A., Arruda, A., Peters, M. and Sohn, W. (2011). Incidence of caries lesions among patients treated with comprehensive orthodontics. *American Journal of Orthodontics and Dentofacial Orthopedics*, 139(5), pp.657-664.

Rosenbloom, R. and Tinanoff, N. (1991). Salivary Streptococcus mutans levels in patients before, during, and after orthodontic treatment. *American Journal of Orthodontics and Dentofacial Orthopedics*, 100(1), pp.35-37.

Santin, G., Queiroz, A., Palma-Dibb, R., Oliveira, H., Nelson Filho, P. and Romano, F. (2018). Glass Ionomer Cements can be used for Bonding Orthodontic Brackets After Cancer Radiation Treatment?. *Brazilian Dental Journal*, 29(2), pp.128-132.

Savariz, A., Marquezan, M. and Mezomo, M. (2012). Preventive effect of an orthodontic compomer against enamel demineralization around bonded brackets. *Braz J Oral Sci.*, 11(1), pp.10-13.

Scribante, A., Sfondrini, M., Collesano, V., Tovt, G., Bernardinelli, L. and Gandini, P. (2017). Dental Hygiene and Orthodontics: Effect of Ultrasonic Instrumentation on Bonding Efficacy of Different Lingual Orthodontic Brackets. *BioMed Research International*, 2017, pp.1-6.

Sfondrini, M., Cacciafesta, V., Scribante, A., De Angelis, M. and Klersy, C. (2004). Effect of blood contamination on shear bond strength of brackets bonded with conventional and self-etching primers. *American Journal of Orthodontics and Dentofacial Orthopedics*, 125(3), pp.357-360.

Sfondrini, M., Gatti, S. and Scribante, A. (2010). Shear bond strength of self-ligating brackets. *The European Journal of Orthodontics*, 33(1), pp.71-74.

Sharma-Sayal, S., Rossouw, P., Kulkarni, G. and Titley, K. (2003). The influence of orthodontic bracket base design on sheer bond strength. *American Journal of Orthodontics and Dentofacial Orthopedics*, 124(1), pp.74-82.

Shintcovsk, R., Knop, L., Gandini Jr, L., Martins, L. and Pires, A. (2015). Comparison surface characteristics and chemical composition of conventional metallic and Nickel-Free brackets. *Brazilian Oral Research*, 29(1).

Sorel, O., El Alam, R., Chagneau, F. and Cathelineau, G. (2002). Comparison of bond strength between simple foil mesh and laser-structured base retention brackets. *American Journal of Orthodontics and Dentofacial Orthopedics*, 122(3), pp.260-266.

Sperber, R., Watson, P., Rossouw, P. and Sectakof, P. (1999). Adhesion of bonded orthodontic attachments to dental amalgam: In vitro study. *American Journal of Orthodontics and Dentofacial Orthopedics*, 116(5), pp.506-513.

Srivastava, K., Tikku, T., Khanna, R. and Sachan, K. (2013). Risk factors and management of white spot lesions in orthodontics. *Journal of Orthodontic Science*, 2(2), p.43.

Sudjalim, T., Woods, M., Manton, D. and Reynolds, E. (2007). Prevention of demineralization around orthodontic brackets in vitro. *American Journal of Orthodontics and Dentofacial Orthopedics*, 131(6), pp.705.e1-705.e9.

Sukontapatipark, W., El-Agroudi, M., Selliseth, N., Thunold, K. and Selvig, K. (2001). Bacterial colonization associated with fixed orthodontic appliances. A scanning electron microscopy study. *The European Journal of Orthodontics*, 23(5), pp.475-484.

Swanson, T., Dunn, W., Childers, D. and Taloumis, L. (2004). Shear bond strength of orthodontic brackets bonded with light-emitting diode curing units at various polymerization times. *American Journal of Orthodontics and Dentofacial Orthopedics*, 125(3), pp.337-341.

Tsibel G, and Kuftinec MM. 2004. A bonded transpalatal arch. *Journal of Clinical Orthodontics*, 38, 513 – 5.

Viana, C., Mazzieiro, Ê. and Landre Júnior, J. (2005). A influência da variação da curvatura da base do braquete em uma união ortodôntica submetida a diferentes cargas, através do método dos elementos finitos. *Revista Dental Press de Ortodontia e Ortopedia Facial*, 10(3), pp.75-86.

Wang, W., Li, C., Chou, T., Wang, D., Lin, L. and Lin, C. (2004). Bond strength of various bracket base designs. *American Journal of Orthodontics and Dentofacial Orthopedics*, 125(1), pp.65-70.

Wiegand, A., Buchalla, W. and Attin, T. (2007). Review on fluoride-releasing restorative materials—Fluoride release and uptake characteristics, antibacterial activity and influence on caries formation. *Dental Materials*, 23(3), pp.343-362.

Willmot, D. (2008). White Spot Lesions After Orthodontic Treatment. *Seminars in Orthodontics*, 14(3), pp.209-219.